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Editorial Board

JCCA December 2021 Sports Chiropractic Special Issue: 13th Edition

Mohsen Kazemi, RN, DC, FRCCSS(C), FCCPOR(C), MSc, PhD[1]
Assistant Editor

(JCCA. 2021;65(3):240)

KEY WORDS: sports, chiropractic

MOTS CLÉS : sports, chiropratique

I would like to thank you for your ongoing support of the Journal of the Canadian Chiropractic Association (JCCA) and the annual Sports Chiropractic special issue. I would also like to thank Canadian Chiropractic Association (CCA) and JCCA for keeping manuscript submission and publication free of charge. This kindness has enabled many students and researchers to publish their work and many learners and readers to access the articles freely. This year's issue is packed with very interesting and thought-provoking articles. In this issue you will find a systematic review, a small RCT, a couple of original research papers, and interesting case reports. I hope you enjoy this issue and feel encouraged and empowered by it.

As always, I would like to encourage you to get involved in sports chiropractic research in any way that you can. If you have a dataset, an interesting case, or an innovative research idea and need help developing it, please do not hesitate to contact me, or any member of our Editorial Board or members of the RCCSS(C).

[1] Canadian Memorial Chiropractic College

Corresponding author: Mohsen Kazemi, 6100 Leslie Street, Toronto, ON M2H 3J1
E-mail: mkazemi@cmcc.ca
Tel: 416-482-2340

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Does induced fatigue alter dynamic balance in athletes? A systematic review

Nader Abdelkader, BSc, DC[1]
Andrew Romanelli, BPhEd, DC, MSc[2]
Sheilah Hogg-Johnson, MMath PhD[3,4]

Objectives: *To determine the influence of induced fatigue on dynamic balance in healthy athletes*.

Design: *Systematic review*

Data sources: *PUBMED, MEDLINE, CINAHL, Sports Discus, and the Cochrane library from onset to May 28, 2019*

Eligibility criteria: *Eligible studies included any study examining the effects of induced-fatigue on dynamic balance, as measured by the SEBT/YBT, in healthy athletic populations. Studies with a low risk of bias were considered scientifically admissible for a best evidence synthesis*.

Results: *Fifteen studies with low risk of bias were included – seven investigated recreational athletes while eight focused on competitive athletes. In the recreational population, five of the studies found significant decrease in dynamic balance following the fatiguing intervention*.

La fatigue musculaire modifie-t-elle l'équilibre dynamique chez les athlètes? Étude systématique

Objectifs : *Déterminer si la fatigue musculaire a des effets sur l'équilibre dynamique chez les athlètes en bon état de santé*.

Méthodologie : *Revue systématique*

Sources des données : *PUBMED, MEDLINE, CINAHL, Sports Discus et la bibliothèque Cochrane du début des publications jusqu'au 28 mai 2019*.

Critères d'admission : *Les études admissibles comprenaient toutes celles qui avaient porté sur les effets de la fatigue musculaire sur l'équilibre dynamique, telle qu'elle mesurée par le SEBT/YBT dans des populations de sportifs sains. Les études comportant un faible risque de biais ont été considérées comme scientifiquement admissibles pour faire une synthèse des meilleures données probantes*.

Résultats : *Quinze études présentant un faible risque de biais ont été retenues; sept portaient sur des athlètes amateurs et les huit autres, sur des athlètes de compétition. En ce qui concerne les athlètes amateurs, cinq études ont montré une diminution importante de*

[1] Division of Graduate Studies, Sports Sciences, Canadian Memorial Chiropractic College
[2] Division of Undergraduate Education, Canadian Memorial Chiropractic College
[3] Department of Research & Innovation, Canadian Memorial Chiropractic College
[4] Dalla Lana School of Public Health, University of Toronto.

Corresponding author: Nader Abdelkader, Canadian Memorial Chiropractic College, 6100 Leslie St, North York, ON, Canada M2H 3J1
Tel: 647-867-4720
e-mail:drnaderabdelkader@gmail.com

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However, the remaining two concluded with insignificant changes. As for the competitive population, three studies showed significant effects of induced fatigue on dynamic balance, while five showed no effects.

Conclusion: *There are conflicting results regarding the effects of induced fatigue on dynamic balance. The majority of studies focused on competitive athletes found that fatigue did not alter their dynamic balance. Per contra, the majority of studies focused on recreational athletes concluded the opposite – fatigue did indeed affect dynamic balance.*

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KEY WORDS: postural balance, muscle fatigue, athlete, leg injuries, dynamic balance

l'équilibre dynamique après une activité causant de la fatigue. Cependant, dans les deux autres études, les changements n'étaient pas importants. En ce qui concerne les athlètes de compétition, trois études ont montré que la fatigue musculaire avait d'importants effets sur l'équilibre dynamique, tandis que cinq n'en ont montré aucun.

Conclusion : *Les résultats des études sur les effets de la fatigue musculaire sur l'équilibre dynamique sont contradictoires. La majorité des études portant sur des athlètes de compétition ont montré que la fatigue n'avait aucun effet sur l'équilibre dynamique. Par contre, la majorité portant sur les athlètes récréatifs ont conclu le contraire, c'est-à-dire que la fatigue avait un effet sur l'équilibre dynamique.*

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MOTS CLÉS : équilibre postural, fatigue musculaire, athlète, blessures aux jambes, équilibre dynamique

Introduction

While static balance is defined as maintaining a stable base of support with minimal body movement, dynamic balance is defined as withstanding movement within the base of support.[1] Deviations of the extremities occurring during movement can influence the center of mass (CoM) away from the base of support. Balance is gained by maintaining the CoM within the base of support. It can be argued that dynamic balance is required in skills such as jumping, hopping, and switching directions.

Dynamic balance has previously been identified as a vital athletic skill among gymnasts[2], footballers[3], golfers[4], volleyballers[5], fencers[6], and taekwondo athletes[7]. Deficits of dynamic balance have been shown to be a risk factor for injuries, particularly in the lower extremities such as muscular/tendon strains and ligamentous sprains.[8–11] Furthermore, it has been shown that dynamic balance enhances sport performance.[12,13]

Notwithstanding, this ability to maintain postural control within the base of support during dynamic movements may be compromised during fatigue. Previous soccer studies have identified an increase of musculoskeletal injuries toward the end of matches in both professional[14] and amateur footballers[15], which may be related to fatigue. In light of this, subsequent studies investigated the effects of induced fatigue on dynamic balance in athletes as a potential risk factor for dynamic balance alterations and injury.

One of the most feasible ways to assess dynamic balance, especially for the side-line sport practitioner, is through the Star Excursion Balance Test (SEBT), or its modified version, the Y-Balance Test (YBT). The outcome from the SEBT/YBT is how far the subject can reach with a lower limb without losing balance from the stance limb. Because these tests do not require any special equipment, they are feasible for sideline practicality. They have previously been used to assess lower extremity musculoskeletal injury risk[8–11] and rehabilitation progress[12,13], and have been shown to have excellent inter and intra rater reliability when used in healthy adults[16].

A previous systematic review by Gribble *et al*. [1] investigated the clinical utility of the SEBT as a diagnostic tool and its response to fatiguing, yet only provided a broad overview of its prediction for injury and responsiveness to training. Since its publication in 2012[1], very few studies have investigated the effects of fatigue on balance. There

were only three such studies that demonstrated fatigue negatively affects dynamic postural-control of healthy participants and those with chronic ankle instabilities.[17–19] Given the dearth of available research on the topic, a more updated review focussing particularly on the impact of fatigue on dynamic balance is warranted.

Given the need for adequate dynamic balance within the sports context, this review limits its scope to the athletic population only. Furthermore, this review limits its search to the SEBT/YBT given these tests' feasibility for the sideline practitioner. Thus, this review aims to appraise the literature on the effects of induced fatigue on dynamic balance using the SEBT/YBT to measure dynamic balance in the healthy athletic population.

Methods

A search strategy was developed and reviewed using the Peer Review of Electronic Search Strategies (PRESS) Checklist.[20] The following electronic databases were systematically searched from inception to May 28, 2019: PubMed, MEDLINE, CINAHL, Sports Discus, and Cochrane. Search terms consisted of subject headings specific to each database (e.g., MeSH in MEDLINE) and free text words relevant to fatigue, dynamic balance, and athlete (Appendix 1).

The review targeted healthy asymptomatic athletes, defined as injury free for at least three months. Athletes were defined as engaged in competition, whether at a high school, college, university, provincial, national, international or professional level. Considering the scarce amount of literature analyzing this particular topic, the authors did not exclude studies of subjects described as trained individuals corresponding to physical educational students or recreational athletes.

Studies of interest included any intervention used to induce fatigue. Given variations in the nature of physiological fatigue and its demands on different sports disciplines, any fatigue protocol was acceptable.

The outcome of interest was the assessment of dynamic balance using the SEBT/YBT, regardless of whether it is the primary or secondary outcome measure in a study.

Eligibility for inclusion in the review was based on the following criteria: 1) English language; 2) published in a peer-reviewed journal; 3) study design of randomized controlled trial, cohort, case-control, quasi-experimental, pre-post intervention, or cross-sectional; 4) study population of healthy athletes (studies including injured athletes must have provided separate results for asymptomatic controls); 5) well described fatigue protocol as an intervention; and 6) outcome measures based on SEBT/YBT as dynamic balance assessments.

Studies fulfilling any of the following criteria were excluded: 1) publication types including: guidelines, editorials, unpublished manuscripts, dissertations, books, conference proceedings, meeting abstracts, consensus statements; 2) study designs including: pilot studies, case reports, case series, qualitative studies, non-systematic and systematic reviews, practice guidelines, and studies not reporting on methodology; 3) cadaveric or animal studies; and 4) studies on injured patients, or those with previously diagnosed conditions including severe injuries (e.g. spinal cord injuries, brain injuries, amputations, blindness, joint dislocation, neurologic deficits, or medications that may have affected their balance).

All citations identified by the search strategy were exported into EndNote X8 for reference management and tracking of the screening process. A two-phase approach to screening was used with two independent reviewers screening each citation and article. Phase one included screening of titles and abstracts for possible relevance. Phase two included screening of possibly relevant citations using full text screening, with citations rated as either relevant or irrelevant. Any disagreement was resolved by discussion between the paired reviewers. If consensus was not reached, then a third reviewer independently appraised the citation and discussed with the other two reviewers, until consensus was reached.

All relevant studies were independently critically appraised for risk of bias by the two reviewers. Risk of bias was assessed using the Scottish Intercollegiate Guidelines Network (SIGN) criteria for randomized controlled trials[21], the Joanna Briggs Institute (JBI) critical appraisal checklist tool for Quasi-Experimental studies[22], and the Quality Assessment Tool for Before-After (Pre-Post) Studies with No Control Group for pre-post intervention studies[23]. A quantitative score (or cut point) was used to determine internal validity. Risk of bias scores of 1 to 2 were deemed "Unacceptable", scores of 3 to 4 were deemed "Acceptable", and scores of 5 to 6 were deemed "High Quality". If there were disagreements in the risk of bias assessments between the reviewers, then a third reviewer independently assessed for risk of bias and dis-

cussed with the other two reviewers, until consensus was reached. Following critical appraisal, studies with a low risk of bias ("high quality", or "acceptable") as determined by the quantitative score were considered scientifically admissible for best evidence synthesis. A sensitivity analysis was not performed as this was considered beyond the scope of this review.

The following methodological aspects (where appropriate or applicable) in each study were critically assessed: research question's clarity; randomization method; sample size estimation; population definition and description; appropriate utilization of control group; description of fatigue intervention; methodology of SEBT/YBT administration; repeatability of outcome measure for learning effects; and statistical analysis utilization.

Data was extracted from scientifically admissible studies to build evidence tables such as: effect sizes ((pre-fatigue mean balance minus post-fatigue mean balance)/ SD(pre-fatigue)) and 95% CI where possible, best evidence on each topic, and identified consistencies/inconsistencies in the evidence. Cohen's criteria for effect size were used to guide interpretation, namely d=0.2 as small, d=0.5 as medium and d=0.8 as large.[24] The tables were then used to create summary statements describing the body of evidence. Evidence was stratified based on population, either recreational or competitive athletes. Meta-analyses of findings were considered, but not undertaken due to heterogeneity in study populations, fatiguing protocols, variation in measures of dynamic balance reported, and inability to compute effect sizes for some studies. This systematic review was organized and reported based on the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) statement.[25]

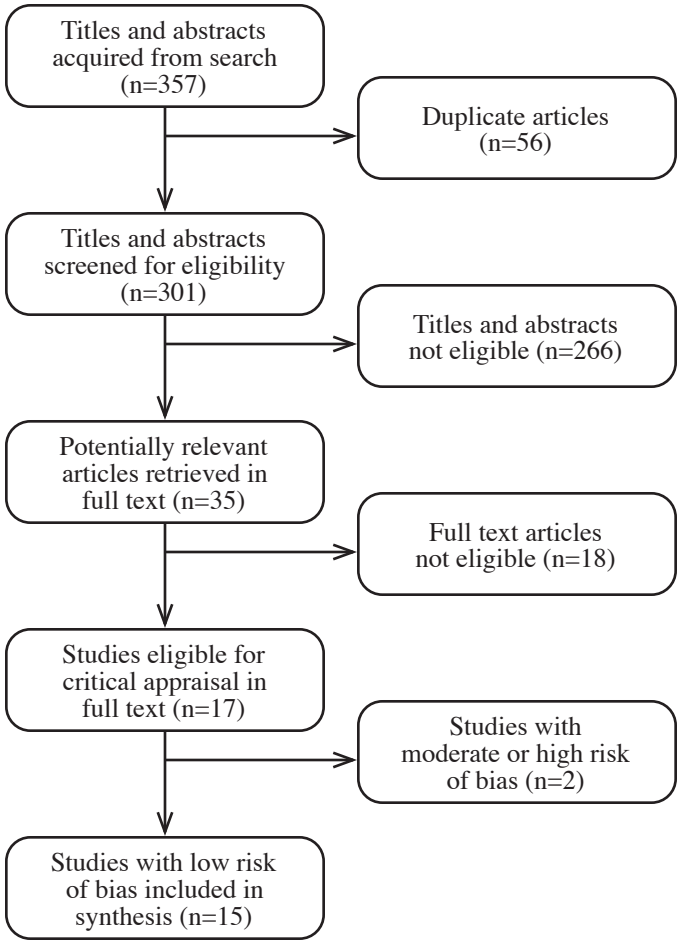

Figure 1.
Flowchart Of literature search and study identification

Results

Figure 1 shows the flow of articles through the systematic review. The search yielded 357 articles. After removing duplicates, 301 met phase 1 eligibility. Phase 1 interrater agreement, showing 91.0% agreement with $\varkappa$=0.58, 95%CI (0.45, 0.72). After reaching consensus at phase 1, thirty-five articles remained eligible for full text phase 2 screening. Phase 2 interrater agreement was 80.0% with $\varkappa$=0.60, 95%CI (0.33, 0.86). Disagreements were primarily related to the screened studies' broad definition of athletes.

Articles were excluded at phase 2 screening for ineligible study design, dynamic balance outcome not measured by SEBT/YBT, and subjects not consistent with the definition of a healthy athlete. Seventeen articles remained eligible for review.

All studies were appraised using the SIGN criteria for RCT, the JBI critical appraisal checklist tool for Quasi-Experimental studies, or the Quality Assessment Tool for Before-After (Pre-Post) Studies with No Control Group. Of the 17 critically appraised studies, two were deemed to have a high risk of bias (Table 1) and were not included in the evidence tables and synthesis. For this review's purpose, methodological weakness of the studies with a high risk of bias included not meeting athlete definition

Table 1.

Risk of bias table for all critically appraised articles (n=17). The sign, JBI, and the quality assessment tool for before-after were used against the included studies. The appraisal was conducted with our systematic review purpose in mind – that is to measure the effects of fatigue on dynamic balance, though this might not have been the main purpose of the original study.

Study	Criteria	Population			Intervention (Fatigue)	Outcome (SEBT/YBT)			Overall
	SIGN/JBI/ Pre-post	Representa-tiveness of athletes	Sample Size estimation	Control Group	Clearly described	Clearly described	Learning effects	Statistics	(++) High Quality; (+) Acceptable; (-) Unacceptable
Gribble et al. 2007 [17]	Pre–Post	No	No	–	Yes	Yes	Yes	Yes	4/6 ; (+)
Baghbani et al. 2016 [32]	Pre–Post	Yes	Yes	–	Yes	Yes	Yes	Yes	6/6 ; (++)
Baghbaninaghadehi et al. 2013 [33]	Pre–Post	Yes	NR	–	Yes	Yes	Yes	Yes	5/6 ; (++)
Mirmoezzi et al. 2018 [26]	Pre–Post	No	NR	–	Yes	No	NR	Yes	2/6 ; (–)
Hosseinimehr et al. 2010 [34]	Pre–Post	No	NR	–	Yes	Yes	Yes	Yes	4/6 ; (+)
Steib et al. 2013 [35]	Pre–Post	Yes	Yes	–	Yes	Yes	Yes	Yes	6/6 (++)
Sarshin et al. 2011 [36]	Pre–Post	No	NR	–	Yes	Yes	Yes	Yes	4/6 (+)
Gribble et al. 2009 [19]	JBI	No	NR	Yes	Yes	Yes	Yes	Yes	5/7 (+)
Zulfikri et al. 2017 [37]	SIGN	No	NR	Yes	Yes	Yes	No	Yes	4/7 (+)
Zech et al. 2012 [38]	Pre–Post	Yes	NR	–	Yes	Yes	No	Yes	4/6 (+)
Valldecabres et al. 2018 [27]	Pre–Post	No	NR	–	Yes	No	NR	Yes	2/6 (–)
Steib et al. 2013 [40]	Pre–Post	No	NR	–	Yes	Yes	No	Yes	3/6 (+)
Whyte et al. 2015 [39]	Pre–Post	Yes	NR	–	Yes	Yes	Yes	Yes	5/6 (++)
Armstrong et al. 2018 [28]	Pre–Post	Yes	No	–	Yes	Yes	Yes	Yes	5/6 (++)
Johnston et al. 2018 [29]	Pre–Post	Yes	NR	–	Yes	Yes	Yes	Yes	5/6 (++)
Cavanaugh et al. 2016 [30]	Pre–Post	No	Yes	–	Yes	Yes	No	Yes	4/6 (+)
Mcmullen et al. 2011 [31]	Pre–Post	No	Yes	–	Yes	Yes	Yes	Yes	5/6 (++)

for population, lack of sample size estimation reporting, poorly described dynamic balance assessment, and lack of reporting on learning effect consideration (n=2).[26,27]

The remaining 15 articles[17,19,36–40,28–35](Table 2), were deemed to have a low risk of bias. These articles include a randomized controlled crossover study[37], a quasi-experimental study with a control group[19] and thirteen pre-post studies with no control group[17,27,29–39]. Their methodological weaknesses include a lack of a precise definition of an athlete regarding their choice of subjects (n =8), lack of sample size estimation (n=10), and lack of reporting on learning effect consideration (n=4).

Variations across the studies include: athlete populations, fatigue protocols, and utilization of SEBT/YBT's reach directions. Seven studies recruited recreational athletes[17,19,30,31,34,36,37] while eight studies recruited competitive athletes[28,29,32,33,35,38–40]. Fatigue protocol variations include: isolated body-segment/muscle[17,19,31], functional movement[17,19,30], multiple exertional stations[32–34,36,37,39], anaerobic treadmill[35,38,40], anaerobic cycling[29], high intensity interval training[39], dance aerobic fitness fatigue[28] or a combination thereof. Two studies utilized the SEBT in 3 directions: anterior, medial, posterior in bilateral stance[17,19]; four studies utilized the SEBT in all eight directions in only the dominant leg[32–34,39]; four studies utilized the SEBT in four directions: anterior, posterior, medial, lateral in unilateral stance[35,37,38,40]; four studies utilized the YBT in the dominant leg[29–31,36]; and one study utilized the YBT in bilateral stance[28].

Of the seven studies investigating the effects of fatigue on dynamic balance in recreational athletes, five found significant decreases, three of which used functional-mul-

Table 2.
Study characteristics of fifteen articles relevant and low risk of bias

Reference	Subjects, number (n) targeted	Study design	Athletic level, involvement	Intervention (fatigue protocol)	Outcome (dynamic balance)	Key findings
Gribble et al. 2007 [17]	30 physically active subjects. Healthy group (8 males, 8 females; (age 22.5 ± 2.4 years) Chronic ankle instability (CAI) group (7 males, 7 females; 21.9 ± 2.9 years)	Pre-post	All subjects participated in at least thirty minutes of exercise three times per week. Exercise description and level is not described. Recreational.	Ankle fatigue induced using an isokinetic dynamometer through a concentric-concentric protocol for plantar flexion/dorsiflexion movement. Lunge fatigue consisted of subjects lunging forward with the testing leg to a target on the floor at a distance equal to the leg length of the testing leg. The rate of lunge performance was generated with a metronome at a rate of one lunge cycle per two seconds.	SEBT; 3 directions: anterior, medial, posterior; bilaterally	Insignificant normalized reaching distance in both groups with both fatigue interventions. However, knee and hip kinematics is affected in CAI group after lunging fatigue protocol in two of the reaching directions. Effect size cannot be computed
Baghbani et al. 2016 [32]	15 healthy female, non-athletes (age 16.1±1.8 years) 15 female athletes (mean age ± sd: 16.1 ± 1.1 years)	Pre-post	All athletes (handball and basketball players) were all competing at the provincial level and had been involved in sport-specific training for at least 7 hrs/week for the previous two years. Competitive.	The fatigue protocol (7-station exertion protocol). The subjects jogged moderately at a self-selected pace for five minutes in station one. In station two, they sprinted up and down the length of a basketball court for three minutes. Station three was two minutes of push-ups. Sit ups were performed in station four for two minutes. Station five was three minutes of 30 cm step-ups. Station six was another three minutes of sprinting up and down the length of basketball court. The final station was two minutes at the fastest speed that each subject could run.	SEBT; 8 directions; dominant leg	The average of the 8 directions of the SEBT balance performance in the non-athlete group significantly decreased after fatigue (p=0.0003). The athlete group however had no significant changes in balance performance before and after the fatigue protocol (p=0.78). Additionally, they found that the athlete group had significantly better balance performance in pre (p=0.005) and post-tests (p=0.0001) when compared to their healthy control counterparts. Effect sizes (post mean – pre mean)/SD(pre)*athletes non-athletes SEBT composite 0.02-0.19 *SD not in publication, obtained from first author via email
Baghbaninaghadehi et al. 2013 [33]	15 female athletes from high school. Subjects' mean (standard error) of age, height, and body weight were: 16.1(1.1) years, 164.1 (4.6) cm and 53.1 (6.7) kg, respectively.	Pre-post	Basketball players who had four to five exercise sessions per week. Competitive.	Seven station exertion protocol. The subjects jogged moderately at a self-selected pace for five minutes in station one. In station two, they sprinted up and down the length of a basketball court for three minutes. Station three was two minutes of push-ups. Sit ups were performed in station four for two minutes. Station five was three minutes of 30 cm step-ups. Station six was another three minutes of sprinting up and down the length of basketball court. The final station was two minutes at the fastest speed that each subject could run.	SEBT; 8 directions; dominant leg	The mean and the standard deviations of dynamic balance performance of the subjects in eight directions before and after the fatigue protocol were not significant. Effect sizes (post mean-pre mean)/SD(pre) Anterior -0.67 Anteromedial 0.05 Medial -0.33 Posteromedial -0.48 Posterior -0.08 Posterolateral 0.92 Lateral 0.57 Anterolateral -1.41 Total -0.14
Hosseinimehr et al. 2010 [34]	30 subjects: healthy group (7 males, 8 females, age = 21.78±0.79 years, height = 168.3±5.6 cm and weight = 63.6±2.6 kg) CAI (7 males, 8 females, age = 21.43±0.83 years, height = 168.4±5.5 cm and weight = 63.3±3.2 kg)	Pre-post	Physical education students. Training level and frequency not specified. Recreational.	Seven stations protocol. Station one consisted of a 5 min moderate jog at the subjects self-selected pace. This jog took place around the perimeter of the gym in order to help the participant maintain a steady pace. Station two consisted of 2 min of sprints up and down the length of a basketball court. Station three was 1 min of push-ups. Station four consisted of 1.5 min of sit-ups. Station five was 2 min of 12 inch step-ups. Station six consisted of another 2 min of sprints up and down the basketball court and station seven was 1.5 min run at as fast a pace as the participant could maintain for the entire 1.5 min	SEBT; 8 directions; dominant leg	Dynamic postural control decreased after fatigue in two groups (p<0.05) Effect sizes (post mean-pre mean)/SD(pre) Control / Experimental Anterior -1.04 / -1.07 Anteromedial -0.80 / -0.73 Medial -1.51 / -0.66 Posteromedial -0.89 / -0.17 Posterior -0.46 / -0.77 Posterolateral -1.00 / -0.95 Lateral -0.76 / -1.43 Anterolateral -1.71 / -1.49

Reference	Subjects, number (n) targeted	Study design	Athletic level, involvement	Intervention (fatigue protocol)	Outcome (dynamic balance)	Key findings
Steib et al. 2013 [35]	19 individuals with functional ankle instability (FAI) (male: 14, female: 5, age 24.95±3.17), 19 ankle sprain copers (male: 16, female: 6, age 24.53±2.76) 19 non-injured controls (male: 13, female: 6, age 23.32±3.79)	Pre-post	All athletes are in local ball sports teams (handball, volleyball, basketball, soccer). Participants exercised at least three times per week for a minimum of 30 min per session. Competitive.	Fatigue was induced by a running exercise on a motorized treadmill until subjective exhaustion. With a constant grade of 1° inclination, the protocol started at 8 km/h, and speed was increased stepwise by 2 km/h every 3 min. Participants were instructed to run as long as possible until complete exhaustion.	SEBT; 4 directions: anterior, posterior, medial, lateral; unilateral	Treadmill running negatively affected dynamic postural control in all three groups. Particularly, it had significantly affected SEBT in medial reach distances in the FAI ($p = .002$; ES = –0.42) and control group ($p = .031$; ES = –0.29), and anterior reach distances in copers ($p \leq .001$; ES = – 0.55). The magnitude of these effects, however, did not differ between groups. Thus, ankle status does not appear to have an effect on fatigue-induced sensorimotor control impairments. Effect sizes (post mean-pre mean)/SD(pre) Control / Copers / FAI Anterior -0.16 -0.31 -0.03 Medial -0.29 -0.13 -0.28 Lateral -0.21 -0.16 -0.08 Posterior -0.13 -0.02 -0.10
Sarshin et al. 2011 [36]	20 healthy athletes (age 21.4 ± 1.63 year)	Pre-post	Physical education athletes that played badminton for at least 2 years. Training level and frequency not specified. Recreational.	Six phases of functional fatigue protocol: agility drill, box jumping, two-legged hop sequence, side-to-side bounds, mini-tramp, resistance arc	YBT; dominant leg	Functional fatigue decreased dynamic balance performance Effect sizes (post mean-pre mean)/SD(pre) Anterior -2.04 Posterolateral -1.92 Posteromedial -0.94
Gribble et al. 2009 [19]	16 physically active athletes (8 men: age 22.5 ± 2.45 years; 8 women: age 22.5 ± 2.56 years)	Quasi-experimental with control	All athletes participated in sustained physical activity at least 3 times per week for 30 minutes. Physical activity is not specified. Recreational.	Fatiguing conditions: Ankle plantar flexion and dorsi flexion. Knee flexion and extension. Hip flexion and extension. Athletes performed 5 continuous maximum trials at 60°/s for the designated movement pattern to determine peak torque. After a 2-minute rest, they repeated the movement pattern at 60°/s continuously until force production dropped below 50% of the peak torque in both directions of motion being tested. 4th fatiguing condition consisted of a lunging task a maximum number of times at the rate of 1 lunge every 2 seconds. Fatigue was induced by having them perform the task a maximum number of times until they could not complete it with proper form or were unable to meet the required rhythm for 2 repetitions in a row. The 5th testing session was used as control condition. No fatiguing task was implemented.	SEBT; 3 directions: anterior, medial, posterior; bilaterally	For anterior direction, fatigue created a decrease in MAXD for both genders compared with the control day. Knee fatigue condition produced a significantly greater decline in MAXD in men(–.043) than in the other conditions (gender-by-condition-by-time interaction: ($p = .012$) For medial direction, all 4 fatigue conditions created pre–post decreases in MAXD (condition-by-time interaction: ($p < .001$) compared with the control day. For posterior direction, fatigue at the ankle, knee, and lunge exercises created significant pre–post decreases in MAXD (condition-by-time: ($p = .001$). Fatigue produced deficits in normalized reach distances in all 3 reaching directions. Women were able to reach farther than men while simultaneously demonstrating a greater amount of knee flexion, and fatigue amplified these differences. Effect sizes cannot be derived. Results presented graphically without values for pre and post mean and SD
Zulfikri et al. 2017 [37]	72 male recreational athletes ranging from 18-25 years old. Four groups: Group A; KTape and fatigue, age 21.32 (1.29) Group B; no tape and fatigue, age 21.79 (1.44) Group C; KTape and no fatigue, age 21.11 (1.33) Group D; no tape and no fatigue, age 21.93 (0.88)	RCT	Recreational athlete was defined as people undertaking any sports for leisure and not representing the college, national nor international. Training level and frequency not specified. Recreational.	Functional agility short term fatigue protocol (fast-fp) was used to induce fatigue for group A and B. This protocol consisted of vertical jumping, stepping up and down, squatting and l-drill. Completing the four tasks was counted as one set of the protocol. This was repeated until maximal fatigue was achieved.	SEBT; 4 directions: anterior, medial, lateral, posterior; dominant leg	Group A (90.10±9.40) and group B (86.14±10.50) attained lower mean for SEBT composite score compared to group C (97.30±10.83) and group D (98.13±9.47) suggests that fatigue have a diminishing effect on dynamic balance. KTape application inhibit the effects of fatigue and preserved lateral and posterior direction of SEBT. KTape application may lower the risk for injuries in the lateral and posterior directions following fatigue induction. Effect sizes (post mean-pre mean)/SD(pre) Group A / Group B Anterior -0.71 -1.29 Medial -0.47 -0.81 Lateral -0.43 -1.31 Posterior -0.40 -1.00

Reference	Subjects, number (n) targeted	Study design	Athletic level, involvement	Intervention (fatigue protocol)	Outcome (dynamic balance)	Key findings
Zech et al. 2012 [38]	19 male team handball players (age: 16.8 6 ± 0.6 years). 2 German youth handball teams, first and second divisions.	Pre-post	Athletes were regularly active and currently engaged in regular summer preseason handball and structured exercise training sessions (2–3 times per week). Competitive.	Whole-body fatigue – treadmill running was induced by running on a motorized treadmill with increasing speed at a constant grade of 1.5% Localized muscle fatigue – unilateral barbell step-ups induced fatigue by using 3 sets of single- leg barbell step-ups on a bench (30-cm height) with subsequent heel raises.	SEBT; 4 directions: anterior, medial, lateral, posterior; dominant leg	No fatigue effects were found for the SEBT. Effect sizes (post mean-pre mean)/SD(pre) Treadmill Localized Overall 0.09 -0.22 Anterior 0.24 -0.15 Medial 0.14 -0.09 Posterior -0.06 -0.41 Lateral -0.03 -0.15
Whyte et al. 2015 [39]	40 university athletes: 20 male (20.83±1.50) and 20 female (20.45±1.34) athletes.	Pre-post	Gaelic football, hurling/ camogie, soccer. Training level and frequency not specified. Competitive.	The HIIP consisted of 4 repetitions of 10-m forward sprinting with a 908 change of direction and then backward sprinting for 5 m, 2 repetitions of 2- legged jumping over 5 hurdles, 2 repetitions of high-knee side stepping over 5 hurdles, and 4 repetitions of lateral 5-m shuffles. Participants rested for 30 seconds before repeating the circuit.	SEBT; 8 directions; dominant leg	A main effect for time, with a decreased average of all 8 directions normalized maximal SEBT scores postfatigue ($p < .001$; ES 0.695) indicating HIIP negatively affected dynamic postural control as assessed by the SEBT in athletes. They also found there was a time X sex effect (p 0.007; ES 0.719), indicating that women were affected less negatively (effect sizes closer to zero) by the HIIP. Effect sizes (post mean-pre mean)/SD(pre) Male Female Overall -1.45 -0.71 Anterior -0.93 -0.44 Anteromedial -0.92 -0.31 Medial -1.27 -0.33 Posteromedial -1.12 -0.59 Posterior -1.07 -0.99 Posterolateral -1.21 -0.62 Lateral -0.92 -0.48 Anterolateral -0.82 -0.18
Armstrong et al. 2018 [28]	35 university dancers: 30 females (age 20.09), 5 males (age 20.62)	Pre-post	Dancers enrolled in an undergraduate dance program who performed primarily contemporary dance. Attended dance classes for a minimum of 6 hours per week. Duration and competitiveness not described. Competitive.	Dance aerobic fitness test. Daft is a dance-specialized test involves a 16-beat dance sequence consisting of 5 x 4-minute stages of increasing intensity associated with increased size of movement or additional movements. Subjects were removed from the test if the supervising investigator observed that they fell behind the beat of the test or their performance of the movement was judged to be compromised.	YBT; bilaterally Percentage maximized reach	Post-daft, the mean SEBT percentage maximized reach distances for dominant and non-dominant legs were non-significant compared to pre-daft scores, and in fact for PL and PM directions, the post-fatiguing balance measures were higher on average than the pre-fatiguing. Lack of a main effect for exercise was observed in each of the anterior dominant and non-dominant, posterolateral dominant and non-dominant, and posteromedial dominant and non-dominant scores. Effect sizes (post mean-pre mean)/SD(pre) Non-dominant Dominant Anterior -0.19 -0.07 Posterolateral 0.29 0.17 Posteromedial 0.38 0.19 Composite 0.16 0.24
Johnston et al. 2018 [29]	20 male and female (age 23.75, university students engaged in competitive sport	Pre-post	University students engaged in competitive sport. Training type, level and frequency not specified. Competitive.	Modified version of the Wingate anaerobic test was performed. The test required the participant to cycle for 60 s rather than the traditional 30 s. Prior to maximal exercise testing, the subject initially completed a low-resistance warm-up for 5 min. During the warm-up, participants completed 3 × 5 s sprints. On completion of the warm-up, participants commenced cycling at a cadence of between 50–60 rpm for 30 s. The participants were instructed that the test would commence at the completion of the 30s and that they should accelerated maximally. Participants were encouraged to maintain maximal effort throughout the 60 s in order to ensure maximal fatigue. Changes in the power generated were monitored over the course of the test to ensure that each individual had maintained a maximal effort throughout the Wingate protocol.	YBT; dominant leg	All 3 reach directions of YBT showed statistically significant differences between pre-fatigue and the first post-fatigue measurement (anterior; p = 0.019, posteromedial; p = 0.019 & posterolateral; p = 0.003). The anterior reach direction returned to pre-fatigue levels within 10min (p=0.632). The posteromedial reach direction returned to pre-fatigue levels within 20 min (p = 0.236), while the posterolateral direction maintained a statistically significant difference at 20 min (p = 0.023). Effect sizes cannot be derived. Pre and post means presented graphically without SD.

Reference	Subjects, number (n) targeted	Study design	Athletic level, involvement	Intervention (fatigue protocol)	Outcome (dynamic balance)	Key findings
Cavanaugh et al. 2016 [30]	12 healthy and recreationally active participants from university population 7 male (age 24.1 years) 5 women (age 23.7 years)	Pre-post	Does not indicate type, level, or frequency of activity. Recreational.	Participants performed 4 sets of unilateral (dominant leg) Bulgarian squats to failure with 1 minute rest between sets. The Bulgarian squats were conducted in a lunge position with the nondominant leg extended and the foot resting on a platform (50 cm) behind the participant. Using body weight as resistance, the participants were instructed to flex the front knee (dominant) to 90 degrees and return to an extended knee position, until they were unable to continue. With the aid of a metronome, the frequency of concentric and eccentric contractions was 1 per second. The number of repetitions performed in each set was recorded.	YBT; dominant leg	There were no significant main effects or interactions for the y balance test Effect sizes for prefatigue 2 to postfatigue 1 min Effect sizes (post mean-pre mean)/SD(pre) Anterior -0.24 Posterior medial -0.18 Posterior lateral -0.21
McMullen et al. 2011 [31]	18 men (avg. age 22 years) and 18 women (avg. age 22).	Pre-post	All volunteers had at least a moderately active lifestyle, deemed, participating in 150 to 300 minutes of physical activity per week. Recreational.	Participants performed repeated side-lying, eccentric hip-abduction contractions until the G-Med was fatigued. Participants performed a maximal voluntary isometric contraction before the fatiguing protocol and before any practice trials or testing. This contraction served as the participant's baseline median frequency. Participants were instructed to abduct the hip to 15° with the knees slightly flexed, then lower it back to neutral. Concentric contractions lasted less than 2 seconds, during which time the participants actively abducted the hip to 15°. Eccentric contractions lasted 5 seconds. Participants slowly lowered the abducted hip back to the starting position. With every fifth contraction, participants performed a 2-second isometric contraction against the canvas belt (ie, at 15° of hip abduction), and a 1-second clip of G-Med EMG was recorded during the middle 1.0 second of the contraction. Median frequency was calculated immediately in real time. The participant continued this process until successfully reaching a 15% downward shift in median frequency compared with a baseline measure of median frequency established before the fatiguing exercise.	YBT; dominant leg	After the fatiguing protocol, both groups displayed a decrease in dynamic postural control, as demonstrated by shorter reach distances on the SEBT ($f_{3,32} = 30.3$, $p < .001$). When men and women were pooled, we observed decreases in the anterior ($f_{1,34} = 70.7$, $p < .001$), posteromedial ($f_{1,34} = 57.9$, $p < .001$), and posterolateral ($f_{1,34} = 54.4$, $p < .001$) reach directions. Postural control was affected negatively after a g-med-fatiguing exercise. Pooled results across men and women Effect sizes (post mean-pre mean)/SD(pre) With 95%CI Anterior -1.04 (-1.74, -0.34) Posterior medial -0.62 (-1.28, 0.05) Posterior lateral -0.54 (-1.21, 0.12)
Steib et al. 2013 [40]	30 young athletes: Ankle sprain copers, consisting of 14 athletes with a history of a severe ankle sprain (22.71±2.81) Control group of 16 healthy athletes (25.88 6 2.66)	Pre-post	Athletes from different sports. Training level and frequency not specified. Competitive.	Whole-body fatigue was induced by having participants run on a motorized treadmill with increasing speed. The protocol started at 8 km/h, and speed was increased stepwise by 2 km/h every 3 minutes. Participants were instructed to run as long as possible until complete exhaustion.	SEBT; 4 directions: anterior, posterior, medial, lateral; dominant leg Mean over 4 directions used for each subject	Treadmill running had significantly reduced the mean of 4 directions of the normalized SEBT maximum reach distance in the copers group ($p \leq 0.00$), the healthy athletes had insignificant reductions in SEBT. A group x time interaction ($p = .03$) was evident for the SEBT, with larger reductions in mean reach distances in the coper group (-2.43) than in the control group (-0.37). Fatiguing running significantly affected dynamic postural control in participants with a history of ankle sprain. Fatigue-induced alterations of dynamic postural control were greater in athletes with a previous ankle sprain. Effect sizes (post mean-pre mean)/sd(pre) Controls Copers SEBT -0.09 -0.27

tiple station protocols. Hosseinimehr *et al*.[34] fatigued 15 healthy (age 21.78±0.79 years) physical education students and 15 students with chronic ankle instability (age 21.43±0.83 years), using a seven-station protocol including sprinting, push-ups, and sit-ups. For the healthy control group, paired t-tests showed significant differences ($p<0.05$) in the mean of reached distance (cm) between pre and post-tests in eight directions. Sarshin *et al*.[36] fatigued 20 physical education students (age 21.4±1.63 years) with two years of badminton experience and found a significant decrease in the YBT ($p\leq0.001$) after a six-phase functional fatigue protocol involving agility drills, box jumps, two-legged hop sequences, side-to-side bounds, mini-trampoline, and resistance band exercises. Zulfikri *et al*.[37] studied 72 male recreational athletes in a randomized controlled study design involving four groups: Group A (Kinesiology Tape (KT) application and fatigue), Group B (no tape and fatigue, age 21.79±1.44 years), Group C (KT and no fatigue), Group D (no tape and no fatigue). Their protocol involved functional agility stations involving vertical jumping, stepping up/down, squatting, and L-Drill. Results showed group A and group B attaining lower mean SEBT composite scores compared to Group C and Ground D. More importantly, significant reductions were found in mean normalized reach distance in Group B for anterior ($p<0.001$), medial ($p<0.001$), lateral ($p<0.001$), posterior ($p<0.001$) direction, and composite score ($p<0.05$). The fourth study by Gribble *et al*.[19] utilized a five-arm quasi-experimental study-design including four different fatigue conditions: 1) isolated ankle dorsi-and-planar-flexion, 2) isolated knee flexion and extension, 3) isolated hip flexion and extension, 4) a functional repeated lunging task, and 5) control of no fatigue. Subjects were 16 physically active individuals (eight men: age 22.5 ± 2.45 years; eight women: age 22.5 ± 2.56 years) and all underwent all four fatiguing protocols, each separated by at least one week. All fatigue conditions created a decrease in maximum normalized reaching distance for both genders compared with the control condition ($p<0.05$). However, women performed farther than men while demonstrating a greater amount of knee flexion, and fatigue amplified these differences. Similarly, McMullen *et al*.[31] studied 36 moderately active men (age 22 ± 3.64 years) and women (age 22 ± 3.14 years) performing the YBT before and after repeated side-lying, eccentric hip-abduction contractions. After the fatiguing protocol, both groups displayed a decrease in dynamic balance, as demonstrated by shorter reach distances on the SEBT ($p<0.001$). When men and women were pooled, they found significant decreases in anterior ($p<0.001$), posteromedial ($p<0.001$), and posterolateral ($p<0.001$) reach directions. When considering the effect sizes for the aforementioned studies, they were typically in the medium-to-large range: 1.04-2.04 in the anterior direction; 0.8 in the anteromedial direction; 0.81-1.51 in the medial direction; 0.62-0.94 in the posteromedial direction; 0.46-1.00 in the posterior direction; 0.54-1.00 in the posterolateral direction; 0.76-1.92 in the lateral direction; 1.71 in the anterolateral direction. Effect sizes for Gribble *et al*.[19] could not be computed.

In contrast to the previously mentioned studies, two studies also involving recreational athletes, found insignificant changes. Gribble *et al*.[17] studied 30 physically active (16 healthy (22.5 ± 2.4 years) and 14 chronic ankle instability (CAI) (21.9 ± 2.9 years)) subjects. Each subject underwent the following fatiguing protocols on different days: 1) ankle fatigue isokinetically in a concentric-concentric protocol for plantar flexion/dorsiflexion movement, and 2) repeated lunging tasks. Results demonstrated insignificant normalized distances in both groups with both fatigue interventions. The second study by Cavanaugh *et al*.[30], found that 12 recreationally active university participants also showed no significant differences in the YBT before-and-after fatigue protocol involving unilateral, repeated concentric and eccentric contractions of one Bulgarian split squat per second. The effect sizes for the Cavanaugh *et al*.[30], were typically in the small-to-medium range: 0.24 in the anterior direction, 0.18 in the posteromedial direction, and 0.21 in the posterolateral direction. Effect sizes for Gribble *et al*.[17] could not be computed.

As for the competitive athletes, three studies showed significant effects of induced fatigue on dynamic balance. In the first study by Steib *et al*.[40], 57 local athletes (including 19 healthy controls (age 23.32±3.79)) involved in handball, volleyball, basketball, and soccer practicing at least three times per week were fatigued by running on a treadmill until exhaustion. The running significantly affected SEBT in medial reach distances in the healthy control group ($p = 0.031$; ES = –0.29). A second study by Whyte *et al*.[39] used a high-intensity intermittent exercise protocol (HIIP) to fatigue two groups of university

athletes (20 male (age 20.83±1.50) and 20 female (age 20.45±1.34)) involved in Gaelic football, hurling, and soccer, with no mention of training level or frequency. Results showed a decreased average for all eight directions of normalized maximal SEBT scores post fatigue (P < .001; ES 0.695) indicating HIIP's negative effect on dynamic postural control. Of note, there was an interaction in effect based on gender (P 0.007; ES 0.719), as women were affected less negatively than men (P <.001; ES 0.695). The third study by Johnston *et al*.[29] investigated 20 male and female university students (age 23.75 ± 4.79) engaged in competitive sport with no mention of type of sport, training level, or frequency. This is the first study to investigate SEBT/YBT at pre-determined times post fatigue, rather than immediately following fatigue. Subjects underwent a modified Wingate anaerobic fatigue cycling test, and were tested at zero, 10, and 20 minutes post fatigue. All three reach directions of the YBT demonstrated statistically significant differences between pre-fatigue and the first post-fatigue measurements (anterior; p = 0.019, posteromedial; p = 0.019 & posterolateral; p = 0.003). The anterior reach direction returned to pre-fatigue levels within 10min (p = 0.632); the posteromedial reach direction returned to pre-fatigue levels within 20 min (p = 0.236); while the posterolateral direction maintained a statistically significant difference at 20 min (p = 0.023). These results indicate a negative effect of maximal anaerobic fatigue on normalised YBT scores in all three directions. The effect sizes for the aforementioned studies varied considerably ranging from small-to-large: 0.16-0.93 in the anterior direction; 0.31-0.93 in the anteromedial direction; 0.29-1.27 in the medial direction; 0.59-1.12 in the posteromedial direction; 0.13-1.07 in the posterior direction; 0.62-1.21 in the posterolateral direction; 0.21-0.92 in the lateral direction; and 0.18-0.82 in the anterolateral direction. Effect sizes for Johnston *et al*.[29] could not be computed.

While the aforementioned three studies showed significant effects, there were five studies that concluded otherwise. In a comparison of 16 healthy athletes (n=16, age 25.88±2.66) with 14 ankle-sprain copers (n=14 age 22.71±2.81), Steib *et al*.[35] showed no significant changes among the healthy control athletes from pre- to post-treadmill running. A second study by Baghbani *et al*.[32] recruited 15 healthy female non-athletes (age 16.1±1.8 years) and 15 female (mean age ± SD: 16.1 ± 1.1 years) handball and basketball athletes, competing at a provincial level and involved in sport-specific training for a minimum of seven hours weekly for two years. They measured SEBT before and after induced fatigue involving multiple exertional stations comprised of jogging, sprinting, push-ups, sit-ups, and step-ups. The average of the eight directions of the SEBT balance performance in the non-athlete group significantly decreased after fatigue (p = 0.0003); however, the athlete group had no significant changes in balance performance (p = 0.78). Additionally, the athlete group had significantly better balance performance in pre (p = 0.005) and post-tests (p = 0.0001) when compared to the healthy control counterparts. The third study by Baghbaninaghadehi *et al*.[33] studied 15 female basketball athletes who had four to five practices per week for two years. Fatigue was induced using multiple exertional stations comprised of jogging, sprinting, push-ups, sit-ups, and step-ups. Results concluded no significant difference in the mean deviation of dynamic balance performance of the subjects in eight directions before and after the fatigue protocol. A fourth study by Zech *et al*.[38] fatigued 19 male 1st and 2nd division handball athletes engaged in summer preseason training two to three times per week. Subjects were tested under two fatigue conditions: 1) treadmill running for whole-body fatigue, and 2) unilateral barbell step-ups for localized muscle fatigue. Results showed no fatigue effects for mean SEBT under either fatigue condition. The fifth study by Armstrong *et al*.[28] investigated undergraduate dancers who attended classes a minimum of six hours per week, though level of intensity was not reported. The dancers were fatigued with a Dance Aerobic Fitness Test (DAFT) requiring increasing sequence dance intensity. Mean YBT results revealed insignificant post-DAFT YBT compared to pre-DAFT YBT. The effect sizes for the five aforementioned studies were typically in the low-to-high range: 0.07-0.67 in the anterior direction; 0.05 in the anteromedial direction; 0.09-0.33 in the medial direction; 0.19-0.48 in the posteromedial direction; 0.06-0.41 in the posterior direction; 0.17-0.92 in the posterolateral direction; 0.03-0.57 in the lateral direction; and 1.41 in the anterolateral direction; 0.02-0.24 for the composite of all directions.

Discussion

Our review found that the impact of inducing fatigue on dynamic balance as measured by the SEBT/YBT in the

athletic population was inconsistent. Of the 15 articles comparing recreational and competitive athletes, eight suggest significant effects of various induced fatigue protocols on SEBT/YBT in both groups, while seven suggest insignificant effects of various induced fatigue protocols on SEBT/YBT.

Heterogeneity in the populations studied may in part explain the variety of findings in the relationship between fatigue and dynamic balance. The two types of athletes assembled in this review can be distinguished by their training regimens. When considering recreational athletes, there is a stronger trend supporting significant effects of induced fatigue affecting dynamic balance[19,31,34,36,37]; and only two studies reporting insignificant effects[17,30]. However, in studies involving competitive athletes, the opposite trend was seen: three studies supported the effects of induced fatigue on dynamic balance[29,39,40], whereas five studies negated the effect of induced fatigue on dynamic balance[28,32,33,38]. However, these trends may be explained by the competitive athletes' increased capacity to withstand the deleterious effects of induced fatigue. This may explain why the majority of studies analyzing competitive athletes yield insignificant results, while those analyzing recreational athletes yield otherwise. This assessment of the studies' findings is supported by the results of Baghbani *et al*.[32] , where athletes compared with healthy controls noted that only the latter had significant differences following fatigue.

A second reason that might explain the equivocal findings is the heterogenous types of sports included in single studies. All but three studies including competitive sports were heterogenous. Namely, Baghbaninaghadehi *et al*.[33] studied 15 female basketball athletes, Zech *et al*.[38] studied 19 male handball 1st and 2nd division athletes, and Armstrong *et al*.[28] studied 35 undergraduate dancers. Depending on the requirements of each sport, different balance control strategies may be developed.[6,41,42] Thus, it may be more appropriate to consider a homogenous athlete population in order to avoid confounding the relationship between fatigue and balance by different athletic endeavors.

Finally, a third reason behind the equivocal findings is that laboratory-induced fatigue may not be challenging enough (in method or duration) to alter dynamic balance postural control in these athletes.

This systematic review is the first to consider effects of induced fatigue on the SEBT/YBT in the athletic population. A previous review by Gribble *et al*.[1] investigated the effect of fatigue on dynamic balance but did not focus on the athletic population. Since then, more studies have been published on this topic. Only two of the three studies from the previous review[1] were included in the current review as one of them did not meet the current eligibility criteria.

This systematic review finds the impact of induced fatigue on dynamic balance to be equivocal. Currently, the relevance of considering fatigue as a risk factor for poor dynamic posture control is unclear. Further investigation with greater methodological rigor is required. Future investigators should carefully consider the variations in training regiments, the heterogeneity of the athletic population recruited, and the fatigue protocols. They should utilize adequate sample size with control groups that don't receive fatiguing protocols and assess outcomes over longer temporal intervals. Lastly, they should record any difficulty the subjects encounter while performing the SEBT/YBT post fatigue (i.e. failed attempts) as this may provide important information regarding the effects of fatigue on balance assessments.

Additionally, the majority of studies included in the review are pre-post study design, in which the subjects serve as their own control by measuring a pre-SEBT/YBT assessment prior to the intervention. However, this does not fulfill the criteria of having a control that does not undergo the fatiguing regimen. Only two studies fulfill this criteria: Gribble *et al*.[19] in quasi-experimental study-design used the same subjects but had a control condition where they did not render any fatigue on a different experimental day and; the randomized control trial of Zulfikri *et al*.[37] which had subjects randomly allocated to not receive any fatigue. Utilizing proper control arms better attributes any changes in dynamic balance to the fatiguing protocol used. Moreover, only one study by Johnston *et al*.[29] followed up on their outcome at different intervals: immediately after intervention, 10 minutes after, and 20 minutes after, noting that dynamic balance remained significantly affected at 20 minutes. The implication of fatigue affecting balance longer than 20 minutes may be clinically meaningful within the context of injury and prolonged training hours.

The strengths of this review include a search strategy that was verified through peer review and adapted for a broad set of databases to ensure identification of all pos-

sibly relevant articles. The authors narrowed search terms to include only athletic (and not "generally healthy") populations to draw distinction between the two demographics, which may enhance the direction of future research in this field of knowledge. Additionally, two independent reviewers were used for screening and critical appraisal purposes to minimize error and bias, using a well-accepted and valid set of criteria for critical appraisal of relevant studies.

Limitations of this systematic review include lack of sensitivity analysis on thresholds for low risk of bias studies. Additionally, the definition of athlete in the research question was broad, which may have made it difficult to identify relevancy during the critical appraisal and evidence syntheses process. Lastly, inclusion of studies published solely in English may have excluded relevant studies. However, previous reviews have found that this has not led to biases in the reported results.[43]

Future studies investigating the effects of fatigue on dynamic balance should consider the following suggestions: recruit homogenous athletic populations whose training is well described; conduct a sample size estimation to ensure an adequate numbers of subjects; use non-laboratory fatigue protocols to simulate a more realistic fatigue intervention (especially for the competitive athlete population); use a control group not receiving any fatigue intervention; repeat follow-up outcome measures to assess for longevity of fatigue effects, and report frequency of errors while subjects attempt the SEBT/YBT post-fatigue as an additional outcome.

Conclusions

The impact of induced fatigue on dynamic balance is inconsistent as measured by the SEBT/YBT in the athletic population. In the competitive athletic population, evidence suggests dynamic balance performance remains intact following induced fatigue. However, in the recreational athletic population, evidence suggests dynamic balance performance is significantly impacted by fatigue. Further high-quality athlete specific studies are required to confirm these preliminary findings. Nevertheless, there is no conclusive evidence that induced fatigue affects dynamic balance outcomes in the asymptomatic athletic population.

Practical implications

- Evidence suggests the impact of induced fatigue on dynamic balance in the athletic population is inconsistent.
- Preliminary evidence suggests that competitive athletes' dynamic balance performance is more likely to remain unaffected by induced fatigue.
- Preliminary evidence suggests that recreational athletes' dynamic balance performance is more likely to be affected by induced fatigue.

Key Points

- Evidence suggests the impact of induced fatigue on dynamic balance in the athletic population is inconsistent.
- Preliminary evidence suggests that competitive athletes' dynamic balance performance is more likely to remain unaffected by induced fatigue.
- Preliminary evidence suggests that recreational athletes' dynamic balance performance is more likely to be affected by induced fatigue.

References

1. Gribble PA, Hertel J, Plisky P. Using the star excursion balance test to assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. J Athl Train. 2012;47(3):339-357. doi:10.4085/1062-6050-47.3.08
2. Ringhof S, Stein T. Biomechanical assessment of dynamic balance: specificity of different balance tests. Hum Mov Sci. 2018;58:140-147. doi:10.1016/j.humov.2018.02.004
3. López-Valenciano A, Ayala F, De Ste Croix M, Barbado D, Vera-Garcia FJ. Different neuromuscular parameters influence dynamic balance in male and female football players. Knee Surgery, Sport Traumatol Arthrosc. 2019;27(3):962-970. doi:10.1007/s00167-018-5088-y
4. Choi A, Sim T, Mun JH. Improved determination of dynamic balance using the centre of mass and centre of pressure inclination variables in a complete golf swing cycle. J Sports Sci. 2016;34(10):906-914. doi:10.1080/02640414.2015.1076572
5. Vitale JA, Vitale ND, Cavaleri L, et al. Level- and sport-specific star excursion balance test performance in female volleyball players. J Sports Med Phys Fitness. 2019;59(5):733-742. doi:10.23736/S0022-4707.18.08691-7
6. Herpin G, Gauchard GC, Lion A, Collet P, Keller D, Perrin PP. Sensorimotor specificities in balance control of expert fencers and pistol shooters. J Electromyogr Kinesiol. 2010;20(1):162-169. doi:10.1016/j.jelekin.2009.01.003

7. Hrysomallis C. Balance ability and athletic performance. Sport Med. 2011;41(3):221-232. doi:10.2165/11538560-000000000-00000
8. Grassi A, Alexiou K, Amendola A, et al. Postural stability deficit could predict ankle sprains: a systematic review. Knee Surgery, Sport Traumatol Arthrosc. 2018;26(10):3140-3155. doi:10.1007/s00167-017-4818-x
9. De Noronha M, França LC, Haupenthal A, Nunes GS. Intrinsic predictive factors for ankle sprain in active university students: a prospective study. Scand J Med Sci Sport. 2013;23(5):541-547. doi:10.1111/j.1600-0838.2011.01434.x
10. Hertel J, Braham RA, Hale SA, Olmsted-Kramer LC. Simplifying the star excursion balance test: analyses of subjects with and without chronic ankle instability. J Orthop Sports Phys Ther. 2006;36(3):131-137. doi:10.2519/jospt.2006.36.3.131
11. Plisky PJ, Rauh MJ, Kaminski TW, Underwood FB. Star excursion balance test as a predictor of lower extremity injury in high school basketball players. J Orthop Sports Phys Ther. 2006;36(12):911-919. doi:10.2519/jospt.2006.2244
12. Cloak R, Nevill AM, Clarke F, Day S, Wyon MA. Vibration training improves balance in unstable ankles. Int J Sports Med. 2010;31(12):894-900. doi:10.1055/s-0030-1265151
13. Cloak R, Nevill A, Day S, Wyon M. Six-week combined vibration and wobble board training on balance and stability in footballers with functional ankle instability. Clin J Sport Med. 2013;23(5):384-391. doi:10.1097/JSM.0b013e318291d22d
14. Ekstrand J, Hägglund M, Waldén M. Injury incidence and injury patterns in professional football: the UEFA injury study. Br J Sports Med. 2011;45(7):553-558. doi:10.1136/bjsm.2009.060582
15. Kofotolis ND, Kellis E, Vlachopoulos SP. Ankle sprain injuries and risk factors in amateur soccer players during a 2-year period. Am J Sports Med. 2007;35(3):458-466. doi:10.1177/0363546506294857
16. Powden CJ, Dodds TK, Gabriel EH. The reliability of the star excursion balance test and lower quarter Y-balance test in healthy adults: a systematic review. Int J Sports Phys Ther. 2019;14(5):683-694. doi:10.26603/ijspt20190683
17. Gribble PA, Hertel J, Denegar CR. Chronic ankle instability and fatigue create proximal joint alterations during performance of the star excursion balance test. Int J Sports Med. 2007;28(3):236-242. doi:10.1055/s-2006-924289
18. Gribble PA, Hertel J, Denegar CR, Buckley WE. The effects of fatigue and chronic ankle instability on dynamic postural control. J Athl Train. 2004;39(4):321-329. doi:10.3844/pisp.2010.22.26
19. Gribble PA, Robinson RH, Hertel J, Denegar CR. The effects of gender and fatigue on dynamic postural control. J Sport Rehabil. 2009;18(2):240-257. doi:10.1123/jsr.18.2.240
20. McGowan J, Sampson M, Salzwedel DM, Cogo E, Foerster V, Lefebvre C. PRESS Peer Review of Electronic Search Strategies: 2015 Guideline Statement. J Clin Epidemiol. 2016;75:40-46. doi:10.1016/j.jclinepi.2016.01.021
21. Scottish Intercollegiate Guidelines Network Critical appraisal: notes and checklists. Accessed December 23, 2020. https://www.sign.ac.uk/what-we-do/methodology/checklists/
22. Khairuzzaman MQ. Joanna Briggs Institute (JBI) critical appraisal checklist tool for quasi-experimental studies. 2016;4(1):64-75. Accessed December 23, 2020. https://joannabriggs.org/sites/default/files/2019-05/JBI_Quasi-Experimental_Appraisal_Tool2017_0.pdf
23. Agency for Healthcare Research and Quality (AHRQ) Evidence-Based Practice Centers the USPSTF, the Scottish Intercollegiate Guidelines Network, and the National Health Service Centre for Reviews and Dissemination the CC. Study Quality Assessment Tools – NHLBI, NIH. April. Published 2014. Accessed December 23, 2020. https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools
24. Cohen J. Statistical Power Analysis for the Behavioral Sciences. Second Edi. New York: Lawrence Erlbaum Associates,; 1988.
25. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ. 2009;339(7716):332-336. doi:10.1136/BMJ.B2535
26. Mirmoezzi M, Taheri M. Effects of closed and open kinetic chain exercise induced-localized fatigue on static and dynamic balance in trained individuals. Asian J Sports Med. 2018;9(4). doi:10.5812/asjsm.80069
27. Valldecabres R, De Benito AM, Littler G, Richards J. An exploration of the effect of proprioceptive knee bracing on biomechanics during a badminton lunge to the net, and the implications to injury mechanisms. PeerJ. 2018;2018(12). doi:10.7717/peerj.6033
28. Armstrong R, Brogden CM, Milner D, Norris D, Greig M. The nifluence of fatigue on star excursion balance test performance in dancers. J Dance Med Sci. 2018;22(3):142-147. doi:10.12678/1089-313X.22.3.142
29. Johnston W, Dolan K, Reid N, Coughlan GF, Caulfield B. Investigating the effects of maximal anaerobic fatigue on dynamic postural control using the Y-Balance Test. J Sci Med Sport. 2018;21(1):103-108. doi:10.1016/j.jsams.2017.06.007
30. Cavanaugh MT, Quigley PJ, Hodgson DD, Reid JC, Behm DG. Kinesiology tape or compression sleeve applied to the thigh does not improve balance or muscle activation before or following fatigue. J Strength Cond Res. 2016;30(7):1992-2000. doi:10.1519/JSC.0000000000001297

31. McMullen KL, Cosby NL, Hertel J, Ingersoll CD, Hart JM. Lower extremity neuromuscular control immediately after fatiguing hip-abduction exercise. J Athl Train. 2011;46(6):607-614. doi:10.4085/1062-6050-46.6.607
32. Baghbani F, Woodhouse LJ, Gaeini AA. Dynamic postural control in female athletes and nonathletes after a whole-body fatigue protocol. J Strength Cond Res. 2016;30(7):1942-1947. doi:10.1519/JSC.0000000000001275
33. Baghbaninaghadehi F, Ramezani AR, Hatami F. The effect of functional fatigue on static and dynamic balance in female athletes. Int Sport J. 2013;14(2):77-85. Accessed December 23, 2020. https://journals.co.za/content/ismj/14/2/EJC138122?fromSearch=true
34. Hosseinimehr SH, Daneshmandi H, Norasteh AA. The effects of fatigue and chronic ankle instability on dynamic postural control. Physics International. 2010;1(1):22-26. doi: 10.3844/pisp.2010.22.26
35. Steib S, Zech A, Hentschke C, Pfeifer K. Fatigue-induced alterations of static and dynamic postural control in athletes with a history of ankle sprain. J Athl Train. 2013;48(2):203-208. doi:10.4085/1062-6050-48.1.08
36. Sarshin A, Mohammadi S, Shahrabad H, Sedighi M. The effects of functional fatique on dynamic postural control of badminton players. Biol Exerc. 2011;7(2).
37. Zulfikri N, Justine M. Effects of Kinesio® Taping on dynamic balance following fatigue: a randomized controlled trial. Phys Ther Res. 2017;20(1):16-22. doi:10.1298/ptr.e9887
38. Zech A, Steib S, Hentschke C, Eckhardt H, Pfeifer K. Effects of localized and general fatigue on static and dynamic postural control in male team handball athletes. J Strength Cond Res. 2012;26(4):1162-1168. doi:10.1519/JSC.0b013e31822dfbbb
39. Whyte E, Burke A, White E, Moran K. A high-intensity, intermittent exercise protocol and dynamic postural control in men and women. J Athl Train. 2015;50(4):392-399. doi:10.4085/1062-6050-49.6.08
40. Steib S, Hentschke C, Welsch G, Pfeifer K, Zech A. Effects of fatiguing treadmill running on sensorimotor control in athletes with and without functional ankle instability. Clin Biomech. 2013;28(7):790-795. doi:10.1016/j.clinbiomech.2013.07.009
41. Lion A, Gauchard GC, Deviterne D, Perrin PP. Differentiated influence of off-road and on-road cycling practice on balance control and the related-neurosensory organization. J Electromyogr Kinesiol. 2009;19(4):623-630. doi:10.1016/j.jelekin.2008.03.008
42. Perrin P, Deviterne D, Hugel F, Perrot C. Judo, better than dance, develops sensorimotor adaptabilities involved in balance control. Gait Posture. 2002;15(2):187-194. doi:10.1016/S0966-6362(01)00149-7
43. Johnson AP, Sikich NJ, Evans G, et al. Health technology assessment: a comprehensive framework for evidence-based recommendations in Ontario. Int J Technol Assess Health Care. 2009;25(2):141-150. doi:10.1017/S0266462309090199

Appendix 1.
Search strategy

MEDLINE SEARCH STRATEGY – May 28, 2019	
1.	MH Athletes
2.	MH Sports +
3.	TI athlete* or AB athlete*
4.	TI sport* or AB sport*
5.	TI archery* or AB archery*
6.	TI badminton* or AB badminton*
7.	TI biath* or AB biath*
8.	TI bmx* or AB bmx*
9.	TI bobsle* or AB bobsle*
10.	TI bowling* or AB bowling* or TI bowler* or AB bowler*
11.	TI boxing* or AB boxing* or TI boxer* or AB boxer*
12.	TI basketball* or AB basketball*
13.	TI baseball* or AB baseball*
14.	TI canoe* or AB canoe*
15.	TI cricket* or AB cricket*
16.	TI curling* or AB curling*
17.	TI cycling* or AB cycling* or TI cyclist* or AB cyclist*
18.	TI diving* or AB diving* or TI diver or AB diver or TI divers or AB divers
19.	TI equest* or AB equest*
20.	TI fencing* or AB fencing* or TI fencer* or AB fencer*
21.	TI golf* or AB golf*
22.	TI football* or AB football*
23.	TI gymnast* or AB gymnast*
24.	TI hockey* or AB hockey*
25.	TI jiu jitsu* or AB jiu jitsu* or TI jiu-jitsu* or AB jiu-jitsu* or TI ju-jitsu* or AB ju-jitsu*
26.	TI jogging* or AB jogging* or TI jogger* or AB jogger*
27.	TI judo* or AB judo*
28.	TI karate* or AB karate*
29.	TI kayak* or AB kayak*
30.	TI kendo* or AB kendo*
31.	TI kung fu* or AB kung fu* OR TI kung-fu* or AB kung-fu*
32.	TI lacrosse* or AB lacrosse*
33.	TI luge* or AB luge*
34.	TI martial art* or AB martial art*
35.	TI mountaineer* or AB mountaineer*
36.	TI qigong* or AB qigong*
37.	TI racquet* or AB racquet*
38.	TI ringette* or AB ringette*
39.	TI rower* or AB rower* or TI rowing* or AB rowing*
40.	TI rugby* or AB rugby*
41.	TI runner* or AB runner*
42.	TI running* or AB running*

APPENDIX 1 – MEDLINE SEARCH STRATEGY – May 28, 2019 – continued	
43.	TI sailing* or AB sailing* or TI sailor* or AB sailor*
44.	TI soccer* or AB soccer*
45.	TI skiing* or AB skiing* or TI skier* or AB skier*
46.	TI skating* or AB skating* or TI skater* or AB skater*
47.	TI sledding* or AB sledding*
48.	TI snowboard* or AB snowboard*
49.	TI softball* or AB softball*
50.	TI speed-skat* or AB speed-skat*
51.	TI squash* or AB squash*
52.	TI swim* or AB swim*
53.	TI taekwondo* or AB taekwondo*
54.	TI tai ji or AB tai ji or TI tai chi* or AB tai chi* or TI taiji* or AB taiji* or TI taichi* or AB taichi*
55.	TI tennis* or AB tennis*
56.	TI (track n2 field) or AB (track n2 field)
57.	TI triath* or AB triath*
58.	TI volleyball* or AB volleyball*
59.	TI wakeboard* or AB wakeboard*
60.	TI water polo* or AB water polo*
61.	TI wrestling* or AB wrestling* or TI wrestler* or AB wrestler*
62.	TI weightlift* or AB weightlift* or TI weight lift* or AB weight lift*
63.	TI walking* or AB walking*
64.	**1-63/OR [** sports]**
65.	TI star excursion* or AB star excursion* or TI star-excursion* or AB star-excursion*
66.	TI y-balance* or AB y-balance*
67.	**TI** y balance* or AB y balance*
68.	TI y-test* or AB y-test*
69.	TI star n2 test* or AB star n2 test*
70.	TI ybt* or AB ybt*
71.	TI sebt or AB sebt
72.	MH Postural Balance
73.	TI dynamic* n2 postural balance* or AB dynamic* n2 postural balance*
74.	TI dynamic* n2 balance test* or AB dynamic* n2 balance test*
75.	TI postural balance n2 test*
76.	**65-76 / OR [** star-excursion test]**
77.	MH Fatigue
78.	MH Muscle Fatigue
79.	TI fatigu* or AB fatigu*
80.	**77-80/ OR [**fatigue]**
81.	64 AND 76 AND 80
82.	LIMIT 81 English language

APPENDIX 1 – SportDiscus Search Strategy	
1.	DE Athletes +
2.	DE Sports +
3.	TI athlete* or AB athlete*
4.	TI sport* or AB sport*
5.	TI boxing* or AB boxing* or TI boxer* or AB boxer*
6.	TI basketball* or AB basketball*
7.	TI baseball* or AB baseball*
8.	TI cycling* or AB cycling* or TI cyclist* or AB cyclist*
9.	TI diving* or AB diving* or TI diver or AB diver or TI divers or AB divers
10.	TI fencing* or AB fencing* or TI fencer* or AB fencer*
11.	TI golf* or AB golf*
12.	TI football* or AB football*
13.	TI gymnast* or AB gymnast*
14.	TI hockey* or AB hockey*
15.	TI jiu jitsu* or AB jiu jitsu* or TI jiu-jitsu* or AB jiu-jitsu* or TI ju-jitsu* or AB ju-jitsu*
16.	TI jogging* or AB jogging* or TI jogger* or AB jogger*
17.	TI judo* or AB judo*
18.	TI karate* or AB karate*
19.	TI kayak* or AB kayak*
20.	TI kendo* or AB kendo*
21.	TI kung fu* or AB kung fu* OR TI kung-fu* or AB kung-fu*
22.	TI martial art* or AB martial art*
23.	TI mountaineer* or AB mountaineer*
24.	TI qigong* or AB qigong*
25.	TI racquet* or AB racquet*
26.	TI rugby* or AB rugby*
27.	TI runner* or AB runner*
28.	TI running* or AB running*
29.	TI soccer* or AB soccer*
30.	TI skiing* or AB skiing* or TI skier* or AB skier*
31.	TI skating* or AB skating* or TI skater* or AB skater*
32.	TI swim* or AB swim*
33.	TI taekwondo* or AB taekwondo*
34.	TI tai ji or AB tai ji or TI tai chi* or AB tai chi* or TI taiji* or AB taiji* or TI taichi* or AB taichi*
35.	TI tennis* or AB tennis*
36.	TI (track n2 field) or AB (track n2 field) track*
37.	TI volleyball* or AB volleyball*
38.	TI water polo* or AB water polo*
39.	TI wrestling* or AB wrestling* or TI wrestler* or AB wrestler*
40.	TI weightlift* or AB weightlift* or TI weight lift* or AB weight lift*
41.	TI walking* or AB walking*
42.	**1-41 /OR**
43.	DE Exercise Test

APPENDIX 1 – SportDiscus Search Strategy – continued	
44.	TI star excursion* or AB star excursion* or TI star-excursion* or AB star-excursion*
45.	TI y-balance* or AB y-balance*
46.	TI y balance* or AB y balance*
47.	TI y-test* or AB y-test*
48.	TI star n2 test* or AB star n2 test*
49.	TI ybt* or AB ybt*
50.	TI sebt or AB sebt
51.	**43-50 / OR**
52.	DE Fatigue
53.	TI fatigu* or AB fatigu*
54.	**52-53/ OR**
55.	DE Posture
56.	TI dynamic* n2 postural balance* or AB dynamic* n2 postural balance*
57.	TI dynamic* n2 balance test* or AB dynamic* n2 balance test*
58.	**55-57/OR**
59.	42 AND 51 AND 54
60.	42 AND 54 AND 58
61.	59 OR 60
62.	LIMIT 61 English language

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Characteristics of adolescent athletes seeking early versus late care for sport-related concussion

Darrin Germann, BSc (Hons), DC[1]
Carol Cancelliere, DC, PhD[2,3]
Mohsen Kazemi, RN, DC, FRCCSS(C), FCCPOR(C), MSc, PhD[1]
Cameron Marshall, DC, FRCCSS(C)[4]
Sheilah Hogg-Johnson, MMath, PhD[2,3,5,6]

Objectives: *1) To determine which characteristics of adolescent athletes with SRC are associated with 'early' versus 'late' presentation for multimodal treatment; 2)*

Commotion cérébrale liée au sport (CCLS) : caractéristiques des athlètes adolescents consultant rapidement et celles des adolescents qui consultent tardivement
Objectifs : *1) Trouver les caractéristiques des athlètes adolescents ayant subi une CCLS qui sont associées à la*

[1] Department of Graduate Studies, Canadian Memorial Chiropractic College
[2] Faculty of Health Sciences, Ontario Tech University
[3] Institute for Disability and Rehabilitation Research, Ontario Tech University and Canadian Memorial Chiropractic College
[4] Complete Concussion Management Inc.
[5] Department of Research and Innovation, Canadian Memorial Chiropractic College
[6] Dalla Lana School of Public Health, University of Toronto

Corresponding author: Darrin Germann, Canadian Memorial Chiropractic College, 6100 Leslie St., Toronto, Ontario, M2H 3J1
Tel: 905-435-6074
E-mail: germann.darrin@gmail.com

Author contributions: Drs. Germann and Hogg-Johnson had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.
Concept and design: All authors. *Acquisition, analysis, or interpretation of data*: All authors.
Drafting of the manuscript: Germann, Hogg-Johnson. *Critical revision of the manuscript for important intellectual content*: All authors. *Statistical analysis*: Germann, Hogg-Johnson.

Conflict of Interest Disclosures: Dr. Marshall is the founder and current president of Complete Concussion Management Inc. (CCMI) but did not receive any personal fees in relation to the conduct of this study. Dr. Germann has completed the CCMI Healthcare Practitioner Certification Course but did not receive any personal fees in relation to the conduct of this study. No other disclosures were reported. No funding was provided for the completion of this study. Carol Cancelliere holds a Research Chair in Knowledge Translation in the Faculty of Health Sciences, Ontario Tech University, which is funded by the Canadian Chiropractic Research Foundation. The content of this report is solely the responsibility of the authors and does not necessarily represent the official view of CMCC, Ontario Tech University Institute for Disability and Rehabilitation Research at Ontario Tech University and Canadian Memorial Chiropractic College, nor the University of Toronto.

to build a propensity score to investigate the effects of treatment timing during the management of SRCs.

Methods: *Associations between early (0-7 days) versus late (8-28 days) presentation for treatment and pre-specified sociodemographic, pre-injury and injury characteristics were investigated in a historical cohort study of 2949 multi-sport athletes across Canada aged 12-18 years diagnosed with a SRC in community-based healthcare clinics.*

Results: *Early presentation was associated with being male, completing a pre-injury baseline assessment, and responding 'yes' or 'no' to having a diagnosed learning disability. Older athletes who reported previous SRCs were less likely to present early. The propensity score demonstrated an area under the curve of 0.71 (95% CI, 0.69 to 0.73).*

Conclusions: *Male athletes with a completed baseline assessment were more likely to seek early treatment following a SRC, and older athletes who reported a greater number of previous SRCs were less likely to present early. External validation of the propensity score is needed before examining the impact of treatment timing on adolescent athlete recovery outcomes.*

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KEY WORDS: chiropractic, concussion, mild traumatic brain injury, multi-modal treatment, rehabilitation, sport related concussion

consultation précoce et à une consultation tardive; 2) établir *un score de propension pour* étudier *les effets du moment du traitement pendant la prise en charge de la CCLS.*

Méthodologie : *Les liens entre la consultation précoce (de 0 à 7 jours) et la consultation tardive (de 8 à 28 jours) et les caractéristiques sociodémographiques, les caractéristiques avant la blessure et les caractéristiques après des blessure prédéterminées ont* été *examinés au cours d'une* étude de *cohorte historique menée auprès de 2 949 adolescents multisports répartis dans toutes les régions du Canada,* âgés *de 12 à 18 ans, chez lesquels une CCLS avait* été *diagnostiquée dans des cliniques de santé communautaires.*

Résultats : *La consultation précoce a* été *associée au sexe masculin, à une* évaluation *de départ avant la blessure et à la présence ou à l'absence d'un trouble de l'apprentissage. Les athlètes plus* âgés *ayant signalé des CCLS antérieures* étaient *moins susceptibles de consulter précocement. Le score de propension a démontré une aire sous la courbe de 0,71 (IC à 95 % : 0,69 à 0,73).*

Conclusions : *Les athlètes masculins ayant subi une* évaluation *de départ* étaient *plus susceptibles de consulter précocement après une CCRS alors que les athlètes* âgés *ayant déclaré un plus grand nombre de CCRS antérieures* étaient *moins susceptibles de consulter précocement. Une validation externe du score de propension serait nécessaire avant d'examiner l'effet du moment de la consultation sur les résultats de récupération chez les athlètes adolescents.*

(JCCA. 2021;65(3):260-274)

MOTS CLÉS : chiropratique, commotion, lésion cérébrale traumatique légère, traitement multimodal, réadaptation, commotion liée au sport

Introduction

Sport-related head and neck injuries, including concussions, are common in young athletes.[1,2] In a recent survey of 13,000 adolescents (Grade 8, 10, and 12) in the US, 19.5% reported having at least one concussion in their lifetime.[3] However, this figure is thought to be grossly underestimated.[4] Sports with the highest rates of concussion for athletes less than 18 years old are Rugby (4.18/1000 athlete exposures (AEs)), Ice hockey (1.20/1000 AEs), American football (0.53/1000 AEs).[5]

The symptoms associated with sport-related concussion (SRC) may be of cognitive, visual, vestibular, physiological, or cervical spine origin.[6–9] Such symptoms can have a significant negative impact on an athlete's educational and sport-related activities and aspirations. Recent evidence suggests that greater symptom severity is associated with

higher levels of concern for reduced academic performance, and more school-related problems in adolescents.[10] It has also been shown that high school students not yet recovered from concussion report significantly more perceived adverse academic effects than younger students suffering from SRC.[10] The typical recovery time for adolescents with concussion is already greater than that seen in adults[5], at four weeks [8,11] compared to the usual 10 to 14 days seen in adults[11]. This further reinforces the need for greater SRC research in this population.

Emerging evidence from observational studies suggests that favourable recovery outcomes are obtained through the use of individualized, multi-modal plans of management [6,8,9] particularly if initiated early after concussion versus later[12,13]. However, when the timing of treatment initiation is of primary interest, a phenomenon called Immortal Time Bias – "a span of time in the observation or follow-up period of a cohort during which the outcome under study could not have occurred"[14], can lead to a systematic under-or-overestimation of an intervention's true influence on the outcome of interest. Therefore, the apparent treatment effects seen in these previous observational studies may, in part, be due to characteristic or prognostic differences between the athletes who present for treatment earlier versus later.

Propensity scores provide a methodology for observational studies that may be useful in controlling for systematic differences among participants by making those participants within the exposed/experimental and non-exposed/control groups more directly comparable.[15] Further, such methodology may allow for a greater number of covariates to be adjusted for in the model.

There are currently no studies that describe the association between patient characteristics and the timing of patient presentation for treatment, nor completely describe a propensity score that can be used to balance subjects on such characteristics in future observational studies. We hypothesized that those with a greater number of previous concussions would present for care earlier, and that individuals with a previous diagnosis of an anxiety disorder, depression, or with a history of headache would present for treatment later. Similarly, we expected that athletes who suffered loss of consciousness (LOC), post-traumatic amnesia (PTA), or post-traumatic seizures (PTS) at the time of their concussion would also present at a later time[12], as they may initially be sent to the hospital rather than a treatment clinic.

This study represents the initial step in a line of research aimed at better understanding the relationship between timing of treatment and athlete recovery outcomes. Therefore, our objectives were to 1) determine which pre-determined characteristics of adolescent athletes (12-18 years old) with SRC are associated with 'early' versus 'late' presentation to concussion management clinics for multimodal treatment; 2) to build a propensity score to investigate the effects of treatment timing during the management of SRCs in future studies. This study is reported in compliance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement.[16]

Methods

Study design and setting

We conducted a historical cohort study using a concussion management database containing electronic healthcare records from community-based healthcare clinics in Canada. The Complete Concussion Management Inc. (CCMI) database is an electronic medical record system used by healthcare providers who undergo additional evidence-based training in concussion management provided by CCMI to document patient characteristics and baseline testing (e.g., demographics, geographic location, sport participation, and pre-injury conditions), post-injury concussion assessments (e.g., validated patient-reported outcome measures such as the Post-Concussion Symptom Scale (PCSS) score, and physical examination findings), and clinical notes. Ethical approval was obtained from the Canadian Memorial Chiropractic College (CMCC) research ethics board (Certificate #1907X02).

Participants

We investigated the records of athletes who sought care for a SRC at a community healthcare clinic between January 2017 and August 2019. Eligible participants were male and female athletes between 12-18 years of age. We excluded participants with concussions/mild traumatic brain injuries that were not associated with sport (i.e. motor vehicle accidents, workplace injuries, blast injuries), those with moderate or severe traumatic brain injuries, and those presenting later than 28 days post-concussion.

Sport-Related Concussion (SRC) case definition

SRC was defined according to the Berlin Consensus

Statement on Concussion in Sport.[11] SRC is the onset of short-lived impairments of neurological function following a direct blow to the head, face, neck, or elsewhere on the body with an impulsive force transmitted to the head.[11]

Data extraction procedure

De-identified data was extracted by independent data management personnel to a password protected spreadsheet and imported into a data analysis software (SPSS Statistics, version 26).

Primary outcome

Our outcome of interest was the time to presentation for care defined as the number of days between the self-reported date of the athlete's concussion and the date of their initial assessment at a healthcare clinic. A presentation period of 0-7 days post-injury was selected to define the 'early' group to remain consistent with the most recent published literature[12], while a period of 8-28 days defined the 'late' group[12] considering that most concussive symptoms in adolescents resolve within one month[11].

Independent variables

We selected sixteen variables *a priori* based on the scientific literature and clinical knowledge including demographic and pre-injury information (i.e. age, sex, geographic location, number of previous SRCs, completion of a baseline assessment, or a history of anxiety, depression, headache, learning disability, or ADD/ADHD), injury characteristics (i.e. sport played at the time of injury, location of impact on the head or body), and immediate post-concussion features (i.e. loss of consciousness, post-traumatic amnesia, post-traumatic seizures).

Sample size

In order to estimate a minimum sample size, we applied a general statistical rule of thumb for logistic regression described by Harrell, requiring at least 10 events and non-events per independent variable (i.e., 160 events and 160 non-events).[17]

Analysis

We analyzed the data descriptively using frequencies or means (standard deviations (SD)) and used two-tailed t-tests and Pearson χ^2 tests to analyze the relationships between the independent variables and outcome group.

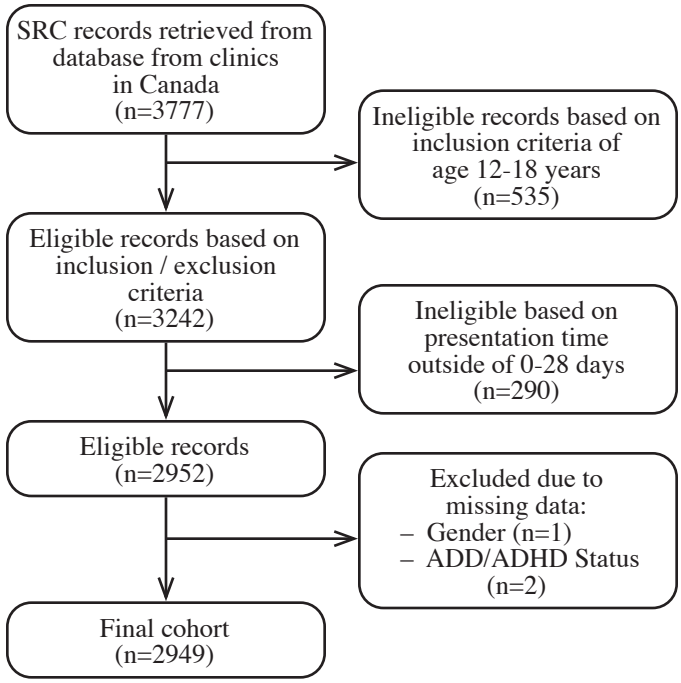

Figure 1.
Cohort Assembly. ADD/ADHD = Attention deficit disorder / attention deficit hyperactivity disorder; SRC = Sport-related concussion;

A multiple logistic regression model was fit with all the pre-determined independent variables. Associations were expressed as odds ratios with 95% confidence intervals.

The predicted probabilities of an athlete presenting early vs. late obtained from the multiple logistic regression was used to develop a propensity score.[15] Quintile stratification by propensity score was then used to examine whether there was a balance of early and late presenters within quintiles.[11] Overall performance of the propensity score model was gauged by calculating the Area Under the Curve (AUC) and model-fit assessed via the Hosmer & Lemeshow Goodness-of-Fit test.[18]

Results

Cohort Assembly & Missing Data

A total of 3777 records were retrieved from the database, and 2949 patient records were included in the final analysis (Figure 1). Less than 10% of the retrieved records had missing data (225/2949, 7.5%). Three records (0.1%) with

Table 1.
Participant characteristics

Characteristic	Count (% of Column)		
	Early Group (N = 2163/2949; 73.3%)	**Late Group (N = 786/2949; 26.7%)**	**Early vs. Late Groups (P-Value)a**
Age (years), (mean ±SD)			
Mean ± SD	14.30 ± 1.45	14.56 ± 1.43	<.001
Sex			
Male	1257 (58.1)	402 (51.1)	.001
Province			
Atlantic Provinces	224 (10.4)	71 (9.0)	<.001
Quebec	311 (14.4)	150 (19.1)	
Ontario	784 (36.2)	287 (36.5)	
Saskatchewan	305 (14.2)	89 (11.3)	
Alberta	166 (7.7)	55 (7.0)	
British Columbia	373 (17.2)	134 (17.0)	
Time to Clinic Presentation (days)			
Mean ± SD	3.12 ± 1.84	14.07 ± 5.48	<.001
Completed Baseline			
Yes	911 (42.1)	163 (20.7)	<.001
History of Diagnosed Anxiety			
Yes	164 (7.6)	69 (8.8)	.287
History of Diagnosed Depression			
Yes	52 (1.3)	28 (6.6)	.087
History of Diagnosed Headache			
Yes	21 (1.0)	11 (1.4)	.321
History of Diagnosed Learning Disability			
Yes	106 (4.9)	43 (5.5)	<.001
No	1992 (92.1)	631 (80.3)	
Missing	65 (3.0)	112 (14.2)	
History of Diagnosed ADD/ADHD:			
ADD	29 (1.3)	18 (2.3)	.089
ADHD	76 (3.5)	35 (4.5)	
None	2058 (95.1)	733 (93.3)	
Number of Previous self-reported SRCs:			
Mean ± SD	0.54 ± 0.83	0.67 ± 0.94	.001
0	1358 (62.8)	458 (58.3)	
1	530 (24.5)	196 (24.9)	
2	179 (8.3)	68 (8.7)	
≥3	96 (4.4)	64 (8.1)	
Loss of Consciousness:			
Yes	115 (5.3)	55 (7.0)	.173
No	1912 (88.4)	688 (87.5)	
Unsure	136 (6.3)	43 (5.5)	
Post-Traumatic Amnesia:			
Anterograde	162 (7.5)	69 (8.8)	.152
Retrograde	150 (6.9)	67 (8.5)	
None	1851 (85.6)	650 (82.7)	
Post-Traumatic Seizures:			
Yes	24 (1.1)	9 (1.1)	.595
No	2103 (97.2)	768 (97.7)	
Missing	36 (1.7)	9 (1.1)	

[a] Two-sided t-test or chi-square
ADD/ADHD = Attention Deficit Disorder / Attention Deficit Hyperactivity Disorder; LOC = Loss of Consciousness; PCS = Post-Concussion Syndrome; PCSS = Post-Concussion Symptom Score; SD = Standard Deviation; SRC(s) = Sport Related Concussion(s); WAD = Whiplash Associated Disorder.

Table 1.
Participant characteristics – Continued

Characteristic	Count (% of Column)		
	Early Group (N = 2163/2949; 73.3%)	Late Group (N = 786/2949; 26.7%)	Early vs. Late Groups (P-Value)a
PCSS Score (/132)			
Mean ± SD	26.6 ± 21.8	25.35 ± 21.25	.167
PCSS Symptom Number (/22)			
Mean ± SD	10.12 ± 6.098	9.80 ± 6.37	.212
Mechanism of Injury:			
Hockey	916 (42.3)	282 (35.9)	<.001
Soccer	275 (12.7)	102 (13.0)	
Football	213 (9.8)	58 (7.4)	
Rugby	128 (5.9)	64 (8.1)	
Basketball	126 (5.8)	47 (6.1)	
Lacrosse	86 (4.0)	19 (2.4)	
Skiing	60 (2.8)	40 (5.1)	
Volleyball	60 (2.8)	23 (2.9)	
Cheerleading	55 (2.5)	24 (3.1)	
Ringette	50 (2.3)	17 2.2)	
Martial Arts	39 (1.8)	24 (3.1)	
Watersport	31 (1.4)	9 (1.1)	
Skating	17 (0.79)	9 (1.1)	
Gymnastics	18 (0.83)	9 (1.1)	
Baseball	15 (0.69)	10 (1.3)	
Cycling	8 (0.37)	8 (1.0)	
Dance	9 (0.42)	6 (0.76)	
Dodgeball	6 (0.28)	6 (0.76)	
Equestrian	7 (0.32)	2 (0.25)	
Other	44 (2.0)	27 (3.4)	
Location of Impact – Head			
Crown	28 (1.3)	12 (1.5)	.630
Frontal Bone – Left	436 (20.2)	164 (20.9)	.673
Frontal Bone – Right	545 (25.2)	199 (25.3)	.946
Temporal Bone – Left	258 (11.9)	90 (11.5)	.722
Temporal Bone – Right	265 (12.3)	92 (11.7)	.687
Parietal Bone – Left	97 (4.5)	45 (5.7)	.164
Parietal Bone – Right	130 (6.0)	51 (6.5)	.632
Occipital Bone – Left	468 (21.6)	145 (18.4)	.059
Occipital Bone – Right	492 (22.7)	162 (20.6)	.217
Location of Impact – Body			
Front	191 (8.8)	79 (10.1)	.310
Rear	218 (10.1)	62 (7.9)	.073
Left Side	130 (6.0)	36 (4.6)	.136
Right Side	143 (6.6)	52 (6.6)	.996
Diagnosis at Time of Assessment (community clinic):			
WAD	861 (39.8)	184 (23.4)	<.001
Chronic WAD	0 (0.00)	34 (4.3)	<.001
PCS	1 (0.05)	75 (9.5)	<.001
SRC with LOC	131 (6.0)	62 (7.9)	.075
SRC without LOC	1645 (76.1)	521 (66.3)	<.001
None	230 (10.6)	119 (15.1)	.001
Other	54 (2.5)	24 (3.1)	.405
Not Provided	21 (0.97)	5 (0.64)	.390

[a] Two-sided t-test or chi-square
ADD/ADHD = Attention Deficit Disorder / Attention Deficit Hyperactivity Disorder; LOC = Loss of Consciousness; PCS = Post-Concussion Syndrome; PCSS = Post-Concussion Symptom Score; SD = Standard Deviation; SRC(s) = Sport Related Concussion(s); WAD = Whiplash Associated Disorder.

small amounts of missing data (gender = 1 record, ADD/ADHD status = 2 records) that interfered with cross-tabulation analyses were removed. For two predictors with larger amounts of missing data (post-traumatic seizures = 45 (1.5%) records, and history of learning disability = 177 (6%) records) that did not interfere with statistical testing, missing was maintained as a category and they were included in the model with three categories – Yes, No and Missing.

Participants

Participants were aged 14.37 (± 1.45) years (Table 1). The majority were male (n = 1659, 56.3%), and evaluated in clinics located in Ontario (n = 1071, 36.3%). A total of 2163 participants (73.3%) presented to the clinic within seven days of their injury (early group), whereas 786 (26.7%) presented 8-28 days after their injury (late group). Those in the early group presented to the clinic 3.12 (± 1.8) days post-injury, versus 14.07 (± 5.5) days in the late group.

A completed baseline assessment was recorded for 1074 (36.4%) of the participants. Participants reported previously diagnosed anxiety (233, 7.9%), depression (80, 2.7%), headache (32, 1.1%), learning disability (149, 5.1%), ADD (47, 1.6%), and ADHD (111, 3.8%). The majority reported no previous SRCs (1816, 61.6%).

Most participants reported no loss of consciousness (n = 2600, 88.2%), no post-traumatic seizure (n = 2871, 97.4%), and no post-traumatic amnesia (n = 2501, 84.8%), but those who did experienced similar rates of anterograde and retrograde amnesia.

Participants had a mean Post-Concussion Symptom Scale (PCSS) score of 26.6 ± 21.66 / 132 and reported an average of 10.03 ± 6.17 / 22 possible symptoms. Most SRCs were sustained playing hockey (n = 1198, 40.6%), followed by soccer (n = 377, 12.8%), football (n = 271, 9.2%), and rugby (n = 192, 6.5%).

Factors associated with early versus late presentation time

Early presentation was associated with being male (OR,

Table 2.
Participant and injury characteristics associated with treatment presentation time from multiple logistic regression model

Characteristic	Odds Ratio	95% Confidence Interval	P Value
Male (Ref = female)	1.24	1.00 – 1.52	.047
Completed Baseline (Ref = no)	2.58	2.10 – 3.18	<.001
Older Age	0.93	0.87 – 0.99	.020
Greater Number of Previous self-reported SRCs	0.83	0.75 – 0.92	<.001
History of Diagnosed Anxiety (Ref = no)	1.04	0.74 – 1.46	.833
History of Diagnosed Depression (Ref = no)	0.90	0.53 – 1.53	.691
History of Diagnosed Headache (Ref = no)	0.92	0.41 – 2.04	.834
History of Diagnosed Learning Disability (Ref = missing)			
No	5.34	3.80 – 7.50	<.001
Yes	4.98	2.99 – 8.31	<.001
History of Diagnosed ADD/ADHD (Ref = none)			
ADD	0.61	0.31 – 1.17	.137
ADHD	0.70	0.44 – 1.09	.110
Loss of Consciousness (Ref = no)			
Unsure	1.17	0.79 – 1.72	.441
Yes	0.94	0.64 – 1.39	.768
Post-Traumatic Amnesia (Ref = retrograde)			
Anterograde	1.06	0.69 – 1.64	.783
None	1.20	0.85 – 1.68	.303
Post-Traumatic Seizures (Ref = no)			
No	0.62	0.27 – 1.41	.252
Yes	0.79	0.25 – 2.56	.696

ADD/ADHD = Attention Deficit Disorder / Attention Deficit Hyperactivity Disorder; Ref = Reference value used in logistic regression; SRCs = Sport Related Concussions; P-values of characteristics with significant associations are bolded. **NOTE**: Non-significant (p >.05) characteristics not reported in the table include – Province, location of impact on the head and body, and sport / mechanism of injury with the exception of Skiing which was the only sport significantly associated with presentation time (OR, 0.39 [95% CI, 0.16 – 0.99]; p<.046).

1.24 [95% CI, 1.00 – 1.52]), completing a pre-injury baseline assessment (OR, 2.58 [95% CI, 2.10 – 3.18]), and responding (vs. not responding) to having a diagnosed learning disability – whether 'yes' (OR, 4.98 [95% CI, 2.99 – 8.30] or 'no' (OR, 5.34 [95% CI, 3.80 – 7.50]) (Table 2).

Older adolescent athletes were less likely to present early (OR, 0.93 [95% CI, 0.87 – 0.99]), as were those who had sustained a greater number of previous SRCs (OR, 0.83 [95% CI, 0.75 – 0.92]). Reports of prior diagnoses of anxiety, depression, headache, or ADD/ADHD were not significantly associated with presentation time. The same was true for reports of loss of consciousness, post-traumatic amnesia, post-traumatic seizure, and location of impact on the head or body. The type of sport being played at the time of injury was also not associated with presentation time, except for snow skiing, which was associated with late presentation (OR, 0.39 [95% CI, 0.16 – 0.99]).

The propensity score classified patients as early vs. late (AUC = 0.71 [95% CI, 0.69 – 0.73]; Hosmer and Lemeshow Goodness-of-Fit $\chi^2 = 5.23$, p = 0.73) (Table 3). Figure 2 presents side-by-side boxplots of early versus late presenters by quintile of propensity score. The plot shows good overlap of distribution of propensity score between early and late presenters indicating the propensity score achieves good balance of covariates between the two groups. Appendix 1 further demonstrates how balance of the included covariates is achieved when stratified across quintiles.

Discussion

We determined baseline patient and injury characteristics associated with time to treatment presentation for SRC among 12-18-year-old athletes seeking care from Canadian concussion clinics. Our propensity score demonstrated modest ability (AUC = 0.71; 95% CI, 0.69 – 0.73) to classify participants as either early or late presenters.

Our results indicated that males were more likely to present to the clinic early compared to females. The association between male sex and early presentation for care was unexpected, as current research suggests that adolescent males are less likely than females to report concussion symptoms[19,20], and generally have more negative perceptions about the consequences of symptom reporting[19]. It is possible that a delay in symptom reporting would result in a later presentation for treatment, but this was not demonstrated in our data. Athletes with a completed baseline assessment were approximately 2.6 times more likely to present early than those without a completed baseline. This finding aligns with our hypothesis, as athletes who have previously established relationships with

Table 3.
Propensity model performance measures

Test			
Overall Model Evaluation	AUC (95% CI)		
	0.71 (0.69 – 0.73)		
Hosmer & Lemeshow Goodness-of-Fit Test	Chi-square	df	P-Value
	5.23	8	.73

AUC = Area under the curve; df = degrees of freedom

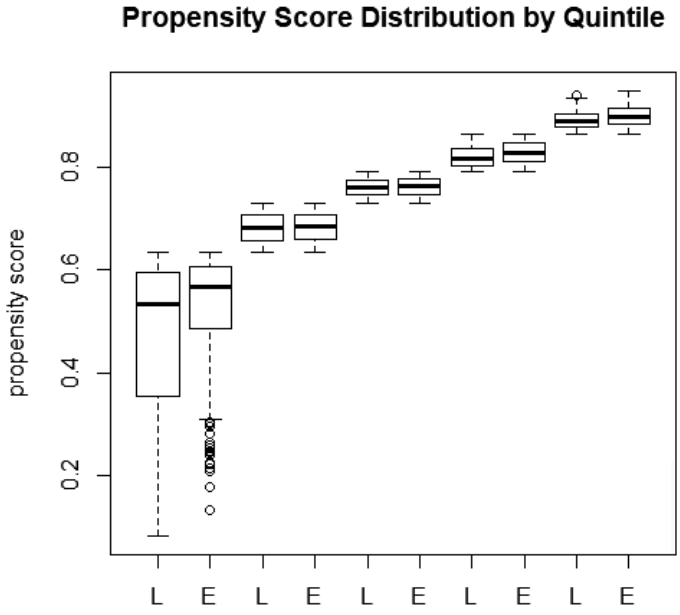

Figure 2.
Propensity score distribution by quintile (Q1-Q5) dichotomized by early (E) or late (L) grouping. Boxes represent the interquartile ranges (25th percentile to 75th percentile) of each quintile for both the early (E) and late (L) groups. Median values are represented by the line in the middle of the box, and whiskers represent the minimum and maximum propensity score values. Circles plotted beyond the whiskers denote outlier data.

a local clinician may also have more readily available access to care compared to those without these pre-existing relationships. Additionally, athletes with recorded data on a previous diagnosis of a learning disability (yes or no) were upwards of five times more likely to present early than those for whom this data was missing. This too, could relate to a previous relationship with the clinic, or prior education from the treating clinician on seeking earlier care.

We found that older athletes were more likely to present late. It is possible that as the competitive culture of sport intensifies in older age groups, older athletes may be less inclined to report concussion related symptoms and seek treatment. Factors that may explain the reduced self-reporting behaviours in older athletes include a fear of reduced playing time, fear of letting down parents, coaches, or teammates, underestimation of the injury severity, a decline in one's athletic identity, or loss of scouting/scholarship opportunities.[4,19,21] A study by Kuroski *et al*.[19] on concussion knowledge and reporting behaviours in 496 high-school athletes found that younger athletes were more likely to self-report SRC symptoms despite older athletes demonstrating greater concussion education and knowledge.[19] We had also hypothesized that athletes who had suffered previous concussions would have a greater odds of presenting early, but this was not observed. It may be that those with previous concussion experience are more familiar with concussion management techniques and therefore opt to self-manage their symptoms in the early stages of recovery. However, this theory has yet to be demonstrated in the literature.

A number of acknowledged negative prognostic factors for recovery from SRC (i.e. a history of a diagnosed anxiety disorder, depression, or headache disorder) and surrogate markers of injury severity (i.e. LOC, PTA, PTS, location of impact on the head/body)[22,23] were not associated with athlete presentation time. Given that early presentation for care may be associated with better clinical outcomes[12,13,24], it is encouraging that mental health issues (anxiety, depression) and headaches do not seem to act as barriers to accessing early treatment. A possible explanation for the lack of association observed may be related to how these questions are asked during the clinical assessment (i.e., previously *diagnosed* anxiety or depression). Athletes may have experienced significant feelings of anxiety or depression but have not been formally diagnosed with a mental health disorder, prompting clinicians to record negative answers when asking about these conditions. Regarding surrogate markers of injury severity, we expected that athletes with these injury characteristics would take longer to access care, as they may be initially directed to emergency departments for assessment. The relationship between surrogate markers of injury severity and clinical recovery is still unclear in adolescent athletes, however, most studies indicate that factors such as LOC and PTA are not strong predictors of clinical outcome.[22,23] Our findings suggest that injury severity characteristics also do not seem to impede athletes from seeking early care.

Given that this is, to our knowledge, one of only two observational studies to develop a propensity score to balance patient characteristics associated with early vs. late care seeking behaviour, there is limited data to which we can compare the performance of our propensity model to. Lawrence *et al*.[13] conducted a smaller observational study of 253 acute (<14 days) concussion cases to see if earlier initiation of exercise influenced return to sport and school/work in athletes aged 15-20 years. The authors used a similar propensity score to stratify participants into quintiles based on nine covariates. The authors provide a supplemental table demonstrating that their propensity score achieves adequate balance of the included covariates when stratified across quintiles. We present similar data in Appendix 1 demonstrating a shift from imbalance between the 'early' and 'late' subjects in the pooled data, to balance between early and late subjects across the five quintiles.

Strengths and limitations

Our study had strengths. It is the first to describe the characteristics of this subpopulation of athletes within the large national database. Consequently, we were able to generate a large sample size (n = 2949). Further, the limiting sample size of our smallest group was 786 (late group) which far exceeded the minimum requirement of 160 estimated during the planning of this study. Recent studies investigating the impact of treatment timing on recovery rates by Kontos *et al*.[12] and Lawrence *et al*.[13] had sample sizes of 416 and 253 participants respectively. The completeness and quality of data provided through the database aided in maximizing our sample size, as only 225 (7.5%) of the retrieved records had missing data inputs.

Also, we included 16 covariates in our model that are associated with health outcomes in people with concussion. Lawrence *et al*.[13] developed a propensity score through multiple logistic regression for time-to-aerobic exercise consisting of nine covariates, and it included symptom severity at presentation to the clinic which may be unfitting since it is likely confounded with time to presentation. Our study captured each of the same covariates plus seven additional factors with the exception of symptom severity. Symptom severity scores for each patient were not included in the multiple logistic regression because they were not recorded at a uniform point in time following injury for each subject.

Our study had limitations. First, despite including a large number of covariates in the development of our propensity score, such scores cannot balance participants within each quintile based on unmeasured covariates. Further, such scores cannot account for bias due to chance to the same degree as true randomization.[15] Thus, there may be other covariates that influence athlete presentation time that our model did not consider, and residual confounding may still be present even after stratification by propensity score. Therefore, our model should first be externally validated in an independent sample of adolescent athletes with SRCs before further comments are made on its generalizability to this population. Second, the possibility of selection bias in favour of the early group should be considered. It is possible that athletes who are more proactive about accessing care may preferentially seek out concussion management clinics, and be more inclined to seek earlier treatment. This may partly explain why significantly more athletes presented early versus late in our study, and may further limit our findings to this specific group of proactive athletes.

Directions for future research

Subsequent investigations should focus on identifying additional patient and/or injury characteristics that may be associated with early care seeking behaviour among adolescent athletes. For instance, a recent study by Eagle *et al*.[25] reported that cognitive, migraine, and fatigue factors assessed via the PCSS were the most robust predictors of prolonged recovery for patients presenting within one week of a SRC, whereas the affective factors were the most robust predictors of prolonged recovery for patients presenting within two-to-three weeks of a SRC. Furthermore, our propensity score should be validated in an independent sample of adolescent athletes. The above recommendations will allow for the development of a more robust propensity score, leading to improved stratification of participants into quintiles, further minimization of residual sample bias, and therefore increased confidence in group similarity before outcome comparisons are made.

Conclusions

This is, to our knowledge, the first study to investigate patient and injury characteristics associated with time to presentation for care for SRCs in 12 to 18-year-old athletes. Being male, having a completed pre-injury baseline assessment, and responding to having a diagnosed learning disorder were associated with early presentation; whereas older age and self-reported previous SRCs were associated with a late presentation. Our propensity score had a modest ability to balance participants based on presentation time. Further patient and injury characteristics should be assessed for inclusion in the propensity score, which then needs to be externally validated before recommending it for use in future research.

Key Points

Question: Which characteristics of adolescent athletes with sport-related concussions (SRC) are associated with 'early' versus 'late' presentation to concussion management clinics for multimodal treatment?

Findings: This is a cohort study that included 2949 participants. Male athletes with a completed baseline assessment are more likely to seek early treatment following a SRC, and older athletes with a greater number of previous SRCs are less likely to present early.

Meaning: Following external validation, our propensity score will be used to examine the impact of treatment timing on adolescent athlete recovery outcomes.

References

1. Kimbler DE, Murphy M, Dhandapani KM. Concussion and the adolescent athlete. J Neurosci Nurs. 2011;43(6): 286-290. doi:10.1097/jnn.0b013e31823858a6
2. Harmon KG, Clugston JR, Dec K, et al. American Medical Society for Sports Medicine position statement on concussion in sport. Brit J Sport Med. 2019;53(4): 213. doi:10.1136/bjsports-2018-100338

3. Veliz P, McCabe SE, Eckner JT, Schulenberg JE. Prevalence of concussion among US adolescents and correlated factors. J Am Med Assoc. 2017;318(12): 1180-1182. doi:10.1001/jama.2017.9087
4. Register-Mihalik JK, Guskiewicz KM, McLeod TCV, Linnan LA, Mueller FO, Marshall SW. Knowledge, attitude, and concussion-reporting behaviors among high school athletes: a preliminary study. J Athl Train. 2013;48(5): 645-653. doi:10.4085/1062-6050-48.3.20
5. Pfister T, Pfister K, Hagel B, Ghali WA, Ronksley PE. The incidence of concussion in youth sports: a systematic review and meta-analysis. Br J Sports Med. 2016;50(5): 292-297. doi:10.1136/bjsports-2015-094978
6. Kontos AP, Collins MW, Holland CL, et al. Preliminary evidence for improvement in symptoms, cognitive, vestibular, and oculomotor outcomes following targeted intervention with chronic mTBI Patients. Milit Med. 2018;183(suppl_1): 333-338. doi:10.1093/milmed/usx172
7. Kontos AP, Deitrick JM, Collins MW, Mucha A. Review of vestibular and oculomotor screening and concussion rehabilitation. J Athl Train. 2017;52(3): 256-261. doi:10.4085/1062-6050-51.11.05
8. Lennon A, Hugentobler JA, Sroka MC, et al. An exploration of the impact of initial timing of physical therapy on safety and outcomes after concussion in adolescents. J Neurol Phys Ther. 2018;42(3):123-131. doi:10.1097/npt.0000000000000227
9. Grabowski P, Wilson J, Walker A, Enz D, Wang S. Multimodal impairment-based physical therapy for the treatment of patients with post-concussion syndrome: a retrospective analysis on safety and feasibility. Phys Ther Sport. 2017;23(C): 22-30. doi:10.1016/j.ptsp.2016.06.001
10. Ransom DM, Vaughan CG, Pratson L, Sady MD, McGill CA, Gioia GA. Academic effects of concussion in children and adolescents. Pediatrics. 2015;135(6): 1043-1050. doi:10.1542/peds.2014-3434
11. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport—the 5 thinternational conference on concussion in sport held in Berlin, October 2016. Br J Sports Med. 2017;12:bjsports-2017-097699-10. doi:10.1136/bjsports-2017-097699
12. Kontos AP, Jorgensen-Wagers K, Trbovich AM, et al. Association of time since injury to the first clinic visit with recovery following concussion. JAMA Neurology. Published online January 6, 2020:1-6. doi:10.1001/jamaneurol.2019.4552
13. Lawrence DW, Richards D, Comper P, Hutchison MG. Earlier time to aerobic exercise is associated with faster recovery following acute sport concussion. Janigro D, ed. PLOS ONE. 2018;13(4):e0196062-12. doi:10.1371/journal.pone.0196062
14. Suissa S. Immortal time bias in pharmacoepidemiology. Am J Epidemiol. 2008;167(4): 492-499. doi:10.1093/aje/kwm324
15. Rosenbaum P, Rubin D. Reducing bias in observational studies using subclassification on the propensity score. J Am Stat Assoc. 1984;79: 516-524.
16. E von E, DG A, M E, SJ P, PC G, JP V. Strengthening the reporting of observational studies in epidemiology (StroBE) statement: guidelines for reporting observational studies. BMJ. 2020;335(7624): 806-808. doi:10.1136/bmj.39335.541782.ad.
17. Harrell FE. Regression modeling strategies: with applications to linear models, logistic regression, and survival analysis. New York: Springer; 2001: 11-103.
18. Hosmer DW, Lemeshow S. Applied Logistic Regression. Second Edition. John Wiley & Sons, Inc.; 2000. doi:10.1002/0471722146
19. Kurowski B, Pomerantz WJ, Schaiper C, Gittelman MA. Factors that influence concussion knowledge and self-reported attitudes in high school athletes. J Trauma Acute Care. 2014;77(3): S12-S17. doi:10.1097/ta.0000000000000316
20. Sullivan L, Molcho M. Gender differences in concussion-related knowledge, attitudes and reporting-behaviours among high school student-athletes. Int J Adolesc Medicine Heal. 2018;33(1). doi:10.1515/ijamh-2018-0031
21. Malinauskas R. College athletes' perceptions of social support provided before injury and after it. J Sports Med Phys Fitness. 2008;48(1): 107-112.
22. Iverson GL, Gardner AJ, Terry DP, et al. Predictors of clinical recovery from concussion: a systematic review. Br J Sports Med. 2017;51(12): 941-948. doi:10.1136/bjsports-2017-097729
23. Davis GA, Anderson V, Babl FE, et al. What is the difference in concussion management in children as compared with adults? A systematic review. Br J Sports Med. 2017;51(12): 949-957. doi:10.1136/bjsports-2016-097415
24. Schneider KJ. Early return to physical activity post-concussion associated with reduced persistent symptoms. J Pediatr. 2017;184:235-238. doi:10.1016/j.jpeds.2017.02.049
25. Eagle SR, Womble MN, Elbin RJ, Pan R, Collins MW, Kontos AP. Concussion symptom cutoffs for identification and prognosis of sports-related concussion: role of time since injury. Am J Sports Med. 2020;48(10): 2544-2551. doi:10.1177/0363546520937291

Appendix 1.

Balance diagnostics for the distribution of covariates on dichotomized early vs. late presentation based on propensity score quintile stratum.

	All (n=2949)					Q1 (n=590)					Q2 (n=590)				
	Early (n = 2163)		Late (n = 786)		χ^2	Early (n = 293)		Late (n = 297)		χ^2	Early (n = 409)		Late (n = 181)		χ^2
	n	%	n	%	p-value	n	%	n	%	p-value	n	%	n	%	p-value
Sex – male	1257	58.1	402	51.2	0.0007	121	41.3	122	41.1	0.9	200	48.9	84	46.1	0.6
Location – Postal Code															
A	224	10.4	71	9.0	0.0001	15	5.1	16	5.4	0.9	37	9.0	19	10.5	0.5
H	46	2.1	22	2.8		10	3.4	10	3.4		12	2.9	8	4.4	
J	125	5.8	66	8.4		38	13.0	33	11.1		41	10.0	24	13.3	
K	140	6.5	62	7.9		25	8.5	33	11.1		45	11	12	6.6	
L	573	26.5	171	21.8		43	14.7	45	15.2		90	22	31	17.1	
M	74	3.4	48	6.1		38	13.0	35	11.8		18	4.4	9	4.9	
N	84	3.9	35	4.5		14	4.8	15	5.1		24	5.9	9	4.9	
P	53	2.5	33	4.2		16	5.5	24	8.1		13	3.2	4	2.2	
S	305	14.1	89	11.3		19	6.5	17	5.7		36	8.8	24	13.3	
T	166	7.7	55	7.0		22	7.5	15	5.1		26	6.4	12	6.6	
V	373	17.2	134	17.1		53	18.1	54	18.2		67	16.4	29	4.9	
Completed Baseline Assessment	911	42.1	163	20.7	<.0001	18	6.1	23	7.7	0.4	18	4.4	11	6.1	0.4
Hx Anxiety	164	7.6	69	8.8	0.3	39	13.3	29	9.8	0.2	33	8.1	13	7.2	0.7
Hx Depression	52	2.4	28	3.6	0.09	22	7.5	14	4.7	0.2	10	2.4	9	5.0	0.1
Hx Headache	21	1.0	11	1.4	0.3	7	2.4	6	2.0	0.8	4	1.0	2	1.1	0.9
Hx Learning Disability															
Yes	106	4.9	43	5.5	0.0001	27	9.2	20	6.7	0.0003	25	6.1	6	3.3	0.05
No	1992	92.1	631	80.3		205	70.0	171	57.6		380	92.9	169	93.4	
Missing	65	3.0	112	14.3		61	20.8	106	35.7		4	1.0	6	3.3	
Hx ADD/ADHD															
ADD	29	1.3	18	2.3	0.09	14	4.8	13	4.4	0.9	3932	0.7	3	1.7	0.6
ADHD	76	3.5	35	4.5		21	7.2	21	7.1		14	3.4	6	3.3	
None	2058	95.2	733	93.3		258	88.1	263	88.6		392	95.8	172	95.0	
Mechanism of Injury															
Basketball	126	5.8	47	6.0	<.0001	13	4.4	17	5.7	0.8	28	6.9	11	6.1	1.0
Cheerleading	55	2.5	24	3.1		10	3.4	13	4.4		14	3.4	7	3.9	
Football	213	9.9	58	7.4		9	3.1	9	3.0		30	7.3	8	4.4	
Hockey	916	42.4	282	35.9		77	26.3	82	27.6		134	32.8	63	34.8	
Lacrosse	86	4.0	19	2.4		1	0.3	3	1.0		7	1.7	3	1.7	
Martial Arts	39	1.8	24	3.1		17	5.8	12	4.0		11	2.7	8	4.4	
Other	156	7.2	85	10.8		43	14.7	55	18.5		46	11.3	18	9.9	
Ringette	50	2.3	17	2.2		4	1.4	4	1.4		12	2.9	6	3.3	
Rugby	128	5.9	64	8.1		46	15.7	32	10.8		37	9.1	20	11.1	
Skiing	59	2.7	41	5.2		32	10.9	29	9.8		9	2.2	3	1.7	
Soccer	275	12.7	102	13.0		35	12.0	35	11.8		66	16.1	27	14.9	
Volleyball	60	2.8	23	2.9		6	2.1	6	2.0		15	3.7	7	3.9	

ADD/ADHD = Attention Deficit Disorder / Attention Deficit Hyperactivity Disorder; Hx = History; L = Left; LOC = Loss of Consciousness; n = number; PTA = Post Traumatic Amnesia; PTS = Post Traumatic Seisure; Q1-5 = Quintile 1 through to 5; R = Right; SD = Standard Deviation; SRC(s) = Sport Related Concussion(s); t-test = Two-sided t-test or chi-square (χ^2); = Mean.

	All (n=2949)					Q1 (n=590)					Q2 (n=590)				
	Early (n = 2163)		Late (n = 786)		χ^2	Early (n = 293)		Late (n = 297)		χ^2	Early (n = 409)		Late (n = 181)		χ^2
	n	%	n	%	p-value	n	%	n	%	p-value	n	%	n	%	p-value
Location of Impact – Body															
front	191	8.8	79	10.1	0.3	36	12.3	39	13.1	0.8	47	11.5	14	7.7	0.2
rear	218	10.1	62	7.9	0.07	21	7.2	12	4.0	0.1	28	6.9	16	8.8	0.4
left	130	6.0	36	4.6	0.1	9	3.1	10	3.4	0.8	12	2.9	8	4.4	0.4
right	143	6.6	52	6.6	1.0	20	6.8	17	5.7	0.6	24	5.9	14	7.7	0.4
Location of Impact – Head															
crown	28	1.3	12	1.5	0.6	5	1.7	6	2.0	0.8	11	2.7	3	1.7	0.4
L frontal	436	20.2	164	20.9	0.7	55	18.8	66	22.2	0.3	85	20.8	37	20.4	0.9
L parietal	97	4.5	45	5.7	0.2	21	7.2	27	9.1	0.4	22	5.4	7	3.9	0.4
L temporal	258	11.9	90	11.5	0.7	29	9.9	34	11.5	0.5	51	12.5	19	10.5	0.5
L occipital	468	21.6	145	18.45	0.06	41	14.0	43	14.5	0.9	69	16.9	33	18.2	0.7
R frontal	545	25.2	199	25.3	0.9	72	24.6	77	25.9	0.7	93	22.7	44	24.3	0.7
R parietal	130	6.0	51	6.5	0.6	20	6.8	19	6.4	0.8	29	7.1	10	5.5	0.5
R temporal	265	12.3	92	11.7	0.7	36	12.3	28	9.4	0.3	51	12.5	23	12.7	0.9
R occipital	492	22.8	162	20.6	0.2	50	17.1	50	16.8	0.9	90	22	36	19.9	0.6
LOC															
Yes	115	5.3	55	7	0.17	24	8.2	29	9.8	0.6	25	6.1	10	5.5	0.96
No	1912	88.4	688	87.5		252	86.0	255	85.9		362	88.5	161	88.9	
Unsure	136	6.3	43	5.5		17	5.8	13	4.4		22	5.4	10	5.5	
Post Traumatic Amnesia															
None	1851	85.6	650	82.7	0.15	234	79.9	229	77.1	0.7	347	84.8	153	84.5	0.6
Anterograde	162	7.5	69	8.8		29	9.9	32	10.8		36	8.8	13	7.2	
Retrograde	150	6.9	67	8.5		30	10.2	36	12.1		26	6.4	15	8.3	
PTS															
Yes	24	1.1	9.0	1.2	0.6	3	1.0	3	1.0	0.9	4	0.98	3	1.7	0.8
No	2103	97.2	768	97.7		286	97.6	290	97.6		402	98.3	177	97.8	
Missing	36	1.67	9	1.2		4	1.4	4	1.4		3	0.73	1	0.55	
	$\overline{X}$	SD	$\overline{X}$	SD	t-test p-value	$\overline{X}$	SD	$\overline{X}$	SD	t-test p-value	$\overline{X}$	SD	$\overline{X}$	SD	t-test p-value
Age	15.8	1.5	16.1	1.5	<.0001	16.4	1.3	16.4	1.4	0.9	16.0	1.4	16.2	1.4	0.1
Number of Previous SRC	0.6	0.9	0.7	1.2	.0005	1.0	1.3	1.1	1.5	0.5	0.69	0.97	0.57	0.9	0.1

ADD/ADHD = Attention Deficit Disorder / Attention Deficit Hyperactivity Disorder; Hx = History; L = Left; LOC = Loss of Consciousness; n = number; PTA = Post Traumatic Amnesia; PTS = Post Traumatic Seisure; Q1-5 = Quintile 1 through to 5; R = Right; SD = Standard Deviation; SRC(s) = Sport Related Concussion(s); t-test = Two-sided t-test or chi-square (χ^2); = Mean.

	Q3 (n=590)					Q4 (n=590)					Q5 (n=589)				
	Early (n = 438)		Late (n = 152)		χ^2	Early (n = 492)		Late (n = 98)		χ^2	Early (n = 531)		Late (n = 58)		χ^2
	n	%	n	%	p-value	n	%	n	%	p-value	n	%	n	%	p-value
Sex – male	253	57.8	89	58.6	0.9	307	62.4	62	63.3	0.9	376.	70.8	45	77.6	0.3
Location – Postal Code															
A	62	14.2	19	12.5	0.8	58	11.8	12	12.2	0.7	52	9.8	5	8.6	0.9
H	5	1.1	3	1.8		13	2.6	1	1.0		6	1.1	0	0	
J	19	4.3	3	2.0		22	4.5	5	5.1		5	0.9	1	1.7	
K	22	5.0	8	5.3		20	4.1	5	5.1		28	5.3	4	6.9	
L	141	32.2	48	31.6		27	27.5	120	24.4		179	33.7	20	34.5	
M	2	0.5	2	1.3		15	3.1	2.0	2.0		1	0.2	0	0	
N	20	4.6	5	3.3		10	2.1	2.0	2.0		16	3.0	4	6.9	
P	6	1.4	3	2.0		16	3.3	2	2.0		2	0.4	0	0	
S	77	17.6	24	15.8		85	17.3	15	15.3		88	16.6	9	15.5	
T	36	8.2	14	9.2		27	5.5	11	11.2		55	10.4	3	5.2	
V	48	11	23	15.1		106	21.5	16	16.3		99	18.6	12	20.7	
Completed Baseline Assessment	49	11.2	20	13.2	0.5	295	60.0	52	53.1	0.2	531	100	57	98.3	0.003
Hx Anxiety	33	7.5	19	12.5	0.06	31	6.3	7	7.1	0.8	28	5.3	1	1.7	0.2
Hx Depression	9	2.1	3	2.0	1.0	6	1.2	2	2.0	0.5	5	0.9	0	0	0.5
Hx Headache	4	0.9	3	2.0	0.3	5	1.0	0	0	0.3	1	0.2	0	0	0.7
Hx Learning Disability															
Yes	15	3.4	7	4.6	0.5	24	4.9	6	6.1	0.6	15	2.8	4	6.9	0.1
No	423	96.6	145	95.4		468		95.1	92	93.9		516	97.2	54	93
Missing	0	0	0	0		0	0	0	0		0	0	0	0	
Hx ADD/ADHD															
ADD	5	1.1	2	1.3	0.8	5	1.0	0	0	0.6	2	0.4	0	0	0.9
ADHD	17	3.9	4	2.6		13	2.6	3	3.1		11	2.1	1	1.7	
None	416	95	146	96		474	96.3	95	96.9		518	97.6	57	98.3	
Mechanism of Injury															
Basketball	36	8.2	14	9.2	0.8	26	5.3	2	2.0	0.5	23	4.3	3	5.2	0.4
Cheerleading	4	0.9	0	0		25	5.1	4	4.1		2	0.4	0	0	
Football	52	11.9	13	8.6		62	12.6	18	18.4		60	11.3	10	17.2	
Hockey	196	44.8	64	42.1		198	49.2	38	38.8		311	58.6	35	60.3	
Lacrosse	13	3.0	7	4.6		26	5.3	2	2.0		39	7.3	4	6.9	
Martial Arts	4	0.9	2	1.3		5	1.0	2	2.0		2	0.6	1	1.7	
Other	15	3.4	6	4.0		31	6.3	4	4.1		21	3.4	2	3.5	
Ringette	14	3.2	4	2.6		8	1.6	1	1.0		12	2.3	2	3.5	
Rugby	12	2.7	3	2.0		32	6.5	8	8.2		1	0.2	1	1.7	
Skiing	13	3.0	9	5.9		4	0.8	0	0		1	0.2	0	0	
Soccer	60	13.7	22	14.5		64	13	18	18.4		50	9.4	0	0	
Volleyball	19	4.3	8	5.3		11	2.2	1	1.0		9	1.7	1	1.7	

ADD/ADHD = Attention Deficit Disorder / Attention Deficit Hyperactivity Disorder; Hx = History; L = Left; LOC = Loss of Consciousness; n = number; PTA = Post Traumatic Amnesia; PTS = Post Traumatic Seisure; Q1-5 = Quintile 1 through to 5; R = Right; SD = Standard Deviation; SRC(s) = Sport Related Concussion(s); t-test = Two-sided t-test or chi-square (χ^2); = Mean.

	Q3 (n=590)					Q4 (n=590)					Q5 (n=589)				
	Early (n = 438)		Late (n = 152)		χ^2	Early (n = 492)		Late (n = 98)		χ^2	Early (n = 531)		Late (n = 58)		χ^2
	n	%	n	%	p-value	n	%	n	%	p-value	n	%	n	%	p-value
Location of Impact – Body															
front	32	7.3	11	7.2	1.0	34	5.8	9	9.2	0.4	42	7.9	6	10.3	0.5
rear	48	11	16	10.5	0.9	50	10.2	8	8.2	0.5	71	13.4	10	17.2	0.4
left	27	6.2	8	5.3	0.7	31	6.3	5	5.1	0.7	51	9.6	5	8.6	0.8
right	21	4.8	12	7.9	0.2	40	8.1	5	5.1	0.3	38	7.1	4	6.9	0.9
Location of Impact – Head															
crown	3	0.71	1	0.7	0.1	5	1.0	1.0	1.0	1.0	4	0.8	1	1.7	0.4
L frontal	99	22.6	29	19.1	0.4	103	20.9	14	14.3	0.1	94	17.7	18	31.0	0.01
L parietal	16	3.7	4	2.6	0.5	20	4.1	4	4.1	1.0	18	3.4	3	5.2	0.5
L temporal	51	11.6	18	11.8	0.9	53	10.8	12	12.2	0.7	74	13.9	7	12.1	0.7
L occipital	103	23.5	34	22.4	0.8	116	23.6	23	23.5	1.0	139	26.2	12	20.7	0.4
R frontal	119	27.2	40	26.3	0.8	131	26.6	19	19.4	0.1	130	24.5	19	32.8	0.2
R parietal	23	5.3	12	7.9	0.2	32	6.5	6	6.1	0.9	26	4.9	4	6.9	0.5
R temporal	49	11.2	23	15.1	0.2	57	11.6	10	10.2	0.7	72	13.6	8	13.8	0.1
R occipital	111	25.3	34	22.4	0.5	104	21.1	29	29.6	0.07	137	25.8	13	22.4	0.6
LOC															
Yes	32	7.3	10	6.6	0.7	14	2.9	3	3.1	0.8	20	3.4	3	5.2	0.6
No	389	88.8	134	88.2		443	90.0	86	87.8		466	87.8	52	89.7	
Unsure	17	3.9	8	5.3		35	7.1	9	9.1		45	8.5	3	6.2	
Post Traumatic Amnesia (PTA)															
None	367	83.8	132	86.8	0.6	430	87.4	84	85.7	0.6	473	89.1	52	89.7	0.5
Anterograde	37	8.5	11	7.2		27	5.5	8	8.2		33	6.2	5	8.6	
Retrograde	34	7.8	9	5.9		35	7.1	6	6.1	25	4.2	1	1.7		
Post Traumatic Seisure (PTS)															
Yes	5	1.1	1	0.7	0.5	7	1.4	0	0	0.09	5	0.9	2	3.5	0.2
No	430	98.2	151	99.3		481	97.8	95	96.9		504	94.9	55	94.8	
Missing	3	0.7	0	0		4	0.8	3	3.1		22	4.1	1	1.7	
	$\bar{X}$	SD	$\bar{X}$	SD	t-test p-value	$\bar{X}$	SD	$\bar{X}$	SD	t-test p-value	$\bar{X}$	SD	$\bar{X}$	SD	t-test p-value
Age	15.8	1.4	15.5	1.6	0.07	15.6	1.6	15.8	1.4	0.3	15.5	1.4	15.6	1.2	0.6
Number of Previous SRC	0.4	0.8	0.5	0.8	0.4	0.6	0.9	0.5	0.9	0.6	0.4	0.6	0.6	0.8	0.02

ADD/ADHD = Attention Deficit Disorder / Attention Deficit Hyperactivity Disorder; Hx = History; L = Left; LOC = Loss of Consciousness; n = number; PTA = Post Traumatic Amnesia; PTS = Post Traumatic Seisure; Q1-5 = Quintile 1 through to 5; R = Right; SD = Standard Deviation; SRC(s) = Sport Related Concussion(s); t-test = Two-sided t-test or chi-square (χ^2); = Mean.

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Concussion knowledge among North American chiropractors

Mohsen Kazemi, RN, DC, FRCCSS(C), FCCPOR(C), MSc, PhD[1]
Kevin Rajin Deoraj, BHSc, DC[1]
Milcah Hiemstra, BHSc, DC[1]
Lauren Kimberly Santiago, BHSc, DC[1]

Objectives: *To investigate the degree of knowledge North American chiropractors have in regards to concussion diagnosis and management.*

Methods: *A Concussion Knowledge Assessment Tool (CKAT) survey was administered to North American chiropractors through SurveyMonkey.com. This survey was sent to all practicing members of the American Chiropractic Association (ACA) and Canadian Chiropractic Association (CCA).*

Results: *1321 surveys were completed and analyzed (response rate of 3.3%). The average score of the CKAT amongst North American Chiropractors was 4.82 out of 9. Using our modified scoring method, chiropractors scored 39.44 out of 48.*

Conclusions: *North American chiropractors who participated in this study demonstrated concussion knowledge and management using the CKAT tool.*

Connaissances des chiropraticiens nord-américains sur la commotion cérébrale

Objectifs : *Examiner le degré de connaissances des chiropraticiens nord-américains sur le diagnostic et la prise en charge de la commotion cérébrale.*

Méthodologie : *On a effectué un sondage sur l'outil d'évaluation des connaissances sur la commotion cérébrale auprès de chiropraticiens nord-américains par SurveyMonkey.com. Ce sondage a été envoyé à tous les membres en exercice de l'American Chiropractic Association (ACA) et de l'Association chiropratique canadienne (ACC).*

Résultats : *1 321 personnes ont répondu au questionnaire (taux de réponse de 3,3 %). Le score moyen obtenu chez les chiropraticiens nord-américains était de 4,82 sur 9. En utilisant notre méthode de notation modifiée, les chiropraticiens ont obtenu un score de 39,44 sur 48.*

Conclusions : *Les chiropraticiens nord-américains qui ont participé à cette étude ont montré qu'ils avaient des connaissances sur la commotion cérébrale et qu'ils utilisaient l'outil d'évaluation pour la prise en charge.*

[1] Department of Graduate Studies and Research, Canadian Memorial Chiropractic College

Corresponding author: Mohsen Kazemi, Canadian Memorial Chiropractic College, 6100 Leslie St. Toronto. ON, Canada M2H 3J1
e-mail: mkazemi@cmcc.ca

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Further investigation is recommended in order to address learning gaps and updating the CKAT based on current literature and guidelines.

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KEY WORDS: chiropractic, concussion, diagnosis, knowledge, management, North America

On recommande de poursuivre les recherches afin de combler les lacunes en matière d'apprentissage et de mettre à jour l'outil d'évaluation en fonction de la documentation et des lignes directrices actuelles.

(JCCA. 2021;65(3):275-291)

MOTS CLÉS : chiropratique, commotion cérébrale, diagnostic, connaissances, prise en charge, Amérique du Nord

Introduction

Harmon *et al*.[1] describe concussion as, "…a traumatic, transient disturbance of brain function that involves a complex pathophysiological process. Concussion is considered a subset of mild traumatic brain injury (mTBI) and a condition whose symptoms cannot be explained by drugs, alcohol, medication use or other injuries". This type of injury to the brain presents in an array of different symptoms, including headaches, irritability, drowsiness, dizziness, as well as neurological signs.[2] The expected recovery in the majority of adults (age 19 and above) is about two weeks, whereas in children (age 18 and under) it is about four weeks.[2] However, not all resolve in this way, and it is essential that chiropractors know how to manage these types of cases.

The research on chiropractors' knowledge of concussions is limited, however, research on the topic is ongoing. Kazemi, Bogumil and Vora[3] found that sports chiropractors have the skills and knowledge to correctly manage concussion patients. Kazemi *et al*.[4] also found that fourth year chiropractic interns and postgraduate chiropractic specialty college residents earned scores that are comparable to fourth year medical students and residents. The researchers noted that there are some knowledge gaps with both chiropractic and medical students when it comes to recognizing concussions.

Evaluation tools

Several methods are used to help recognize concussions in patients. In combination with a thorough history and physical examination, there are several diagnostic tests utilized for concussion recognition. The Glasgow Coma Scale (GCS) differentiates a mild traumatic brain injury from a severe traumatic brain injury and defines level of consciousness for all types of acute medical and trauma victims.[2,5] The GCS score is only one component which may differentiate between TBI subtypes. The Head Injury Severity Scale (HISS) is based on the GCS and is used to grade severity of traumatic brain injuries, also including recommendations based on presence of confounding factors.[2,5] The Sport Concussion Assessment Tool 5 (SCAT5) is a sideline concussion diagnostic tool used to determine whether a concussion occurred in an athlete aged 13 and above. It is a tool to aid in clinical decision-making regarding sideline concussion presentation. SCAT5 includes an immediate, on-field assessment of cognitive, neurological, and physical function. The SCAT5 was developed to include the GCS. For athletes 12 years old and below, the Child SCAT5 is used.[6]

Current best practice recommendations

Best practice guidelines for treating concussions revolves around initial relative rest from physical and cognitive activities to prevent further injury and prevent second impact syndrome.[2] However, complete bed rest and complete cognitive rest are not recommended.[2] After relative rest, an eventual return to activity plan comes into action to ensure that the affected patient can function normally without any concussion symptoms.[2,5] Among medical professionals there is a noted variability in concussion treatment leading to a subpar treatment plan for concussion patients. Zemek *et al*.[7] surveyed Canadian paediatric emergency doctors in regards to their knowledge and treatment of concussion. Despite 89% of these emergency physicians diagnosing 20+ concussions per year, only 64% of these physicians implemented proper return-to-

play guidelines.[7] Cognitive rest from concentration activities which aggravate concussion symptoms was not prescribed as frequently as recommended per best practice guidelines.[7]

Health care practitioner education

It has been stated in the literature that there are gaps in knowledge in regards to concussions. This trend is seen in medical doctors, chiropractors, medical students and residents, chiropractic students and residents, physiotherapists, occupational therapists, athletic trainers, pediatricians and neurology and neurosurgery residents.[3,4,7-10] Donaworth *et al*.[11] stated that many of the American medical students who took part in their survey reported never having any formal lectures about concussions. They also reported that they did not have adequate clinical experience dealing with concussions. This has resulted in an inability to recognize symptoms, diagnose and manage concussions effectively.[11] Interestingly, Burke *et al*.[12] surveyed Canadian medical schools in 2012 and found that only four schools out of the fourteen who participated in the survey included concussion related information in the curriculum. Six included information about general head injuries in the curriculum and four did not have any concussion information in the curriculum. Four medical schools did not participate in the study.[12] Mathieu, Ellis and Tator in a follow-up study of the same fourteen Canadian medical schools, received responses from 13 Canadian medical schools. Eleven of those 13 schools reported providing concussion-specific education and all 13 respondents offered head injury education which included a concussion component. Two Canadian medical schools as part of this study did not provide any training in concussion diagnosis, prognosis or management.[13] Salisbury *et al*.[10] surveyed concussion knowledge among 561 rehabilitation professionals including physiotherapists, occupational therapists and athletic trainers in America. They found that although these professionals were able to identify the basics of how concussions present, there was a large variability when it came to diagnosis, prognosis and recovery duration of a concussed patient, potentially leading to suboptimal care.[10,13] Physiotherapists scored on average 63.7% (n=252), occupational therapists scored on average 57.4% (n=47) and athletic trainers scored on average 72.1% (n=112) correct responses for their survey. They did not use the concussion knowledge assessment tool developed by Boggild and Tator[9] for their study. Their survey was designed using information from the fourth International Conference on Concussion in Sport as well as from six neuropsychologists and a literature search on concussion. Their survey featured two sections totalling 20 questions clarifying the health care practitioner's experiences with concussion in the first section and knowledge on concussion diagnosis, treatment and recovery in the second section.[14] Keenan, Bratton and Dixon[15] surveyed pediatricians' understanding of concussion and found that many pediatricians were unaware of potential long-term consequences of concussion. Over one-third of pediatricians surveyed were unsure of possible attention difficulties as a result of complications from a concussion.[15] They did not use the concussion knowledge assessment tool developed by Boggild and Tator[9] for their survey. Boggild and Tator surveyed fourth year medical students, neurology and neurosurgery residents in 2010 using the original version of the CKAT they designed.[9] They found that more than half of the residents sampled were not able to identify post-concussion syndrome and chronic traumatic encephalopathy as potential long-term consequences of concussion.[9] Fourth year medical students scored on average 4.2 out of 9 whilst residents scored on average 5.8 out of 9 on the CKAT.[9] Transfer of knowledge is necessary to fill this gap and improve correct diagnosis and management of concussions. To the authors' knowledge, there has not been any investigation into North American Chiropractors' level of concussion knowledge. As such, the aim of this study was to investigate the actual and self-ranked level of concussion knowledge with regards to diagnosis and management among North American chiropractors.

Methods

Study design

We conducted a cross-sectional study of all currently practicing North American chiropractors within the Canadian Chiropractic Association (CCA) and American Chiropractic Association (ACA), during the Spring of 2019. The CCA and ACA members received three emails over the month of March 2019.

Participants and recruitment

Three groups of participants were contacted for this study:

English speaking chiropractors who were members of the ACA, English speaking chiropractors who were members of the CCA and French speaking chiropractors who were members of the CCA. Participants were recruited via an email sent by ACA and CCA to their current practicing chiropractors. Participants were emailed a SurveyMonkey link that led to our survey. A total of 40,580 surveys were sent to the three groups of participants.

Measures

A 30-question survey originally created by Boggild and Tator[9] which was modified for a chiropractic population by Kazemi *et al*.[3] was uploaded to SurveyMonkey. The survey consisted of three sections. Section 1 consisted of eleven questions and collected information on demographic data of the participant, chiropractic education and lifestyle. Section 2 consisted of nine questions and collected information on concussion knowledge and management. Section 3 consisted of ten questions and collected information on past learning experiences on concussions and preferred learning formats.

Changes to the original survey by Boggild and Tator[9] included modifications to the language used in the questions to make the survey more applicable to a chiropractic population.[3] For example, question 2 was modified from originally asking, "what medical school…" to "what chiropractic college…". Question 18, "what is the appropriate management of concussion? Select all that apply", a response option was changed from "every concussed individual should see a physician" to "every concussed individual should see a healthcare professional". Question 19, "what are some 'red flags' that may predict the potential for more prolonged symptoms and may influence your investigation and management of concussion? Select all that apply?", response "age" was changed to "younger age" in order to avoid ambiguity. The complete questionnaire is available within Appendix 1.

The main outcome measure of interest from this survey came from the information collected in section 2; which measured the knowledge of concussion management of the participant- Concussion Knowledge Assessment Tool (CKAT). Original scoring of the CKAT as described by Boggild and Tator[9] involves scoring section 2 from 0 to 9 with each question in section 2 being worth one point. Question 15, 18, 19 and 20 involves selecting the multiple correct answers and not selecting any of the incorrect answers in order to be awarded a point for that question. For example, question 18 consists of ten possible responses with six of those being correct responses. In order to be awarded a correct response for that question, the six correct responses must be chosen and none of the incorrect responses can be chosen. For this study, an alternative scoring method was utilized where one point is possible for each of the compound questions. Responses are recorded as either correct or incorrect, the correct responses were then summed. This yielded a scoring range of 0 to 49, opposed to the original method of scoring 0 to 9. The revised method of scoring the CKAT is favorable as it shows fair test-retest reliability opposed to the original having poor test-retest reliability. Utilizing the old scoring method of 0 to 9 resulted in an intra-class correlation coefficient of test-retest reliability of 0.56 whilst the new scoring method of 0 to 49 yielded an intra-class correlation coefficient of test-retest reliability of 0.68 when comparing first year chiropractic students, fourth year chiropractic interns and sport chiropractic Fellows of the Royal College of Chiropractic Sports Sciences (Canada) [FRCCSS(C)].[16] However, when implementing the Survey Monkey, question 12 which asks "Which of the following is a sign or symptom of a concussion? Select all that apply.", vertigo and amnesia were set as one correct response instead of being separate correct answers. As such, our alternative scoring range became 0-48 instead of 0-49. Another measure from this survey, included in our study, was in section 3 where participants were asked to self-rank their knowledge about concussions on a scale of 0 to 10. In this instance with 0 representing inadequate and 10 representing completely adequate.

Analysis

Descriptive statistics were used to summarize the data. Counts and percentages were used for categorical variables and means and standard deviations were used for continuous variables. CKAT scores were quantified using boxplots, means and 95% confidence intervals (CI). Scatterplots and Pearson correlation coefficients (r) with 95% CI were utilized to compare participants self-reported rank of concussion knowledge to their CKAT score. CKAT data was collected to represent all North American chiropractors and to compare American trained chiropractors against Canadian trained chiropractors. The

analysis for this study was generated using SAS software v9.4.

Sample size

This study planned for all current practicing members of the ACA and CCA.

Ethics

The authors of this study were blinded to the names of the participants or any identifying information of the participants since the members were contacted by ACA and CCA via email. This study was approved by the research ethics board of Canadian Memorial Chiropractic College.

Results

A total of 40 580 surveys were emailed out to current practicing members of the ACA and CCA in March of 2019. 1321 completed surveys were returned yielding a 3.3% response rate. 1184 respondents were English speaking chiropractors and 118 respondents were French speaking chiropractors. 748 respondents graduated from American Chiropractic colleges and 573 respondents graduated from Canadian Chiropractic colleges. The average for concussion knowledge of North American chiropractors was 4.82 out of 9 on the original CKAT and 39.44 out of 48 on the revised CKAT.

In the concussion knowledge section of the survey, English speaking chiropractors scored an average of 4.88 standard deviation (SD = 1.20); 95% confidence interval (95% CI = 4.82-4.95) and an average of 39.54 (SD = 3.40; 95% CI = 39.35-39.73) for original and revised scoring respectively. English speaking chiropractors self-ranked their concussion knowledge an average of 6.29 out of 10, (SD = 1.87; 95% CI = 6.18-6.40). French speaking chiropractors scored an average of 4.18 (SD = 1.14; 95% CI = 3.98-4.39) and an average of 38.40 (SD = 3.40; 95% CI = 37.78-39.01) respectively. French speaking chiropractors self-ranked their concussion knowledge an average of 6.01 out of 10, (SD = 1.68; 95% CI = 5.70-6.31).

American educated chiropractors scored an average of 4.72 (SD = 1.22) and an average of 39.38 (SD = 3.37) respectively. American educated chiropractors self-ranked their concussion knowledge an average of 6.26 out of 10, (SD = 1.95). Canadian educated chiropractors scored an average of 4.65 (SD = 1.17) and an average of 39.33 (SD = 3.11). Canadian educated chiropractors self-ranked their concussion knowledge an average of 6.18 out of 10, (SD = 1.77). Male chiropractors scored an average of 4.87 (SD = 1.22; 95% CI = 4.8-5.0) and an average of 39.41 (SD = 3.56; 95% CI = 39.17-39.66). Whereas female chiropractors scored an average of 4.74 (SD = 1.19; 95% CI = 4.63-4.84) and an average of 39.48 (SD = 3.17; 95% CI = 39.20-39.75).

Table 1.
Self ranking and scores of concussion knowledge by graduates of various chiropractic colleges across North America

School	N	Self-Rank (out of 10)		Original CKAT Scoring		Revised CKAT Scoring	
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
CMCC	578	6.21	1.80	4.97	1.17	39.58	3.39
Life	47	6.28	2.20	4.51	1.30	39.02	3.11
Logan	40	6.24	2.17	4.73	1.18	39.50	3.27
NYCC	68	5.98	1.86	4.57	1.07	39.38	2.93
NUHS	48	6.34	1.98	4.88	1.41	38.83	3.45
NWHSU	70	6.03	1.64	4.96	1.28	40.27	3.45
Palmer	155	6.41	1.90	4.74	1.19	38.90	3.79
Parker	36	6.51	2.08	4.61	1.20	39.36	3.34
UQTR	78	6.05	1.73	4.33	1.16	39.09	2.83
UWS	108	6.27	1.75	4.80	1.09	39.80	2.93

Legend: Canadian Memorial Chiropractic College (CMCC), New York Chiropractic College (NYCC), National University of Health Sciences (NUHS), Northwestern Health Science University (NWHSU), Université du Québec à Trois-Rivières (UQTR) and University of Western States (UWS)

The chiropractic colleges which were a part of this study are as follows: Canadian Memorial Chiropractic College (CMCC), Life, Logan, New York Chiropractic College (NYCC), National University of Health Sciences (NUHS), Northwestern Health Science University (NWHSU), Palmer, Parker, Université du Québec à Trois-Rivières (UQTR) and University of Western States (UWS). Table 1 summarizes the self-rank and scoring for each school.

Higher education degrees for the purpose of this study

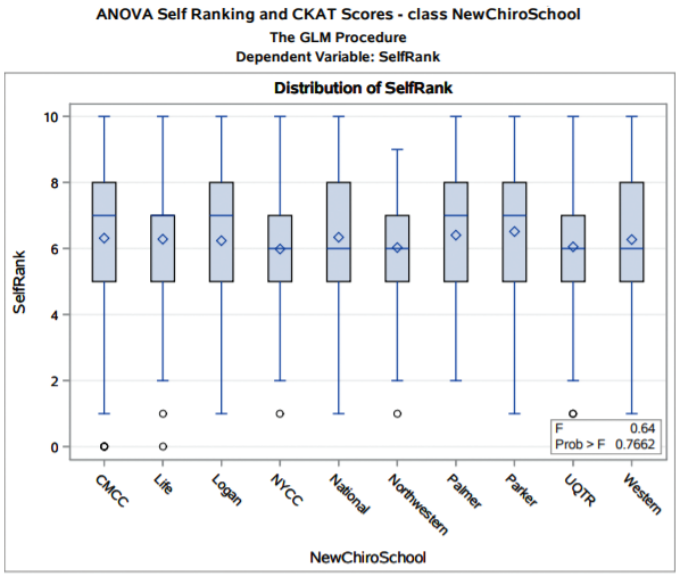

Figure 1.
Self-ranking of concussion knowledge by graduates of various chiropractic colleges across North America. Canadian Memorial Chiropractic College (CMCC), New York Chiropractic College (NYCC), National University of Health Sciences (National), Northwestern Health Science University (Northwestern), Université du Québec à Trois-Rivières (UQTR) and University of Western States (Western)

were limited to MSc and PhDs. Chiropractors of recognized residencies and Fellowships were also ranked in separate categories. Table 2 summarizes the concussion knowledge of chiropractors who completed higher education (MSc and PhDs), chiropractic residency and chiropractic Fellowship showing self-rank, original CKAT scoring and revised CKAT scoring. Chiropractors who completed a Fellowship in sport, rehabilitation, or neurology performed the best, scoring 5.24 (SD = 1.27) on the original scoring for the CKAT, 40.46 (SD = 3.27) on the revised scoring for the CKAT, and self-ranked their concussion knowledge an average of 7.63 out of 10, (SD = 1.59). The group that performed the poorest was chiropractors who were not complete Fellows, scoring 4.79 (SD = 1.20), 39.36 (SD = 3.43) on the revised scoring for the CKAT, and self-ranked their concussion knowledge an average of 6.15 out of 10, (SD = 1.85).

Table 3 summarizes North American Chiropractors'

Table 2.
Concussion knowledge of chiropractors who completed higher education (MSc and PhDs), chiropractic residency and chiropractic Fellowship.

Level of Education	Self-Rank (out of 10)		Original CKAT Scoring		Revised CKAT Scoring	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Higher Education (MSc, PhDs)	6.38	1.82	4.87	1.16	39.52	3.21
No Higher Education	6.25	1.86	4.81	1.21	39.42	3.44
Chiropractic Residents	6.76	2.03	4.92	1.26	39.88	2.57
No Chiropractic Residency	6.25	1.86	4.82	1.21	39.42	3.43
Chiropractic Fellows	7.07	1.77	5.05	1.25	39.93	3.30
No Chiropractic Fellowship	6.15	1.85	4.79	1.20	39.36	3.43
Chiropractic Fellows in Sport, Rehabilitation, or Neurology	7.63	1.59	5.24	1.27	40.46	3.27

Legend: CKAT Concussion Knowledge Assessment Tool, SD = Standard deviation

preferred methods of learning, showing self-rank, original CKAT scoring and revised CKAT scoring. Chiropractors who preferred pamphlet-based learning self-ranked the lowest with a mean of 5.83 out of 10, (SD = 1.56), whereas chiropractors who preferred seminars or workshops self-ranked the highest with a mean of 6.38 out of 10, (SD = 1.85). Chiropractors who preferred letters scored the lowest on the original and revised CKAT with a mean score of 4.07 (SD = 1.22) and 37.40 (SD = 5.89), respectively. Chiropractors who preferred seminars and workshops scored the highest on the original and revised CKAT with a mean score of 4.88 (SD = 1.22) and 39.57 (SD = 3.41), respectively.

Female chiropractors self-ranked their concussion knowledge an average of 6.02 out of 10, (SD = 1.87; 95% CI = 5.86-6.19) and scored an average of 4.74 (SD = 1.19; 95% CI = 4.63-4.84) and 39.48 (SD = 3.17; 95% CI = 39.20-39.75), whereas male chiropractors self-ranked their concussion knowledge an average of 6.42 out of 10, (SD = 1.84; 95% CI = 6.29-6.54) and scored an average of 4.87 (SD = 1.21; 95% CI = 4.79-4.96) and 39.41 (SD = 3.56; 95% CI = 39.17-39.66).

Those who participated in contact sports self-ranked

Table 3.
North American Chiropractors' preferred methods of learning – self-rank, original CKAT and revised CKAT scores

Preferred method of learning	N	Self-Rank (out of 10)		Original CKAT Scoring		Revised CKAT Scoring	
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Informational E-mail	190	5.93	1.82	4.71	1.17	39.16	3.18
Lecture	131	6.05	1.90	4.74	1.06	39.48	3.32
Letter	15	5.87	2.61	4.07	1.22	37.40	5.89
Pamphlet	30	5.83	1.56	4.20	1.10	38.10	3.46
Seminar or workshop	936	6.38	1.85	4.88	1.22	39.57	3.41
Legend: CKAT Concussion Knowledge Assessment Tool							

their concussion knowledge higher than those who did not participate in contact sports. Non-contact sport participants self-ranked their concussion knowledge an average of 5.64 out of 10, (SD = 1.94; 95% CI = 1.74-2.2) and scored an average of 4.56 (SD = 1.21; 95% CI = 1.10-1.36) and 39.00 (SD = 4.17; 95% CI = 3.74-4.72). Contact sport participants self-ranked their concussion knowledge an average of 6.34 out of 10, (SD = 1.83; 95% CI = 1.76-1.91) and scored an average of 4.85 (SD = 1.20; 95% CI = 1.16-1.25) and 39.50 (SD = 3.31; 95% CI = 3.18-3.45). Using the original and revised CKAT scoring method, chiropractors who participated in contact sports performed better than chiropractors who did not participate in contact sports. It is important to note that the sample size of chiropractors who participated in contact sports was much larger than the sample size of chiropractors who did not participate in contact sports – 1176 and 145 respectively.

Table 4.
Number of concussions and Chiropractors' reported self-rank, original CKAT and revised CKAT scores

Number of Concussions	Self-Rank (out of 10)		Original CKAT Scoring		Revised CKAT Scoring	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
0	6.01	1.94	4.71	1.19	39.12	3.61
1	6.34	1.77	4.83	1.27	39.56	3.36
2-5	6.47	1.80	4.92	1.16	39.66	3.21
>5	7.11	1.37	5.30	1.13	40.63	2.68
Legend: CKAT Concussion Knowledge Assessment Tool						

Discussion

The purpose of this study was to investigate the extent of knowledge that North American chiropractors have regarding concussion diagnosis and management, and to identify any knowledge gaps present. The study population was large (n = 40 580); however, the response rate was low (n = 1321 respondents: 3.3%). From the pool of respondents, 506 identified as male (38%), and 815 identified as female (62%). When comparing both groups' knowledge of concussions, they performed similarly using both the original and revised CKAT scoring methods.

Results from our study were compared to previous studies which have utilized the CKAT to compare against other healthcare practitioners to identify areas where chiropractors excel and where they are deficient in managing a concussed patient. Section 1 involved asking the definition of a concussion and the mechanisms of concussions. The majority of chiropractors were able to correctly identify the characteristics of concussions. These findings suggest that the chiropractors who participated in this study have concussion knowledge similar to other healthcare practitioners who have taken the CKAT and are possible first contact practitioners to a concussed patient.

In the second section, chiropractors were asked to correctly identify symptoms of concussion. Chiropractors' scores varied and showed lower scores compared to section 1. This trend is common among other healthcare fields, including medical residents, medical students, chiropractic interns and chiropractic residents.[3,4,9,11] Sport chiropractors scored the highest amongst all healthcare fields mentioned above.[3] Section 3 asked about management of concussions. Results were similar to those in section 2, where all healthcare fields showed a decrease in scores except for the sport chiropractor population.[3,4,9,11]

English-speaking chiropractors self-ranked higher compared to French-speaking chiropractors. When comparing the self-ranking scores and original CKAT

scores, all chiropractors self-ranked higher than their actual scores, with English-speaking chiropractors having higher scores. English speaking chiropractors also scored higher on the revised CKAT than the original CKAT when compared to their French-speaking counterparts. It is unknown whether the higher scores in the English-speaking population are due to increased concussion knowledge or merely due to the accuracy of the translation of the survey from English to French, resulting in poorer scores in the French-speaking population in self-rank, original CKAT and revised CKAT scores. To the authors' knowledge no other study has compared these two groups.

All schools' graduates self-ranked their concussion knowledge similarly and scored similarly using the original CKAT scoring method. Using the revised CKAT scoring method, graduates of NWHSU scored the best (40 out of 48), followed by CMCC, Life, Logan, NYCC, Parker, UWS, and UQTR all scoring 39 out of 48. Graduates of NUHS and Palmer scored 38 out of 48. To the authors' knowledge no other study has investigated this in the past.

133 respondents reported that they hold an advanced degree (MSc or PhD). Chiropractors who hold an advanced degree only scored slightly higher on the original and revised CKAT scoring methods, when compared to chiropractors who do not hold an advanced degree. One possible explanation for the similarity between groups could be linked to the fact that their advanced degrees were not related to learning that involved concussion education.

In Canada, available residencies include Clinical Sciences, Diagnostic Imaging, and Sports Sciences programs offered at the Canadian Memorial Chiropractic College.[17] In the United States, Radiology and Rehabilitation residency programs are available at multiple colleges. The Clinical Sciences residency offered by CMCC is a two year program focusing on advanced clinical knowledge and critical thinking, through interactive experiences, in a multidisciplinary environment. CMCC's Sports Sciences two year residency program involves thorough academic and clinical preparation for the participation in a multidisciplinary sports injury care environment. The Canadian Diagnostic Imaging residency program follows a three year curriculum guided by the American College of Chiropractic Radiology.[17] Similarly, the American radiology residency features a three year curriculum of in-depth diagnostic imaging, where residents are eligible for the examination by the American Chiropractic Board of Radiology (DABCR).[18] The Rehabilitation residency features a three year intensive clinical experience with a focus on neuromusculoskeletal rehabilitation in an interdisciplinary setting, where residents are eligible for the Diplomate in Chiropractic Rehabilitation (DACRB).[19]

Once again, North American chiropractic residents were found to have nearly the same concussion knowledge as those not enrolled in a residency program with residents scoring slightly higher compared to non-residents. Chiropractic residents in our population of study scored 4.92 out of 9 on the original scoring and 39.88 out of 48 on the revised scoring; comparatively in a previous study by Kazemi *et al*.[4] Canadian chiropractic residents scored 5.25 out of 9. In the study by Kazemi *et al*.[4] the residents surveyed were only from Canadian Memorial Chiropractic College and were not indicative of the entire North American population of chiropractors and residents from different chiropractic institutions across Canada and the United States. In a study by Boggild and Tator[9], neurology and neurosurgery residents scored 5.8 out of 9. The difference in scores can be attributed to the differences in population between their study and ours. In their study, neurosurgery and neurology residents were found to be more likely to have experience treating patients with concussions and similar brain injuries. In our study, chiropractic residents include those who are clinical science, rehabilitation, radiology, orthopaedics and neurology; some of whom have differing experiences with seeing concussed patients.

Chiropractic Fellows in rehabilitation, sport sciences and neurology are graduates from programs that potentially cover concussion and brain injuries topics in more details than other programs. Furthermore, these Fellows may also see more concussed patients in their practices. Sport sciences programs are available in Canada, while rehabilitation and neurology are offered in the United States.[19] These fellows scored 5.24 out of 9 on the original scoring and 40.46 out of 48 on the revised scoring, considerably higher than other sub-populations analyzed for this study. Compared to the rehabilitation, sport sciences and neurology residents, the neurology and neurosurgery residents in the study by Boggild and Tator scored 5.8 out of 9 on the CKAT.[9] This elevated score can possibly be attributed to the fact that both respective fields have more education dealing with conditions pertaining to head trauma and concussion. Surveying sports chiropractors

Table 5.
Concussion survey results comparison

	Current study North American Chiropractors	Kazemi 2017 Sports Chiropractors[3]	Donaworth 2016 Medical Students[11]	Kazemi 2016 Chiropractic Interns[4]	Kazemi 2016 Chiropractic Residents[4]	Boggild 2012 Medical Students[9]	Boggild 2012 Medical Residents[9]
Mean Overall Score	4.82	5.57	NS	5.2	5.25	4.1	5.8
Correctly identified that less than 1/3 of all concussions involve LOC	85%	95%	60%	75%	NS	66%	NS
Correctly identified that a whiplash effect to the brain caused by an impact to any part of the body may cause a concussion	86%	100%	68%	100%	100%	67%	76%
Correctly answered that a concussion is a brain injury with no abnormalities on structural neuroimaging	84%	93%	84%	98%	NS	94%	100%
Correctly identified that it is only necessary to have one or more symptoms to diagnose a concussion	52%	84%	37%	64%	50%	60%	72%
Correctly recognized chronic traumatic encephalopathy as long-term consequences of repetitive concussive injury	67%	80%	56%	50%	50%	52%	52%
Correctly recognized that second impact syndrome are consequences of recurrent concussions	47%	95%	86%	43%	43%	43%	43%
Believed that every concussed individual should see a physicians as appropriate management of concussion	81%	55%	73%	64%	NS	76%	76%
Legend: NS – not explicitly stated in article.							

solely, they scored the highest among chiropractors with a score of 5.57 out of 9.[3]

In a study by Salisbury *et al*.[10] assessing concussion knowledge among rehabilitation staff across US hospitals, a general trend was found that rehabilitation professionals were able to accurately recognize some signs of a concussion, however, there was a great deal of variability, and thus lack of consistency, when it came to best care, recovery and long-term consequences of concussions. Consistent with our research, chiropractors were able to correctly identify concussions in patients and variability in answers when queried about the nuances of managing these patients. These findings suggest that chiropractors are capable of being a source of first line care for patients who have suffered a concussion.

Self-rank of concussion knowledge increased with the amount of concussions that the chiropractor experienced. The same pattern can be seen with the scores of the original and revised CKAT, where chiropractors who have had no prior concussion scored poorest and chiropractors who have suffered more than five concussions performed the best. It can be theorized that chiropractors who themselves have suffered concussions have sought out a better understanding of concussions as a result of their injury which could account as to why with increased amount of concussions, self-rank and CKAT scores increased subsequently.

Chiropractors who indicated that they participated in contact sports self-ranked their knowledge of concussions higher than those who indicated that they did not participate in contact sports. Chiropractors who indicated that they participated in contact sports outperformed those who did not in both original and the revised CKAT scoring method. This finding suggests that chiropractors who participated in contact sports were further exposed to concussion knowledge due to inherent risk of concussion in these sports. It is reasonable to assume that chiropractors who have not had personal experience or experience assessing/treating concussions may have been less likely to participate in this survey or may have scored lower compared to other clinicians.

Table 5 demonstrates the results of this study and other studies which used CKAT.[3] Several knowledge gaps were presented by chiropractors who participated in this study. Only 52% of chiropractors correctly identified that it is

necessary to have a minimum of one symptom to diagnose a concussion, 67% correctly recognized chronic traumatic encephalopathy as a long-term consequence of repetitive concussive injury and 47% correctly recognized that second impact syndrome is a consequence of recurrent concussions. Interestingly, low scores in these categories were reported in all populations who took the CKAT except sport chiropractors who scored the highest amongst North American chiropractors, medical students, chiropractic interns, chiropractic residents and medical residents.[3] This result may be due to the limitations of observational studies and the lack of a consensus on causal association between mTBI and neurodegenerative disease. As such, the removal of Parkinsonism, chronic traumatic encephalopathy and dementia from question 18 is recommended.

Individuals who preferred lecture-based learning and seminar/workshops scored higher on the original and revised CKAT scoring method, scoring 4.88 and 39.57 in their respective categories. Individuals who attended seminar/workshops self-ranked the highest compared to all other preferred methods of learning. This could be due to increased adherence and participation during lectures and seminars/workshops. In a previous study by Kazemi *et al*.[3] assessing the concussion knowledge of sport chiropractors, their preferred learning method was seminar or workshops where they achieved a CKAT score of 5.57. Comparing this study and our study, it is possible that seminars and workshops promote an environment where learning about concussions occurs the most. In a study by Boggild and Tator[9], when querying fourth year medical students, neurosurgery and neurology medical residents, their preferred learning methods were workshops or seminars with 43% (n = 33) of their respondents preferring workshops or seminars for learning about concussions. In their study, they did not show a score of how those who preferred seminars/workshops scored on the CKAT. They did find, however, that those who self-ranked their ability to manage concussed patients lower also performed worse on the CKAT.[9] This possibly suggests that this population recognizes that their ability to manage concussed patients is lackluster and seek out an evidence-based treatment for their patients.[20] Perhaps the most effective way for healthcare practitioners to learn about concussion post-graduation, would be through the implementation of seminars or workshops. However, it is the authors' opinion that inclusion of concussion in the curriculum of chiropractic colleges would be the best approach to enhance general knowledge of future chiropractors.

Limitations

Despite the large population size, the response rate was low. Furthermore, conducting survey always runs the risk of only attracting those participants who have a vested interest in the topic. As such the result of this study may not be a true presentation of the North American chiropractors' concussion knowledge. Additionally, the large number of chiropractors who have had personal experiences with concussions themselves may have resulted in a general overestimation of chiropractors' knowledge on concussions, which could have influenced the results of the study.

The initial survey[9] that this study was based on was created utilizing information from the 2008 Zurich consensus statement on concussion.[21] Since then, there has been new consensus statements every four years with the last one developed in Berlin in 2016.[2] To enhance CKAT addition of following questions based on the most recent guidelines[2] are recommended:

- immediate management of the athlete on field with red flags[2];
- management of athlete based on return to play and return to school protocols[2];
- the eleven Rs[2] (Recognize; Remove; Re-evaluate; Rest; Rehabilitation; Refer; Recover; Return to sport; Reconsider; Residual effects and sequelae; Risk reduction) in recognition and management of the concussion;
- the effects of past medical history such as depression, headaches, learning disabilities, Attention Deficit Disorder (ADD)/Attention Deficit Hyperactivity Disorder (ADHD);
- baseline testing;
- prevention strategies.

A limitation exists such that in a practical setting, a clinician uses a combination of history, physical and clinical experience in order to evaluate a patient, whereas this study presents a multiple-choice questionnaire to quantify a clinician's knowledge.

When implementing the Survey Monkey, question 12

which asks "Which of the following is a sign or symptom of a concussion? Select all that apply.", vertigo and amnesia were set as one correct response instead of being separate correct answers. As such, our alternative scoring range became 0-48 instead of 0-49. This could have affected the scoring and validity/reliability of the revised scoring reported by Savic *et al*.[16]

Conclusions

Concussions are injuries to the brain that present to chiropractors in practice. It is important for chiropractors to accurately recognize, diagnose and manage concussions. Implementation of best practice concussion guidelines should be increased within a chiropractor's education in order to be able to manage concussions effectively.

Chiropractors who had experience with concussions showed an increased knowledge of concussions, however, not by a great deal. Chiropractors with Fellowships in sport, neurology and rehabilitation scored on the higher ends of all the different chiropractic populations, as well as chiropractors who have suffered concussions themselves in the past.

The chiropractors participated in this study could accurately identify the basics of concussions in patients, however, the subtle nuances of concussions lead to variability in managing these patients. This trend is consistent with many different rehabilitation practitioners involved with managing concussion patients, including physical therapists, athletic trainers and physicians.[10] Further enhancement and updating of the CKAT based on current literature and guidelines and an item by item construct validity assessment are highly recommended. Education should be designed to address the learning gaps and further investigation is needed to understand what method is most effective in the delivery of concussion knowledge.

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References

1. Harmon KG, Clugston JR, Dec K, Hainline B, herring S, Kane SF, Kontos AP, Leddy JJ, McCrea M, Poddar SK, Putukian M, Wilson JC, Roberts WO. American Medical Society for Sports Medicine position statement on concussion in sport. Br J Sports Med. 2019;53: 213–225.
2. McCrory P, Meeuwisse W, Dvorak J, Aubry M, Bailes J, Broglio S, Cantu RC, Cassidy D, Echemendia RJ, Castellani RJ, Davis GA. Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016. Br J Sports Med. 2017;51(11): 838-847.
3. Kazemi M, Bogumil ME, Vora K. Concussion knowledge among sport chiropractic Fellows from the Royal College of Chiropractic Sports Sciences (Canada). J Can Chiropr Assoc. 2017;61(3): 239–252.
4. Kazemi M, Pichini A, Scappaticci S, Savic M. Concussion assessment and management knowledge among Chiropractic fourth year interns and residents. J Can Chiropr Assoc. 2016;60(4): 273–285.
5. Henry L, Twichell M. Concussion. London, England; 2018 Mar. Available from https://bestpractice.bmj.com/topics/en-us/967
6. Echemendia RJ, Meeuwisse W, McCrory P, Davis GA, Putukian M, Leddy J, Makdissi M, Sullivan SJ, Broglio SP, Raftery M, Schneider K. The sport concussion assessment tool 5th edition (SCAT5): Background and rationale. Br J Sports Med. 2017;51(11): 848–850.
7. Zemek R, Eady K, Moreau K, Farion KJ, Solomon B, Weiser M, Dematteo C. Canadian pediatric emergency physician knowledge of concussion diagnosis and initial management. CJEM. 2015;17(2): 115–122.
8. Taylor DN, Ponce FJ, Dyess SJ. Survey of primary contact medical and chiropractic clinicians on self-reported knowledge and recognition of mild traumatic brain injuries: a pilot study. J Chiropr Med. 2017;16(1): 19–30.
9. Boggild M, Tator CH. Concussion knowledge among medical students and neurology/neurosurgery residents. Can J Neurol Sci. 2012; 39(3): 361–368.
10. Salisbury D, Kolessar M, Callender L, Bennett M. Concussion knowledge among rehabilitation staff. Proc Bayl Univ Med Cent. 2017;30(1): 33–37. doi:10.1080/08998280.2017.11929519
11. Donaworth MA, Grandhi RK, Logan K, Gubanich PJ, Myer GD. Is current medical education adequately preparing future physicians to manage concussion: an initial evaluation. Phys Sportsmed. 2016; 44(1): 1–7.
12. Burke MJ, Chundamala J, Tator CH. Deficiencies in concussion education in Canadian medical schools. Can J Neurol Sci. 2012; 39(6): 763–766.
13. Mathieu F, Ellis M, Tator C. Concussion education in Canadian medical schools: a 5 year follow-up survey. BMC Med Educ. 2018; 18(316) doi: https://doi.org/10.1186/s12909-018-1416-7
14. McCrory P, Meeuwisse WH, Aubry M, Cantu RC, Dvorak J, Echemendia RJ, Engebretsen L, Johnston KM, Kutcher JS, Raftery M, Sills A. Consensus statement on concussion in sport: the 4th International Conference on

Concussion in Sport held in Zurich, November 2012. Br J Sports Med. 2013;47: 250-258.
15. Keenan HT, Bratton SL, Dixon RR. Pediatricians' knowledge, attitudes, and behaviors to screening children after complicated mild TBI: a survey. J Head Trauma Rehabil. 2017;32(6): 385–392. doi:10.1097/HTR.0000000000000265
16. Savic M, Kazemi M, Lee A, Starmer D, Hogg-Johnson S. Construct Validity & Reliability of a Concussion Assessment Tool (CKAT). J Can Chiropr Assoc. 2020;64(3): 201-213.
17. Canadian Memorial Chiropractic College. Chiropractic Residency Programs [cited 13 July 2020]. Available from: https://www.cmcc.ca/academic-programs/chiropractic-residency-programs
18. American Chiropractic College of Radiology. Residency Program Information [cited 5 August 2020]. Available from: https://www.accr.org/radiology-information/residencies
19. American Chiropractic Rehabilitation Board. Program Info [cited 5 August 2020]. Available from: https://www.acrb.org/board-certification-information.html
20. Taylor D, Wynd S. Survey of chiropractic clinicians on self-reported knowledge and recognition of concussion injuries. Chiropr Man Ther. 2018; 26(19).
21. McCrory P, Meeuwisse W, Johnston K, Dvorak J, Aubry M, Molloy M, Cantu R. Consensus statement on concussion in sport: the 3rd international conference on concussion in sport held in Zurich, November 2008. Br J Sports Med. 2009; 43: i76–i84.

Appendix 1.
Modified CKAT questionnaire

Part 1: ID questions and Sports and Recreation background:	
1.	What is your gender? 1. Male 2. Female
2.	Which chiropractic college did you graduate from?
3.	Do you have any chiropractic speciality Fellowships or diplomate certificate? If so, what are they?
4.	Are you enrolled in any Chiropractic specialty residency program? If so, what program and year are you in?
5.	Have you done any of the following in the past 2 years? Mark all that apply. i. Walking for exercise ii. Jogging or running iii. Swimming iv. Bicycling v. Weight-training vi. Exercise class or aerobics vii. Golfing viii. Baseball or softball ix. Tennis or squash x. Volleyball xi. Basketball xii. Ice hockey or ice skating xiii. Downhill skiing or snowboarding xiv. Boxing martial arts (judo/karate) xv. Wrestling xvi. Football xvii. Soccer xviii. Equestrian xix. Inline skating xx. Gymnastics xxi. Cheerleading xxii. Trampoline xxiii. Diving xxiv. Rugby xxv. Skydiving xxvi. Mountain climbing xxvii. Martial arts xxviii. ATV, Motorcycle, automobile racing, or snowmobiling xxix. Other

Modified CKAT questionnaire – Part 1: ID questions and Sports and Recreation background *(continued)*	
6.	Last week, how many times did you participate in sports or physical activity? i. 1 time ii. 2 times iii. 3 times iv. 4 times v. 5 times vi. 6 times vii. 7 times
7.	About how much time did you spend on each occasion? i. 1 to 15 minutes ii. 16 to 30 minutes iii. 31 to 60 minutes iv. More than one hour
8.	In the past, have you ever suffered a concussion? You may have been "knocked out", knocked unconscious, confused, or had your "bell rung". You may have felt lightheaded, not knowing where you are, etc. i. Yes – once ii. Yes – 1-5 times iii. Yes – more than 5 times iv. No
9.	If you answered yes to the previous question, how did your concussion(s) occur? Please select all that apply. 1. Work related 2. Motor Vehicle Crash 3. Sport or recreational activity 4. Fall 5. Other

Part 2: Knowledge questions about concussions (Answers that were considered correct are bolded):	
10.	What is the definition of concussion? Select the best answer. 1. Loss of consciousness for <5 mins after an impact to the head **2. A complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces** 3. A structural brain injury caused by mild traumatic force that transiently decreases cerebral blood flow
11.	Is a concussion a brain injury? Select the best answer. i. No, as there is no abnormality seen on standard structural neuroimaging ii. No, as symptoms are only psychological in nature **iii. Yes, as there is a functional disturbance that cannot be seen on standard neuroimaging** iv. Yes, as there is structural abnormality seen on standard neuroimaging

Modified CKAT questionnaire – Part 2: Knowledge questions about concussions *(continued)*	
12.	Which one of the following is true? i. A period of unconsciousness is necessary for the diagnosis of a concussion ii. Over 2/3 of all concussions involve loss of consciousness (LOC) iii. 1/3 to 2/3 of all concussions involve loss of consciousness (LOC) **iv. Less than 1/3 of all concussions involve loss of consciousness (LOC)**
13.	Which of the following is a sign or symptom of a concussion? Select all that apply. **1. Headache** 2. Hemiparesis **3. Dizziness** **4. Confusion** 5. Fixed dilated pupil **6. Nausea and/or Vomiting** **7. Vertigo, Amnesia** **8. Tinnitus** **9. Emotional or personality changes** 10. Papilledema 11. Intention tremor **12. Fatigue** **13. Temporary loss of consciousness** 14. Prolonged coma
14.	How many symptoms of a concussion are required to diagnose a concussion? **1. One or more symptoms** 2. three or more symptoms 3. five or more symptoms
15.	Which of the following is true regarding the mechanism of concussion? i. Direct physical contact to the head is necessary to sustain a concussion ii. Localized damage to the brainstem is the cause a concussion iii. Localized damage to the prefrontal cortex is the cause of a concussion iv. Localized damage to the hippocampus is the cause of a concussion **v. A whiplash effect to the brain caused by an impact to any part of the body may cause a concussion**
16.	What is the appropriate management of concussion? Select all that apply. **i. Every concussed individual should see a healthcare professional** ii. A concussed player can return to play in the same game or practice if examined by a healthcare professional **iii. A stepwise increase in exercise and activity if symptomatic** **iv. Physical rest is always recommended after a concussion** **v. Mental rest is always recommended after a concussion** **vi. Signs and symptoms should be monitored for increasing severity** **vii. Full neurological exam at initial assessment is recommended** viii. The standard mini mental status exam at initial assessment as an adequate cognitive test for concussion ix. MRI of the brain is mandatory x. CT of the brain is mandatory

Modified CKAT questionnaire – Part 2: Knowledge questions about concussions *(continued)*	
17.	What are some "red flags" that may predict the potential for more prolonged symptoms and may influence your investigation and management of concussion? Select all that apply: i. Nose bleed **ii. Prolonged loss of consciousness** **iii. Number and duration of symptoms** **iiv. Younger Age** **v. Repeated concussions occurring with progressively less impact force** **vi. Slower recovery after each successive concussion** **vii. Repeated concussions over time** **viii. Concussions close together in time** ix. Being hit on the left side of the head
18.	What are the long-term consequences of repetitive concussive injury? Select all that apply. **i. Dementia** **ii. Depression** **iii. Headaches** iv. Increased risk of hemorrhagic stroke **v. Death or disability with second concussion before recovery from a first concussion** vi. Increased risk of schizophrenia **vii. Prolonged fatigue** **viii. Impairment of concentration and memory** **ix. Parkinsonism** **x. Chronic traumatic encephalopathy**

Part 3: Learning needs about concussions::	
19.	In your undergraduate chiropractic education, how did you learn about concussions? Select all that apply. i. Lecture ii. PBL (problem-based learning) iii. Seminar iv. Interest Group v. Shadowing/ Observership vi. Other vii. Never, I can't remember
20.	In your residency to date, how did you learn about concussions? Select all that apply. 1. Clinical experience 2. Self-study 3. Lecture 4. Never, I can't remember 5. Other

Modified CKAT questionnaire – Part 3: Learning needs about concussions *(continued)*	
21.	To date, have you seen a patient with: – concussion in the acute phase? (select one) 1. Yes, 2. No, 3. I don't know – post-concussive syndrome? (select one) 1. Yes, 2. No, 3. I don't know
22.	How would you self-rank your knowledge about concussions? Inadequate Completely adequate 1 2 3 4 5 6 7 8 9 10
23.	What resource would you most likely use to find information about concussions? 1. Google 2. Wikipedia 3. Up-to-date 4. Textbook 5. Pubmed 6. an agency website 7. Thinkfirst.ca 8. other
24.	Are concussions something you want to learn more about as part of your medical curriculum? Not at all Very much 1 2 3 4 5 6 7 8 9 10
25.	What is your preferred format for healthcare professional learning material? 1. Pamphlet 2. letter 3. seminar or workshop 4. lecture 5. informational email
26.	What challenges, if any, do you think healthcare professionals face when diagnosing and managing a concussion?
27.	This concussion assessment tool was created from knowledge extracted from the 2008 Zurich Consensus Statement on Concussion. Given that there have been recent advances in concussion research since 2008, are there any changes you recommend to the assessment tool, as a result of newer research?

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A qualitative study investigating research priorities and investigative capacity in sports-focused chiropractic research, part 1 – identifying research priorities to inform a Delphi study

Alexander Dennis Lee, BSc(Hons), DC, FRCCSS(C)[1]
Lara C. deGraauw, BSc, DC, FRCCSS(C)[1]
Bradley J. Muir, HBSc(Kin), DC, FRCCSS(C)[1]
Melissa N. Belchos, BSc(Hons), DC[2]
Kaitlyn M. Szabo, BSc.Kin, DC[3]
Christopher deGraauw, DC, FRCCSS(C)[1]
Scott D. Howitt, MSc, DC, FRCCSS(C), FCCPOR[1]

Objectives: *To identify sports-focused research priorities to inform the development of a research agenda for sports chiropractors*.

Methods: *A qualitative description study was conducted using semi-structured interviews with 20 sports chiropractic researchers from 8 different countries and focus group interviews with 12 sports chiropractic leaders from Canada*.

Results: *150 research priorities were identified, and*

Étude qualitative sur les priorités de recherche et la capacité de recherche en chiropratique sportive, partie 1 - identification des priorités de recherche pour guider une étude Delphi

Objectifs : *Identifier les priorités de recherche axées sur le sport pour guider le développement d'un programme de recherche pour les chiropraticiens du sport*.

Méthodologie : *Une étude de description qualitative a été menée à l'aide d'entretiens semi-structurés auprès de 20 chercheurs en chiropratique sportive de huit pays et d'entretiens en groupes de discussion avec 12 dirigeants de la chiropratique sportive du Canada*.

Résultats : *150 priorités de recherche ont été*

[1] Department of Clinical Education, Canadian Memorial Chiropractic College
[2] Graduate Education and Research Programs, Canadian Memorial Chiropractic College
[3] Private Practice

Corresponding author: Alexander Lee, Canadian Memorial Chiropractic College, 6100 Leslie Street, Toronto, ON M2H 3J1
Email: alee1@cmcc.ca
Tel: 416-482-2340

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three main themes emerged: area of research, research actions, and research methodology. Six areas of research were identified: basic science and mechanism research, clinical research, health services research, population health, specific conditions and topics in sport, and chiropractic research in sport. Collaboration in research and contributing to the broader sports research effort were two subthemes identified as research actions, and the remaining codes were related to research methodology.

Conclusions: *The research priorities identified can be utilized to plan future research prioritization studies to inform a research agenda for the sports chiropractic field.*

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KEY WORDS: sports, chiropractic, qualitative research, research

identifiées, et trois thèmes principaux sont ressortis : le domaine de recherche, les actions de recherche et la méthodologie de recherche. Six domaines de recherche ont été identifiés : la science fondamentale et la recherche sur les mécanismes, la recherche clinique, la recherche sur les services de santé, la santé de la population, des conditions et des sujets particuliers liés au sport et la recherche en chiropratique sportive. La collaboration dans la recherche et de façon plus générale, la contribution à l'effort de recherche sur le sport sont deux sous-thèmes identifiés comme des actions de recherche, et les autres codes sont liés à la méthodologie de recherche.

Conclusions : *Les priorités de recherche identifiées peuvent servir à préparer de futures études sur la priorisation de la recherche et à guider un programme de recherche dans le domaine de la chiropratique sportive.*

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MOTS CLÉS : sports, chiropratique, recherche qualitative, recherche

Introduction

In Canada, $1.5 billion in annual healthcare costs has been attributed to sports and physical activity-related injuries.[1,2] With up to 55% of adults[3,4] and 74% of youth[5] partaking in sports and physical activity in Canada, the importance of managing these injuries has implications for the Canadian healthcare system. Chiropractors are primary contact healthcare practitioners who possess the skills to manage sports injuries. In Canada, nearly a third of chiropractors surveyed in 2011 reported treating sports injuries as a main component of their practice, and a practice focus of treating sports injuries was identified as a variable that was associated with receiving increased physician referrals.[6] In Australia, 49.5% of chiropractors reported treating athletes, and of the chiropractors who treated athletes, they more often reported collaborative professional and referral relationships compared to chiropractors who did not often treat athletes.[7] For these reasons, sports injury management is an important area of professional activity with collaborative opportunities for the chiropractic field.

In many countries, sports chiropractic is recognized as an accredited specialty within the profession or is regarded as an area of practice concentration. The International Federation of Sports Chiropractic/Fédération Internationale de Chiropratique du Sport (FICS) is an assembly of national chiropractic sports councils and individual members worldwide that serves to coordinate the advancement of sports chiropractic, globally.[8] In Canada, sports chiropractic is an accredited specialty within the chiropractic profession, and the Royal College of Chiropractic Sports Sciences (Canada) (RCCSS(C)) is the governing and organizing body that coordinates the involvement of the chiropractic profession with amateur and professional athletic sport organizations.[9] Fellows of the RCCSS(C) in Canada are leaders in clinical practice, education and research with respect to sports chiropractic.[10]

While general chiropractic practice can involve the treatment of sports injuries, previous reports have identified characteristics common to sports chiropractic practice.[7,10–12] In Australia, sports chiropractors more often reported utilizing a multi-modal treatment approach in-

volving a range of treatment techniques such as spinal manipulation/mobilization, extremity manipulation/mobilization, soft tissue therapies, acupuncture, taping techniques, rehabilitation and specific exercise therapies.[7] In a survey of Fellows of the RCCSS(C), 95% of respondents felt that "chiropractic treatment involved more than a chiropractic adjustment", and the majority felt that their treatment could cause improvements in an athlete's sport performance. The most utilized interventions reported to affect performance were spinal joint manipulation/mobilization (92%), extremity joint manipulation/mobilization (89%), exercise prescription (86%), sport-specific training advice (86%), manual soft tissue therapies (84%), and rehabilitation prescription (81%). All respondents felt that inter-disciplinary health professional relationships were important in the treatment of athletes.[10] Any research endeavors conducted to advance the sports chiropractic field should take into consideration these distinctive approaches to sports chiropractic practice.

Research is vital to advance knowledge and provide evidence-informed, up-to-date, and safe patient care. Recently, chiropractic research agendas have been developed in North America and Europe utilizing the Delphi method to achieve expert consensus on research priorities.[13,14] The Delphi method is a systematic voting procedure that involves recruiting experts to participate in an iterative survey process where experts vote upon a list of statements (often referred to as seed statements) and rank their importance with the purpose of determining consensus.[15–17] While these research agendas facilitate broad research planning for the chiropractic profession, they do not specifically address the research needs of sports chiropractors. From an interview study, sports chiropractic practitioners emphasized the importance of conducting research on topics unique to their field, such as the effectiveness of sports chiropractic treatment on athletic performance, injury recovery, and injury prevention.[11] A limitation of previous chiropractic research agendas is that the Delphi panels to create such agendas had minimal sports chiropractic input.[13,14]

To the authors' knowledge, a research agenda has not been published for the sports chiropractic field. It is our intention to conduct Canadian and International Delphi studies to determine consensus on sports-focused research priorities for sports chiropractors. Prior to conducting a Delphi study, an appropriate sample of experts must be identified, and research priorities must be identified to create seed statements for the Delphi procedure for experts to vote on. To determine these essential components, we developed a three-phase plan to create a sports-focused research agenda for sports chiropractors that involves the following: phase one – an exploratory study to uncover the opinions of sports chiropractors about research topics, phase two – a qualitative study designed to extract a list of research priorities from sports chiropractic experts and to explore investigative capacity within the sports chiropractic field, and phase three – conducting both Canadian and International Delphi studies.

The phase one exploratory study involved interviewing chiropractors with a sports-focused practice to explore their opinions about research using quantitative text analysis methods.[8] Chiropractors with a sports-focused practice concentrated their discussions about research on topics specific to the sports context, such as the effects of various sports chiropractic interventions on athletic performance, injury prevention for athletes, chiropractic care of sports injuries, and the care of athletes in clinical practice.[8] These sports-related research interests were not captured by previous Delphi studies conducted for the general chiropractic profession[13,14], highlighting the need to perform separate research prioritization Delphi studies for the sports chiropractic field.

Previous chiropractic research agenda studies utilized qualitative methods to identify research themes and priorities to generate seed statements for their Delphi process; however, these approaches were published as an appendix, and their methods were not reported in their entirety.[13,14] We believe there is richness in the qualitative data collected to create seed statements when planning a Delphi study that should be explored, as the knowledge gleaned from the analysis can assist with research planning and inform the implementation of a research agenda. This present project was conducted in two parts. The aim of the first part of this project was to conduct a qualitative description study of semi-structured and focus group interviews from sports chiropractic researchers and organizational leaders to better understand the research priorities important to these experts. The data from the first part of this study will inform seed statements for a Canadian Delphi study to determine consensus on research priorities for Canadian sports chiropractors and will also provide an initial framework for planning a similar Inter-

national Delphi study. The second part of this project involves exploring investigative capacity in sports-focused chiropractic research and will be reported as a separate article.

Methods

Study design

We conducted a cross-sectional qualitative description study using semi-structured interviews of sports-focused chiropractic researchers and focus group interviews of organizational leaders of sports chiropractic in Canada. Qualitative description is a method that aims to acquire a rich description of the phenomenon under study, but is not used to develop substantive theory or explanations from the data.[18] It is especially relevant in questionnaire development and in studies aiming to gain first-hand knowledge of professionals' experiences with a particular topic.[19] Considering the aim of this study was to extract research priorities from sports chiropractic researchers and leaders to inform questionnaire development for a Delphi study, this study design was chosen.

Although semi-structured and focus groups interviews are independent data collection methods, the rationale for their combination is advantageous when seeking data completeness where each method reveals different parts of the phenomenon of interest (e.g., complementary views) and for pragmatic reasons.[20] To identify research themes and priorities to inform the development of seed statements for a Canadian Delphi study and to inform the planning of a similar international Delphi study, we sought to obtain a broad view of the contributors to the sports chiropractic research landscape, particularly in Canada. Recognizing that the research effort in a field of study can be influenced by the investigators conducting the research and decision-makers that govern a field's resources, we sought to obtain qualitative data from sports chiropractic researchers and decision-makers of sports chiropractic organizations in Canada, specifically members of the Boards of Directors of the RCCSS(C) and its Foundation. We did not seek to recruit clinicians for this study, as many sports chiropractic researchers and decision-makers also maintain a clinical practice or have previous clinical practice experience. We believe their viewpoints would also include the clinician's perspective.

Since researchers work in areas of specialization, operate with relative autonomy, and can be influenced by their regional research environment, we decided individual semi-structured interviews would best capture the unique views about research that these investigators would have in relation to the study's aim. In contrast, Boards of Directors of organizations are naturally occurring groups that engage in context-dependent group interactions to make collaborative decisions on issues of governance. Consequently, we felt that separate focus group interviews of the Boards of Directors of the RCCSS(C) and its Foundation would best capture the views of these groups on research themes and priorities.

This study received approval by the Canadian Memorial Chiropractic College (CMCC) Research Ethics Board (#1708E01, approval date 09/14/2017) prior to commencement. All participants signed a written informed consent form before the start of each semi-structured or focus group interview.

Participants and eligibility criteria

To be eligible as a participant for the semi-structured interview component of this study, participants had to be a registered chiropractor or a researcher who has either conducted, been a collaborator or supervisor of sports-focused chiropractic research, and who has also published at least one sports-focused research paper within the past 10 years. For the purpose of this study, sports-focused research was defined using the RCCSS(C) definition[21] that states sports-focused research is "a field of research directly related or relevant to anyone involved in the sport, athletic, or exercise community. These topics may include but are not limited to the following: injuries, injury prevention, treatment, rehabilitation, biomechanics, performance, assessment metrics, nutrition, epidemiology, diagnostic imaging, emergency care, athletic event coverage, team travel, education, exercise physiology, and sport psychology."

For the semi-structured interviews, purposive and snowball sampling was used to identify sports chiropractic investigators that met our selection criteria and who would yield appropriate and useful information for the aim of this study.[22] Recognizing that certain researcher characteristics can impact their opinions and viewpoints about research, we sought to interview researchers with different levels of experience, roles/position in research and from different geographical regions. As the aim of

this study was to extract a list of research themes and priorities to inform seed statements for a Canadian Delphi study and to provide preliminary insight for planning a future International Delphi study, we chose to weight our recruitment towards a Canadian sample, with the inclusion of at least one participant from North America (in addition to Canada), South America, Europe, Africa and Australasia.

Sports chiropractic researchers were identified by reviewing publication lists provided by the RCCSS(C), conducting literature searches of the PubMed and Index to Chiropractic Literature databases (see Appendix 1 for search strategy example), and by emailing editorial board members of peer-reviewed chiropractic journals who have conducted work in the sports chiropractic field for recommendations of sports chiropractic researchers. A three-step screening process was used to create a list of eligible sports chiropractic researchers to recruit for this study. Step one – the citations from the RCCSS(C) publication list and literature searches were reviewed to identify citations that met the RCCSS(C) definition[21] of sports-focused research. Step two – author searches of these citations and of the researchers recommended by journal editorial board members were conducted using PubMed and Google to identify those who met the study's inclusion criteria. Step three – of the sports chiropractic researchers identified from step two, internet searches were conducted to identify their institutional affiliation, research role/position, geographical location, and number of sports-focused publications.

Once compiled, two of the investigators (AL and MB) reviewed this list and stratified these eligible sports chiropractic researchers based on number of publications, research experience, role/position in research, and geographical location. After reviewing these characteristics of the eligible participants, we sought to interview a minimum of one novice researcher, senior researcher, research chair, journal editorial board member, academic program director, and research administrator. The two investigators (AL and MB) who compiled this list met to decide which sports chiropractic researchers to invite to participate in a semi-structured interview based on these attributes. Once these minimums were met, the two investigators continued to meet to decide which researchers would yield appropriate and useful information for the aim of this study. At the completion of each interview, each participant was asked if they could recommend other sports chiropractic researchers we should contact for this study. Individuals identified by snowball sampling were reviewed against the study's inclusion criteria and researcher characteristics of interest, and the research team decided whether to invite these individuals to participate.

For the focus group interviews, purposive sampling was conducted to identify organizational leaders of sports chiropractic in Canada by contacting board members of the RCCSS(C) and its Foundation. The RCCSS(C) is the governing and organizing body that coordinates the involvement of the Canadian chiropractic profession with amateur and professional athletic sport organizations. It provides post-graduate education to chiropractors to allow them to attain a Fellowship in chiropractic sports sciences and represents approximately 170 chiropractic sports fellows and residents.[9] The Foundation for the RCCSS(C) is a fundraising organization that collaborates with the RCCSS(C) to fund education and scientific research in chiropractic sports healthcare.[23] To be eligible to participate in the focus group interviews, participants had to be an active member of the board of directors of either the RCCSS(C) or its Foundation.

Once individuals were identified by our sampling methods, all prospective participants were recruited by the principal author by email invitation. To provide an estimate of the sample size for this study, we analyzed our study's characteristics against the items theorized to impact the information power[24] of the data that we intended to gather (Appendix 2). We anticipated a sample size of approximately 20 to 30 participants. This is within the sampling range of a previous investigation that demonstrated data saturation occurring in as low as six to eight participants in homogenous samples, and up to 12 to 30 when looking for disconfirming evidence or trying to achieve maximum variation.[25]

Research team and reflexivity

The interviews were conducted by two members of the research team (ADL – male, LD – female). At each interview, another member of the research team (MB or KS) attended the interview (in person, virtually, or by telephone) to take field notes. Both interviewers (ADL, LD) are practicing chiropractors, Fellows of the RCCSS(C) and are full-time faculty members at the Canadian Memorial Chiropractic College (CMCC). ADL has 13 years

of practice and research experience, and LD has 23 years. In the planning phases of this study, ADL and LD consulted with a senior qualitative researcher at their academic institution for guidance and advice. During the time of conducting the interviews, the field note takers (KS, MB) were a practicing chiropractor and fourth year clinical intern at CMCC, respectively.

Considering the sports chiropractic field is a relatively small field of study, pre-existing relationships within the field can exist. The interviewers, ADL and LD, are both involved in committee work with the RCCSS(C) and are actively involved in the sports-focused chiropractic research field. As a result, they have previous relationships with some of the participants who were interviewed. To mitigate any bias that may have occurred during the interviews, the interviewers regularly reiterated the study's aim and purpose, which was to extract research priorities from the interviews to develop seed statements for a future Delphi study to determine consensus on sports-focused research priorities for sports chiropractors. During the qualitative analysis, ADL and LD aimed to decrease their own bias by regularly meeting to reflect on their coding decisions in relation to the study's aim.

Data collection procedures

Setting and interviews

The semi-structured interviews were conducted in-person or remotely using the Skype Application (Skype Technologies, Microsoft, USA), dependent on the availability of the participants. At each interview, one of the lead authors (ADL or LD) conducted the interview, while another member of the research team (MB or KS) took field notes. The semi-structured interviews were audio-recorded using a digital audio recorder (SONY ICD-PX333 Digital Flash Voice Recorder) and Callnote audio recording software (Callnote, Kanda Software Inc., USA).

Two separate focus group interviews of the organizational leaders of sports chiropractic in Canada were conducted in-person: one for the Board of Directors of the RCCSS(C) and another for the Board of Directors of the Foundation for the RCCSS(C). These focus group interviews were conducted in a meeting room at the location of the RCCSS(C) Annual Board Meeting. Three members of the research team were present at both focus group interviews. The lead author (ADL) moderated the focus group while LD and MB took field notes. The focus group interviews were audio-recorded using a digital audio recorder (SONY ICD-PX333 Digital Flash Voice Recorder) and Audacity audio recording software (Audacity, USA).

The development of the interview guide was informed by previous work that interviewed chiropractors with a sports-focused practice about sports chiropractic research priorities[11], and was distributed to members of the Research and Education Committee of the RCCSS(C) for their feedback related to the questions developed and their relevance to our research question. Prior to data collection, the interview guide was piloted in a mock focus group session involving a group of nine chiropractic clinical interns, and a pilot semi-structured interview was conducted with a research assistant. The same interview guide was used for both the focus group and semi-structured individual interviews. All participants were sent our interview guide (Appendix 3), a minimum of two days in advance of their interview, to provide them with the opportunity to familiarize themselves with the questions and to allow them to consider potential responses.

In addition to the interviews, the participant's age, sex, years of practice, clinical practice status, number of publications, academic positions, geographical location, and education were collected to characterize our sample.

Analysis

At the completion of each focus group and semi-structured interview, ADL and LD met to debrief the interview notes and review the interview recordings to determine if changes should be made to the interview guide and if any researchers suggested by snowball sampling should be considered for recruitment. Two members of the research team, MB and KS, transcribed all audio recordings verbatim with transcripts reviewed for accuracy by the lead author (ADL). All participant names were removed from the transcripts and replaced with unique identifiers. Each participant was sent their transcript for their review with instructions to make any edits or additions to the transcripts that they saw fit. Upon receiving the reviewed and edited transcripts from the participants, they were imported into NVivo™ software (QSR International Pty Ltd., Victoria, Australia) for qualitative analysis.

Qualitative analysis commenced after completing the interviews, with the two focus groups being analyzed first, to determine if changes to the interview guide was neces-

sary before conducting the semi-structured interviews. While it was the intention to analyze each semi-structured interview prior to conducting subsequent ones, to take advantage of opportunities to schedule interviews, the analysis of the semi-structured interviews was conducted after the majority were complete. The decision to stop recruiting participants for further interviews was determined when data saturation was reached, which was defined as the point where further data collection and analysis produced little or no change to the qualitative codes within the data.[25]

A qualitative content analysis of the interview transcripts was conducted using an interpretivist perspective. The intention of an interpretivist approach is to describe and interpret, but not to develop a substantive theory. It is concerned with how people feel, respond and give meaning to their experiences.[26] Since we did not seek to develop theory from the data or compare and contrast the viewpoints of the participants, the semi-structured interviews of the researchers and focus-group interviews of the leaders were given equal weight in our analysis. The unit of analysis were the interview transcripts from each participant. Comparisons between the sports chiropractic researchers and leaders were not made as it was deemed to be beyond the scope of this study.

Two members of the research team (ADL and LD) coded the transcriptions independently using an inductive content analysis for both manifest and latent content, and regularly met for peer debriefing to discuss and resolve any coding discrepancies. Similar codes were sorted and collapsed together to create categories. Themes were abstracted from the codes and categories generated from the data with guidance from research categories utilized by previous chiropractic research prioritization studies.[13,14] An audit trail of the coding and reflexive process was recorded throughout the analysis. The qualitative analysis and reporting of the data was guided by the consolidated criteria for reporting qualitative research.[27]

Table 1.
Participant demographic characteristics

Number of participants	32
Age in years (mean ± SD)	47.4 ± 10
Sex (male/female)	25 (78%) / 7 (22%)
Average years of practice (mean ± SD)	20.1 ± 9.7
Number maintaining a clinical practice	25 (78%)
Number of publications (mean ± SD)	16.2 ± 23.4
Academic positions	
Faculty (adjunct or primary)	23 (72%)
Professor	18 (56%)
Lecturer/Tutor	7 (22%)
University affiliation	13 (41%)
Chiropractic academic institution affiliation	21 (66%)
Journal editor/editorial board	3 (9%)
Board/committee position in a chiropractic association	16 (50%)
Research chair	1 (3%)
Director of a research program	2 (6%)
Director or coordinator of an academic program	5 (16%)
Education	
Undergraduate	22 (69%)
DC	31 (97%)
Masters	18 (56%)
PhD	5 (16%)
PhD (candidate)	6 (19%)
Sports specialization fellowship/diplomate/degree	19 (59%)
Country	
Canada	21 (66%)
United States of America	4 (13%)
Australia	2 (6%)
Sweden	1 (3%)
Brazil	1 (3%)
England	1 (3%)
Germany	1 (3%)
South Africa	1 (3%)

Results

Participants

For the semi-structured interviews, 25 sports-focused chiropractic researchers were recruited (22 from purposive and 3 from snowball sampling) and 20 participated (80% response rate). Of those who declined participation, four researchers reported a lack of time as the reason they could not participate, and one individual cited personal reasons to decline. For the focus groups, all 12 individuals recruited participated fully in the study (100% response rate). A total of 32 participants completed this study. The average interview durations for the semi-structured and focus group interviews were 56.87 and 52.55 minutes respectively. After analyzing the focus group interviews, it

was determined no changes were required to the interview guide prior to conducting the semi-structured interviews.

All participants reviewed and returned their transcripts to the research team, and 12 participants made minor revisions to clarify statements made in their interviews with no significant changes to the content. No new codes emerged from the data in semi-structured interview 17, only one new code was identified from interview 18, and interviews 19 and 20 did not yield any new codes. At this point, we determined further interviews were unlikely to generate any significant new codes and themes from the targeted population and recruitment was concluded.[25]

Table 1 lists the demographic characteristics of our participants. Our sample had a larger proportion of males (78%), and there was large variability in the average years of practice and number of publications of our participants, demonstrating that participants had varying levels of experience. Most participants held faculty positions (72%), had affiliations with chiropractic academic institutions (66%), and maintained a clinical practice (78%). Nearly all participants were chiropractors (97%), and 59% had some form of sports specialization training. Of the participants, 29 (90%) reported having post-graduate research training (master's degree or higher). Reflective of our sampling strategy, our sample was comprised of 21 (66%) Canadians and 11 (34%) from other countries.

Identified research priorities and themes

A total of 150 individual research priorities were identified from our qualitative analysis and were categorized into three major themes: 1) area of research, 2) research actions and 3) research methodology. The area of research theme was used to categorize research priorities into topics of research to create sub-themes. Similar to previous research prioritization studies for the chiropractic profession[13,14], many of the research priorities could be categorized into the sub-themes: basic science and mechanism research, clinical research, and population health. A variety of research priorities emerged from the data that were related to health services research applied to the sport context. As a result, the sub-theme, health services research, was created for these priorities. Consistent with our previous work[11], research priorities were frequently identified about chiropractic research conducted in the sport setting, so the sub-theme chiropractic research in sport, was created for this reason. The remaining research priorities in the area of research theme were related to specific conditions and topics in sports.

Table 2.
Number of segments of coded text attributed to each research theme

Major research themes and sub-themes	Segments of coded text
Area of research	1065
Clinical research	513
Chiropractic research in sport	243
Specific sports conditions and topics	126
Health services research	91
Basic science and mechanism research	72
Population health	20
Research actions	319
Collaboration in research	303
Contributing to the broader sports research effort	16
Research methodology	66

The research actions theme was created to capture research priorities that pertained to efforts related to conducting research. Considering there were a range of research priorities extracted related to research collaboration, the collaboration in research sub-theme was created. In the interview transcripts, many participants mentioned the importance of having sports chiropractors involved in collaborative research teams investigating large sports research topics, and many interviewees recommended that sports chiropractors should contribute to the overall sports research effort that is shared by all professionals working in sport. Consistent with these recommendations, we created the sub-theme contributing to the broader sports medicine research effort to capture these recommendations.

Lastly, the remaining research priorities were related to study design and methodological approaches to research, such as conducting systematic reviews and creating practice- and field-based research networks. These directives were grouped together to form the major theme, research methodology. Table 2 outlines the number of segments of coded text that were attributed to research priorities for each theme and subtheme. All research priorities identified are presented in Table 3 categorized into their respective themes along with supporting quotes.

Table 3.
Research themes and priorities with supporting quotes

Major theme: Area of research	
Basic Science and Mechanism Research	
Fields of Study ➢ Biomechanics ➢ Biomechanics of Injury ➢ Sports Biomechanics ➢ Cellular Biology & Physiology ➢ Exercise Physiology ➢ Nerve and Neurophysiology	*"We also need to do some basic science research, like, look at biomechanics for instance. Cause, it's, it's great getting results but you also want to see, you want to be able to explain why and how with the results that take place. So, doing some research in that area would be helpful."* (Focus Group 2, Participant 3)
Interventions ➢ Acupuncture ➢ Extremity Manipulative Therapy ➢ Rehabilitation ➢ Soft Tissue Therapy ➢ Spinal Manipulative Therapy	*"I think the questions people have [are], the biological mechanisms associated with manual therapy, with manipulation specifically, how does spinal manipulation work? Both, in probably the sports chiropractic population as well as the non-sports chiropractic population…what happens when we do some type of manual intervention? Are there biomechanical effects? Are there neurophysiological effects? Or are there both, basically?"*(Semi-structured Interview, Participant 5)
Clinical Research	
Consensus & Position Statements	*"…I think the lowest hanging fruit on the tree is to get involved in some consensus statements, so whether that's with CASEM [Canadian Academy of Sports and Exercise Medicine] or CPA [Canadian Physiotherapy Association] or CATA [Canadian Athletic Therapist's Association] or somewhere else, or whether that's just part of the concussion thing or exercise is medicine. There are groups that are already forming consensus, and we don't necessarily have a chiro in the group. So, there's probably some opportunities to be jumping in on some consensus statements, that in and of themselves, would be a collaboration."* (Focus Group 1, Participant 1)
Diagnosis Research ➢ Clinical Prediction Rules ➢ Functional Assessment ➢ Orthopedic Assessment	*"…research into things like clinical prediction rules trying to put patients into categories where we can find the best treatment combination to get them the best outcomes. So, something that centers around being effective and efficient in getting to the problem quickly, and being able to address that effectively and efficiently."* (Semi-structured interview, participant 10) *"…I think this idea of functional movement, the quality of movement and how do you move, I think that is wide open and should be a question that chiropractic, especially chiropractic sports researchers, might be asking."* (Semi-structured Interview, Participant 5) *"And obviously diagnostic skills as well, so if we look at our you know, if we were looking at certain clinical tests, what tests are most specific and sensitive in terms of picking up a condition that can help with our overall diagnostic abilities?"* (Semi-structured interview, Participant 3)
Epidemiology ➢ Injury Incidence & Surveillance	*"… you'd gather as much data as you can on baseline demographics, previous health history and then you can follow them over time to see who develops certain injuries, and you can compare those who didn't develop the injury to those who did or those who were exposed to an injury and those who weren't. You know, we could look at risk factors or you can follow a group of people with certain types of injuries and follow them over time to see who gets better compared to those who don't, compare baseline demographics. We call those prognostic factors."* (Semi-structured Interview, Participant 9)
Guidelines & Evidence-based Care Pathways	*"…clinical guidelines is a very good way, maybe, to try to produce, uh, I think if, if that's supposed to be like a kind of a research directive to producing clinical guidelines, I think that's, that's one way forward actually."* (Semi-structured Interview, Participant 12)
Intervention & Clinical Efficacy ➢ Comparative Effectiveness Studies ➢ Intervention Effects on Specific Outcomes ➢ Performance ➢ Recovery ➢ Return to Play ➢ Intervention Profile ➢ Treatment Safety ➢ Treatment Timing & Dosage ➢ Specific Interventions ➢ Acupuncture ➢ Manipulative Therapy – Extremity ➢ Manipulative Therapy – Spinal ➢ Mobilization Therapy – Extremity ➢ Mobilization Therapy – Spinal ➢ Modalities ➢ Laser ➢ Microcurrent ➢ Ultrasound ➢ Vibration Therapy ➢ Neural Mobilization ➢ Nutrition ➢ Patient Counselling and Patient Education ➢ Rehabilitation & Exercise ➢ Soft Tissue Therapy ➢ Supportive Devices & Taping ➢ Treatment Approaches ➢ Functional Treatment Approach ➢ Multi-modal Interventions	*"First, we need to compare the effectiveness of a treatment, then show that the treatment is safe, and then assess its cost-effectiveness. It seems to me that you can sell this to third party payers, governments, etc. if you can prove that we firstly work, two – that it does no harm, and then three – it's cheaper than the next option."* (Semi-structured Interview, Participant 8) *"I'll break it down into three areas. The first one is outcomes-based research on actual treatments, secondarily – outcomes-based research on prevention, and thirdly – on performance or performance enhancement."* (Semi-structured Interview, Participant 8) *"I think return to play in general is an important area where we can definitely get more involved and should get ourselves more involved inter-professionally, because typically it's a team of people helping bring that person back to play."* (Focus Group 1, Participant 6) *"Should we adjust before performance? …when is the best time to do soft tissue treatment? Is it a day before? Is it an hour before? Is it 5 minutes before? That's stuff I think that can be pertinent for clinical practice. When within somebody's periodization of training should we focus on more soft tissue work versus fine tuning? When's the best place to put rehab? That's probably quite a big topic, but clinically it might help."* (Focus Group 1, Participant 2) *"…so we need to look at, you know, both indicators and contraindications to doing manipulation and extremity manipulation. Also, and then, what the effect of those are…if there is a dose response."* (Semi-structured Interview, Participant 11) *"Most of the sports chiropractors that I know, most of them do some form of myofascial release, whether its active release or what have you, and they'll do some type of instrument-assisted soft tissue mobilization or IASTM, whether it's Graston® or FAKTR®, whatever other named technique, to me there is still so little efficacy research in those areas, in particularly when applied to sports injuries. So, to me, that's [what] I think a lot of where the exploration could be going."* (Semi-structured Interview, Participant 7) *"The second part would be what we call the multimodal effect…systematic review on multimodal effect of chiropractic on different conditions, which is what we do. We do adjusting, we do soft tissue, we do rehab, all of that together; and looking at that to see if all of that we do, does it affect the performance?"* (Semi-structured Interview, Participant 2)

Prognosis Research ➢ Illness Prevention ➢ Injury Prevention ➢ Risk Factors	*"I would look at risk or prognosis research. We could look at the determinants of sports injuries."* (Semi-structured Interview, Participant 9) *"…this holy grail with the injury prevention, it may be possible, it may not be possible, but I think that's gonna be, or that will continue to be one of the major, or the hottest topic in sports medicine. Can we identify players pre-season, during the season, that are more likely to get injured and can we intervene early?"* (Semi-structured Interview, Participant 17)
Research & Development of Outcome Measures	*"…1) we may need to develop valid and reliable outcome measures which are specific to our research needs if they don't already exist, 2) that the needs of outcome measures may be different from a research perspective compared to the needs of a field doc."* (Semi-structured Interview, Participant 1)
Health Services Research	
Athletic Field Services ➢ Multi-sport Games ➢ Pre-participation Physicals/Examination ➢ Team Care & Travel with Athletes	*"What we can and can't do on the field and where we have to then…look at other professions for help."* (Focus Group 2, Participant 3) *"I think researching into utilization rates in using chiropractors as emergency care or field care and then looking into what is our duties, what does our practice entail, what do we cover, what do we don't?"* (Semi-structured Interview, Participant 2)
Cost-effectiveness	"*.. is it cost-effective to see a chiropractor versus another practitioner? Because a lot of athletes are, you know, don't have a lot of funding, so..do we do things faster, more efficient, that is better for their pocket book?"* (Focus group 1, Participant 4) "*…one thing could be, looking into, is this actually economically feasible for society?...looking into health economics maybe? If we could prove that what we do, whatever that is I'm still not clear on it as a chiropractor, but what we do actually is more cost effective than something else, maybe that could be a part of an opportunity for chiropractic researchers in sport."* (Semi-structured Interview, Participant 12)
Interprofessional Dynamics	*"…understanding the dynamics within the sports fraternity and how to interdigitate with that best."* (Semi-structured Interview, Participant 10)
Knowledge Translation	"*…if we would have best evidence constantly updated, treatment algorithms for the most common treatments for the most common conditions, I think it would definitely be beneficial for the field practitioner*." (Semi-structured Interview, Participant 17) "*…I think another thing could be to actually inform practitioners how to actually interpret research findings and how these can actually be used in clinical practice*." (Semi-structured Interview, Participant 12)
Sports Healthcare Teams	*"…from a point of view of working with others, I think research into factors that enable or disable effective teamwork within a sports-sanctioned environment, that would enable best delivery of care to the patient…"* (Semi-structured Interview, Participant 10)
Utilization of Sports Healthcare Services	"*…how to collaborate with other health practitioners, so whether that be sport physios, ATs [athletic therapists], how to do the utilization of all us together…on the field, or whatever that might be."* (Focus Group 1, Participant 4) "*…if you got the data as to what they were presenting with, how many times they came in to that environment, how many times, you know, what that was utilized, that would be increasing our capacity and capabilities within the profession."* (Semi-structured Interview, Subject 7)
Population Health	
Physical Activity ➢ Exercise Is Medicine	*"…with physical activity levels and population health, then we need to look at the exercise is medicine and physical activity levels of our patients and how to get better knowledge translations to practitioners so that they're also making that part of their patient care*". (Focus Group 1, Participant 6)
Public Awareness & Education	*"…I think around patient education and now we're getting into things around consensus statements and public awareness campaigns…"* (Semi-structured Interview, Participant 1)
Special Populations ➢ Elite Athletes ➢ Masters Level Athletes ➢ Pediatric Athletes	"*We need to look at populations of athletes, we need to look at the mature athlete, as well as injury rates in younger athletes as well as adults*." (Semi-structured Interview, Participant 8)
Specific Conditions and Topics in Sport ➢ Ankle Sprains ➢ Anterior Cruciate Ligament & Knee Ligament Injuries ➢ Athletic Pubalgia ➢ Concussion ➢ Extremities in General ➢ FIFA Injury Prevention Program ➢ Hamstrings Strain ➢ Labral Injuries, Hip ➢ Lateral Epicondylitis ➢ Lisfranc Injuries ➢ Low Back Pain ➢ Meniscus, Knee ➢ Metacarpal Injuries ➢ Neck Pain ➢ Neuropathies ➢ Osteoarthritis ➢ Patellofemoral Pain Syndrome ➢ Pectoralis Tears ➢ Plantar Fasciitis ➢ Platelet-Rich Plasma Injection Therapy ➢ Rotator Cuff ➢ SLAP Injuries ➢ Soft Tissue Injuries & Myofascial Pain ➢ Spondylolysis ➢ Sports Psychology ➢ Sprains & Strains – General ➢ Tendinopathy ➢ Thoracic Pain ➢ Turf Toe	*"We should look at what the bigger picture is in sports medicine, the delivery of sports medical care, where is it all going and we should target our research to be relevant in that area."* (Semi-structured Interview, Participant 15) *"Being a part of the sports medicine community is what we want to do um, rather than just prove ourselves. And, essentially, you get to prove yourself through being a part of the community rather than the other way around trying to be a part of the community by proving yourself."* (Semi-structured Interview, Participant 6) *"…research related to concussion, it's a hot topic,…and this will help demonstrate our role in the assessment and management of concussion. It's a huge opportunity for us to participate in interdisciplinary research."* (Focus Group 2, Participant 2) *"…to me, chiropractors need to have a seat at the table when it comes to research on those topics...whether it's just advancing conservative management of those topics, like an example would be something like ACL tears."* (Semi-structured Interview, Participant 7) *"…big topics, probably sprain, strain, the ankle sprain is one of the one[s] in all of our own sports [practices] and that's also another one to look at with the chiropractic care of that."* (Semi-structured Interview, Participant 2) *"…hamstring injuries, soft tissue-based, number one occurring soft tissue injury, number one occurring ligamentous injury – in the ankle and in other joints. I'd say start with patellofemoral pain, go to meniscal injury. In the shoulder, I'd say have a look at rotator cuff and impingement syndromes. Many of the really common presentations of these conditions now have recently had a lot of bad PR [public relations] when it comes to both medication and surgeries, and so if we begin to provide evidence-based alternatives that are multimodal in nature, the treatments that is, I suspect that we will stack up quite favorably, if we can."* (Semi-structured Interview, Participant 8) *"…if you talk hot topics, I would say labrum, a big one – rotator cuff,..throwing injuries and I mean you, I feel like any of these, the chiropractic's perspective should be there."* (Semi-structured Interview, Participant 1)

Chiropractic Research in Sport	
Comparing Sports Chiropractors to Other Practitioners	"*…if we are able to show comparative studies, like that which don't bring it down to this adjustment caused this, but the chiropractic model of care introduced into a multidisciplinary setting improves outcomes, I think that's valuable*." (Semi-structured Interview, Participant 6) "*…something along the lines of a job analysis, I think would be critically important to get done again, and seeing an in-depth level what do sports chiropractors do? You know, is that different from what regular chiropractors do? And, if so, how is it different? And then, also looking at how is what sports chiropractors do, how is it different from what other therapists or specialists who see athletes and work with athletes, how does, how is that different?"* (Semi-structured Interview, Participant 7)
Competency of Sports Chiropractors	*"Well, I think that we have to be able to show that we have certain competencies. This is important."* (Semi-structured Interview, Participant 8) *"Well, I guess fundamentally, the first thing that I think that needs to be understood is what makes a sports chiropractor, and so defining the characteristics of what chiropractic sports training entails would be important. I would suggest that understanding the scope of what chiropractors do in sports care is important."* (Semi-structured Interview, Participant 13)
Historical Research in the Sports Chiropractic Field	*"…maybe historical aspects of things, and who the chiros were in charge, like Dr. XXXXX, others who were in charge of major [and] minor games,…how they managed and what happened."* (Semi-structured Interview, Participant 2)
Integration of Sports Chiropractic Into Healthcare Teams	*"…just getting on the field requires some cultural authority, and to do that you need to prove there is a value for chiropractors being with a team, being on the field, being at major games. We have established that to a great extent, but it's not universal, so building the case for chiropractic to be included in the healthcare teams is the direction."* (Focus Group 2, Participant 4) *"…showing the impact of chiropractors within the multi-disciplinary team, I think is an important part of the research, which helps get chiropractors sideline, helps them integrate into that setting. So, rather than anything specifically technique based… setting-specific research that talks about interaction, and a lot of that is going to be more qualitative-type research rather than quantitative, that have chiropractors interact within that environment."* (Semi-structured Interview, Participant 6)
Perception of Sports Chiropractic	"*We need to start simple here and ask the public about their knowledge on what is it we do as sports specialist chiropractors and identify knowledge gaps and issues with our public perceptions."* (Semi-structured Interview, Participant 3)
Research Supporting the Strategic Planning For Sports Chiropractic	"*...it's just a matter of having organizational meetings, focus groups, think tank sessions so that we can share opportunities, ideas, and have some strategic planning*." (Focus Group 2, Participant 2)
Self-analysis Studies of the Sports Chiropractic Field	*"…we need to document the scope of activities that we perform from in field, in clinic, at games triage all the way through to treatment in all those arenas, to the advice we give and our supporting therapies. We need to document the whole lot. Therefore, some of the research we need to perform is the documentation of sports chiropractic activity in each of these domains"* (Semi-structured Interview, Participant 8)
Sports Chiropractors as Diagnosticians	*"…and then probably on the diagnosis capacity of the sports chiropractor. I'm not sure how we could do that, but maybe kind of an inter-reliability [study], uh, on diagnosis and compare us with others because that would be pretty hard, but maybe to see that we are consistent with our diagnosis and that we can be accurate. I don't think that this is emphasized enough on [in] the field.* (Semi-structured Interview, Participant 20)
Surveillance of Professional Activity in Sports Chiropractic	*"..it would be nice as far as field work goes for us to actually get some numbers of how many sports chiropractors are actually doing field work, and how we're represented in the field work."* (Focus Group 1, Participant 2) *"…what we do as sport chiropractors…where we are treating, what teams we're affiliated with, what are the stats of our utilization rates."* (Sem-structured Interview, Participant 3)
Understanding the Sports Chiropractic Patient	"*…chiropractors need to take a step back and think about what is important for the patient, in this case the athlete… so taking away preconceived ideas of how we can best help the patient and replace that with what does the patient actually need and can we fulfill that need in a way that benefits the patient*." (Semi-structured Interview, Participant 10) *"…often the practitioner will say well this is what you need without necessarily completely listening to what the athlete has to say...that sort of common ground needs to be nurtured more and perhaps investigated as a source for research questions as oppose to us trying to predict what the athlete may or may not want*." (Semi-structured Interview, Participant 10)
Utilization of Sports Chiropractic Services	*"Utilization, I guess. What the athletes are looking for, what the athletes want. Are the athletes seeking out sports chiropractic? Is that communication happening to the outside organization, the sporting organizations? Is that something that's even wanted by the public? So coming into a sport, organizing it from a sports standpoint, are the athletes and the organizations looking to have sports chiropractic represented?"* (Focus Group 1, Participant 3)
Major theme: Research actions	
Collaboration In Research	
Funding Agencies	*"…the next steps for your group would be to compare your research perspectives and priorities to those of the provincial and national federal funding agencies. They're the ones with the dollars. Everyone is chasing them, although the success rates are very low, you have to get into the process even though the sharks are there. You have to get into the water with them, because that's where the credibility is and the big bucks are. Without the big bucks you won't go very far."* (Semi-structured Interview, Participant 18)
Industry	*"…you then have to partner up with the universities, and also the private enterprise groups within the profession to say, 'well who's truly about evidence here and who wants to promote this', because it's not going to get done with unicorns and prayers. It's going to need money and it's got to come from somewhere. Academics can help get there, but largely speaking, you know, the response rate on grants is abysmal in general chiro and in the sports chiropractic field it's going to be even worse than just spinal chiropractic."* (Semi-structured Interview, Participant 8)
Interinstitutional ➢ Chiropractic Educational Institutions ➢ Universities	*"…accessibility to academic institutions or to fellows with Masters or PhDs in institutions that we can collaborate with. …to have the team to be able to support the research, whether it's lab focused, whether it's the statisticians, whether it's the research assistants, to help the accessibility to that type of support staff."* (Focus Group 1, Participant 2)

Interprofessional ➢ Individual Professions ➢ Athletic Therapists ➢ Biomechanists ➢ Cardiologists ➢ Dentists ➢ Exercise Physiologists ➢ Kinesiologists ➢ Neurologists ➢ Orthopedic Surgeons ➢ Physiatrists ➢ Physicians (General) ➢ Physiotherapists ➢ Psychologists ➢ Pulmonologists ➢ Registered Massage Therapists ➢ Sports Physicians ➢ Professional Organizations ➢ American College of Sports Medicine ➢ Canadian Academy of Sport and Exercise Medicine ➢ Canadian Athletic Therapists Association ➢ Canadian Physiotherapy Association ➢ Canadian Society of Exercise Physiologists ➢ Canadian Sport Massage Therapists Association ➢ Sports Physiotherapy Canada	*"Research should focus on interdisciplinary relations. Uh, collaboration between chiropractic and all the other health professionals, especially, medical specialties."* (Focus Group 2, Participant 2) *"…do we want to partner with Sports Physiotherapy Canada or CASEM [Canadian Academy of Sports and Exercise Medicine] in terms of getting some of their authors and some of their personnel in our studies, so that collectively we're working towards a bigger picture?"* (Semi-structured Interview, Participant 3) *"…you have to be more cross disciplinary, more inter-disciplinary. You have to engage with many other professions, and many other researchers."* (Semi-structured Interview, Participant 18) *"…build a group of people from within that have, you know, the advanced degrees and have, have a drive to actually chase questions related to sports and chiropractic. From there, then you can start to build these collaborative networks of individuals with, …multidisciplinary backgrounds,.. including PTs, ..sports med docs,..other individuals into the team, because when you get the collaborative network together, then the group productivity, that actually is a lot greater than just the productivity of the individual person."* (Semi-structured Interview, Participant 4)
Intra-professional ➢ Canadian Chiropractic Research Foundation – Research Chairs ➢ Chiropractic Associations ➢ Chiropractic Specialty Colleges ➢ Chiropractic Organizations ➢ Sports Chiropractic Associations ➢ Sports Residents	*"I think that we want to look in a few areas for collaboration because I think we can definitely start by collaborating intra-professionally, so looking at some of our other specialties, like collaborating with our clinical specialists and radiology specialists, and the other specialties in Canada"* (Focus Group 1, Participant 6)
Leading Experts in A Field	*"…before you start any project you need to identify the experts in that area. I think that if you let the profession that, what you know, the letters behind their name define expertise, you are making a mistake. So,…for example, we do some concussion research. We identified world leaders in that domain and then we just reach out to them and see if we have any common interest for a project or a proposed project that we think their expertise could help us with."* (Semi-structured Interview, Participant 16)
Sports Community ➢ Coaches ➢ Non-profit Organizations ➢ Specialized Sports Training & Development Centres (eg. Olympic Training Centres, Canadian Sports Centres) ➢ Sports Organizations, Federations & Associations ➢ Sports Teams and Clubs	*"I think collaborating also with coaches and national sporting organizations. So, like where are the athletes and can we tap into their resources to do research from those institutions, like out in Calgary and Olympic teams, things like that."* (Focus Group 1, Participant 5)
Contributing to the Broader Sports Research Effort	
Contributing to the Broader Sports Research Effort	*"…we should look at what the bigger picture is in sports medicine, the delivery of sports medical care, where is it all going, and we should target our research to be relevant in that area."* (Semi-structured Interview, Participant 15) *"…trying to find this direction where we show that we are contributing to the sports medicine community rather than just trying to prop up the profession…"* (Semi-structured Interview, Participant 6)
Major theme: Research methodology	
➢ Cohort Studies ➢ Descriptive Studies ➢ Multi-centre Research ➢ Multivariate Research ➢ Practice- and Field-based Research Networks ➢ Qualitative Research ➢ Randomized Clinical Trials ➢ Survey Research ➢ Systematic Reviews & Meta-analysis	*"I think we need to set up practice-based research networks at the 'country' level and at the 'international' level. This is possible now because of the interest and because of the advancement in computing power."* (Semi-structured Interview, Participant 8) *"...we need to be able to deliver a platform for field practitioners to translate their experience into research. So, we have, we seem to have our researchers over in one corner and our field practitioners over in the other corner, and the researchers say, 'gee it would be nice to get out and get some data from, you know, sporting events and what we do' and the sports practitioners saying, 'gee it would be nice to covert what I do into some research.' And they are not talking."* (Semi-structured Interview, Participant 6) *"Randomized clinical trials, it's very important for us. Ideally we should do RCTs with some follow up or mixing RCT with cohort studies, so we can not only see the immediate effects of whatever we are testing, but if that [effect] lasts long or not."* (Semi-structured Interview, Participant 14)

Discussion

To our knowledge, this is the first qualitative study that investigated the opinions of sports chiropractic researchers and leaders about sports-focused research priorities. Our study extracted a list of 150 research priorities categorized into three major research themes, 1) areas of research with six sub-themes with each representing a separate topic area of research, 2) research actions with two sub-themes, and 3) research methodology. In this present study, we interviewed 21 participants from Canada, and 11 from seven other countries. We purposefully interviewed participants from countries other than Canada, to provide a broader international perspective on identifying research priorities. Future studies can utilize these research priorities in a Delphi process to inform a research agenda for sports chiropractors.

Consistent with our previous work, sports chiropractors believed that research advancement in their field should include sports-specific research priorities.[11] This present study extracted research topics that are unique to sports-focused research that have not been identified as priorities by previous chiropractic research agenda studies.[13,14] This is evidenced by the research themes chiropractic research in sport, specific conditions and topics in sport, and contributing to the broader sports research effort, that emerged from our qualitative analysis. Interestingly, the former research theme is primarily focused on research specific to chiropractic, and the two latter themes refer to general sports research not exclusive to the chiropractic profession. There have been arguments amongst experts about what constitutes sports chiropractic research. Is it research about the chiropractic profession and its clinical methods applied to sport, and does it also include sports research unrelated to the chiropractic profession conducted by chiropractors? Our identification of the two themes – specific conditions and topics in sport and contributing to the broader sports research effort – provides evidence that sports chiropractic researchers and leaders consider the contribution of their members to the broader sports research effort a component of research that should be conducted by sports chiropractors. Also, given that sports healthcare teams are often inter-disciplinary, some of the experts interviewed made mention of the importance of having sports chiropractors on multi-disciplinary research teams investigating key sports healthcare research topics, such as concussion. Given these findings, we propose utilizing the term "sports-focused research for chiropractors" as a more encompassing label of the research effort that is conducted by sports chiropractors instead of the term "sports chiropractic research". This distinction may help provide a broader framework for understanding sports chiropractors and their contributions to research.

While some of the areas of research identified were broad and general, such as basic science and mechanism research and clinical research, the sport-specific focus of the research priorities identified was observed within all research themes. For example, the study of biomechanics was often discussed applied to the sports setting and in the prevention of sports injuries. Also, the study of various interventions, such as spinal manipulative therapy, soft tissue therapy and extremity manipulative therapy was often discussed in relation to outcomes of sports performance, return to play and recovery. Additionally, within the theme of population health, research priorities identified were specific to certain athletic populations, such as the study of elite, masters-level and pediatric athletes.

Similarly, while the theme collaboration in research was identified in previous studies investigating research priorities for the general chiropractic profession[13,14], many research collaborations identified in our study were specific to the sport context. Collaborations amongst different sports healthcare providers and their respective member organizations were identified, such as sports medicine physicians, orthopedic surgeons, sports physiotherapists, sports massage therapists and athletic trainers to name a few. Also, collaborations with the sports community (sports organizations, coaches and athletes) were identified as an important partnership integral to advancing the sports-focused research effort. In addition to sport-specific collaborations, many of our interviewees made mention of the importance of collaborating with academic institutions, such as universities, and intra-professionally with chiropractic researchers and chiropractic educational institutions.

In addition to identifying research topics unique to sport and sports chiropractic, the extracted priorities also identified research topics that were common to previously published chiropractic Delphi studies investigating research priorities.[13,14] Similar themes across these studies include basic sciences, clinical, and population health re-

search. Overlapping sub-themes, such as dose-response and safety of spinal manipulative therapy were also identified.[13,14] It is not surprising the sports chiropractic field share common research priorities with the general chiropractic profession, as some areas of research (e.g., treatment safety) has applicability to the entire profession, including its sub-disciplines. We believe it is important to identify areas of overlapping priorities in general and sports-focused chiropractic research, as collaborative research efforts involving these common research topics could improve investigative capacity within these priority areas.

Limitations and future directions

The limitations of this present study include the possibility of sampling and responder bias. We used purposive sampling to identify chiropractic researchers and leaders; however, it is possible that we may have missed identifying key experts. Additionally, depending on the availability and geographical locations of the interviewees, we used three different interviewing mediums (online via Skype, in-person and telephone) to conduct the individual semi-structured interviews. Recent studies comparing features of qualitative datasets generated from in-person and online interviews have found modest differences in the amount of data provided by participants, but very little difference in the thematic content of responses.[28,29] Mixed evidence has also been reported of an "online disinhibition effect" during online interviewing, where participants may be more likely to express socially unsanctioned or highly personal opinions or behavior in online settings.[30] For the present study, online and telephone interviewing were conducted to deal with the geographical dispersion and preferences of the researchers we sought to interview. It is possible that the different interviewing modes may have impacted the data collected. However, given the results of previous studies[28,29] comparing online versus in-person interview methods, we suspect this had minimal impact on our overall analysis.

Another limitation is our study was weighted toward a North American sample (66% and 13% of participants were from Canada and the United States of America, respectively). Our results should be interpreted with this bias in mind. While we are confident that we reached data saturation during the coding process, it is unknown whether a random sample of experts or the inclusion of more sports chiropractic experts from different countries would yield different results in our qualitative analysis. Also, despite our attempts to focus on the study's aim and limit our own biases, with the nature of qualitative analysis, it is possible that the data interpretation may have yielded different results if analyzed from a different perspective.

Future research can utilize the results of this study to inform the development of seed statements for research prioritization Delphi studies. To minimize the regional bias of our results, we recommend that future Delphi studies revise these research priorities in consultation with regional experts prior to conducting the Delphi process. Also, participants of the Delphi panel can be given the opportunity to suggest additional research priorities on the first round Delphi questionnaire. In the present study, we did not make any comparisons in the qualitative data between participants from different regions or between those holding different roles (e.g., researcher or organizational leaders) as it was determined to be beyond the scope of this study. It is possible contrasting opinions may exist. Future qualitative studies can be conducted to explore this topic, and subgroup analyses from Delphi studies can be conducted to explore regional or role differences in research priorities.

Conclusions

To the authors' knowledge, this is the first qualitative study that investigated the opinions of sports chiropractic researchers from eight countries in the world and Canadian sports chiropractic organization leaders about sports-focused research priorities for chiropractors. This study identified 150 individual research priorities and three major research themes. The majority of research priorities identified were unique to the sports context. In addition to extracting research priorities that were specific to the chiropractic profession, the experts interviewed emphasized the importance of having sports chiropractors collaborate and contribute to the broader sports research effort that is shared by all professionals working in the sports community. The research priorities identified in this study can be utilized by researchers, sports chiropractic organizations and academic institutions to plan future research prioritization studies to inform a research agenda for the sports chiropractic field.

References

1. Parachute. The cost of injury in Canada. Toronto, ON; 2015.
2. Forbes S. Injury prevention in sport & physical activity in Ontario: What's the game plan? Toronto, ON; 2016.
3. Bulletin 1: Sport Participation in Canada. Ottawa; 2018. Available from: https://cflri.ca/bulletin-1-sport-participation-canada
4. Statistics Canada. Table 13-10-0096-13: Physical activity, self reported, adult, by age group. Government of Canada. 2018. p. 1–3. Available from: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1310009613
5. Bulletin 1: Participation in sport among children and youth. Ottawa; 2013. Available from: https://cflri.ca/bulletin-1-participation-sport-among-children-and-youth
6. Blanchette MA, Rivard M, Dionne CE, Cassidy JD. Chiropractors' characteristics associated with physician referrals: results from a survey of Canadian doctors of chiropractic. J Manipulative Physiol Ther. 2015;38(6): 395–406.
7. Adams J, Lauche R, de Luca K, Swain M, Peng W, Sibbritt D. Prevalence and profile of Australian chiropractors treating athletes or sports people: a cross-sectional study. Complement Ther Med. 2018;39: 56–61.
8. International Federation of Sports Chiropractic [accessed 2016 Jun 20]. Available from: www.fics-sport.org
9. Royal College of Chiropractic Sports Sciences (Canada). [accessed 2019 Aug 19]. Available from: http://rccssc.ca/
10. Miners AL, Degraauw C. A survey of fellows in the college of chiropractic sports sciences (Canada): their intervention practices and intended therapeutic outcomes when treating athletes. J Can Chiropr Assoc. 2010;54(4): 282–292.
11. Lee AD, Szabo K, Mcdowell K, Granger S. Opinions of sports clinical practice chiropractors, with sports specialty training and those without, about chiropractic research priorities in sports health care: a centering resonance analysis. J Can Chiropr Assoc. 2016;60(4): 342–369.
12. Pollard H, Hoskins W, McHardy A, Bonello R, Garbutt P, Swain M, et al. Australian chiropractic sports medicine: half way there or living on a prayer? Chiropr Osteopat. 2007;15: 1–13.
13. Rubinstein SM, Bolton J, Webb AL, Hartvigsen J. The first research agenda for the chiropractic profession in Europe. Chiropr Man Therap. 2014;22(1):9.
14. French SD, Beliveau PJH, Bruno P, Passmore SR, Hayden JA, Srbely J, et al. Research priorities of the Canadian chiropractic profession: a consensus study using a modified Delphi technique. Chiropr Man Therap. 2017;25(38):1–8.
15. Hsu C, Sandford B. The delphi technique: making sense of consensus. Pract Assessment Res Eval. 2007;12(10): 1–8.
16. Powell C. The delphi technique: myths and realities. Methodol Issues Nurs Res. 2003;41(4): 376–382.
17. Hasson F, Keeney S, McKenna H. Research guidelines for the Delphi survey technique. J Adv Nurs. 2000;32(4):1008–1015.
18. Ghorbani A, Matourypour P. Comparison of interpretive description and qualitative description in the nursing scope. Rev Bras Enferm. 2020;73(1): 1–2.
19. Neergaard MA, Olesen F, Andersen RS, Sondergaard J. Qualitative description-the poor cousin of health research? BMC Med Res Methodol. 2009;9(1): 1–5.
20. Lambert SD, Loiselle CG. Combining individual interviews and focus groups to enhance data richness. J Adv Nurs. 2008;62(2): 228–237.
21. RCCSS(C). Sports Sciences Residency Program (SSRP) Supervisor Handbook. 2018.
22. Campbell S, Greenwood M, Prior S, Shearer T, Walkem K, Young S, et al. Purposive sampling: complex or simple? Research case examples. J Res Nurs. 2020;25(8): 652–661.
23. Foundation for the Royal College of Chiropractic Sports Sciences.2020 [accessed 2019 Oct 10]. Available from: www.frccss.ca
24. Malterud K, Siersma VD, Guassora AD. Sample size in qualitative interview studies: guided by information power. Qual Health Res. 2016;26(13): 1753–1760.
25. Guest G, Bunce A, Johnson L. How many interviews are enough? An experiment with data saturation and variability. Field Methods. 2006;18(1): 59–82.
26. Verhoef M, Mulkins A, Boon H. Integrative health care: how can we determine whether patients benefit? J Altern Complement Medi. 2005;11(suppl 1): S57–S65.
27. Tong A, Sainsbury P, Craig J. Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. Int J Qual Health Care. 2007;19(6): 349–357.
28. Namey E, Guest G, O'Regan A, Godwin CL, Taylor J, Martinez A. How does mode of qualitative data collection affect data and cost? Findings from a quasi-experimental study. Field Methods. 2020;32(1): 58–74.
29. Krouwel M, Jolly K, Greenfield S. Comparing skype (video calling) and in-person qualitative interview modes in a study of people with irritable bowel syndrome – an exploratory comparative analysis. BMC Med Res Methodol. 2019;19(1).
30. Namey E, Guest G, O'Regan A, Godwin CL, Taylor J, Martinez A. How does qualitative data collection modality affect disclosure of sensitive information and participant experience? Findings from a quasi-experimental study. Qual Quant. 2021:1-20.

Appendix 1.
Search strategy example

PubMed searches

- (((Bursitis) OR "Bursitis"[Mesh])) AND (((chiropract*) OR ("Chiropractic"[Mesh] OR "Manipulation, Chiropractic"[Mesh])))
- (((chiropract*) OR ("Chiropractic"[Mesh] OR "Manipulation, Chiropractic"[Mesh]))) AND ((hockey) OR "Hockey"[Mesh])
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- (((rugby) OR "Football"[Mesh])) AND ((chiropract*) OR ("Chiropractic"[Mesh] OR "Manipulation, Chiropractic"[Mesh]))
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- ((((shin splints) OR medial tibial stress syndrome) OR “Medial Tibial Stress Syndrome”[Mesh])) AND (((chiropract*) OR (“Chiropractic”[Mesh] OR “Manipulation, Chiropractic”[Mesh])))
- (((performance) OR “Athletic Performance”[Mesh])) AND (((chiropract*) OR (“Chiropractic”[Mesh] OR “Manipulation, Chiropractic”[Mesh])))

- (((achilles tendon rupture) OR "Achilles Tendon"[Mesh])) AND (((chiropract*) OR ("Chiropractic"[Mesh] OR "Manipulation, Chiropractic"[Mesh])))

ICL Searches

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- Subject:\"Manipulation, Chiropractic\" OR All Fields:Chiropract* AND Subject:\"Bursitis\" OR All Fields:Bursitis

Appendix 2.

Information power analysis of the present study – utilizing the framework by Malterud et al.[24]

Higher information power ⟷ Lower information power

Study aim		
Narrow	Our aim in this study is to identify and extract research priorities from interviews with sports chiropractic researchers and leaders. This aim sits in the middle of the spectrum of narrow and broad aims. ☑	Broad
Sample specificity		
Dense ☑	We will be sampling from a dense and specific sample. We will use purposive sampling methods to target participants that have characteristics that are highly specific to the study's aim. Our sample will be comprised of specialized experts in the sports chiropractic field, which is a relatively small field of study.	Sparse
Established theory		
Applied ☑	This is a second phase study in a three-phase plan to develop a research agenda for sports chiropractors. The first phase study interviewed sports chiropractors and explored their discourse about their opinions about research direction using quantitative text analysis methods.[11] This phase one study provided some applied theory about the research question sought in this present study and informed the development of the interview guide for this qualitative study. Previous Delphi studies that investigated research priorities for the general chiropractic field have categorized research priorities into research themes and categories.[15,16] These previous studies helped guide our methods for this present study.	None
Dialogue		
Strong ☑	This qualitative study will interview researchers and leaders from the sports chiropractic field about research priorities. This is a topic area that our participants will be highly familiar with. Moreover, the investigators of this present study are also sports chiropractic researchers who possess sufficient knowledge about the topic area to facilitate strong dialogue during the interviews to obtain information related to this study's research aim. In addition, the preceding phase one exploratory study[11] helped inform the topics likely to be encountered in the interviews, and it helped inform the interview guide for this present study. Considering these factors, we anticipate a strong dialogue between the interviewers and the participants.	Weak
Analysis		
Case ☑	This is a qualitative description study designed to identify research priorities from researchers and leaders from the sports chiropractic field. The unit of analysis will be the interview transcripts for each participant. We will be conducting a qualitative content analysis of the interview transcriptions using an interpretivist perspective. The intention of an interpretivist approach is to describe and interpret, but not to develop a substantive theory. We will be extracting research priorities and themes from the transcripts. We will be interviewing researchers and leaders from the sports chiropractic field from different geographical regions; however, we will not be conducting any cross-case analyses between the participants or groups of participants in our analysis.	Cross-case

Smaller Sample Size (n) ⟷ Larger Sample Size (n)

After analyzing this study's characteristics against these items theorized to impact the information power of the data that we intend to gather, and guided by a previous investigation that demonstrated data saturation in interview studies can occur in homogenous samples as low as 6 to 8 subjects to up to 12 to 30 subjects when looking for disconfirming evidence or trying to achieve maximum variation,[25] we anticipate a sample size of approximately 20-30 participants.

Appendix 3.
Interview guide

A qualitative study investigating research priorities and investigative capacity in sports-focused chiropractic research.

Introduction

Thank you for participating in this interview/focus group. We are investigating research priorities and investigative capacity in sports-focused chiropractic research. Please note that this interview/focus group will be audio recorded and all information collected will be confidential. Please note this is a voluntary process, and your consent may be withdrawn at any time.

For the purposes of our interview/focus group today, "Sports-focused research" is defined as a field of research directly related or relevant to anyone involved in the sport, athletic, or exercise community. These topics may include but are not limited to the following: injuries, injury prevention, treatment, rehabilitation, biomechanics, performance, assessment metrics, nutrition, epidemiology, diagnostic imaging, emergency care, athletic event coverage, team travel, education, exercise physiology, and sport psychology.

Describe the purpose for the interview or focus group

- Identify research priorities that can be utilized as voting items in a future Delphi study to determine a consensus of a research agenda in sports chiropractic.
- Gain insight into research capacity issues within sports-focused chiropractic research.

Outline the rules and procedures for the interview or focus group

- This session will be audio recorded, and will be transcribed and analyzed by the investigators. Confidentiality will be maintained as identified by the consent form provided upon entry to the study.
- Once transcribed, you will receive a copy of your responses. You may choose to alter your responses or remove them entirely if you wish.
- All comments are important, please express your opinions freely.

(Focus group only)

- I would like to walk you through the consent form that is in front of you (go through consent form).
- First and foremost, everyone's views are welcome and important.
- We will be audio recording this focus group interview, and upon transcription we will be removing your names from any transcripts by using a unique pseudonym instead of your name.
- While we may identify and present quotes from the discussion in our published reports or presentations, we will use a pseudonym so that we can protect your confidentiality.
- Because of the nature of small communities or groups, it is possible that people could link participants in this room to quotes in our report/presentations. This is why we need to talk about confidentiality.
- In a small community like sports chiropractic in Canada, it is possible that people may be identifiable to some degree by their views and opinions. As a result, we ask that all participants keep what has been shared in this focus group confidential, and do not share what was said to others outside of this room.
- Having said this, and having made these requests, we cannot guarantee that the request will be honoured by everyone in the room. Inherent in focus group studies, there is a risk that information discussed might be shared to others outside of the study.
- So, we are asking you to make only those comments that you would be comfortable making in a public setting; and to hold back making comments that you would not say publicly.
- Overall, anything heard in the room should stay in the room.
- A few other housekeeping rules: Please allow one person to speak at a time so that the audio recording is captured clearly, and please identify yourself with your first name when you speak, unless the facilitator does so for you.

Facilitator: XXXXX

Observers/Recorders: XXXXXX

Since we are aiming to identify as many research priorities as possible in this study to help develop a Delphi study to obtain consensus on a research agenda, please expand as much as possible in your answers

Section 1: Research Priorities Questions

1. What research do you think we need to conduct to advance the sports chiropractic field?
   PROBES: Research that will enhance the profession, or advance the science of sports chiropractic practices

2. What research do you think would impact sports-focused chiropractic clinical practice the most?
   PROBES: Clinical practice guidelines, Topics and consensus statements around diagnosis or treatment

3. What research do you think would impact sports chiropractic field work the most?
   PROBES: Event coverage, Performance, Emergency care

4. Where do you feel sports-focused chiropractic research is lacking?
   PROBES: Quantity of research, Quality of methodology, Specific research topics

5. What research do you think would improve interprofessional relationships and collaboration? (Between professions, eg. chiro/physio/AT/MD/biomechanists/nutritionists/physiologists/etc.)
   PROBES: Research with other professions such as orthopedic surgeons and topics such as post-operative treatment/rehab/recovery time

6. What research do you think would improve intraprofessional relationships and collaboration? (within our own profession)
   PROBES: Research with other chiropractors such as SMT or STT research

7. What collaborations could benefit sports-focused research?
   PROBES: Universities, Orthopedic Surgeons, Sports Medicine Doctors

8. What research would help set sports chiropractic apart from other sports healthcare providers?
   PROBES: Research that defines a niche for sports chiropractors such as SMT and performance

9. What sports-focused chiropractic research do you feel could benefit patients/athletes the most?
   PROBES: Research that could impact the patients or athletes such as rehab protocols, return to play guidelines

End this section with this question –

10. Since we are aiming to identify as many research priorities as possible in this study to help develop a Delphi study to obtain consensus on a research agenda, are there any other research priorities you have not mentioned that you can think of that would help us further advance the sports chiropractic field?

If required, see "Additional Interview Guide Probes" document for possible follow-up probes that are topic-specific to Athletic Event Coverage, Biomechanics, Diagnostic Imaging, Education, Emergency Care, Epidemiology, Exercise Physiology, Injuries (Concussion, Tendinopathies, etc.), Injury Prevention, Nutrition, Performance, Position Statements, Rehabilitation, Spinal Manipulative Therapy, Sports Psychology, Team Travel, and Treatment.

Section 2: Research Capacity Questions

In this section of the interview, we will be asking you questions about Research Capacity within the sports chiropractic field. When thinking about your answers for this section, please keep in mind one of the aims of our study is to identify research capacity issues within our field, and obtain opinions on how to address them.

11. How can we improve the research capability and capacity within the sports chiropractic field?
    PROBES: Ways to improve our ability to conduct research, Do you have opinions on how to solve it?

12. Do you have any opinions on how we can build our resources to successfully conduct sports-focused research in our field?
    PROBES: Reach out to NSOs, Collaborate

13. What do you see as barriers to conducting research in chiropractic and sport?
    PROBES: Finances, Time, Logistics

14. What do you see as enablers for research success in chiropractic and sport?
    PROBES: Grants for sports-focused research, NSOs

15. What do you see are the opportunities for chiropractic research in sport?
    PROBES: Research collaborations, Professional athlete research

16. What can individual sports-focused chiropractors do to improve our potential to conduct research?
    PROBES: Collaborate, Share resources and knowledge

17. How do we go about building sustainable research programs in chiropractic and sport?
    PROBES: Collaborations, Funding initiatives

18. What types of research methodology would you like to see in sports-focused chiropractic research?
    PROBES: Prospective studies, RCT, Case studies

19. Since one of the aims of our study is to identify research capacity issues within our field, and obtain opinions on how to address them. Prior to ending this interview, are there any other research capacity issues you can think of, and possible solutions on how to address them?

Additional interview guide probes

Additional Interview Guide Probes

This document includes topic-specific probes to be used with the interview guide questions if required.

PART 1: RESEARCH INITIATIVES

Athletic Event Coverage
PROBES: Emergency care, Injury prevention, Performance enhancement

Biomechanics
PROBES: Throwing mechanics, Hip mechanics, Gait mechanics

Diagnostic Imaging
PROBES: US, MRI, MRA, fMRI, bone scan, CT, ECG, Education/Training, Referral rates

Education
PROBES: sports chiropractic education, Interprofessional education – Orthopedic surgeons, Sports medicine Medical Doctors, Physiotherapists

Emergency Care
PROBES: emergency preparedness, protocols for equipment removal, first aid, etc.

Epidemiology
PROBES: Populations – Elite athletes, Competitive athletes, Non-competitive athletes, Adolescents, Seniors, Adults, injury rates, injury surveillance

Exercise Physiology
PROBES: Chronic exercise adaptations, Metabolic changes, Acute response to exercise, overtraining, sports specialization, performance enhancement

Specific Injuries (Concussion, Tendinopathies, etc)
PROBES: Treatment, Management, Prevention, Rehabilitation, Diagnosis, Return to Play, Diagnostic accuracy, injury prevention

Injury Prevention
PROBES: How to prevent injuries, What injuries are preventable, which injuries to study for prevention, manual therapy (SMT/STT/Taping) for prevention

Nutrition
PROBES: Performance enhancement, Exercise recovery

Performance
PROBES: Speed, Agility, Reaction time, Dose-response, When to treat, validity studies, outcome measure, specific interventions

Position Statements
PROBES: Concussion, Burn out, Nutrition, cap-

acity to conduct position statements, collaborate on position statements

Rehabilitation

PROBES: development of specific rehabilitation protocols, post-surgical rehab, specific injuries

Spinal Manipulative Therapy/ Extremity Manipulative Therapy

PROBES: mechanisms, clinical trial, performance, dosage, types of adjustments

Sport Psychology

PROBES: is this important, what type of research, affect clinical practice

Team Travel

PROBES: Frequency of treatment, Utilization rates, Type of treatment provided

Treatment

PROBES: Treatment protocols, Effectiveness, modalities, manual methods, soft tissue, biological effects, clinical trials, pre-operative care, post-operative care

PART 2: RESEARCH CAPACITY

Barriers

PROBES: Finances, Logistics, Resources, Time, prioritize barriers, how to overcome them

Enablers

PROBES: how to increase research capacity, how to leverage enablers, individual chiropractor contributions

Sustainability

PROBES: funding, mentorship, collaborations, how to take advantage of enablers

Methodology

PROBES: types of methodology for sports research, performance research

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A clinical crossover trial of the effect of manipulative therapy on pain and passive and active range of motion of the painful hip

Mohsen Kazemi, RN, DC, FRCCSS(C), FCCPOR(C), MSc, PhD[1]
Sydney Hubbel Leguard, BHSc (Hons), DC[1]
Sebastian Lilja, BHSc (Hons), DC[1]
Steven Mahaise, BHSc (Hons), DC[1]

Objectives: *This study aims to determine whether manipulative therapy of the hip joint can increase range of motion (ROM) and/or decrease pain in individuals experiencing symptomatic hip pain.*

Methods: *Non-disabled young adults were recruited on campus of a chiropractic college for this randomized crossover study. Subjects' hip active and passive ROM and pain perception were measured. Subjects then received a drop-piece hip manipulation (DPHM) or an alternative treatment, followed by measurement of active and passive ROM and pain.*

Results: *Eight males and 12 females (n=20) between the ages of 21-32 years completed the study. Statistically significant improvements in numeric pain scale (NRS) and passive abduction were observed for the manipulation group when compared to the alternative*

Essai clinique croisé sur l'effet des manipulations sur la douleur et l'amplitude des mouvements actifs et passifs de la hanche douloureuse

Objectifs : *Cette étude vise à déterminer si les manipulations de la hanche peuvent augmenter l'amplitude du mouvement et/ou diminuer la douleur chez les personnes ayant des douleurs à la hanche.*

Méthodologie : *On a recruté de jeunes adultes non handicapés sur le campus d'un collège chiropratique pour participer cette étude croisée à répartition aléatoire. L'amplitude des mouvements actifs et passifs de la hanche et la perception de la douleur ont été mesurées. Les sujets ont ensuite subi des manipulations de la hanche sur une table à sections mobiles qui chutent ou un autre traitement, puis on a mesuré l'amplitude des mouvements actifs et passifs et l'intensité de la douleur.*

Résultats : *Huit hommes et 12 femmes (n=20) âgés de 21 à 32 ans ont participé à l'étude. Des améliorations statistiquement significatives sur l'échelle numérique de la douleur et de l'abduction passive ont été observées dans le groupe ayant eu des manipulations par rapport à l'autre traitement. Aucun changement significatif*

[1] Department of Graduate Studies and Research, Canadian Memorial Chiropractic College

Corresponding author: Mohsen Kazemi, Canadian Memorial Chiropractic College Leslie St. Toronto, ON, Canada, M2H 3J1
Tel: 416-482-2340
e-mail: mkazemi@cmcc.ca

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treatment. No significant change was observed for all other hip ranges.

Conclusions: *DPHM of the symptomatic hip joint in a small sample of young adults resulted in statistically significant improvements in pain and passive abduction when compared to sham manipulation. Due to low sample size, further research is recommended.*

(JCCA. 2021;65(3):318-329)

KEY WORDS: hip joint, pain, ROM, manipulation, symptomatic, drop piece, chiropractic

d'amplitude n'a été observé pour les autres mouvements de la hanche.

Conclusions : *Les manipulations sur table à sections mobiles qui chutent pour traiter la hanche symptomatique sur un petit échantillon de jeunes adultes a permis d'obtenir des améliorations statistiquement significatives de la douleur et de l'abduction passive par rapport à la manipulation fictive. En raison de la faible taille de l'échantillon, des recherches supplémentaires sont recommandées.*

(JCCA. 2021;65(3):318-329)

MOTS CLÉS : articulation de la hanche, douleur, amplitude du mouvement, manipulation, symptomatique, table chiropratique à sections mobiles qui chutent, chiropratique

Introduction

Poor levels of hip joint range of motion (ROM) have been shown to be an indication for future hip replacement surgery.[1] According to the Canadian Joint Replacement Registry (CJRR) there were 47,075 hospitalizations for hip replacements in Canada during the 2012-2013 year. Of the total number of hip replacement cases, 76.5% were due to osteoarthritis (OA).[2] A determinant of both self-reported and observed disability in individuals with hip OA is decreased ROM at the hip joint. Therefore, there may be a positive relationship between optimal hip joint ROM, and hip joint health.[3]

The hip joint is a multiaxial ball and socket synovial joint that connects the lower limb and pelvic girdle by way of the femoral head and the acetabulum.[4] To increase the articular surface area, the acetabulum contains a labrum, which allows nearly half of the femoral head to sit inside it.[4] It is a highly mobile joint, second to only the glenohumeral joint, capable of many movements: flexion-extension, abduction-adduction, internal-external rotation, and circumduction.[4] When the knee is bent, the hip is capable of a high degree of flexion due to a lack of resistance from the hamstring musculature.[4] In extension, fibers from the iliofemoral ligament become taut and greatly limit extension ROM, especially when compared to flexion.[4] The hip joint's range of abduction is far greater than that of adduction, and the action of external rotation (ER) is much more powerful than that of internal rotation (IR).[4]

Though the hip joint's ROM is typically broad, a wide range of pathological conditions can affect the hip joint's ability to move through its full ROM. Of these conditions, two of the most prevalent pathologies affecting hip joint ROM include OA and femoroacetabular impingement (FAI).[5,6] It is widely accepted that individuals with FAI are predisposed to decreased ranges of motion at the hip joint.[6] Clinical findings have shown patients with FAI to have a significantly decreased ROM in flexion, IR at 90-degree flexion, and abduction compared to patients without hip joint pathology.[6] Patients with hip OA have also been found to present with decreased hip ROM, notably in abduction, and internal/external rotation. In addition, a positive relationship exists between the progression of OA and the subsequent decrease in ROM at the hip joint.[5]

Various interventions have been used to facilitate a change in ROM at the hip joint. Currently, traditional static stretching, trunk muscle strengthening protocols, and proprioceptive neuromuscular facilitation (PNF) are some of the interventions used to attempt to increase ROM in individuals with and without hip joint pathologies.[7-10] Additionally, several studies have investigated the effects of hip mobilization on both short and long-term changes in hip

ROM.[11-15] Beselga *et al*.[11] found significant improvements in hip flexion after a single treatment of mobilizations with movement. Hoeksma *et al*.[12] compared a manual therapy program including manipulation and mobilizations to an exercise program and found significantly better outcomes in pain, stiffness, hip function, and hip range of motion after 5 weeks. Mosler *et al*.[13] studied changes in hip range of motion after a 4-week manual therapy program in junior elite male water polo players and found significant improvement in passive IR and ER. Estébanez-De-Miguel *et al*.[14] examined the effects of three treatment sessions of high force long axis distraction mobilization on passive hip ROM when compared to low and medium force long axis distraction mobilization. They found significant improvements in passive flexion, extension, abduction, adduction, IR, and ER in the high force group and no significant changes in the low and medium force groups.[14] Stathopoulos[15] did a systematic review and meta-analysis regarding the efficacy of mobilizations with movement on ROM of various joints and found statistically and clinically significant improvements in ROM consistently for hip pain. Currently, there is limited evidence examining multiple ranges of motion with a single intervention.

Another common and effective treatment used to treat limitations in hip ROM is manipulation.[16] Manipulation involves the use of a high velocity, low-amplitude (HVLA) thrust into a joint with various intents, including the improvement in joint ROM.[16] Manipulation can also include the use of tools to execute the procedure, including an activator or a drop piece. The present study focuses on the use of drop piece manipulation. Although no supporting clinical evidence exists, drop-piece mechanisms have been promoted as a technology for increasing the efficiency of manipulation.[17] One explanation for this claim suggests that the degree of adjustive effort and force may be reduced. This is due to the drop piece decreasing the counter-resistance of both the table and the patient. Another explanation is that the force of the manipulation is enhanced by the counter-reactive force generated across the joint when adjustive thrusts are maintained through the impact of the drop piece.[18] Both of these proposed explanations consider Newton's first law which states that a body is in equilibrium if no force is acting upon it. If at rest it remains so, if in action it persists in motion unless an opposing motion is met. When drop pieces are used, the thrust executed by the practitioner imparts motion to the targeted joint. This joint remains in motion until the end of the drop.[18]

Bergmann and Davis[19] outline the basic procedure for using a drop piece as follows: first, the targeted joint is positioned over the drop section. Then, the drop section is set, and its tension is checked. The tension should be enough to support the patient's weight without dropping, but light enough so only minimal force is needed to overcome the resistance.[20] Finally, contacts are established over the structure to receive the thrust, and a thrust is generated to make the section drop. This procedure is repeated for a total of three times.[19]

The principal author had been using drop piece hip manipulation for his patients in clinical practice and saw significant improvement in their ROM and reduced pain after the manipulation. Since there are no studies that have used this type of manipulation on the hip joint, we decided to investigate drop piece hip long axis manipulation on hip ROM and pain.

Therefore, the purpose of this study was to examine the changes in pain, and passive and active ROM at the hip joint in patients with a hip complaint or limited ROM at the hip following a femoral-acetabular manipulative procedure compared to an alternative femoral-acetabular treatment.

Methods

Design

The study was a randomized crossover design. Student researchers were blinded to the type of intervention provided (drop-piece manipulation or alternative), and the doctor was blinded to the measurements recorded before and after the intervention. The participants were blinded to whether they were in the manipulation or alternative treatment group. Subjects were fitted with sensors compatible with the Optotrak® System on bilateral aspects of the pelvis and distal to the hip joint on the affected side (Figure 1). Subjects were then asked to perform active hip ROM, including flexion, ER, IR, abduction, and adduction while in the supine position and hip extension in the prone position (Figure 2). The researcher then helped the subject to maintain a 90-degree bend at the knee, and passive ROM with overpressure to the point of pain was performed. Passive hip ROM was measured for flexion, ER, IR, abduction, and adduction in the supine position

and hip extension in the prone position (Figure 3). ROM data was collected by the student researchers. Each set of ROM was conducted one time before the intervention and one time after the intervention, unless there was an error in measurement with the Optotrak® sensor. If there was an error, the single errored ROM was repeated. The subjects did not warm-up prior to conducting ROM to simulate day to day clinic setting testing.

After the pre-intervention ROM was measured, the principal investigator entered the room and received a sealed opaque envelope with a slip of paper inside stating if the subject was in the control or experimental group. The student researchers then exited the room. The doctor proceeded with a drop-piece hip manipulation or alternative treatment (see manipulation treatment and alternative treatment below), then left the room. The student researchers then re-entered the room and post-intervention ROM was measured. In addition, the doctor resealed the allocation in the envelope and returned it to the assessors who labeled the envelope with '2' to indicate the first intervention had occurred. When the subject returned, at least a week later, to receive the opposite treatment, the same procedure occurred, however, when given the same sealed opaque envelope, the principal investigator performed the opposite treatment which was stated on the cue card inside.

Participants

Participants were included in our study if they were students enrolled at the Canadian Memorial Chiropractic College and if they were experiencing self-reported symptomatic pain or limited ROM at the hip joint. Exclusion criteria included any past hip surgery, knee replacement, acute pain due to trauma, radicular pain, numbness or tingling in the involved lower limb, avascular necrosis of the femoral head, stress fracture of the hip joint, received hip manipulation in the past week, severe arthritis of the hip joint, and full ROM of the hip. Data collection occurred between September 2018 and December 2019 in the Biomechanics Lab of the Canadian Memorial Chiropractic College.

Interventions

Manipulation treatment

The patient was supine with the drop-piece under the affected hip. The tension was set by determining the

Figure 1.
Sensor placement and digitization.

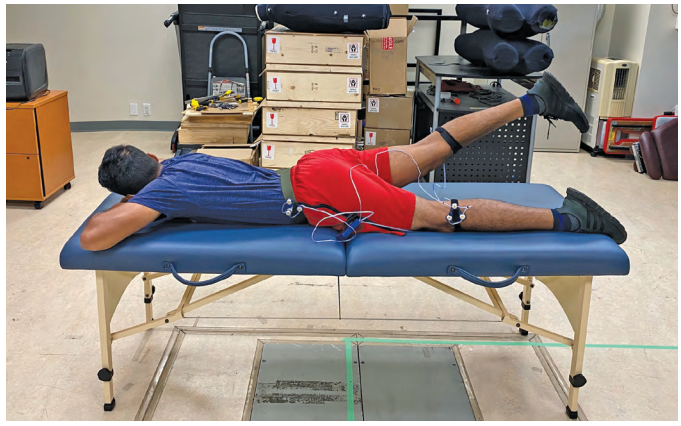

Figure 2.
Active hip extension measurement.

Figure 3.
Passive hip extension measurement

Figure 4.
Manipulation treatment starting point.

Figure 5.
Manipulation treatment end point.

amount necessary for the drop piece to engage under the patient's body weight and then increased by a 1/2 rotation. The doctor took the patient's affected leg with one hand contacting the thigh proximal to the knee while the other hand contacted the leg just proximal to the ankle with 20-30 degrees of hip abduction and 15 to 20 degrees of ER. The doctor initiated a postero-caudal long axis thrust ending in 15 to 20 degrees of hip extension similar to a whip motion, which engaged the drop-piece. (Figures 4 and 5). The doctor repeated the procedure 3 times.

Alternative treatment

The patient was supine with the drop-piece under the affected hip. The tension was set by determining the amount necessary for the drop piece to engage under the patient's body weight and then increased by a 1/2 rotation. The doctor contacted the thigh with a one hand contact on the thigh mid-way between the knee and hip (Figure 6). The doctor initiated a purely anterior to posterior thrust into the table with the other hand, which engaged the drop-piece (Figure 7). The doctor repeated the procedure 3 times.

Outcome measures

Outcome measures included passive/active hip ROM and pain perception. ROM of the hip joint was measured in extension, flexion, abduction, adduction, ER, and IR. External and IR were performed with the knee flexed to 90 degrees. Pain perception was measured by a numeric pain scale (NPS) (1-10) and was measured both before and after the intervention.

Figure 6.
Alternative treatment starting point.

Figure 7.
Alternative treatment end point.

Table 1.
Sample size and effect size estimate[21]

Motion	Side	Rotation	Mean	SE	SD	Diff	Effect size d
Active	left	internal	34.30	3.00	13.42	6.86	0.51
Active	left	external	46.00	2.80	12.52	9.20	0.73
Active	right	internal	36.00	3.20	14.31	7.20	0.50
Active	right	external	46.50	2.50	11.18	9.30	0.83
Passive	left	internal	44.40	3.10	13.86	8.88	0.64
Passive	left	external	45.50	2.20	9.84	9.10	0.92
Passive	right	internal	45.50	3.10	13.86	9.10	0.66
Passive	right	external	54.60	2.80	12.52	10.92	0.87
SE= Standard Error; SD= Standard deviation; Diff= Difference in mean; d= Cohen's d							

Sample size estimate

For a crossover design, the main statistical test was a paired t-test comparing change in hip ROM with the intervention of interest to change in hip ROM without the intervention of interest. Sample size was set at twenty for feasibility reasons. With significance α=0.05, power 1-β=0.80 for a two-sided paired t-test, 20 subjects were found to be sufficient to detect an effect size of d=0.626, as shown below:

$$d=((Z\_(1-\alpha/2)+Z\_(1-\beta)))/\sqrt{n}= (1.96+0.84)/\sqrt{20}=0.626$$

Using data from Aefsky *et al*.[21] for values of both internal and external hip rotation measured in the prone position with both active and passive motion, and considering a change of interest in mean of 20%, the effect sizes ranging from 0.50 to 0.92 were obtained (Table 1). Therefore, the target of 20 subjects were found to be adequate to detect an effect size of 0.62, capturing six of the eight rows (highlighted) in Table 1.[22-23]

Randomization

Randomization occurred by labeling 20 cue cards with either "manipulation treatment" (10 cards) or "alternative treatment" (10 cards). Each card was enclosed and sealed within an opaque envelope. The envelopes were shuffled by hand by the student investigators and then chosen at random to be assigned to each subject. Each subject's assigned subject code was labelled on one envelope, which was stored and then handed to the principal investigator on the day each subject participated in data collection.

Statistical methods

Means with standard deviation, confidence intervals (95%), a paired t-test and effect size estimates were used to analyse the data. A dependent samples t-test was used rather than a two-sample (independent) t-test in order to account for within participant differences. This study received ethics approval from the Canadian Memorial Chiropractic College Research Ethics Board with approval number: 1604A01.

Results

Twenty-one participants with a painful hip were screened for eligibility criteria. All met the eligibility criteria and agreed to participate in the study. One participant dropped out due to personal reasons prior to commencing data collection. Twenty participants completed the study. Participant demographic information are summarized in Table 2.

Table 2.
Participant demographics

	Manipulation	Alternative
No. of participants	10	10
Sex	2 males, 8 females	6 males, 4 females
Age (year)	23-31	21-32
Mean Age (year)	25.4	26.0
Weight (kg)	50.0-90.7	53.1-108.9
Mean Weight (kg)	69.2	77.0
Height (cm)	158.0-180.3	152.4-190.5
Mean Height (cm)	167.6	175.8
kg=kilogram; cm=centimeter		

Table 3.
Range of motion, changes in range of motion and differences between manipulation and alternative treatment - statistical analysis results

			Manipulation change in ROM	Alternative change in ROM	Difference in change (Manipulation –Alternative, bigger positive mean value indicates more change with Manipulation than with Alternative)						
ROM	**Active/ Passive**	**n**	**Mean ± SD (°)**	**Mean ± SD (°)**	**Mean ± SD (°)**	**95%CI - L**	**95%CI - U**	**t-statistic**	**df**	**p-value**	**Effect size**
Abduction	Passive	12	10.6 ± 13.2	-1.2 ± 9.0	11.8 ± 11.3	4.6	19.0	3.62	11	0.004*	1.31**
	Active	12	0.4 ± 8.5	-3.8 ± 12.8	4.1 ± 17.0	-6.6	14.9	0.84	11	0.418	0.32^
Adduction	Passive	17	2.4 ± 6.9	-0.4 ± 6.9	2.8 ± 9.5	-2.1	7.7	1.20	16	0.248	0.41^
	Active	17	3.7 ± 5.4	0.2 ± 7.8	3.5 ± 9.5	-1.4	8.3	1.50	16	0.153	0.45^
Extension	Passive	17	3.7 ± 10.0	0.3 ± 9.0	3.4 ± 14.5	-4.0	10.9	0.98	16	0.342	0.38^
	Active	11	5.8 ± 7.9	0.5 ± 9.5	5.3 ± 11.1	-2.2	12.7	1.58	10	0.146	0.56^
Flexion	Passive	20	-0.6 ± 18.7	1.0 ± 16.0	-1.5 ± 27.3	-14.3	11.3	-0.25	19	0.804	-0.09
	Active	20	0.9 ± 18.9	3.6 ± 12.4	-2.6 ± 26.4	-15.0	9.8	-0.44	19	0.664	-0.21
Internal Rotation	Passive	19	1.6 ± 20.7	3.9 ± 13.0	-2.3 ± 25.7	-14.7	10.1	-0.38	18	0.705	-0.18
	Active	19	6.1 ± 12.7	5.1 ± 11.8	1.1 ± 17.9	-7.6	9.7	0.26	18	0.795	0.09
External Rotation	Passive	18	10.5 ± 18.4	2.7 ± 11.3	7.8 ± 24.0	-4.2	19.7	1.38	17	0.187	0.69**
	Active	19	9.4 ± 15.8	1.6 ± 11.2	7.8 ± 20.9	-2.3	17.9	1.63	18	0.121	0.70**

ROM = range of motion; SD= standard deviation; df=differential; p-value< 0.05 significant; effect size: high**> 0.62, moderate^ 0.30-0.61, low <0.29

Passive range of motion

Statistical analysis (Table 3) revealed a statistically significant change in passive abduction (11.8 ± 11.3, p = 0.004) in the manipulation treatment group when compared to the alternative treatment group. No significant change was observed for passive adduction (2.8 ± 9.5, p = 0.248), extension (3.4 ± 14.5, p = 0.342), flexion (-1.5 ± 27.3, p = 0.804), IR (-2.3 ± 25.7, p = 0.705), and ER (7.8 ± 24.0, p = 0.187).

Active range of motion

Statistical analysis (Table 3) revealed no statistically significant change in active abduction (4.1 ± 17.0, p = 0.418), adduction (2.8 ± 9.5, p = 0.248), extension (5.3 ± 11.1, p = 0.146), flexion (-2.6 ± 26.4, p = 0.664), IR (-2.3 ± 25.7, p = 0.705), and ER (7.8 ± 24.0, p = 0.121) in the manipulation group when compared to the alternative treatment.

Numeric pain scale change

Statistical analysis (Table 4) showed significant improvements in numeric pain scale after the manipulation (-1.05 ± 0.81, p<0.0001) and alternative treatments (-0.44 ± 0.89, p=0.0351) when compared to before the treatment. There was a statistically significant improvement in numeric pain scale when the manipulation treatment

Table 4.
Analysis of change in numeric pain scale following manipulation and alternative treatments and the difference in change

	n	**Mean ± SD**	**95%CI - L**	**95%CI - U**	**t-statistic**	**df**	**p-value**	**Effect Size**
Manipulation	20	-1.05 ± 0.81	0.67	1.43	5.80	19	<0.0001	0.54
Alternative	20	-0.44 ± 0.89	0.03	0.87	2.27	19	0.0351	0.23
Difference in change (manipulation-alternative)	20	-0.60 ± 1.20	-1.16	-0.04	-2.24	19	0.0374	0.71

SD= standard deviation; df=differential; CI= confidence interval; p-value< 0.05 significant

Table 5.
Perceived intervention received by rate of correct guess

	Correct Guess Rate (%)
Initial visit	85
Crossover	75

was compared to the alternative treatment (-0.60 ± 1.20, p=0.0374).

Perceived intervention received

On average, the participants' ability to correctly guess which intervention that was received was 85% and 75% for the initial visit and crossover visit, respectively (Table 5).

Effect size

Calculation of effect sizes (Table 3) revealed large effect sizes for passive abduction (1.31) and ER (0.69), and active ER (0.70). Moderate effect sizes were noted for active abduction (0.32), adduction (0.45), and extension (0.56) as well as passive adduction (0.41) and extension (0.38). For the numeric rating scale results, the effect size comparing change in pain with manipulation to change in pain with sham was 0.71.

Discussion

This study evaluated the effects of femoral-acetabular high velocity low amplitude manipulation with drop piece (HVLA MDP) compared to an alternative femoral-acetabular procedure on pain perception and passive and active ROM at the hip joint in symptomatic students with a hip complaint and/or limited ROM at the hip.

In this study the Optotrak® system was used to measure active and passive hip ROM. Schmidt *et al*. reported all four Optotrak® systems they tested produced high precision, repeatability and accuracy of under 10 μm when the distance between the camera system and rigid body was minimized to within the manufacturer's recommended range.[24] This procedure was used and followed in the current study. However, although all hip ranges of motion were measured in all 20 participants, some data was omitted from statistical analysis due to corruption that was not apparent during the initial measurement and collection. The use of the Optotrak® system involved the use of wired sensors that were strapped to the participants' hips and shanks. As stated previously, for the comfort of the participants, the hip sensor was attached to a belt that was wrapped tightly around the participants' hips. Although there was an intended effort to ensure all sensors were securely fixed to the participants, especially during the motion trials; there were cases the Optotrak® markers still slipped/shifted from their fixed position. In most cases this marker slippage was caused by the participants movement during hip flexion, when the participants thigh would contact the Optotrak® marker itself. In other cases, marker slippage was a result of the sensor straps loosening up during testing. To address these issues: the Optotrak® markers were strapped on a little tighter than usual, tape was sometimes used, and/or the marker was repositioned to prevent any of the participants anatomy from making contact with the markers during testing. Even despite these countermeasures, several trials were omitted because marker slippage was hard to detect during data collection, unless it was obvious to the tester (i.e., tester witnessed the marker fall off or come undone). Sometimes it was not until the visual 3D bone model was applied to the data and successive trials compared to identify a definite marker slippage. Therefore, the data for those trials were omitted, leading to differing sample sizes for the statistical analysis of each ROM, as seen in Table 3. The greatest omission of data occurred for passive (n=12) and active (n=12) abduction as well as active extension (n=11). All ranges except passive and active flexion were affected by this issue.

For the data that was analyzed, as summarized in Table 3, it was found that there was a significant increase in passive abduction in the manipulation treatment in comparison to the alternative treatment.

There are numerous theoretical mechanisms of action for manipulation therapy (MT). [25-27] These theories are based around three major concepts: the biomechanical effects, the muscular reflexogenic effects and the neurophysiological effects.[28] The hip joint is a synovial joint and has synovial folds that are highly innervated and capable of generating pain. Hip synovial folds have been reported to be involved in production of catching, locking and clicking of the joint.[29]

MT is suspected to gap the joint, therefore reducing the impaction on the trapped synovial folds and allowing it to return to its normal position.[27,30] This will allow the joint to regain full or improved ROM.

It has been reported that MT can have hypoalgesic as well as muscle reflex effects.[31-35] The hypoalgesic effects of MT can be attributed to the gate-control theory of pain.[26,28] The joint capsule and surrounding musculature have numerous proprioceptors in the form of muscle spindles and type I and type II afferents.[26,28] With MT, there is a dynamic stretch to the tissue that will cause an increase in afferent discharge from these receptors.[35-37] This increase in afferent input will attenuate the pain sensation at the dorsal horn, thereby creating a hypoalgesic effect.[26] The muscle-reflexogenic effects of MT are believed to occur through the effects on the muscle spindles surrounding the joint. As with the gate-control theory, during the act of the manipulation, there is an increase in the afferent output from the surrounding muscle spindles.[35-37] Directly after MT, the muscle spindles become silent for a short period.[35,37] After this silent period, the spindles return to firing at their appropriate rate, which can cause a relaxation of the surrounding muscles. The hip manipulation in this study was done with 20-30 degrees of hip abduction. This may have increased hip abduction by further stretching of the hip capsule in abduction resetting the muscle spindle, inhibiting the hip adductor groups, releasing of any synovial fold entrapment, gaping the joint and resulting in increased abduction and decreased pain.[24, 26-29, 31-37]

Although statistical significance was found only for passive abduction, the effect sizes appear to show a moderate to high trend towards improvement in ROM following manipulation for active and passive ER (effect size =0.70 and 0.69 respectively). Effect size is a quantitative measure of the magnitude of the experimental effect. The larger the effect size the stronger the relationship between two variables. The higher effect sizes in ER may also have been due to the direction of the manipulation which included 15 to 20 degrees of ER and ending in 15 to 20 degrees of extension. Further investigation using a larger sample size may clarify the effects of manipulation as multiple data sets were omitted due to sensor movement.

Other studies have investigated the effects of manipulation and mobilization of the hip joint on ROM but did not use a drop piece. Stathopoulos *et al*.[15] found statistically significant differences in hip flexion and IR after hip mobilizations with movement as they mobilized the joint in these directions. This differs from results of the current study in which an increase in passive abduction of the hip was observed possibly due to the direction of the MT. Additionally, a case study by Strunk and Hanses[38] used a combination of manipulation, mobilization, and passive stretching with the intent of improving the ROM of 70-year-old patient with an osteoarthritic hip. For manipulation, a gentle prone P-A drop piece technique was used.[38] This differs from our technique, which used a long-axis manipulation combined with a drop piece. After 12 weeks of care, the patient had improved disability scores and a small increase in active IR of the hip.[38] Hoeksma *et al*.[12] compared manual therapy to exercise therapy in the treatment of hip OA. The manual therapy intervention was a traction manipulation, in the limited position of the hip, using a high velocity thrust, similar to our design.[12] They concluded that manual therapy was far superior to exercise therapy in improving hip function in patients with OA.[12] Brantingham *et al*.[39] investigated the short-term effectiveness of full kinematic chain manual and manipulative therapy (MMT) plus exercise compared with targeted hip MMT plus exercise for symptomatic mild to moderate hip OA. The treatment consisted of a targeted hip manipulation, using high-velocity, low-amplitude thrust-type along with pre- and post-treatment stretching of the same hip.[39] They concluded that there was no statistically significant difference between the two groups however, both groups did have improved Western Ontario and McMasters Osteoarthritis Index (WOMAC) scores.[39]

There was a statistically significant improvement in numeric pain scale scores for both the manipulation treatment and the alternative treatment. However, when the two treatments were compared, there was a statistically significant difference in the magnitude of improvement for the manipulation treatment. The decrease in pain perception may be due to the hypoalgesic effects of MT.[26,28] There are no studies evaluating the minimal clinically important change in the NPS for hip pain; however, Child *et al*.[40] concluded that a change of two points (20%) represents a clinically meaningful change in patients with low back pain. As such, although the reduction of pain seen in our study was statistically significant, it may not be clinically significant. Furthermore, our sample included participants from a young healthy student population. Further research is needed to determine if clinically meaningful pain reduction can be achieved in populations with more severe and limiting hip ROM. Regardless, a one-week washout period was used in this study which was reported

to be an appropriate length of time for crossover studies in manipulation.[41]

Notably of all the participants undergoing manipulation, only one participant reported a short episode of tingling in their ipsilateral foot during the procedure. No other side effects were reported.

The alternative treatment in the current study involved setting up the participant similarly to the manipulation treatment, however, the alternative used a thrust directly into the drop piece as opposed to the manipulation treatment which used a thrust into the joint, which then engaged the drop piece. In regard to the quality of the alternative procedure as a sham, 85% of participants at the initial visit correctly guessed whether they received the manipulation or alternative treatment and 75% of the participants guessed correctly at the crossover visit indicating the quality of the alternative procedure as a sham to be poor. This may have been influenced by the population used in the study. Due to the fact that all participants included were chiropractic students, some may have been exposed to drop piece hip manipulation during their education and therefore were able to identify whether they received the manipulation treatment or alternative treatment. Since there are no other drop piece mechanism studies that exist, this study establishes a baseline for improving sham procedures involving drop pieces. The procedure could be improved on by excluding chiropractic students and including individuals who have never received manipulation before or by blindfolding the participants so they cannot see what is being done.

Limitations

A reduction in the initial sample size was the result of data collection errors due to movement of the Optotrak® sensors. The equipment available to us included wired sensors that were attached to the participants using a Velcro strap. Unfortunately, in some cases, this resulted in the sensors shifting during data collection. We were able to identify these errors using our re-digitizing protocol after every trial. The data that was found to be corrupt was omitted from the study, which resulted in smaller and differing sample sizes for the statistical analysis of each ROM. As such we were not able to reach the sample size estimate (except for active and passive flexion) we desired which increased the likelihood of type II error.

Furthermore, differences between groups (i.e., sex ratio, weight, and height) have not been accounted for in the statistical analysis. As such, there may have been an unequal distribution of important known or unknown confounding factors between groups. This may have contributed to the differences in outcomes observed between groups.

During the intake no information on participant's diagnosis, duration of symptoms nor outcome measures were collected, which restricts the ability to infer findings to a wider population. For future studies obtaining information on diagnosis, duration and appropriate outcome measures are recommended. One pre- and post-intervention measurement was used to simulate real clinical testing. However, this may have increased the chances of errors in measurement and the potential for unusable data due to corrupt files.

Establishing a convincing alternative sham manipulation was difficult. Subjects in this study were chiropractic students, who may have been familiar with the manipulation used in our study. This led to a high percentage of participants correctly guessing which treatment they received, thus decreasing the quality of blinding, and could have resulted in an overestimation of the treatment effect. Repeating the study with non-chiropractic students and modifying the alternative treatment are recommended.

This study investigated the immediate effect of hip HVLA MDP. Future research investigating both the short- and long-term effects of hip manipulation is recommended.

Conclusions

HVLA MDP of the symptomatic hip joint in young adults (21 to 32 years of age) statistically significantly improved the perception of pain. It may also lead to significant increases in passive hip abduction; however, not achieving the desired estimated sample size for ROM measurement increased type II error in this study. Further research including larger sample size and improved sham procedures are recommended.

References

1. Crawford RW, Murray DW. Total Hip Replacement: indications for surgery and risk factors for failure. Ann Rheum Dis. 1997; 56: 455-457.
2. Canadian Joint Replacement Registry. Hip and knee replacements in Canada: Canadian joint replacement registry 2014 annual report. 2014 [cited 2015 Sept 11].

Available from: https://secure.cihi.ca/free_products/CJRR%202014%20Annual%20Report_EN-web.pdf
3. Steultjens M, Dekker J, van Baar M, Oostendorp R, Bijlsma J. Range of joint motion and disability in patients with osteoarthritis of the knee or hip. Rheumatol. 2000;39(9): 955-961.
4. Moore KL, Dalley AF, Agur AMR. Clinically Oriented Anatomy 7th Ed. Lippincott Williams & Wilkins. 2013; pp. 626-634.
5. Arokoski MH, Haara M, Helminen HJ, Arokoski JP. Physical function in men with and without hip osteoarthritis. Arch Phys Med Rehabil. 2004; 85(4): 574–581.
6. Tannast M, Kubiak-Langer M, Langlotz F, Puls M, Murphy SB, Siebenrock KA. Noninvasive Three-dimensional assessment of femoroacetabular impingement. J Orthopaed Res. 2007; 25(1): 122-131.
7. Godges JJ, MacRae PG, Engelke KA. Effects of exercise on hip range of motion, trunk muscle performance, and gait economy. Phys Ther J. 1993;73(7): 468-477.
8. Minshull C, Eston R, Bailey A, Rees D, Gleeson N. The differential effects of PNF versus passive stretch conditioning on neuromuscular performance. Eur J Sport Sci. 2014;14(3): 233-241.
9. Moreside JM, McGill SM. Hip joint range of motion improvements using three different interventions. J Strength Cond Res. 2012;26(5): 1265-1273.
10. Ayala F, De Baranda Andujar PS. Effect of 3 different active stretch durations on hip flexion range of motion. J Strength Cond Res. 2010;24(2): 430-436.
11. Beselga C, Neto F, Alburquerque-Sendín F, Hall T, Oliveira-Campelo N. Immediate effects of hip mobilization with movement in patients with hip osteoarthritis: a randomised controlled trial. Man Ther. 2016;22: 80-85.
12. Hoeksma HL, Dekker J, Ronday HK, Heering A, Van Der Lubbe N, Vel C, Breedveld FC, Van Den Ende CH. Comparison of manual therapy and exercise therapy in osteoarthritis of the hip: a randomized clinical trial. Arthr Care Res. 2004;51(5): 722-729.
13. Mosler AB, Blancha PD, Hiskins BC. The effect of manual therapy on hip joint range of motion, pain and eggbeater kick performance in water polo players. Phys Ther Sport. 2006;7: 128-36.
14. Estébanez-De-Miguel E, Fortún-Agud M, Jimenez-Del-Barrio S, Caudevilla-Polo S, Bueno-Gracia E, Tricás-Moreno JM. Comparison of high, medium and low mobilization forces for increasing range of motion in patients with hip osteoarthritis: a randomized controlled trial. Musculoskel Sci Pract. 2018;36: 81–86.
15. Stathopoulos N, Dimitriadis Z, Koumantakis GA. Effectiveness of Mulligan's mobilization with movement techniques on range of motion in peripheral joint pathologies: a systematic review with meta-analysis between 2008 and 2018. J Manip Physiol Ther. 2019;42(6): 439-449. doi: 10.1016/j.jmpt.2019.04.001.
16. Brantingham JW, Bonnefin D, Perle SM, Cassa TK, Globe G, Pribicevic M, Hicks M, Korporaal C. Manipulative therapy for lower extremity conditions: update of a literature review. J Manip Physiol Ther. 2012; 35(2): 127-166.
17. Bergmann T, Peterson D. Chiropractic Technique. St. Louis, Mo.: Elsevier/Mosby; 2011
18. Minardi J. The Complete Thompson Textbook. Ontario, Canada: John Minardi; 2014.
19. Bergmann TF, Davis PT. Mechanically Assisted Manual Techniques: Distraction Procedures. Mosby Incorporated; 1998.
20. Barber M. Chiropractic Manipulative Skills. Byfield D, editor. Edinburgh; New York: Elsevier/Churchill Livingstone; 2005.
21. Aefsky B, Fleet N, Myers H, Butler RJ. Reliability and validity of a novel approach to measure hip rotation. J Sport Rehabil. 2016;25: 330-337.
22. Rosner B. Fundamentals of Biostatistics. Ed. Duxbury Press: Boston Massachusetts. 1986.
23. Cohen J. Statistical power analysis for the behavioural sciences second edition. Lawrence Erlbaum Associates: New York. 1988.
24. Schmidt J, Berg DR, Ploeg HL, Ploeg L. Precision, repeatability and accuracy of Optotrak® optical motion tracking systems'. Int J Experiment Comput Biomech. 2009; 1(1):114–127.
25. Potter L, McCarthy C, Oldham J. Physiological effects of spinal manipulation: a review of proposed theories. Phys Ther Rev. 2005;10(3): 163-170.
26. Evans DW. Mechanisms and effects of spinal high velocity, low-amplitude thrust manipulation: previous theories. J Manipulative Physiol Ther. 2002;25(4): 251-262.
27. Pickar JG. Neurophysiological effects of spinal manipulation. Spine J. 2002;2(5): 357-371.
28. Pettman E. A history of manipulative therapy. J Man Manip Ther. 2007;15(3): 165-174.
29. McGrath B, Kuechle J. Synovial Disorders of the Hip. Hip Arthroscopy and Hip Joint Preservation Surgery. Spinger 2015th edition, pages 1183-1191.
30. Sandoz R. Some physical mechanisms and effects of spinal adjustments. Ann Swiss Chiro Assoc. 1976;6(2): 91-142.
31. McLain RF. Mechanoreceptor endings in human cervical facet joints. Iowa Orthop J. 1993;13: 149-154.
32. Vernon H. Qualitative review of studies of manipulation induced hypoalgesia. J Manipulative Physiol Ther. 2000;23(2): 134-138.
33. Millan M, Leboeuf-Yde C, Budgell B, Amorim MA. The effect of spinal manipulative therapy on experimentally induced pain: a systematic literature review. Chiropr Man Ther. 2012; 20(26):1-22.

34. Coronado RA, Gay CW, Bialosky JE, Carnaby GD, Bishop MD, George SZ. Changes in pain sensitivity following spinal manipulation: a systematic review and meta-analysis. J Electromyog Kines. 2012;22(5): 752-767.
35. Pickar JG, Kang Y. Paraspinal muscle spindle responses to the duration of a spinal manipulation under force control. J Manipulative Physiol Ther. 2006;29(1): 22-31.
36. Cao D, Reed WR, Long CR, Kawchuk GN, Pickar JG. Effects of thrust amplitude and duration of high-velocity, low-amplitude spinal manipulation on lumbar muscle spindle responses to vertebral position and movement. J Manipulative Physiol Ther. 2013;36(2): 68-77.
37. Pickar JG, Bolton PS. Spinal manipulative therapy and somatosensory activation. J Electromyog Kines. 2012;22(5): 785-794.
38. Strunk RG, Hanses M. Chiropractic care of a 70-year-old female patient with hip osteoarthritis. J Chiropr Med. 2011;10(1): 54-59.
39. Brantingham JW, Smith Parkin, Cassa T, Globe GA, Globe D, Pollard H, deLuca K, Jensen M, Mayer S, Korporaal C. Full kinetic chain manual and manipulative therapy plus exercise compared with targeted manual and manipulative therapy plus exercise for symptomatic osteoarthritis of the hip—a randomized clinical trial. Arch Phys Med Rehabil. 2012;93: 259-267.
40. Childs JD, Piva SR, Fritz JM. Responsiveness of the numeric pain rating scale in patients with low back pain. Spine. 2005;30: 1331–1334.
41. Corso M, Mior S, Batley S, Tuff T, da Silva-Oolup S, Howitt S, Srbely JZ. The effects of spinal manipulation on performance-related outcomes in healthy asymptomatic adult population: a systematic review of best evidence. Chiropr Man Ther. 2019;27(1):25.

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Hip pain in an elite cyclist with Non-Hodgkin's Follicular Lymphoma: a case report

Melissa Belchos, BSc(Hons), DC[1]
Varsha Kumar, BSc(Hons), DC, DACBR, FCCR(C)[2]
Carol Ann Weis, MSc, DC[3]

Objective: *We present a case of an elite cyclist that hesitated to follow the medical advice from her practitioners, as she was determined to train and compete resulting in delayed diagnosis and management of a rare hip pathology.*

Case presentation: *A 51-year old elite female cyclist had a history of years of hip pain with insidious onset. The chiropractor in this case observed a lack of response to treatment, and advised the patient to get an MRI with suspicion of a labral tear. She eventually agreed to further investigations and was diagnosed with Non-Hodgkin's follicular lymphoma and a labral tear.*

Summary: *Elite athletes are not immune to serious pathology. Chiropractors should be vigilant and ensure*

Douleur à la hanche chez un cycliste d'élite atteint d'un lymphome folliculaire non hodgkinien : un rapport de cas.

Objectif : *Nous présentons le cas d'une cycliste d'élite qui a hésité à suivre les conseils médicaux de ses praticiens, car elle était déterminée à s'entraîner et à participer à des compétitions, ce qui a retardé le diagnostic et la prise en charge d'une pathologie rare de la hanche.*

Présentation du cas : *Une cycliste d'élite de 51 ans avait des antécédents de douleurs à la hanche depuis des années; le début de ses douleurs avait été insidieux. Le chiropraticien a observé une absence de réponse au traitement et a conseillé à la patiente de subir un examen par IRM en soupçonnant une déchirure du labrum. La patiente a fini par accepter de subir des examens complémentaires. Un lymphome folliculaire non hodgkinien et une déchirure labrum ont été diagnostiqués.*

Résumé : *Les athlètes d'élite ne sont pas à l'abri d'une pathologie grave. Les chiropraticiens doivent*

[1] Division of Graduate Studies, Canadian Memorial Chiropractic College
[2] Diagnostic Imaging, Division of Graduate and Undergraduate Studies, Canadian Memorial Chiropractic College
[3] Department of Graduate Education and Research, Canadian Memorial Chiropractic College

Corresponding author: Melissa Belchos, Canadian Memorial Chiropractic College 6100 Leslie Street, Toronto, ON M2H 3J
Tel: 416-482-2340
e-mail: mbelchos@cmcc.ca

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to investigate any patients with a lack of response to conservative management. Chiropractors should be aware of the risk of athletic patients that continue to train and compete when advised not to.

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KEY WORDS: cyclist, diagnosis, elite, hip, labrum, lymphoma, pain, chiropractic

être vigilants et s'assurer d'examiner tous les patients réfractaires à un traitement conservateur. Les chiropraticiens doivent être conscients du risque que représentent les patients sportifs qui continuent à s'entraîner et à participer à des compétitions alors qu'on leur a conseillé de ne pas le faire.

(JCCA. 2021;65(3):330-337)

MOTS CLÉS : cycliste, diagnostic, élite, hanche, labrum, lymphome, douleur, chiropratique

Introduction

Elite athletes undergo substantial physical and mental demands in both their training and sport performance. A cross-sectional study of 518 cyclists reported that 85% of these athletes sustained one or more non-traumatic overuse injuries (with the most common sites including the neck, knees, groin, hands, and back) within the previous year.[1] Of the cyclists in that study, 31% sought medical treatment for their injuries, and on average, had symptoms that persisted for 3.7 months.[1] When the patient's symptoms are not fitting of a musculoskeletal pathology, further investigations are warranted. Whether the patient will follow through with the recommendations of a medical provider, is a separate challenge. Oftentimes, elite athletes may want to return to sport before they are advised to do so.[2] When athletes perceive their identities to be strongly linked to their sport, they may undergo grief and a loss of existence leading to depression, should they withdraw from sport due to injury.[3] Consequently, the constant drive to continue and persevere may stand in the way of an athlete receiving a timely diagnosis or recovery.

Elite athletes are not immune to serious pathology such as infection or malignancies; therefore, chiropractors should be vigilant when patients are not responding to care or if there are signs and symptoms of sinister pathology. One such serious pathology to consider that spans multiple age groups, is lymphoma. Lymphoma is a lymphoid malignancy which typically develops in the lymph nodes.[4] Hodgkin's or Non- Hodgkin's Lymphoma (NHL) should be suspected if a patient presents with generalized lymphadenopathy that is painless and persistent.[4] We present a case report of a 51-year old female elite cyclist with ongoing hip pain who was diagnosed with Non-Hodgkin's follicular lymphoma and a labral tear. The purpose of this report is to describe the challenges in diagnosing sinister pathology in athlete patients, and describe one such sinister pathology that chiropractors should consider when evaluating patients with hip pain.

Case presentation

Initial evaluation by the chiropractor

A 51-year old female elite cyclist presented to a chiropractor with a chief complaint of left adductor and hip pain in June of 2018. One month prior she had been on a three-day stage race where she developed a sudden onset of muscle cramping in her left thigh. The cramping started on the first day of the race, 60km into a 140km stage, while on a climb. She reported she had never experienced this symptom before and felt as though she had no power pushing off with her left leg, however she finished that stage of the race. That night she received a massage, and rested. The following day the athlete reported that her left leg was swollen, particularly on the anterior aspect of her thigh, compared to the right. The athlete was able to complete the second stage of 110km with discomfort, though she reported she had to change her race strategy by keeping her wattage low to prevent cramping of her leg and to avoid an "exploding" sensation. Following that stage, she once again, managed her pain with another massage. On the third stage, an uphill 8km time trial, she reported feeling that her left leg pain almost stopped her from finishing the event, but she pushed through to complete it. In

the weeks following this particular race, she managed her symptoms with massage, acupuncture, physiotherapy, and rest. The physiotherapist told the patient that she did not train sufficiently for the race, and that she should stretch. Three months after the initial onset of pain and cramping, she competed in a 24-hour race where she placed first and set a course record. She experienced pain in her left adductor muscles through the entire duration of the race, and performed self-massage for temporary relief.

Red flags (including but not limited to night sweats, unintentional weight loss, previous history of malignancy) were not identified by the chiropractor, and the systems review was normal. This patient had a medical history that included Reynaud's syndrome and eczema, but was otherwise healthy. She was not taking medications. Her family medical history included: maternal hypertension, Sjogren's syndrome, and arthritis; maternal grandmother with hypertension, ovarian cancer and dementia; maternal grandfather with stroke, high cholesterol, and hypertension; paternal colon cancer, hydrocephalus, and hypertension; paternal grandfather with stroke; and sister with uterine cancer. No other malignancies were noted in her family's medical history.

Physical examination

On examination when presenting to the chiropractor, observation revealed no visible swelling or abnormalities of the lower limbs. The femoral triangle on the left side was observed and palpated, with no abnormalities noted. Functional testing revealed a normal squat and quarter squat. Passive hip range of motion was normal bilaterally. Resisted hip flexion with adduction on the left was limited to 2/5 strength due to severe pain in her hip. Orthopaedic testing of the bilateral hips was within normal limits; including hip scour, log roll, FADDIR (Flexion Adduction Internal Rotation), and FABER (Flexion Abduction External Rotation). Neurological examination of the lower limb was normal bilaterally. The patient was diagnosed with a left sided overuse adductor strain. She was advised to stretch her left adductors and quadriceps, as well as cease training for the interim.

Follow-ups

The remainder of the 2018 year until early 2019, the patient trained indoors and managed her pain with massage, physiotherapy, and acupuncture. In May of 2019, the patient returned to the chiropractor with continued pain and discomfort of her left adductor muscles. The patient reported that uphill road cycling would aggravate her pain significantly, but that she never seemed to experience a problem on her indoor bike trainer. The chiropractor noticed pes planus on the left, but no other observable abnormalities. Palpation of the pubic symphysis elicited pain, as well as palpation of the right sacroiliac joint. Passive knee flexion was limited on the left. No hip orthopaedic tests were positive. At this time, the patient was diagnosed with pubic symphysis irritation with sacroiliac joint (SIJ) dysfunction. The chiropractor's plan of management included heat, soft tissue therapy, and manipulative therapy to the right SIJ and pubic symphysis. On follow-up one week later, her pubic symphysis pain had improved but she started experiencing pain in her contralateral SIJ.

On a subsequent follow-up two weeks after her last appointment, the same treatment was applied. However, as the patient had experienced this pain for over a year, her symptoms were not completely resolving, and her pain was aggravated by uphill cycling, the chiropractor recommended she visit her family doctor for magnetic resonance imaging (MRI), querying a labral pathology. The patient did not follow-up with her medical doctor due to her denial that any serious pathology was present and the perception that she may be congesting the medical system. The patient also reported that she would like to continue to train and compete, and thus, participated in a 110km race one month later. At that race, she had horrible cramping and pain in her left anterior thigh at the midway point of the race. She spoke to her chiropractor via a phone call who mentioned the MRI again, but the patient did not follow-up with her medical doctor as she was leaving for Europe within a week's time. She travelled to Italy for a 2-week training camp, followed by another stage race in Norway with the following distances: 145km, 115km, and a 12km time trial with approximately 19,000ft of climbing in total. Upon her return from Europe, she reported a new, burning sensation in the anterior aspect of her left hip and her hip felt fatigued.

For the course of the next two months, the patient decided to follow a self-directed course of massage to the areas of chief complaint. She had seen many different providers for massage and physiotherapy since the pain began, but due to limited improvement of symptoms, she

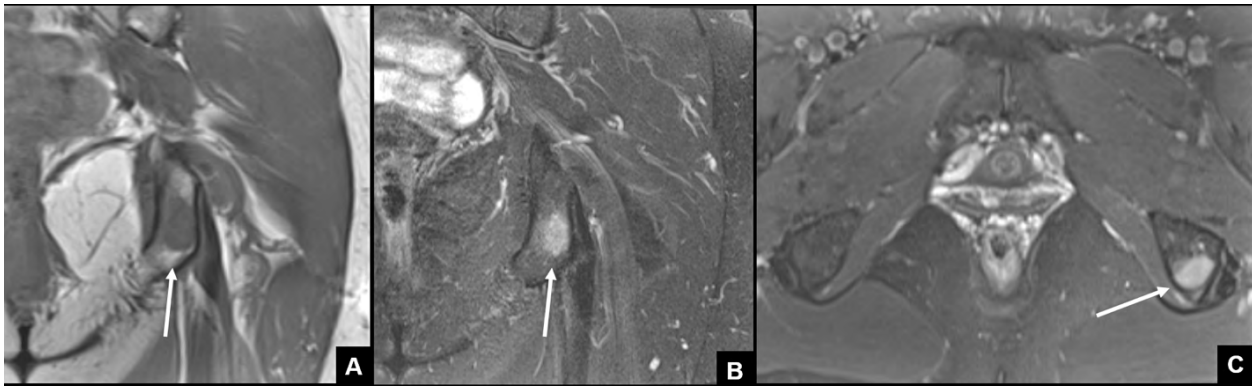

Figure 1.
T1-weighted (A) and T2-weighted FS (B) coronal left hip and T2-weighted FS axial pelvis (C) MRI sequences demonstrating hypointense T1 and hyperintense T2 FS signal signifying bone marrow infiltrative process in the left ischial tuberosity (arrows).

consulted with a sports medical doctor whom she had seen in the past for a different compliant. She was advised to rest, and an MRI of her left hip was requisitioned to rule out a labral tear.

Imaging findings

The MRI revealed a focal low T1-weighted signal, compared to the skeletal muscle, and high fat-saturated T2-weighted bone marrow signal change in the left ischial tuberosity measuring 2.5cm in the cephalad to caudad dimension. A small extraosseous, soft tissue extension is observed posterior to the ischial tuberosity (Figure 1). A second lesion with the same signal characteristics was observed in the anteromedial acetabular wall of the left hip, extending halfway into the superior pubic ramus, with extension into the soft tissues anterior to the acetabular wall (Figure 2). These signal characteristics are consistent with an infiltrative process, of which a neoplastic condition such as metastatic disease or lymphoma is most likely. No pathological fractures within the pelvis or femurs was observed and no evidence of enlarged lymph nodes. Additionally, a tear of the anterosuperior labrum of the left hip was observed with an associated complete chondral tear at the anterior acetabular surface. There was no evidence

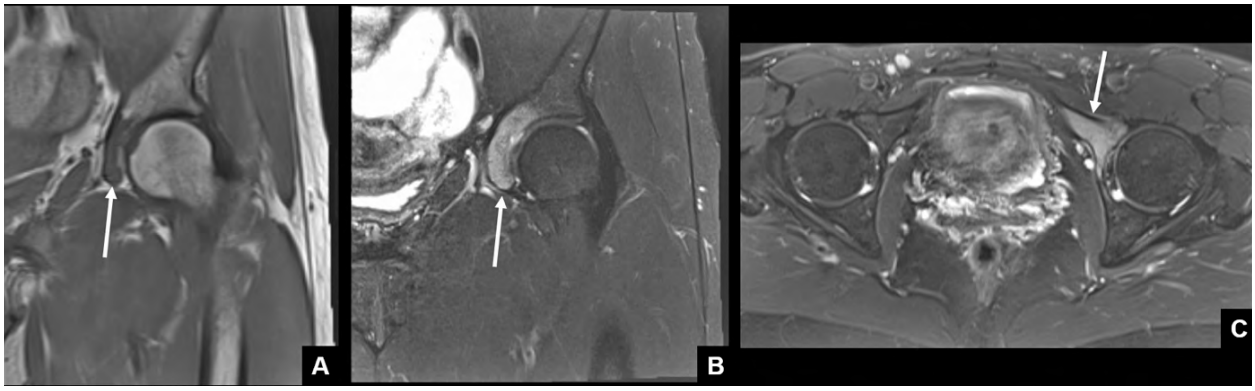

Figure 2
T1-weighted (A) and T2-weighted FS (B) coronal left hip and T2-weighted FS axial pelvis (C) MRI sequences demonstrating hypointense T1 and hyperintense T2 FS signal signifying bone marrow infiltrative process in the left anteromedial acetabulum and superior pubic ramus (arrows).

Figure 3.
Sagittal (A, B) and coronal (C) T2-weighted FS MRI sequences of the left hip demonstrating a tear of the anterosuperior labrum (solid arrows) with a complete chondral tear of the anterior acetabular cartilage (open arrow).

of a labral cyst or bone marrow edema within the adjacent bony attachment (Figure 3).

Given the concerns of a polyostotic condition, a bone scintigraphy scan was performed to assess for other areas of involvement. The whole-body bone scintigraphy demonstrated multiple areas of abnormal radionuclide uptake, most notably involving the right humeral head, the right 7th posterior rib and consistent with the lesions seen on the MRI, in the left ischial tuberosity and anteromedial acetabulum (Figure 4).

Diagnosis

The patient was referred to an oncologist who performed a thorough evaluation, including a fine needle core biopsy. She was subsequently diagnosed with Stage IV Non-Hodgkin's follicular lymphoma that was polyostotic in nature. A left sided anterosuperior labral tear was also noted.

Management

This patient underwent six cycles of four weeks of chemotherapy. During that time, she experienced significant fatigue but strived to walk every day, with an occasional bike ride. On follow-up approximately nine months after her diagnosis, she had a complete response to chemotherapy, with no trace of metabolic activity on her bone scintigraphy scans. The patient was advised she would require consistent monitoring and chemotherapy for the next three years. She began training with a cycling coach again, however sessions were managed and dosed

Figure 4.
Anterior (A) and posterior (B) bone scintigraphy scan of the whole body demonstrates abnormal hot spots at the right humeral head (arrow head), right 7th rib (solid arrow), left ischial tuberosity (open arrow) and left anteromedial acetabulum (thin arrow).

according to her abilities and goals. Presently, she is seeing an oncology physiotherapist to improve her overall functional strength. She aims to ride four to five times per week, complete strengthening exercises every other day, and stretches every day. Her fatigue remains to this day.

Discussion

Background and epidemiology

The majority of injuries sustained by elite cyclists are acute trauma, making up approximately 53% of all injuries in Tour de France athletes from 2010-2017.[5] It has also been reported that these elite cyclists may experience strains and sprains (5%), overuse injuries (4%), or multiple injuries at once (6%).[5] When a cyclist is presenting to a chiropractor with hip pain, pathologies that are intra-articular, extra-articular, or mimickers should be considered as differential diagnoses.[6] Some differential diagnoses to consider in patients with hip pain include but are not limited to: labral tears, femoroacetabular impingement, iliopsoas tendinitis, adductor strain, greater trochanteric bursitis, arthritis, fracture, or malignancy.[6] One such malignancy to consider is lymphoma.[7] Lymphomas are generally classified into categories (Hodgkin's or Non-Hodgkin's), by clinical behaviour (indolent or aggressive), and by cell origin (B-cell or T-cell/Natural killer-cell). Lymphomas may rarely have bone involvement, but when they do, they are classified into the following categories: solitary primary bone lymphoma, polyostotic primary bone lymphoma, and disseminated lymphoma with secondary involvement of the bone [8]. NHL typically develops in the lymph nodes rather than in bone, but can occur in almost any tissue.[4]

Follicular lymphoma is a more indolent form of NHL that presents with painless enlarged peripheral lymph nodes.[4] The majority of NHL cases are B-cell origin (approximately 85-90%), and the remaining either NK or T cells. The patient in this case had a rare presentation, as she was diagnosed with B-cell NHL of a follicular type, with polyostotic bony lesions. The most common risk factor for developing NHL is immuosuppresion.[4] A history of NHL or other lymphoid cancers in close relatives increases the risk of NHL by 2-3 times.[9]

Clinical presentation

The presentation of NHL varies depending on subtype, site of involvement, and presence of additional symptoms such as fever, night sweats and weight loss.[4] Possible symptoms of bone marrow involvement include: recurrent infections, pruritus, anemia, bruising and bleeding.[9] NHL should be suspected if a patient presents with generalized lymphadenopathy that is painless and persistent.[4] Patients may also present with signs of bone marrow involvement, and splenomegaly.[4] Some case reports have documented unilateral limb swelling as an additional sign of NHL.[10,11] This particular symptom was present intermittently in this patient's symptomatology, however was attributed to a race-related injury. In order to achieve the correct diagnosis and staging of the disease, patients will undergo an array of tests including blood work, biopsies of lymph nodes and bone marrow, imaging, and immunophenotyping.[4]

Concurrently, this patient had an anterosuperior labral tear of her left hip. Labral tears are a frequent cause of groin and anterior hip pain.[12] The literature has shown that patients with labral tears may go undiagnosed for an average of greater than two years, as patients are often seen by multiple providers before a definitive diagnosis is obtained.[12] Labral tears are generally insidious in nature, with a possible inciting event of microtrauma.[12] In a study investigating patients with arthroscopically confirmed labral tears, the authors found that 92% of the patients had predominant local groin pain, whereas 52% had associated anterior thigh pain.[12] However, in our study, we cannot say if this patient's symptomatology was related to her labral tear or underlying pathology from her NHL.

Management

The management for NHL varies depending on the grade and stage of the disease.[4] In early stages, radiation therapy, surveillance, immunotherapy or chemotherapy may be considered as treatment options.[4] In later stages, surveillance, immunotherapy, prophylactic antiviral medicine, or immunotherapy may be considered.[4] The patient in this case was treated with rituximab and bendamustine. Rituximab is used in conjunction with chemotherapy medications (such as bendamustine) to for increased survival.[4] Additionally, in order to promote function, psychological wellbeing, independence and quality of life, exercise rehabilitation strategies are typically incorporated in lymphoma patients' plan of management.[13] The athlete in this case continued conservative management

after her chemotherapy with a physiotherapist, to work on her strength and endurance. Although this patient did not seek further management from the chiropractor following her diagnosis, chiropractors can play a role in the management of these patients by promoting exercise and psychological wellbeing strategies in an interdisciplinary collaborative care approach.[13] The literature has shown that NHL survivors who meet exercise guidelines report clinically important better health-related quality of life measures compared to those that do not meet exercise guidelines.[13] Thus, exercise can be recommended and is safe for patients with lymphoma, as there are benefits to their cardiorespiratory fitness, fatigue, and physical functioning.[13] The patient in this case was dedicated to walking every single day throughout her NHL treatment and afterwards. Once she was able to, she began cycling again. With respect to chiropractic care when managing patients with cancer, it is imperative to mention that spinal manipulative therapy and spinal mobilizations are contraindicated in patients with known spinal malignancy according to the World Health Organization.[14]

Delayed diagnosis

In patients with follicular lymphoma, the relative survival rates range from 93.6% at one year, to 61.6% at ten years.[3] Prompt diagnosis is important for a more favourable prognosis.[15] A patient's diagnosis may be delayed when they visit a larger number of healthcare providers or "practitioner shop". This occurs in patients with persistent symptoms, and those that disagree or are in denial of a diagnosis or treatment.[11] This practitioner shopping may hinder a single provider's ability to ensure effective and efficient treatment due to the lack of continuity of care and possible opposing health care views.[11,16] The patient in this case expressed that she chose not to listen to the chiropractor, as she wanted to keep training and wanted to avoid interruptions to her competition schedule. She then chose to see her physiotherapist and massage therapist for treatment and advice. This led to a worsening of her symptoms, and a delayed diagnosis. The patient delayed consultation with both her family doctor and sports medicine physician, against the advice of the chiropractor, to continue her athletic pursuits. She did not want to give up on any opportunity to train or compete.

Athletes are known to push themselves to their limits physically and mentally[17] and have various intrinsic (i.e. achievement) and extrinsic (i.e. sponsorship) factors that contribute to their desire to pursue their sport.[2] Although these strategies can lead to athletic success, a balance must also be prioritized to avoid overtraining and injuries.[17] Some athletes may go against the advice of their medical professionals and refuse to abstain from sport participation. For many athletes their identity is tied intimately to their sport, and abstaining from sport potentially leads to the fear of losing a major part of their life.[3] Athletes may also be in denial of their injuries for fear of losing their ability to train and compete.[3] Chiropractors can help manage this fear with patient education and interdisciplinary collaboration with psychotherapists or mental performance coaches.

Limitations

The major limitation of this report is by nature the type of report being presented. Case studies are considered a lower level of evidence with respect to the hierarchy of evidence.[18] Hence, information such as rates, incidence and generalizability cannot be generated or inferred.[18] However, case reports demonstrate novel patient presentations, which may act as a reminder to practitioners to consider these serious, but rare pathologies. Additionally, it is not possible for us to know the true source of the patient's pain – whether the labral pathology, the underlying lymphoma, both, or neither accounted for her symptoms.

Summary

A 51-year old elite female cyclist had a history of long-standing hip pain with insidious onset. Once she finally agreed to further investigations, she was diagnosed with NHL. The desire to continue to compete and train through injuries and pain is common in athletes, although it can lead to delays in appropriate diagnosis and management. This case is evidence of this scenario; the patient repeatedly denied advice to rest, and to seek further investigations. She sought multiple providers to manage her symptomatology. For various reason (loss of identity, sponsorship, etc.), athletes may avoid the advice of medical professional since they do not want to stop training or competing. The persistence of her medical professionals and her symptoms led to the eventual diagnosis of NHL. The patient has had a complete response to chemotherapy and is returning to sport in a gradual manner with the advice of a coach and her medical professionals. Chiro-

practors may play a role in referring for appropriate diagnosis, education, and exercise prescriptions for patients with NHL.

References

1. Dettori NJ, Norvell DC. Non-traumatic bicycle injuries: a review of the literature. Sport Med. 2006;36(1): 7-18. doi:10.2165/00007256-200636010-00002
2. Bauman J. Returning to play: the mind does matter. Clin J Sport Med. 2005;15(6): 432-435. doi:10.1097/01.jsm.0000186682.21040.82
3. Haluska C, Abreu M, Fagan J. Athlete Injury Denial: The Psychology of Sports Injuries: Techniques for athletes and coaches to help deal with the mental aspect of an injury, concussion prevention, and proposed legislation to protect. Rutgers University Community Repository. 2011. https://doi.org/doi:10.7282/T3M61J2N.
4. Shankland KR, Armitage JO, Hancock BW. Non-Hodgkin lymphoma. Lancet. 2012;380(9844): 848-857. doi:10.1016/S0140-6736(12)60605-9
5. Haeberle HS, Navarro SM, Power EJ, Schickendantz MS, Farrow LD, Ramkumar PN. Prevalence and epidemiology of injuries among elite cyclists in the Tour de France. Orthop J Sport Med. 2018;6(9): 1-5. doi:10.1177/2325967118793392
6. Tibor LM, Sekiya JK. Differential diagnosis of pain around the hip joint. Arthrosc J Arthrosc Relat Surg. 2008;24(12): 1407-1421. doi:10.1016/j.arthro.2008.06.019
7. Siegel RL, Miller KD, Jemal A. Cancer statistics, 2019. CA Cancer J Clin. 2019;69(1): 7-34. doi:10.3322/caac.21551
8. Messina C, Christie D, Zucca E, Gospodarowicz M, Ferreri A. Primary and secondary bone lymphomas. Cancer Treat Rev. 2015;41(3): 235-246.
9. Evans AM, Blum KA. Non-Hodgkin Lymphoma. Spinger; 2015. doi:10.1002/9781119189596.ch30
10. Elmoheen A, Hassan A, Salem W, Bashir K. Follicular lymphoma recurrence presenting as unilateral leg swelling and ipsilateral hydronephrosis. Cureus. 2020;12(3).
11. Biernikiewicz M, Taieb V, Toumi M. Characteristics of doctor-shoppers: a systematic literature review. J Mark Access Heal Policy. 2019;7(1):1595953. doi:10.1080/20016689.2019.1595953
12. Groh MM, Herrera J. A comprehensive review of hip labral tears. Curr Rev Musculoskelet Med. 2009;2(2): 105-117. doi:10.1007/s12178-009-9052-9
13. Amatya B, Khan F, Lew TE, Dickinson M. Rehabilitation in patients with lymphoma: an overview of systematic reviews. J Rehabil Med. 2021;53(3):jrm00163. doi:10.2340/16501977-2810
14. World Health Organization. WHO guidelines on basic training and safety in chiropractic. 2005 [Accessed April 28 2021]. https://www.who.int/medicines/areas/traditional/Chiro-Guidelines.pdf.
15. Armitage JO. Staging Non-Hodgkin Lymphoma. CA Cancer J Clin. 2005;55: 368-376.
16. Sansone RA, Sansone LA. Doctor shopping: a phenomenon of many themes. Innov Clin Neurosci. 2012;9(11-12): 42-46.
17. Carfagno DG, Hendrix JC. Overtraining syndrome in the athlete: current clinical practice. Curr Sports Med Rep. 2014;13(1): 45-51. doi:10.1249/JSR.0000000000000027.
18. Nissen T, Wynn R. The clinical case report: a review of its merits and limitations. BMC Res Notes. 2014;7(1):1-7. doi:10.1186/1756-0500-7-264.

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Delayed diagnosis of osteodiscitis in an adolescent athlete: a case report

Dominique Harmath, DC[1]
Erin Boynton, MD, FRCS(C)
Peter Lejkowski, DC, FRCCSS(C)

Background: *Vertebral osteomyelitis (OM) is an infectious condition of bone caused by an infecting organism, most commonly Staphylococcus aureus (S. aureus). Though rare in adolescents, it is important to remember that this population has vascularized intervertebral discs prior to skeletal maturity and, therefore, is more susceptible to an osteodiscitis infection.*

Purpose: *To determine the possible factors that lead to a delayed diagnosis of osteodiscitis compared to an early diagnosis in an adolescent athlete.*

Summary: *This case provides a unique example of osteodiscitis in an adolescent rowing athlete where an infected heel blister was the only indication toward a diagnosis. Early diagnosis and successful management of osteodiscitis are dependent on recognizing constitutional and non-constitutional signs and symptoms of infection.*

Clinical relevance: *In sport, when skin barriers may be compromised more readily, the risk of infection*

Diagnostic tardif d'une ostéodiscite chez un athlète adolescent: compte rendu de cas

Contexte : L'*ostéomyélite vertébrale (OM) est une affection des os causée par un microorganisme infectieux, le plus souvent Staphylococcus aureus (S. aureus). Bien que cette affection soit rare chez les adolescents, il est important de retenir que cette population a des disques intervertébraux vascularisés avant d'atteindre la maturité squelettique et qu'elle est donc plus exposée à l'ostéodiscite.*

Objectif : *déterminer les facteurs possibles qui conduisent à un diagnostic tardif de l'ostéodiscite par rapport à un diagnostic précoce chez un athlète adolescent.*

Résumé : *Ce cas fournit un exemple unique d'ostéodiscite chez un athlète adolescent de l'aviron présentant une ampoule infectée au talon qui était l'unique signe permettant de poser un diagnostic. Le diagnostic précoce et la prise en charge réussie de l'ostéodiscite dépendent de la reconnaissance des signes et symptômes constitutionnels et non constitutionnels de l'infection.*

Pertinence clinique : *Chez les sportifs, les barrières cutanées peuvent être compromises plus facilement*

[1] Graduate Studies, Sports Sciences, Canadian Memorial Chiropractic College

Corresponding author: Dominique Harmath, Canadian Memorial Chiropractic College, 6100 Leslie Street, Toronto, Ontario M2H 3J1
E-mail: harmath.dominique@gmail.com

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should be considered in the differential diagnosis of unprovoked back pain.

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KEY WORDS: osteodiscitis, osteomyelitis, adolescent, athlete, rowing, chiropractic

et le risque d'infection doit être pris en compte dans le diagnostic différentiel des douleurs dorsales non provoquées.

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mots clés : ostéodiscite, ostéomyélite, adolescent, athlète, aviron, chiropratique

Introduction

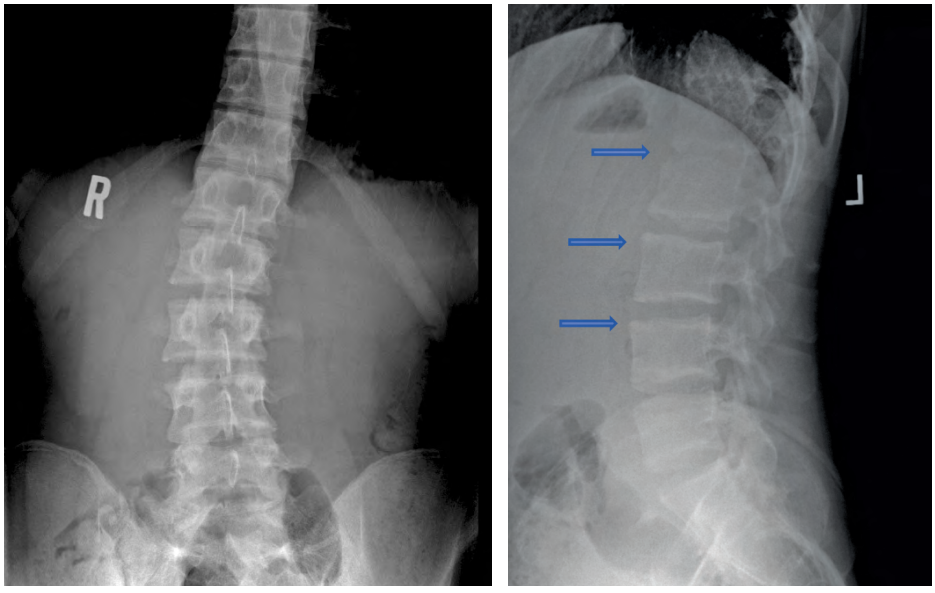
Vertebral Osteomyelitis (OM) is an infectious condition of bone caused by a pathogenic organism, most commonly *Staphylococcus aureus* (*S. aureus*).[1] It is more common in men than in women, and its incidence increases with age with a reported 21.8 cases per 100,000 person-years.[2] Though rare in adolescents, it is essential to keep in mind that unlike adults with avascular intervertebral discs, this population has vascularized intervertebral discs prior to epiphysial growth plate closure and therefore are more susceptible to an osteodiscitis infection.[1] Unfortunately, the diagnosis of OM is difficult and often delayed when constitutional signs such as fever, fatigue and malaise are not present.[3] Delays in diagnosis vary between 2-12 weeks with a 20% mortality rate.[4] To our knowledge, there have been no reported cases of an osteodiscitis infection developing from a heel blister in the sport of rowing in an adolescent individual. The clinical case presented had a delayed diagnosis of two months. Such a delay may leave the individual with long term complications or debilitating symptoms from chronic OM. High clinical suspicion is necessary in the early detection and treatment of the infection in order to prevent further tissue destruction and improve the prognosis.

Case summary

An 18-year-old competitive male rower presented with an acute onset of left-sided lower back pain of two days duration with no previous history of back pain. He woke up with pain and stiffness in his back but could not recall a mechanism of injury. The pain was described as dull at rest and sharp with walking, forward bending and active left hip flexion. The pain was localized to the left lumbar region from L2 to the lumbopelvic region bilaterally. No signs of illness were noted.

Upon examination, the patient was apprehensive to move with a restricted and painful range of motion in all directions, primarily flexion. Bilateral Kemp's, posterior to anterior shear at L5, active single leg raise (ASLR) and FABER's test on the left side were positive tests for left-sided back pain in the L2-L3 and sacroiliac (SI) joint areas. Negative tests included Valsalva, SLR, cross SLR, SI compression and Braggard's. The left quadratus lumborum muscle was in spasm; however, there was no evidence of swelling or deformity. Neurological exam was within normal limits. When asked about a fever, the patient denied having one, and there was no mention of the blister during the initial visit. The treating chiropractor recorded a clinical diagnosis of acute left, flexion-intolerant lower back pain with suspicion of discogenic origin. The day after the initial visit, the patient's parent took the patient to a physician to investigate a heel blister of one-week duration that became red and presented with a fever. The patient was placed on antibiotics (Cephalex, CT, Ger-Germany), no signs of cellulitis were noted. The fever resolved that day and did not return.

Radiographs of the lumbar spine were ordered due to the fact that lower back pain was present with no direct cause, a possible discogenic origin was suspected, the patient was skeletally immature, and that a possibly infected blister with a slight fever was present. The radiograph revealed a dextroscoliosis of the lumbar curve, ill-defined superior and inferior endplates of L2 and a mild loss of L1, L2 disc space was noted (see Figure 1). A bone scan/CT/MRI examination of the lumbar spine was advised by the chiropractor to rule out osteodiscitis. Due to a gap in interprofessional communication, a second set of lumbar radiographs were ordered that confirmed the unremarkable findings of the first radiograph. The patient was recommended to continue with conservative therapy. After



1A. 1B.

Figure 1.
Radiographic imaging. 1A. Initial radiographs with no evidence of infection. 1B. The anterior superior vertebral endplates of L3 and L4, as well as the ill-defined superior and inferior vertebral endplates of L2 with a mild loss of L1, L2 disc space coincidentally, mimic Romanus and Andersson lesions (blue arrows).

four weeks of treatment and only 50% improvement, it was acknowledged that the patient's current condition did not match up with the natural history of the diagnosis. For this reason, the treating provider acted on their clinical suspicion and once again referred the patient for special imaging and/or a second opinion. The patient went for a second opinion to a sports medicine doctor two weeks later, where they were clinically diagnosed with a disc herniation. The chiropractor explained that due to the lack of related findings in the patient's presentation, including the absence of neurological signs (soft and hard), the patient was unlikely to be suffering from a frank disc herniation. The patient was subsequently encouraged to seek further medical work-up, including blood tests.

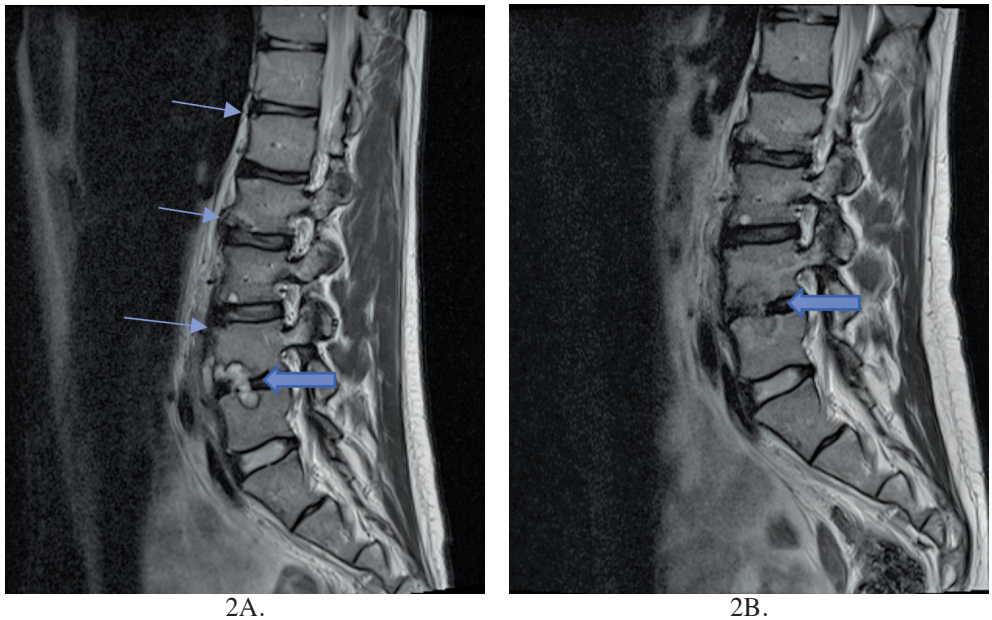
One week later, the blood tests came back positive for inflammatory markers with an elevated erythrocyte sedimentation rate (ESR) and c-reactive protein (CRP); however, HLA B-27 was negative. Three days later, an MRI was taken of the lumbar spine, where a diagnosis of L4-L5 osteodiscitis was confirmed (see Figure 2).

Three days later, a biopsy identified *S. aureus* as the bacterial culprit. Three days following the diagnosis, intravenous (IV) and oral antibiotics were administered for eight weeks. A follow-up MRI was conducted at the 6-week mark of the 8-week treatment plan, where the infection was shown to still be present. The patient saw improvement with treatment; however, there was no planned follow-up. Four months later, the infection was confirmed to still be present on MRI and biopsy, and the individual underwent a second course of IV antibiotic treatment (cefazolin) for suspected chronic osteodiscitis. Upon completing the second round of intravenous antibiotics (ten months post initial presentation), the patient felt he was back to normal and had returned to exercising regularly. The patient's current condition is stable, with a resolution of the infection as indicated with negative blood tests for inflammatory markers.

Discussion

Epidemiology

OM most commonly affects those exposed to a penetrating injury, surgery, intravenous drug use, diabetes, or a compromised immune system. Such risk factors leave in-



2A. 2B.

Figure 2.
L4-L5 Osteodiscitis, magnetic resonance imaging (MRI). 2A. Initial T-2 weighted MRI of the lumbar spine with an L4-L5 intervertebral disc centered process with intervertebral disc height loss, irregularity, and high signal intensity. There is a small enhancing collection within the left paraspinal soft tissues anterior to the L4/L5 intervertebral disc indicative of early abscess formation. Well demarcated destructive lesions are present at the adjacent vertebral endplates (thick blue arrow). Multilevel inflammatory changes of the lumbar spine are also noted with high signal irregularities and erosions at the anterior corners of the vertebral bodies mimicking Romanus lesions with similar lesions centrally at the disco-vertebral junction of the T12, L1 and L3 vertebral bodies mimicking Andersson lesions (thin blue arrows). These findings are suspected to be caused by the infection. 2B. Follow up T-2 weighted MRI of the lumbar spine at 6-weeks of treatment with L4-L5 osteodiscitis still noted (thick blue arrow).

dividuals vulnerable to contracting OM; specifically, its most common bacterial offender, *S. aureus*. In the paediatric population the incidence is no higher than 0.3 per 100,000.[5]

Pathophysiology

S. aureus, the most common perpetrator of OM, may have a hematogenous or contiguous spread or may be transmitted by direct inoculation.[6] Its virulence can be attributed to both its extracellular and intracellular factors. [6] Its ability to adhere to extracellular matrix proteins allows it to establish itself in the host organism.[7] The evasion capability of the bacteria to survive in host cells and its invasion capabilities via exotoxins or hydrolases give it the extra edge to thrive in the human body.[8] Biofilms, a collection of communicating microbes with altered gene expression, can also form during the infection, making antibiotic treatment's success exceptionally difficult.[9] In this case, it is suspected that the *S. aureus* infection of the intervertebral disc occurred due to hematogenous spread from an infected heel blister.

Diagnosis

The diagnosis of vertebral OM is multifactorial and challenging at times when constitutional symptoms are not present. In general, key history findings would include non-specific lower back pain, fever, malaise, fatigue or a trivial skin infection.[10] It is important to note that fever presents in less than 50% of OM cases.[11] Physical findings may mimic discogenic pain, and in cases such as the one currently presented, ambiguous findings paired with a failed response to care should elicit follow up with a ser-

ies of diagnostic imaging. A definitive diagnosis of OM is a combination of clinical signs of infection, laboratory tests, imaging abnormalities, biopsy and isolation of cultures.[6]

In the case presented, the heel blister was key toward the diagnosis. Discitis should be a top differential diagnosis in youth with discogenic pain.[12] Ultimately, it was the high clinical suspicion for discitis that prompted the chiropractor to continue pushing for a second opinion and refer for special imaging while the patient's pain continued to be dismissed as mechanical. In order to prevent future delayed diagnoses, as in the current case where recommendations for advanced imaging were missed, interprofessional communication should be prioritized.

Diagnostic imaging

The diagnostic process is often broken down into two parts: radiographic imaging and bone scan or blood testing, and the second part; magnetic resonance imaging and biopsy cultures.[13] Part two is necessary to determine the underlying organism responsible for the infection to guide antibiotic treatment.

Radiographic imaging is a cost-effective and quick way of ruling in OM and, for this reason, is part of the first line of the diagnostic process. The challenge, however, is that radiographs will appear normal during the first 21 days of spinal infection.[14] Both radiographic imaging and blood testing have high specificity but low sensitivity in OM diagnosis and are commonly used when wait times for magnetic resonance imaging (MRI) are high.[13] The specificity and sensitivity for MRI are reported as 60-90% and 78-90%, respectively, and MRI also can identify areas of soft tissue involvement that may guide treatment decisions.[12] Lastly, microbiologic cultures via CT-guided biopsy is the gold standard in OM diagnosis with 99.9% specificity.[13]

The diagnosis of the case began with radiographic imaging that came back negative for infection, followed by blood testing and MRI that confirmed the diagnosis of an osteodiscitis infection, while a CT-guided biopsy identified the bacterial culprit.

Treatment

As soon as the underlying organism is identified, intravenous antibiotics can be administered for approximately two weeks, followed by oral antibiotics for an additional 2-4 weeks.[6] Surgery is not usually required; however, it may be considered if signs of neural compression, spinal instability, progressive destruction of bone, limb deterioration or signs of the development of an epidural abscess or paravertebral abscess appear in order to prevent progression to a chronic OM.[6] In such instances, the patient should be monitored during treatment and managed appropriately. Lingering complications may last on average up to two years if an acute case of OM becomes chronic.[6]

In the current patient case, infection was still present after the eight weeks of treatment with intravenous and oral antibiotics. Factors responsible for the lack of healing response may have been attributed to the antibiotics received for the heel blister and the presence of an abscess.[6] An abscess is challenging to treat with antibiotics as the drug cannot diffuse into the middle of the abscess. [6] This was likely the case with the patient as abscesses have no blood supply and are surrounded by very necrotic/fibrotic material making penetration of drugs difficult.[6] If there is no drug reaching the bacteria, they continue to grow.

Prognosis

The level of precision for the prognosis of OM is not well studied. Delays in diagnosis vary between 2-12 weeks with a 20% mortality rate.[4] According to Gupta *et al*.[4], longer duration of symptoms prior to diagnosis with a *S. aureus* pyogenic vertebral OM infection were associated with increased rates of treatment failure. Tuberculous and brucellar vertebral OM, however, remain the leading causes of delayed vertebral OM diagnosis at a rate of 21%.[15]

Generally, if the infection is diagnosed and treated early, possibly prior to the infection becoming evident on radiographic imaging (<21 days), the effects with antibiotics should be rapid.[6] This emphasizes that osteomyelitis cannot be ruled out from radiographic imaging alone as it was in our case. On the other hand, chronic OM is dependent on the patient's physiological status and the duration of the infection.[6] Recovery can vary from 2 months to 2 years.[6]

The time from initial presentation to diagnosis in the patient was two months. The condition should have been further assessed with bloodwork and an MRI when the patient's presentation changed revealing a fever and an infected blister. Further delays in prognosis occurred when the patient was discharged from the hospital after receiv-

ing intravenous and oral antibiotics without a scheduled follow up post-treatment. This was especially a problem when the individual's pain persisted for four additional months post-treatment. Though back pain is often present once the infection has resolved, follow up is necessary to ensure resolution of the infection via blood testing of ESR and CRP inflammatory markers and radiographic imaging for evidence of bony fusion.[6,16]

Future studies should investigate the role of range of motion findings and the absence of muscle spasms in conjunction with blood testing of inflammatory markers to provide more insight on clinical signs of improvement.

Summary

This case provides a unique example of osteodiscitis in an adolescent rowing athlete where an infected heel blister was the only clue toward an early diagnosis. Early diagnosis and successful management of osteodiscitis are dependent on recognizing constitutional and non-constitutional signs and symptoms of infection, in our case, an infected heel blister and a mild fever. Frequent monitoring and scheduled follow-up visits during and after the treatment process is advised to avoid further delays in prognosis.

The overseeing practitioner did his due diligence referring the patient for further studies when his clinical suspicion was high. Early investigation is essential for a promising prognosis of osteodiscitis when the clinical course of a musculoskeletal diagnosis does not meet the expectation.

References

1. Principi N, Esposito S. Infectious discitis and spondylodiscitis in children. Int J Mol Sci. 2016;17(4): 539. doi:10.3390/ijms17040539.
2. Kremers HM, Nwojo ME, Ransom JE, Wood-Wentz CM, Melton LJ, Huddleston PM. Trends in the epidemiology of osteomyelitis: a population-based study, 1969 to 2009. J Bone Jt Surg Am. 2015;97(10): 837-845.
3. Nickerson EK, Sinha R. Vertebral osteomyelitis in adults: an update. Br Med Bull. 2016; 117(1): 121-138. doi:10.1093/bmb/ldw003.
4. Gupta A, Kowalski TJ, Osmon DR, Enzler M, Steckelberg JM, Huddleston PM, Nassr A, Mandrekar JM, Berbari EF. Long-term outcome of pyogenic vertebral osteomyelitis: a cohort study of 260 patients. Open Forum Infect Dis. 2014;1.
5. Kang HM, Choi EH, Lee HJ, Yun KW, Lee CK, Cho TJ, Cheon JE, Lee H. The etiology, clinical presentation and long-term outcome of spondylodiscitis in children. Pediatr Infect Dis J. 2016;35: e102–e106.
6. British Medical Journal: Osteomyelitis. 2018 update of the literature. Br Med J Best Pract. 2018.
7. Vaudaux P, Francois P, Lew D, Waldvogel F. Host factors predisposing to and influencing therapy of foreign body infections. In: Waldvogel FA, Bisno AL, eds. Infections associated with indwelling medical devices, 3rd edn. Washington: ASM Press. 2000:1-26.
8. Sinha B, Francois PP, Nusse O, Foti M, Hartford OM, Vaudaux P, Foster TJ, Lew DP, Herrmann M, Krause KH. Fibronectin-binding protein acts as Staphylococcus aureus invasin via fibronectin bridging to integrin alpha5beta1. Cell Microbiol. 1999;1: 101–117.
9. Costerton W, Veeh R, Shirtliff M, Pasmore M, Post C, Ehrlich G. The application of biofilm science to the study and control of chronic bacterial infections. J Clin Invest. 2003;112: 1466-1477.
10. Mader JT,Calhoun JH. Adult long bone osteomyelitis. Musculoskelet Infect. 2003:149-182.
11. Zimmerli W. Clinical practice. Vertebral osteomyelitis. N Engl J Med. 2010;362(11): 1022–1029.
12. Fucs PM, Meves R, Yamada H. Spinal infections in children: a review. Int Orthop. 2012;36: 387–395.
13. Pupaibool J, Vasoo S, Erwin PJ, Murad MH, Berbari E. Clinical study: the utility of image-guided percutaneous needle aspiration biopsy for the diagnosis of spontaneous vertebral osteomyelitis: a systematic review and meta-analysis. Spine J. 2015;15: 122–131.
14. Gold RH, Hawkins RA Katz RD. Bacterial osteomyelitis: findings on plain radiography, CT, MR, and scintigraphy. AJR Am J Roentgenol. 1991;157: 365–370.
15. Gok S, Kaptanoglu E, Celikbas A, Ergönül O, Baykam N, Eroğlu M, Dokuzoğuz B. Vertebral osteomyelitis: clinical features and diagnosis. Clin Microbiol Infect Off Publ Eur Soc Clin Microbiol Infect Dis. 2014;20: 1055–1060.
16. Herren C, Jung N, Pishnamaz M, Breuninger M, Siewe J, Sobottke R. Spondylodiscitis: diagnosis and treatment options. Deutsches Arzteblatt International. 114(51–52): 875–882.

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Pigmented villonodular synovitis of the hip in a recreational runner: a case report

Jaclyn A Kissel, BSc, DC, FRCCSS(C)[1]
Cristina Leonardelli, BScKin, DC, MHK[2]

Objective: *To present the diagnostic, clinical, and radiological features of pigmented villonodular synovitis (PVNS), create awareness of this rare condition, and provide guidance for conservative healthcare practitioners for further referral and appropriate management.*

Case presentation: *We present the case of a 41-year-old recreational runner who presented to the clinic with anterior hip pain of one year duration. Following a clinical history and examination, the patient was diagnosed with clinical femoroacetabular impingement. Radiographs taken at that time displayed mild degenerative joint disease of the left hip joint with coxa profunda. After four weeks of conservative care, the patient reported no improvement in symptoms. The patient was then referred for an MRI, while conservative care continued. Ten weeks later, the patient's symptoms and functional abilities had worsened. The MRI was obtained and the diagnosis of PVNS was made.*

Summary: *PVNS is a rare disease that can mimic mechanical hip pain. A high index of suspicion should*

Une synovite villonodulaire pigmentée de la hanche chez un coureur amateur

Objectif : *Présenter les caractéristiques diagnostiques, cliniques et radiologiques de la synovite villonodulaire pigmentée (PVNP), sensibiliser le public à cette maladie rare et fournir aux praticiens de santé conservateurs des conseils pour le renvoi des patients et la prise en charge.*

Présentation du cas : *Nous présentons le cas d'un coureur amateur de 41 ans qui s'est présenté à la clinique avec une douleur antérieure de la hanche depuis un an. Après une anamnèse et un examen clinique, on a diagnostiqué un conflit fémoro-acétabulaire. Les radiographies prises à ce moment-là révélaient une légère maladie dégénérative de la hanche gauche avec coxa profunda. Après quatre semaines de soins conservateurs, les symptômes du patient n'étaient pas soulagés. On lui a demandé de subir un examen par IRM et on a poursuivi les traitements conservateurs. Dix semaines plus tard, les symptômes et les capacités fonctionnelles du patient s'étaient aggravés. On a obtenu les résultats de l'examen par IRM et on a diagnostiqué une PVNP.*

Résumé : *La PVNP est une maladie rare qui peut imiter une douleur mécanique de la hanche. L'indice de*

[1] Department of Clinical Education, Canadian Memorial Chiropractic College
[2] Graduate Student, Sport Sciences RCCSS (C) SSRP program

Corresponding Author: Jaclyn A Kissel, Canadian Memorial Chiropractic College, 6100 Leslie St., Toronto, ON M2H 3J1
Tel: (416) 482-2340
E-mail: jkissel@cmcc.ca

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be utilized when symptoms worsen despite conservative care. Referral for advanced imaging is critical for appropriate diagnosis of PVNS.

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KEY WORDS: pigmented villonodular synovitis, FAI, hip, mechanical, pain, chiropractic

suspicion est élevé lorsque les symptômes s'aggravent malgré des soins conservateurs. Un examen par imagerie avancée est essentiel pour un établir un diagnostic de PVNP.

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MOTS CLÉS : synovite villonodulaire pigmentée, conflit fémoro-acétabulaire, hanche, mécanique, douleur, chiropratique

Introduction

Pigmented villonodular synovitis (PVNS) is a rare condition that is characterised by a proliferation or hyperplasia of the synovial membrane within joints, bursae, or tendon sheaths.[1] Due to the non-specific nature of the clinical presentation of PVNS, diagnosis is usually delayed.[2,3]

We report a case of PVNS of the hip in a recreational runner. The purpose of this case report is to present the diagnostic, clinical, and radiographic features of PVNS in order to create awareness of this rare condition amongst health care practitioners. It is important for healthcare practitioners to be aware of the clinical presentation and appropriate management for PVNS as it can mimic more common musculoskeletal conditions, as it did in this case.

Case presentation

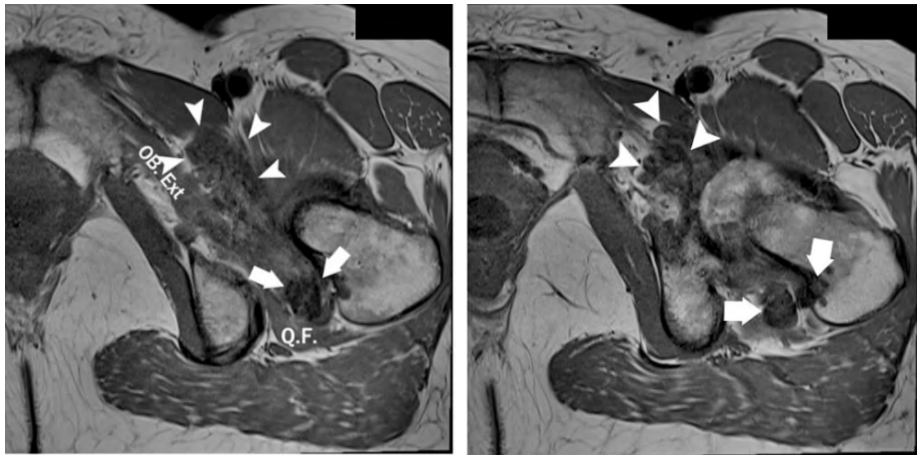
A healthy 41-year-old architect and recreational runner presented to the clinic in November 2019 with a complaint of insidious onset intermittent left anterior hip pain of one year duration. The patient is female and stood 5 feet 9 inches (175.25 cm) and weighed 135 lbs (61.24 kg). Aggravating factors included running, prolonged sitting for more than thirty minutes, and yoga poses that require hip external rotation. Movement helped to relieve their pain. The patient did not report any external or internal hip clicking or clunking. The patient denied any red flags. Radiographs were ordered in May 2019 by the referring physician which displayed mild degenerative joint disease of the left hip joint with coxa profunda, mild facet arthrosis from L4-S1 and minimal degenerative joint disease of the left sacroiliac joint. (See Figures 1 and 2).

Upon physical exam, hip range of motion was full however, pain was elicited at end range internal and external rotation. Flexion Adduction Internal Rotation (FADDIR) and

Figure 1. *Anterior posterior hip radiograph. Mild degenerative joint disease of the left hip joint with coxa profunda, mild facet arthrosis from L4-S1 and minimal degenerative joint disease of the left sacroiliac joint.*

Figure 2. *Frog-leg lateral hip radiograph. Mild degenerative joint disease of the left hip joint with coxa profunda.*

Figure 3.
Coronal Oblique Proton Density Fat Sat sequence (TR/TE: 4090/24) of left hip shows multiple frondlike foci of low signal intensity in the perilabral recess, above the femoral neck (white arrowhead) and in the acetabular fossa extending inferiorly (curved white arrow).



4A *4B*

Figure 4.
4A, 4B. Axial T1 weighted sequence (570/15) images at the level below the acetabular fossa show hypointense nodular masses displacing the obturator externus (OB. Ext.) muscle medially (arrow heads) and quadratus femoris (Q.F.) muscle posteriorly (arrows).

Flexion Abduction External Rotation (FABER) tests were positive and hip distraction was relieving. The hip pain was recreated with the left leg falling into abduction while in right lateral recumbent position. The following tests were found to be negative: hip scour, log roll, Thomas test, cross-legged sitting, resisted hip ranges of motion, sacroiliac joint provocation tests, and an examination of the lumbar spine was normal. Lower limb neurological examination, which included deep tendon reflexes, sensory and motor testing, was found to be within normal limits. A working diagnosis of clinical femoroacetabular impingement was made and the patient was treated one to two times per week for four weeks. The treatment plan included soft tissue therapy, hip joint mobilizations, ergonomic modifications, and a comprehensive rehabilitation program focusing on core endurance, gluteal and hamstring strength.

In this case, the working diagnosis of clinical femoroacetabular impingement was diagnosed based on the Warwick International Consensus Agreement, that defines FAI as a clinical disorder of the hip with a triad of symptoms (motion- or position-related pain in the hip or groin), clinical signs (positive hip impingement tests, such as FADDIR), and imaging findings that show evidence of cam or pincer morphology on plain-film radiographs.[4]

A re-evaluation was conducted after four weeks of care and the patient reported no improvement in symptoms. A letter was sent back to their medical doctor suggesting that further diagnostic imaging may be necessary. Subsequently, an MRI was ordered in January 2020. Meanwhile, care was continued with progression to rehabilitation and modifications to passive treatment. However, by late January 2020 the patient reported worsening of pain post-treatment and the inability to sit for longer than five to 10 minutes. They also reported an uncomfortable clicking sensation with walking and the pain was interrupting their sleep. By February 2020, they reported that the hip felt "out of place" and that the pain was occurring with walking. Care was ceased at this time and the patient awaited the MRI.

The MRI was scheduled for late April 2020, but due to the COVID-19 lockdown, the patient obtained their MRI in October 2020. Based on the MRI findings the patient was diagnosed with pigmented villonodular synovitis (see Figures 3, 4A, 4B, and 5). This patient was then re-

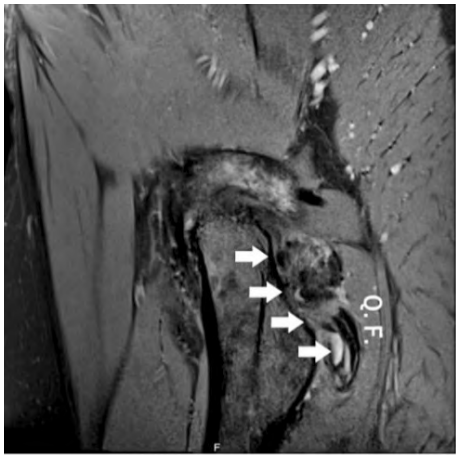


Figure 5.
Sagittal Proton Density fat-suppression sequence (2630/23) shows predominantly hypointense nodular masses (white arrows) posterior to the femoral neck and greater trochanter displacing quadratus femoris (Q.F.) muscle posteriorly.

ferred to an orthopedic specialist and is currently awaiting intervention.

Discussion

Pigmented villonodular synovitis (PVNS) is a type of tenosynovial giant-cell tumour that is defined by the proliferation of the synovial membrane in joints, bursae, or tendon sheaths.[1] It affects 1.8 per million people and the intra-articular form is predominantly found in large joints such as the hip (70% of cases) and knee (15% of cases).[1,5] PVNS of the hip typically occurs between the second and third decade of life.[1]

The etiology of PVNS is not well known, with trauma, neoplasia, genetic predisposition, and chronic inflammation secondary to hemarthrosis suggested as possible causes.[1] There may be a connection to chromosomal anomalies, which has been suggested more recently.[6]

The clinical presentation of PVNS of the hip is non-specific, which requires clinicians to have a high index of suspicion for the diagnosis.[1] Diagnosis is often delayed due to slow progression of symptoms, pain tolerance, and symptom variation, with an average of four years between onset of symptoms and diagnosis.[2,3] The main symptom is pain, which may be localized to the anterior hip or groin, that increases in intensity and duration as the disease progresses.[3] Other signs and symptoms may include painful intra- or extra-articular swelling, which can result in associated limitation in mobility and stiffness of the joint.[1,3]

Imaging studies are critical for the diagnosis and treatment planning of PVNS. Specifically, plain film radiographs, CT, and MRI can be used to assess the presence and severity of the disease. Radiographs are often unremarkable in early stages, as they were in our case. However, in the advanced stage of the disease, radiograph will display osteolytic changes, specifically erosions of bone and subchondral cysts around the axis of the joint capsule or at the acetabulum near the fovea.[3] CT can also be used to visualize smaller erosions and subchondral cysts that are not visible on radiograph, however it is less helpful in evaluating the surrounding soft tissues and synovium.[7,8] Lequesne *et al*.[8] proposed a radiologic classification system for PVNS:

1. "Evocative" – initial stage of disease with or without joint space narrowing as well as large subchondral cysts. This form represents 62% of cases.[1]
2. "Pseudo-coxitis" – localized joint space narrowing with deep erosions of the head of the femur and/or acetabulum in weight bearing surfaces. Possibility of subchondral cysts outside the weight bearing area. This form represents 16% of cases.[1]
3. "Pseudo-coxarthrosis" – localized joint space narrowing is secondary to the expansion of subchondral cysts into the joint space. This form represents 14% of cases.[1]

The preferred imaging modality for examination of PVNS is MRI.[9] It allows for precise visualization of the lesion(s), which allows for accurate diagnosis as well as pre-intervention planning and post-intervention review.[7] Features of PVNS on MRI include: (1) variable extent of synovial proliferation and thickening, (2) intra-articular effusion and erosion of bone, and (3) the deposit of hemosiderin within lesions in the synovium.[7,10] The lesions containing hemosiderin are pathognomic of PVNS.[9,11,12] Hemosiderin is a protein compound that stores iron. Due to the ferromagnetic properties of this protein, when deposited on synovial tissue, it results in a hyposignal on

T1- and T2- weighted images.[10] Fast field echo (FFE) sequence MRI images are best to visualize hemosiderin deposits, which can be visualized as small spotty areas, or diffuse larger areas of hypointense signal.[10]

The current consensus based on large case studies in the literature, is that operative management is the standard for treatment for PVNS.[2,3,9] However, the surgical approach is poorly defined in the case of PVNS of the hip. Joint preservation is preferred as much as possible for younger patients.[1] Total synovectomy of the diseased synovium is typically the approach when the articular cartilage is preserved, in order to prevent further destruction and loss of function of the joint.[2,9] This is typically done with open surgery and surgical hip dislocation which exposes all the synovial recesses.[8,13] However, this procedure does not seem to prevent the development of secondary hip osteoarthritis in the future.[9] Total hip arthroplasty is considered when there is significant joint destruction present.[1,2,9] More recently, arthroscopic excision of the diseased synovium has been studied as a treatment procedure. Byrd and colleagues described good outcomes in their study, including improvements in patient-reported outcome measures, and only one out of thirteen patients undergoing a revision after six years.[14,15] External radiotherapy has been proposed, but not validated in the literature as an effective treatment modality.[1,2,16] There is some literature that supports external radiotherapy post-operative management to help prevent recurrence and address any residual disease.[17]

Given its vague signs and symptoms, PVNS of the hip often masquerades as mechanical hip pain, which is particularly common in runners. This may lead to a delay in diagnosis and appropriate treatment. It is critical for conservative healthcare practitioners, including chiropractors, to have a high index of suspicion for this diagnosis, particularly when there is a lack of improvement with conservative care and a progression of pain intensity and duration, and decrease in functional abilities. If radiographic features are associated with uncharacteristic clinical symptoms, PVNS should be considered as a differential diagnosis.[3] When PVNS of the hip is suspected, referral for diagnostic imaging (specifically, MRI) and subsequent surgical referral are prudent.

Summary

The clinical presentation of the PVNS of the hip in this case was typical of clinical femoroacetabular impingement that presents often to healthcare providers such as chiropractors and physiotherapists. It is prudent for therapists to have an index of suspicion for this diagnosis when symptoms do not improve or worsen with conservative care. Referral for advanced diagnostic imaging is important to accurately diagnose this condition, and further surgical referral is required for appropriate management. Early diagnosis and intervention for PVNS results in better outcomes for the patient.

References

1. Steinmetz S, Rougemont A-L, Peter R. Pigmented villonodular synovitis of the hip. EFORT Open Rev. 2016;1(6): 260–266.
2. Della Valle AGD, Piccaluga F, Potter HG, Salvati EA, Pusso R. Pigmented villonodular synovitis of the hip: 2- to 23-year followup study. Clin Orthop Relat Res. 2001;388: 187–199.
3. Cotten A, Flipo R, Chastanet P, Desvigne-Noulet M, Duquesnoy B, Delcambre B. Pigmented villonodular synovitis of the hip: review of radiographic features in 58 patients. Skelet Radiol. 1995;24(1): 1–6.
4. Griffin DR, Dickenson EJ, O'Donnell J, Agricola R, Awan T, Beck M, et al. The Warwick Agreement on femoroacetabular impingement syndrome (FAI syndrome): an international consensus statement. Br J Sports Med. 2016;50(19): 1169–1176.
5. Myers B, Masi A, Feigenbaum S. Pigmented villonodular synovitis and tenosynovitis: A clinical epidemiologic study of 166 cases and literature review. Medicine (Baltimore). 1980;59(3): 223–238.
6. Ofluogo O. Pigmented villonodular synovitis. Orthop Clin North Am. 2006;37(1): 23–33.
7. Llauger J, Palmer J, Rosón N, Cremades R, Bagué S. Pigmented villonodular synovitis and giant cell tumors of the tendon sheath: radiologic and pathologic features. AJR Am J Roentgenol. 1999;172(4): 1087–1091.
8. Lequesne M, Nicolas J, Kerboull M, Postel M. La synovite villo-nodulaire de la hanche. Int Orthop. 1980;4(2): 133–144.
9. Vastel L, Lambert P, Pinieux GD, Charrois O, Kerboull M, Courpied J-P. Surgical treatment of pigmented villonodular synovitis of the hip. J Bone Jt Surg. 2005;87(5): 1019–1024.
10. Cheng XG, You YH, Liu W, Zhao T, Qu H. MRI features of pigmented villonodular synovitis (PVNS). Clin Rheumatol. 2004;23(1): 31–34.
11. Jelinek J, Kransdorf M, Shmookler B, Aboulafia A, Malawer M. Giant cell tumor of the tendon sheath: MR findings in nine cases. AJR Am J Roentgenol. 1994;162(4): 919–922.

12. Garner H, Ortiguera C, Nakhleh R. Pigmented villonodular synovitis. Radiographics. 2008;28(5): 1519–1523.
13. Gitelis S, Heligman D, Morton T. The treatment of pigmented villonodular synovitis of the hip: a case report and literature review. Clin Orthop Relat Res. 1989;(239): 154–160.
14. Byrd JWT, Jones KS, Maiers GP. Two to 10 years' follow-up of arthroscopic management of pigmented villonodular synovitis in the hip: a case series. Arthroscopy. 2013;29(11): 1783–1787.
15. Levy DM, Haughom BD, Nho SJ, Gitelis S. Pigmented villonodular synovitis of the hip: a systematic review. Am J Orthop. 2016;45(1): 23–28.
16. Ottaviani S, Ayral X, Dougados M, Gossec L. Pigmented villonodular synovitis: a retrospective single-center study of 122 cases and review of the literature. Semin Arthritis Rheum. 2011;40(6): 539–546.
17. Berger B, Ganswindt U, Bamberg M, Hehr T. External beam radiotherapy as postoperative treatment of diffuse pigmented villonodular synovitis. Int J Radiat Oncol Biol Phys. 2007;67(4): 1130–1134.

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Calcaneonavicular coalition: a case study of non-operative management in an adult patient

Kathleen Kurman, BScHK(Hons), DC, RCCSS (C) resident[1]
Andrew Romanelli, BPhEd, DC, MSc[2]

Objective: *This study describes the radiographic diagnosis and nonoperative chiropractic management for a case of a chronic calcaneonavicular coalition in an adult patient.*

Background: *Calcaneonavicular coalition is a congenital/acquired condition of the tarsal bones often diagnosed in individuals 8-12 years old. Considering its rare presentation (less than 1% of the population), there remains little literature on the conservative management of this condition.*

Case presentation: *Chronic calcaneonavicular coalition in a 35-year-old recreational athlete is presented.*

Management/outcome: *Following radiographic diagnosis, the patient was placed in a walking boot for four-weeks. After removal of the boot, the patient was managed nonoperatively. They reported a full resolution of symptoms with noted return to all pre-injury activities.*

Summary: *Presentation of calcaneonavicular*

Coalition calcanéo-naviculaire : étude de cas de prise en charge non chirurgical chez un patient adulte

Objectif : *Cette étude présente le diagnostic à l'aide de radiographies et la prise en charge non chirurgicale par la chiropratique d'un cas de coalition calcanéo-naviculaire chronique chez un patient adulte.*

Contexte : La *coalition calcanéo-naviculaire est une affection congénitale ou acquise des tarses souvent diagnostiquée chez des individus âgés de 8 à 12 ans. Comme il s'agit d'une affection rare (moins de 1% de la population), il existe peu de littérature sur le traitement conservateur de cette affection.*

Présentation du cas : *Présentation d'une coalition calcanéo-naviculaire chronique chez un athlète amateur de 35 ans.*

Prise en charge/résultat : *Après le diagnostic établi à l'aide de radiographies, le patient a été placé dans une botte de marche orthopédique pendant quatre semaines. Après le retrait de la botte, le patient a été pris en charge de manière non chirurgicale. Tous ses symptômes sont disparus et il a pu reprendre toutes les activités qu'il avait avant sa blessure.*

Résumé : *La survenue d'une coalition calcanéo-*

[1] Division of Graduate Studies, Canadian Memorial Chiropractic College
[2] Division of Undergraduate Education, Canadian Memorial Chiropractic College

Corresponding author: Kathleen Kurman, Canadian Memorial Chiropractic College, 6100 Leslie Street, Toronto, Canada M2H 3J1
Telephone: 647-210-6389
E-mail: dr.kurman@sportsidemedical.com

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coalition may be dependent on many factors, including age, medical history, and chronicity of the condition. Previous medical background may include recurrent inversion ankle sprains, aggravated with activity, and alleviated with rest. Nonoperative management of calcaneonavicular coalition may be considered as a viable intervention.

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KEY WORDS: calcaneonavicular coalition, chiropractic, conservative, non-operative management, tarsal coalition

naviculaire peut dépendre de nombreux facteurs, dont l'âge, les antécédents médicaux et la chronicité de l'affection. Les antécédents médicaux peuvent inclure des entorses récurrentes de la cheville en inversion, aggravées par l'activité et soulagées par le repos. La prise en charge non chirurgicale de la coalition calcanéo-naviculaire peut être considérée comme une intervention viable.

(JCCA. 2021;65(3):350-359)

MOTS CLÉS : coalition calcanéo-naviculaire, chiropratique, conservateur, traitement non chirurgical, coalition tarsienne

Introduction

Calcaneonavicular coalition is an abnormal union bridge between the calcaneus and the navicular or tarsal scaphoid bone, and may be osseous (synostosis), cartilaginous (synchondrosis) or fibrous (synfibrosis or syndesmosis).[1] It is a congenital or acquired condition of the foot that is usually diagnosed in individuals between the ages of eight to twelve years old[2], when secondary ossification centres begin to fuse. While being the most common form of tarsal coalitions[3], it presents symptomatically in less than 1% of the population[4,5]. Additionally, Kernbach *et al*.[6] note that bilateral tarsal coalitions are quite common in the adolescent population, occurring in as many as 80% of patients with this condition.

Patients may typically present with a slight antalgic gait, with possible examination findings of a flattened medial longitudinal arch, peroneal spastic flat foot, and decreased subtalar motion.[6,7] Pain will often be worsened with activity and improve with rest, and they may report recurrent ankle sprains.[8] While high-quality evidence for conservative management of patients presenting with this condition remains scarce (consisting mostly of case reports/series)[2], review of the literature involves mostly youth/adolescent patients, with adult population management poorly represented. Of the evidence found, some nonoperative treatment options include activity modification, non-steroidal anti-inflammatory drugs, orthotics, and immobilization in a walking boot.[2] Considering thus far the efficacy of these interventions has been poorly established, many patients and healthcare providers still prefer resection surgery to non-operative interventions. Therefore, the purpose of this case report includes calcaneonavicular coalition and chronic pain presentations, key radiographic findings, along with additional diagnostic imaging options, and collaborative management for this condition.

Case presentation

A 35-year-old male presented to a chiropractor with a complaint of left lateral foot pain of nearly three years duration. The patient reported the pain originally presented on the dorsum of the foot during the first few steps of weightbearing. Examination revealed full ankle ranges of motion and pain was reproduced with only digital pressure between the third and fourth digits. In addition to the orthopaedic examination, x-rays were prescribed to rule out any osseus abnormalities. Due to various possible factors (including human error in foot positioning, or radiographic interpretation), the original radiographic report revealed an os trigonum to be the only abnormal finding, and thus the patient was diagnosed as having an interdigital neuroma.

Following intermittent resolution of his symptoms, the patient returned 18 months later to the same facility complaining of pain more laterally in the foot, aggravated by activities (soccer) involving running for any more than a few minutes. On this occasion examination findings were positive for left ankle instability (anterior drawer test)

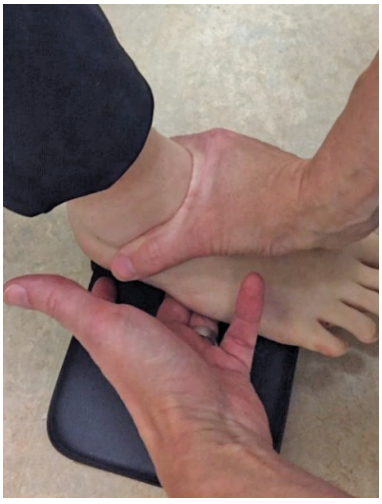


Figure 1.
Cuboid EMT with use of toggle board drop piece.

Figure 2.
2A (left). Cuboid taping with noted beginning of tension direction ("B").
2B (right). Cuboid taping with noted direction of tension (arrows) and end point ("E").

and cuboid syndrome (dorsal plantar cuboid shear test of cuboid on calcaneus), though were notably negative for any navicular tenderness/immobility. Of note, anterior drawer test has a sensitivity of 0.74 95% CI (0.58-0.86) and specificity of 0.38 95% CI (0.24-0.56).[9] Attempts at determining the specificity and sensitivity of the shear test for cuboid syndrome were unsuccessful, with Curall noting a lack of any evidence-based guidelines for this condition.[10]

Intervention originally included soft tissue treatment (Achilles tendon, gastrocnemius/soleus complex, and peroneal musculature), laser (lateral ligaments), proprioception activities, and foot mobilizations to the cuboid as needed. Cuboid intervention was performed through the use of a toggle-board extremity drop piece. The patient's foot was placed in a neutral position with slight eversion on the drop piece. The practitioner placed their second and third digits under the cuboid. Using a high-velocity low amplitude thrust on the dorsal surface of the foot (towards the floor), the cuboid is translated dorsally into its normal biomechanical position in relation to the surrounding tarsals and metatarsals (Figure 1). Additionally, taping of the cuboid was performed to provide additional support and stability to the lateral foot through the use of Leukotape rigid stressing tape and (since it cannot be applied directly on skin) generic surgical dressing tape. A loop of surgical dressing tape is applied around the midfoot area directly to the skin. The rigid tape is then applied on the plantar aspect of the midfoot, and tension is applied around the lateral aspect of the foot to the dorsum of the foot) to simulate proper dorsal stability for the cuboid. Given the ability of prolonged adherence of the surgical dressing tape, the tape job can safely remain for as long as the tape adheres (two to three days) or as needed (Figures 2a and 2b). Additionally, taping or bracing of the ankle was recommended for sporting activities.

After many months of recurrent intermittent foot pain and multiple inversion sprains, the patient's subjective pain reporting would continue to vary. On some days they reported pain and difficulties with activities, and on others reported feeling as beginning to show moderate improvement under the authors' care, even expressing during one visit they might be on the way to a "full recovery". During this time the patient had also noted an increased sensitivity in the foot, with the area of pain changing and widening over time.

Management of the patient reached a turning point when the patient presented to the clinic unable to weight bear on the left foot after a soccer game the previous evening, with no reported mechanism. X-rays were im-

Figure 3.
AP and oblique radiograph views of a 35-year-old male with calcaneonavicular coalition. On the AP view note how the proximal portion of the navicular is wider than the talonavicular joint, and the lateral aspect of the navicular has a tapered, elongated appearance. On the oblique view, the accessory joint formed at the anterior calcaneal process and lateral aspect of the navicular (arrow), consistent with a cartilaginous calcaneonavicular coalition.

Figure 4.
A lateral radiograph of the same patient. Note the elongation of the superior calcaneus (arrow) and flattening of the longitudinal arch. Additionally, a non-united posterior talar process is detected, consistent with an os trigonum (thin arrow).

Figure 5.
Axial T1-weighted MRI image. As in Figure 3, note the proximal portion of the navicular is wider than the talonavicular joint, and the lateral aspect of the navicular has a tapered, elongated appearance. Unlike the radiograph, sclerosis, bone proliferation, and irregularity of the calcaneonavicular joint (arrow) more visibly demonstrates this non-osseous joint coalition.

mediately prescribed under the suspicion of a stress fracture. Radiographic interpretation revealed diagnosis of a calcaneonavicular coalition (see Figures 3 and 4), with no other findings. A walking boot was prescribed, along with referral to a sports medicine physician for further imaging and an orthopaedic consultation.

The sports medicine physician recommended continued use of the walking boot, along with referral for a bone scan and MRI (Figures 5-7) and orthopaedic con-

Figure 6.
Sagittal T1-weighted MRI image. As in Figure 5, there is demonstration of a prominent anterior process of the calcaneus (arrow), equivalent to the radiographic anteater sign.

Figure 7.
Sagittal T2-weighted fat-suppressed MRI image. with a visualized joint and adjacent bone marrow edema (arrow), and a small subchondral cyst in the elongated process of the calcaneus.

sultation regarding possible surgical intervention. The patient remained in a walking boot for four weeks and continued to receive conservative care, while experiencing intermittent bouts of lateral foot pain.

During boot immobilization, intervention involved soft tissue treatment as above, pain control (pre-modular interferential current), intrinsic foot exercises, and isometric ankle strengthening. The patient was also encouraged to continue with non-impact aerobic activities (stationary bike, swimming). Following removal of the walking boot, the patient's rehabilitation consisted of resistance band strengthening (focusing on dorsi-flexion and eversion), single leg proprioception activities (one-legged stance, star excursions, progressing onto unstable surfaces), and closed kinetic chain strengthening (single-leg squat). All exercises began with a focus on functional strength increases (3 sets of 10-12 repetitions), with eventual progression to functional endurance (2 sets of 15-20 repetitions). The patient was instructed to perform these exercises daily (when not in clinic), and sets/reps and frequency were adjusted as the patient's symptoms improved and objective measurement improved (See Table 1).

Passive management consisted of soft tissue treatment, mobilizations of the first ray and talus (ensuring normal accessory movements through the sagittal planes) and pain control (as needed). Upon re-evaluation of the foot a 90% improvement was noted, although with a new complaint of bilateral plantar fascial pain. In addition to above interventions, the patient was prescribed full-length custom orthotics for use in all footwear. Given confirmation of the radiological findings at re-evaluation (and the MRI results), the patient declined the option of coalition resection and decided to modify his activities. At the time, the patient opted for swimming as a primary aerobic activity as they were apprehensive that the impact of soccer

Table 1.
Rehabilitation exercise protocol

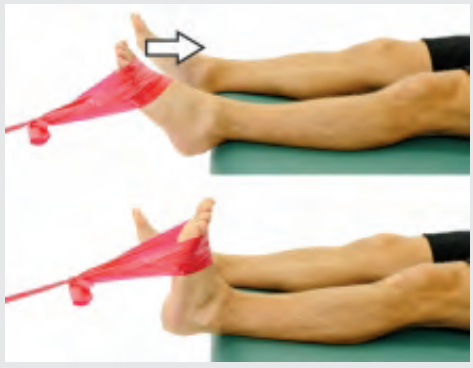
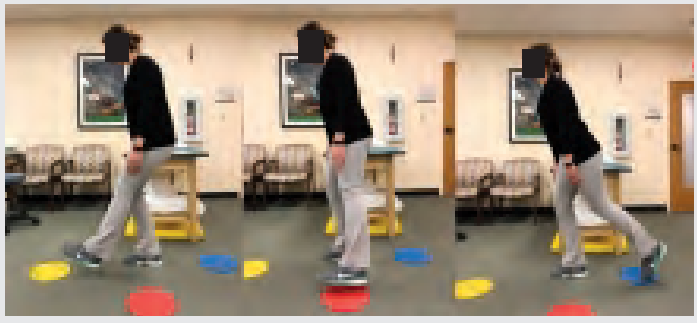
Exercise:	**Description:**	**Visual:**
1. Short Foot	Press the ball of the big toe into the ground actively trying to lift the medial arch of the foot 3 x 10-12 repetitions	
2. Isometric foot strength	i. Dorsiflexion ii. Eversion iii. Inversion iv. Plantarflexion Hold each exercise for 3x30 seconds meeting the resistance of the band, with no added movement	
3. Banded strengthening		
i. Resistance band dorsiflexion	With the resistance of the band, actively pull the toes toward your body Functional Strength: 3 x 10-12 repetitions/daily Functional Endurance: 2 x 15-20 repetitions/daily	
ii. Resistance band eversion	With the resistance of the band, actively turn the foot outward Functional Strength: 3 x 10-12 repetitions/daily Functional Endurance: 2 x 15-20 repetitions/daily	

Table 1.
Rehabilitation exercise protocol – Continued

Exercise:	**Description:**	**Visual:**
4. Single leg stance (star excursions)	While standing on the affected leg, reach forward as far as you can with the opposite leg while maintaining your balance. Do the same reaching out to the side, followed by reaching back. Functional Strength: 3 x 10-12 repetitions/daily Functional Endurance: 2 x 15-20 repetitions/daily	
5. Closed kinetic chain		
i. Single leg calf raises	While standing on the affected leg, raise your heel off the ground Functional Strength: 3 x 10-12 repetitions/daily Functional Endurance: 2 x 15-20 repetitions/daily	
ii. Single leg split squat	While standing on the affected leg, have the opposite foot propped up on a sturdy chair. Bend your knee lowering yourself down, driving the knee over the toe Functional Strength: 3 x 10-12 repetitions/daily Functional Endurance: 2 x 15-20 repetitions/daily	

would re-aggravate his foot pain. However, at one-year follow-up the patient was happy to report that they gradually returned to soccer, using the custom orthotic in their footwear. To date the patient has not experienced any foot discomfort with all activities.

Discussion

Pain presentation

In the adult population, many tarsal coalitions are discovered incidentally while a patient is being evaluated

for a different condition.[11] Varner *et al*.[12] retrospectively reviewed 27 adult patients with a coalition and found that two-thirds of these were discovered during workup for symptoms such as an ankle instability and sinus tarsi pain, whereas one-third of the adult patients were completely asymptomatic. With a calcaneonavicular coalition restricting motion in the midfoot, forceful motion beyond the restricted range may result in partial or complete ligamentous injuries to the ankle. If hindfoot or midfoot motion is restricted, more trauma is inflicted to the ankle ligaments in an effort to dissipate the forces exerted. In cutting, pivoting, or decelerating, different mechanisms may result in different injuries.[13]

In addition to the added stress placed on other structures of the foot due to the coalition, one must also consider the chronic presentation of this condition over time. Osteoarthritic changes were observed on the Sagittal T2-weighted fat-supressed MRI in Figure 7 including: bone marrow edema and a small subchondral cyst. It is likely that these degenerative changes could have contributed to the recurrent bouts of pain experienced by the patient.

Additionally, due to the patient's prolonged pain complaints and change in clinical presentation area, the possibility of nociceptive hypersensitivity was also considered. In states of chronic pain, nociceptive and non-nociceptive sensory afferents are sensitized.[14] One mechanism used to describe the genesis of chronic pain is peripheral sensitization, which constitutes a decreased threshold and increased responsiveness of nociceptors due to post-translational changes in the area and altered trafficking of transducer receptors and ion channels.[15] Also known as primary hyperalgesia, this sensitization of nociceptors is a protective action of the human body to prevent use and consequent further damage to traumatized area and surrounding tissues. However, with a diffuse pain distribution central sensitization, which is a process characterized by generalized hypersensitivity of the somatosensory system[16,17]. As Nijs *et al*.[16] note, the longer pain persists, the more likely central sensitization becomes a more dominant component to the clinical presentation. Given the timelines of the patient's complaint and the fact their pain location (lateral foot) was different from the area of coalition, the practitioner could therefore consider sensitization as an additional contributing factor in the clinical presentation.

Imaging diagnosis

Due to the different types of possible coalition, a review of literature revealed differing viewpoints on imaging for this condition. One review reported that as many as 94% of adult coalitions could be found on plain radiographs alone.[12] However, Hochman *et al*.[18] suggested CT is the best imaging technique for examining coalitions, based on its ease of use, allowance for bilateral comparison, and improved visualization of the location, size, and type of coalition. Yet another paper noted that despite suggestive clinical signs, standard X-rays may miss the diagnosis due to the lack of synostosis.[1] MRI identified, located and characterized symptomatic lesions that were not necessarily visible on CT, enabling preoperative planning for adapted surgery.

In terms of radiographic diagnosis, one paper suggested routine anteroposterior and lateral unenhanced radiographs are a sensitive screening test for both talocalcaneal and calcaneonavicular coalitions, even with observers who had no prior experience.[7] However, others opined that calcaneonavicular coalitions are difficult to visualize on radiographs due to the complex orientation of the joint; thus the best view to see the coalition is an internal oblique view as this lays the calcaneonavicular interface out for inspection and therefore best displays various signs of a calcaneonavicular coalition.[6] In accordance to the literature, the coalition was best visualized in the AP oblique view (Figure 3).

Crim *et al*.[8] note a calcaneonavicular bar can be seen on anteroposterior radiographs in a substantial number of coalition cases if careful attention is paid to the lateral margin of the navicular bone. The shape of the navicular bone is altered by the presence of a coalition.[7] Therefore, in addition to showing the calcaneonavicular bar, the anteroposterior radiograph often reveals that the proximal portion of the navicular bone is wider than the talonavicular joint and that the lateral aspect of the navicular bone has a tapered, elongated appearance. Other radiographic features that have been shown to indicate the presence of a calcaneonavicular coalition (as seen in this case) include the "anteater nose", seen on the lateral view as an elongation of the anterior process of the calcaneus toward the navicular for a calcaneonavicular coalition.[19] Lawrence *et al*.[7] note the presence of this elongated anterior calcaneal process is highly suggestive of a calcaneonavicular coalition, with a specificity of 94%.

Operative versus nonoperative management

In terms of management, most of the literature revealed management through surgical resection of the coalition. Cohen *et al*.[4] noted that resection of a calcaneonavicular coalition in the adult (in the absence of significant degenerative changes of the talonavicular and subtalar joints), could be successful, providing an option to arthrodesis when nonoperative methods have failed. Additionally, Mahan *et al*.[20] noted that although physician-based outcomes such as foot alignment are important in tarsal coalition surgery, patient-reported outcomes of pain, daily function, and return to high-level sports are of paramount importance in assessing whether tarsal coalition surgery can reliably offer a high-quality result. In their study, 73% of patients reported unlimited activity, with no difference in reported outcomes between the calcaneonavicular and talocalcaneal groups.

However, unlike adolescent coalitions, nonoperative treatment may be even more effective in the adult patient, as many are asymptomatic or discovered after injury.[2,4] Various studies note the treatment of adult tarsal coalitions should begin with nonoperative treatment. This can include activity modification, physical therapy, orthotics, nonsteroidal anti-inflammatory drugs (NSAIDs), and short leg cast immobilization for 4 to 6 weeks.[2, 12] However, while some studies have shown a nonoperative treatment protocol to be effective, other authors' results have been variable. In their review, Flynn *et al*.[11] note differing success rates between 15% and 67% in non-operative management of subtalar coalitions[12]. Therefore, it may be difficult to draw any firm conclusions.

In this case, non-operative management was successful once a proper diagnosis was rendered. Given the myriad subjective pain reporting by the patient and undulating clinical presentations, prior interventions resulted in only temporary improvements. Achieving a proper diagnosis was the primary challenge in this case, and was reliant upon multi-disciplinary involvement, including various imaging modalities and chronic pain management.

Summary

Given its rare presentation in adults, differing etiologic factors, pain presentations (including possible pain sensitization), and differing views on imaging diagnosis and management, the evidence base regarding calcaneonavicular coalition, particularly in the adult population, remains quite poor. This case demonstrates the challenges experienced in the diagnosis and management of such a condition, and the options available to a practitioner. Additionally, as was noted earlier, the role of central sensitization contributing to the presentation should have been considered and could have resulted in earlier referral for diagnostic imaging and resolution of this complaint. Ultimately, a cooperative multi-disciplinary approach in diagnosing this condition, along with a nonoperative management, led to a favourable pain and functional outcome result for the patient. While this management protocol was sufficient for this patient, it is important to remember many factors (i.e. presence of arthritic change) not discussed can affect the decision making of such a case. An evidence-based practice approach involving clinical expertise, external evidence, and patient values and expectations must always be considered. Should nonoperative management not result in favourable outcome, then an algorithm for surgical management for adult subtalar coalition should be considered.[11] Prior to implementing any such diagnostic or nonoperative management protocols in a condition such as this, further investigation in larger, controlled trials is recommended.

References

1. Guignand D, Journeau P, Mainard-Simard L, Popkov D, Haumont T, Lascombes P. Child calcaneonavicular coalitions: MRI diagnostic value in a 19-case series. Orthopaed Traumatol Surg Res. 2011;97: 67-72.
2. Shirley E, Gheorghe R, Neal KM. Results of nonoperative treatment for symptomatic tarsal coalitions. Cureus. 2018;10(7): 1-7.
3. Masquijo J, Allende V, Torres-Gomez A, Dobbs MB. Fat graft and bone wax interposition provides better functional outcomes and lower reossification rates than extensor digitorum brevis after calcaneonavicular coalition resection. J Pediatr Orthop. 2017; 1-5.
4. Cohen BE, Hodges Davis W, Anderson RB. Success of calcaneonavicular coalition resection in the adult population. Foot Ankle Intl. 1996;9(17): 569-572.
5. Mubarak SJ, Patel PN, Upasani VV, Moor MA, Wegner DR. Calcaneonavicular coalition: treatment by excision and fat graft. J Pediatr Orthop. 2009;29(5): 418-426.
6. Kernbach KK. Tarsal coalitions: etiology, diagnosis, imaging, and stigmata. Clin Podiatr Med Surg, 2010;27: 105-117.
7. Lawrence DA, Rolen MF, Haims AH, Zayour Z, Moukaddam HA. Tarsal coalitions: radiographic, CT, and MR imaging findings. HSS J. 2014;10: 153-166.

8. Crim JR, Kjeldsberg KM. Radiographic diagnosis of tarsal coalition. Am J Roentgenol. 2004;182: 323-328.
9. Croy T, Koppenhaver S, Saliba S, Hertel J. Anterior talocrural joint laxity: diagnostic accuracy of the anterior drawer test of the ankle. J Orthopaed Sports Phys Ther. 2013;43(12): 911-919.
10. Curall CJ. Examination and treatment of cuboid syndrome: a literature review. Sports Health. 2011;3(6): 514-519.
11. Flynn JF, Wukich DK, Conti SF, Hasselman CT, Hogan MV, Kline AJ. Subtalar coalitions in the adult. Foot Ankle Clin N Am. 2015;20: 283-291.
12. Varner KE, Michelson JD. Tarsal coalition in adults. Foot Ankle Intl. 2000;21: 669-672.
13. Snyder RB, Lipscomb B, Johnston RK. The relationship of tarsal coalitions to ankle sprains in athletes. Am J Sports Med. 1981;9(5): 313-317.
14. Gangadharan V, Kuner R. Pain hypersensitivity mechanisms at a glance. Disease Models Mech. 2013;6(4): 889-895.
15. Spiegel DR, Pattison A, Lyons A, Ansari U, McCroskey AL, Luehrs E, Barr L, Le S. The role and treatment implications of peripheral and central processing of pain, pruritus, and nausea in heightened somatic awareness: a review. Innov Clin Neurosci. 2017;14(5-6): 11-20.
16. Nijs J, Van Houdenhove B, Oostendorp RAB. Recognition of central sensitization in patients with musculoskeletal pain: application of pain neurophysiology in manual therapy practice (Masterclass). Man Ther. 2010;15: 135-141.
17. Woolf CJ. Central sensitization: implications for the diagnosis and treatment of pain. Pain. 2011;152(3): S2-15.
18. Hochman M, Reed MH. Features of calcaneonavicular coalition on coronal computed tomography. Skelet Radiol. 2009;29: 409-412.
19. Thorpe SW. & Wukich DK. Tarsal Coalitions in the adult population. Does treatment differ from the adolescent? Foot Ankle Clin. 2012;17(2): 195-204.
20. Mahan ST, Spencer SA, Vezeridis PS, Kasser JR. Patient-reported outcomes of tarsal coalitions treated with surgical excisions. J Pediatr Orthopaed. 2015;35(6): 583-588.

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Detailed management of post-traumatic distal clavicle osteolysis in a 24-year-old female: a case report

Nader Abdelkader, BSc, DC[1]
Chris deGraauw, DC, FRCCSS(C)[2]

Introduction: *Distal clavicular osteolysis (DCO) is a musculoskeletal pathology characterized by shoulder pain. Given the high prevalence of shoulder pain due to rotator cuff and subacromial injuries, DCO is often overlooked. Conservative therapy is indicated prior to surgical intervention. However, no literature has described conservative management of DCO in detail. This report will outline conservative management details for DCO to guide future research and clinicians.*

Case presentation: *A 24-year-old female hockey player presented with trauma-induced injury, where she was diagnosed with type II acromio-clavicular joint separation. She presented 5-months later with residual pain and limitations in ranges of motion (ROM). Radiographic images revealed DCO.*

Prise en charge détaillée d'une ostéolyse post-traumatique de l'extrémité externe de la clavicule chez une femme de 24 ans : compte rendu de cas

Introduction : *L'ostéolyse de l'extrémité externe de clavicule (OEEC) est une pathologie musculosquelettique caractérisée par des douleurs d'épaule. La fréquence des douleurs d'épaule dues à des lésions de la coiffe des rotateurs et des lésions sous-acromiales est élevée, mais l'OEEC est souvent inaperçue. Un traitement conservateur est indiqué avant l'intervention chirurgicale. Comme aucune littérature ne décrit en détail le traitement conservateur de cette pathologie, nous présentons un compte rendu détaillé de ce traitement pour guider les recherches futures et les cliniciens.*

Présentation du cas : *Une joueuse de hockey de 24 ans s'est présentée avec une blessure traumatique à l'épaule. On a diagnostiqué une disjonction acromio-claviculaire de type II. Elle s'est présentée 5 mois plus tard avec des douleurs résiduelles et des limitations de l'amplitude des mouvements. Les radiographies ont révélé une OEEC.*

[1] Division of Graduate Studies, Sports Sciences, Canadian Memorial Chiropractic College
[2] Associate Professor, Canadian Memorial Chiropractic College

Corresponding author: Nader Abdelkader, 980 Denison St, Markham, ON, L3R 3K5, Canada
Tel: 647-867-4720
E-mail: drnaderabdelkader@gmail.com

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Management and outcome: *Management entailed strict rest from overhead activities followed by rehabilitation and manual therapy. 6-months later the patient reported resolution of symptoms, improved ROMs, and activities of daily living.*

Summary: *DCO can be difficult to diagnose given its limited etiological understanding, low incidence, and poor radiographic sensitivity. DCO diagnosis should be considered in cases with unresolving shoulder pain.*

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KEY WORDS: post traumatic distal clavicle osteolysis, acromio-clavicular separation, chiropractic, rehabilitation, shoulder pain

Prise en charge et résultats : *La prise en charge a consisté en un arrêt complet des activités au-dessus de la tête, suivi d'une rééducation et d'une thérapie manuelle. Six mois plus tard, la patiente n'avait plus de symptômes, avait repris ses activités quotidiennes et l'amplitude de ses mouvements s'était améliorée.*

Résumé : L'*OEEC peut être difficile à diagnostiquer parce que nos connaissances sur son étiologie sont limitées, que sa fréquence peu élevée et que cette pathologie est difficile à visualiser sur les radiographies. Le diagnostic d'une OEEC doit être envisagé dans les cas de douleurs d'épaule qui ne disparaissent pas.*

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MOTS CLÉS : ostéolyse post-traumatique de l'extrémité externe de la clavicule, disjonction acromio-claviculaire, chiropratique, rééducation, douleur à l'épaule

Introduction

Distal clavicular osteolysis (DCO) is a musculoskeletal (MSK) pathology characterized by shoulder pain in adults. There are two types of DCO: atraumatic DCO, caused by repetitive stress and first described in 1959 by Ehricht and colleagues[1], and traumatic DCO, caused by a traumatic injury and first described in 1961 by Kohler in Swiss and German Literature. Atraumatic DCO has been associated with lifting weights and at high intensities[2], whereas traumatic DCO may follow acromioclavicular (AC) joint separation[3].

Although the etiological and exact pathogenesis of DCO is unclear, it has been previously reported by Cahill and colleagues that microfractures of the subchondral bone exist with signs of repair in the distal clavicle of surgical specimens[4]. Although Brunet *et al*.[5] later suggests a pathophysiological process of synovial invasion of the subchondral bone leading to osteolysis, Cahill's hypothesis remains more widely accepted.

Limited epidemiological data exists for DCO. A study by Yu *et al*. [6] reported a 6-12% incidence rate of developing osteolysis of the distal clavicle following AC joint separations. However, the population prevalence of traumatic DCO remains unknown. As for atraumatic DCO, Nevalainen *et al*.[2] found a 5% prevalence in an adult population with shoulder pain and further noted a high correlation with high-intensity bench pressing.

Given the high prevalence of shoulder pain due to rotator cuff and subacromial injuries, DCO is often overlooked. Making matter worse, it is also sometimes misdiagnosed as AC joint separation sequalae, especially following an acute injury. On presentation, DCO patients complain of vague anterior shoulder pain that may radiate to the trapezius or deltoid region. Reported aggravating factors include weight training (e.g., bench presses, push-ups), overhead activities and horizontal adduction. On examination, the pain is reproduced with palpation of the affected AC joint and with a cross-body adduction maneuver.[7]

Following history and physical examination, if clinical suspicion for DCO is present, then radiographic workup of the AC joint should be considered. Imaging may reveal loss of subchondral bone in the distal clavicle, cystic changes in the subchondral bone, as well as widening of the AC joint. As all these findings are often subtle and difficult to detect, the images must be meticulously examined. However, a meticulously examined negative study is still not sufficient to confidently rule out DCO. In a

study by Yu and colleagues[6], x-rays detected DCO findings only 50% of the time; MRIs were more sensitive. MRI findings include cortical irregularity, periarticular erosions, joint widening, soft tissue swelling, and edema.[6]

As for treatment, conservative management is the primary goal prior to surgical considerations.[8,9] Despite this, however, only few studies have outlined non-surgical treatment options for DCO. DeFroda *et al*.[8] recommends nonsteroidal anti-inflammatory drugs (NSAIDS), steroid injections, activity modification, avoidance of provocative exercises, and physical therapy. The reference reporting physical therapy suggests mobilization techniques similar to those utilized in treating AC joint osteoarthritis.[10] There was no pragmatic description of rehabilitative interventions specific to DCO. Another study by Mestran *et al*.[11] examines seven case studies of traumatic and atraumatic DCO patients – all seven patients underwent conservative therapy, with strongly improved clinical outcomes in four out of the seven cases. The authors described varied treatment methods including sling immobilization, ice, and mobilization exercises. Again, however, there was no descriptive mention of the specific mobilization exercises used.

Thus, despite recommendation for conservative management prior to seeking surgical intervention, the literature lacks in providing clinicians with full descriptions of the conservative care treatment options. This report aims to describe detailed conservative management options, effectively highlighted through a successful case, to help guide clinicians and future researchers with DCO management.

Case presentation

A 24-year-old female presented to the clinic with an acute onset of left shoulder pain after a hockey injury the night before. The patient described a mechanism of injury where her opponent had collided with her left shoulder from the back as she was attempting to shoot. After the collision, the patient fell onto the ice on the same shoulder. The patient recalls immediate sharp, 10/10 pain that prevented her from moving her shoulder in any direction. Aggravating factors at the time included any movements involving the left arm, while relieving factors included ice-application and rest. Physical examination revealed a minor step-defect and minimal soft tissue swelling surrounding the AC joint region. Palpation reproduced pain directly at the AC joint and elicited tenderness over the surrounding shoulder musculature. The left glenohumeral (GH) active ranges of motion (ROM) were minimal with associated pain apprehension, and the horizontal adduction test was positive for pain. The patient was ultimately diagnosed with acute type II AC joint separation.

A week after the incident, the patient started to experience significant decrease in symptoms. She regained the majority of her GH ROM and her pain was present only at the end ranges of flexion, abduction, and horizontal adduction. The symptoms continued to subside over the next month and she was able to participate fully in her work duties, daily living activities, and even her normal gym routine.

Five months later, the patient returned to the clinic with residual shoulder pain. Her pain was now described as noticeably dull-achy, rated 3/10 on the numeric pain rating scale, and was diffusely present throughout the anterior and posterior aspects of her left shoulder. It was aggravated by sleeping on the left side, performing work duties, holding the steering wheel while driving, overhead weight-presses and performing handstands. Relieving factors included rest from all the aforementioned aggravating factors. The patient was otherwise healthy with no past medical problems. Her review of systems was unremarkable and no red flags were raised.

Examination of the left shoulder was positive for pain in active ranges of motion, and limited range to 130° of flexion, 20° of extension, 110° of abduction, 90° of external rotation, and 10° of internal rotation. There was decrease of strength (grade 4/5) in both external and internal rotation. Painful Arc test was positive for pain at 90° and at end-range, and scapular dyskinesia was observed. There was also tenderness upon palpation of the AC joint line, as well as the surrounding shoulder and neck musculature. The QuickDASH functional scale was 27.27. Additional exam findings included joint restrictions at the cervicothoracic junction, chest elevation and accentuated rib flaring on functional assessment of resting inhalation, and an anteriorly rolled shoulder.

Radiographic images taken at this time (five months post injury) noted a subtle radiographic suggestion of osteolysis of the distal clavicle (see Figure 1). The patient was diagnosed with left post-traumatic distal clavicle osteolysis.

Rest from provocative ranges of motion was adopt-

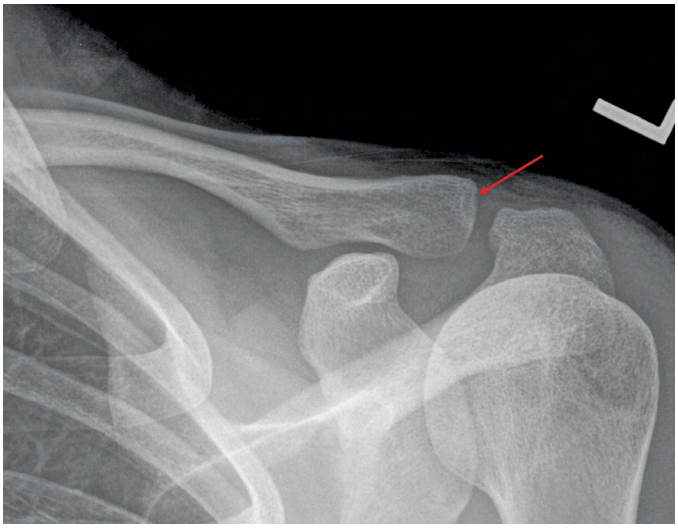


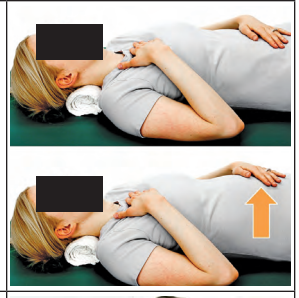
Figure 1.
The arrow points directly at the subtle focal cortical resorption observed in the superior aspect of the left distal clavicular articular margin

ed immediately – again, these ranges were flexion, abduction, internal rotation and horizontal adduction. The patient then underwent a conservative management plan for one to two times per week for ten weeks. This consisted of soft tissue therapy (STT), spinal manipulation therapy (SMT), and rehabilitation exercises. Soft tissue therapy targeted pectoralis minor, teres minor and major, supraspinatus, infraspinatus, subscapularis, rhomboids minor and major, latissimus dorsi, trapezius, and levator scapulae. Spinal manipulative therapy was provided for the cervical and thoracic spine restricted segments. In addition, stretching exercises of the pectoralis minor (where the body rotates away from a fixed arm position against the wall) were also prescribed.

After her symptoms began to improve, rehabilitation exercises were commenced. The following progressive exercises in three-phases (see Tables 1-3) were prescribed. The first phase included exercises below the horizontal plane; the second phase included exercises above the horizontal plane; and the third and last phase included active exercises in a closed kinetic chain (see Tables 1-3 for more details). The overall purpose of the exercises was to improve her scapular kinesis and ultimately GH ROM.

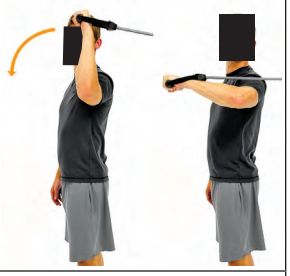
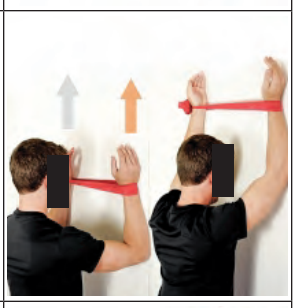
Approximately one year after initial presentation, the

Table 1.
Shoulder rehab below horizontal

Phase 1	**Rehab Exercise**
Concentric and eccentric external and internal rotations of glenohumeral joint using resistive band. Shoulders are 0 degrees flexion. Elbows are at 90 degrees flexion. Sets: 3 Repetitions: 10 Frequency: daily	
Push up-plus against the wall or against a table in incline position. Focusing on scapular control in protraction and retraction Sets: 3 Repetitions: 10 Frequency: daily	
Diaphragmatic breathing in supine position with elevated legs. The focus was to inhale while increasing intra-abdominal pressure, then exhaling while relaxing intra-abdominal pressure. Sets: 3 Repetitions: ~60 seconds Frequency: daily	
Upright-Rows was done with resisted band then eventually with weighted-cables. The elbow is not abducted beyond 90 degrees. Trunk is upright. Sets: 3 Repetitions: 10 Frequency: daily	

patient was re-evaluated and her symptoms were re-assessed. Not only did the patient report complete resolution of symptoms, but prior aggravating factors such as overhead weight-presses, and performing work duties were no longer bothersome or of concern. On examination, follow up Quick DASH score was 4.55; palpation of

Table 2.
Shoulder rehab above horizontal

Phase 2	**Rehab Exercise**
Concentric and eccentric external and internal rotations of glenohumeral joint using resistive band. Shoulders are 90 degrees abduction. Elbows are at 90 degrees flexion. Sets: 3 Repetitions: 10 Frequency: daily	
Push up-plus against horizontal position. Focusing on scapular control in protraction and retraction Sets: 3 Repetitions: 10 Frequency: daily	
Scapular-clocks were performed against the wall. A resistance band was wrapped around both arms. While one arm is stabilized, the other moved downwards, sideways, and upwards against the wall in a controlled fashion without shoulder-hiking. Sets: 3/arm Repetitions: 10/arm Frequency: daily	
Diaphragmatic breathing in supine position with elevated legs was progressed to a Deadbugs exercise. The focus was to allow arm flexion without shoulder-hiking while maintaining diaphragmatic breathing. A yoga ball can be used for guidance. Sets: 3 Repetitions: 10X/side Frequency: daily	
Bent-over rows was done with weights. The emphasis was to focus on scapular retraction without shoulder hiking while maintain spinal neutral position. Sets: 3 Repetitions: 10 Frequency: daily	

the AC joint was no longer painful; and active GH ROM was now full and pain free. The only positive exam finding was residual decrease in strength (grade 4/5) with internal rotation.

Discussion

DCO can be difficult to diagnose given the poorly understood pathology and limited etiological understanding, the low incidence rate, and the lack of radiographic sensitivity. It can be very easily missed, especially following acute trauma. However, identifying this uncommon pathology in patients is crucial in order to execute the appropriate plan of care. Unlike most MSK conditions, initial exercise is ought to be contraindicated in DCO patients. As previously mentioned, Cahill and colleagues in 1982 identified microfractures of the subchondral bone in surgical specimens of DCO patients. Because regular bone fractures are usually treated with casting, splinting, or immobilization as the primary management, the authors suggest that microfractures present in DCO should be

Table 3.
Shoulder rehab in closed kinetic-chain

Phase 3	**Rehab Exercise**
Scapular Hangs were performed from passive hanging position where the trunk is in depressed position relative to the scapula, to an engaged position where the trunk is in elevated relative to the scapula. Sets: 1-2 Repetitions: 10 Frequency: daily	
Low oblique sit according to dynamic neuromuscular stabilization. Isometrically depressing the scapula relative to the trunk. The trunk is elevated off the ground to neutral position relative to the shoulder complex. Ensuring diaphragmatic breathing in this isometric position without fatiguing into shoulder-hiking and depressed trunk. Sets: 3 Repetitions: 30 seconds/side Frequency: daily	

also be treated similarly, with a period of rest before initializing rehabilitation, allowing for physiological bone healing. Therefore, patients should be educated on avoiding painful ROM, to avoid reinjuring the joint pathology. It is in the opinion of the authors that patient education regarding bone healing and limiting provocative ranges of motion is of high priority to improve compliance and prognosis.

In our case, once a sufficient amount of time was given to allow for healing and pain relief, active rehabilitation was commenced with the intention to regain neuromuscular control of the shoulder complex. This is especially important after a period of prolonged rest. Scapular control and its relationship to glenohumeral rhythm was emphasized to reinstate optimum shoulder mechanics.[12] Emerging evidence investigating the association between scapular dynamic stability with shoulder pathologies reported different examples of altered scapular kinematics including: reduced clavicle retraction, scapular upward rotation, scapular posterior tilt and increased clavicle elevation. As such, enhancing optimal clavicle kinematics via scapular dynamic stability exercises is thought to alleviate excessive pressure on the AC joint.[13] This rehabilitation approach was particularly relevant given that our patient demonstrated scapular dyskinesia on repeat examination.

Further addressing functional deficits, our patient demonstrated chest rising with rested inhalation. As this may indicate excessive utilization of the pectoralis minor, deep neck flexors, sternocleidomastoid, and other secondary respiratory musculature, diaphragmatic breathing and deadbugs were prescribed to address this functional deficit. It is thought that diaphragmatic breathing further strengthens core musculature by increasing intra-abdominal pressure (IAP) which stabilizes the spine by activation of the diaphragm, pelvic floor, and transversus abdominis. This provides a fixed stable base from which extremity musculature can generate movement, including the shoulder complex.[14] Ensuring a fixed stable base of support allows for optimal load transference across the joint without mechanical stress on the passive structures such as ligaments, joint surfaces, cartilage, and osseous structures.

Active scapular hangs were included to improve grip strength, as it has been shown to improve shoulder internal and external rotational torque.[15] Altered scapular kinematics may not only be attributed to muscular recruitment patterns[16,17], but also lack of flexibility and tissue compliance in the scapular peri-articular musculature. Lack of flexibility may restrict normal scapular movement.[18] Therefore, passive care of STT and SMT of the cervical and thoracic spine, was provided for relief of tenderness and improving GH ROM.[19]

It is noteworthy to indicate that there is no consensus regarding the cause-consequence relationship between shoulder/neck pain and scapular dyskinesis. It is likely there are several mechanisms that can contribute to shoulder pathology such as DCO, including post-traumatic stress, repetitive altered shoulder kinematics, scapular dyskinesia, thoracic posture and/or soft tissue stiffness. Irrespective of the direction of cause and effect, altered neck or shoulder mechanics may jeopardise optimal shoulder function and consequently decrease width of the AC joint, continuing to insult the DCO pathology. Improving cervical and thoracic ranges of motion was considered necessary to the shoulder biomechanics from a regional interdependence perspective.[20] Stretching was instructed specifically for the pectoralis minor to prevent excessive GH protraction given that our patient demonstrated anteriorly rolled shoulder on the symptomatic side, with the intention to prevent excessive AC joint loading.

Of note, the patient's step-defect did not resolve. However, this is a direct result of the traumatic incident leading to the type II AC joint separation and will not resolve with conservative care.

This case report is not without limitations. Radiographic images were obtained but follow up imaging was not performed to fully explore the long-term changes radiographically. MRI is more sensitive to visualize DCO findings[6] but was not deemed necessary to guide the patient management for this case and is not routinely used due to its high costs and limited availability. Given the decreased sensitivity associated with X-ray findings for DCO[6], one must consider differential diagnoses associated with the persistent symptoms such as: chronic AC joint sprain, AC joint instability, as well as osteoarthritis of the AC joint. The differential diagnosis of chronic AC joint sprain (failure of initial rehab is plausible), it would not explain the cystic findings visualized on X-ray. The second differential of joint instability is also a plausible diagnosis, but this is unlikely since our radiographs found no evidence of vertical instability (grade III injury particularly disrup-

tion of the coracoclavicular (CC) ligaments) and our clinical exam found no signs of malalignment on observation or under loads.[21] It is also plausible to consider horizontal joint instability due to disruption of the AC ligaments but there is a lack of consensus available regarding evaluation and diagnosis.[22] A third differential of osteoarthritis of the AC joint is also plausible but given the short timeline; in this case of five months and young age of the patient; it is unlikely arthritic in nature.

The positive outcome in this case confirms the suggestion from previous literature that conservative management should be attempted prior to pursing surgical options. Unfortunately, there is a literary gap in descriptions of detailed and specific conservative management interventions and protocols from a manual therapy and active rehabilitation standpoint. This case report is to provide guidance for clinicians on a non-surgical approach for patients with DCO. The graduated and multi-modal conservative approach presented is an integral component for successful treatment of DCO.

Clinical applicability

1. Consider a diagnosis of DCO especially with a previous history of a traumatic event to the shoulder or unresolving superior shoulder pain with concurrent history of repetitive overhead shoulder use.
2. Consider radiographic images after prolonged shoulder pain as further investigative workup. However, be aware that DCO cannot reliably be ruled out on radiographs alone and MRI may be necessary to elicit the bony changes.
3. Once diagnosis is confirmed, halt aggravating maneuvers until symptoms completely subside.
4. Consider manual therapy and a sequential rehabilitation protocol to restore shoulder function.

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References

1. Ehricht HG. Die Osteolyse im lateralen Claviculaende nach Preßluftschaden. Arch Orthop Unfallchir. 1959;50(6):576-582. doi:10.1007/BF00416343
2. Nevalainen MT, Ciccotti MG, Morrison WB, Zoga AC, Roedl JB. Distal clavicular osteolysis in adults: association with bench pressing intensity. Skeletal Radiol. 2016;45(11):1473-1479. doi:10.1007/s00256-016-2446-z
3. Asano H, Mimori K, Shinomiya K. A case of post-traumatic osteolysis of the distal clavicle: histologic lesion of the acromion. J Shoulder Elb Surg. 2002;11(2):182-187. doi:10.1067/mse.2002.122229
4. Cahill BR. Osteolysis of the distal part of the clavicle in male athletes. J Bone Jt Surg – Ser A. 1982;64(7):1053-1058. doi:10.2106/00004623-198264070-00015
5. Brunet ME, Reynolds MC, Cook SD, Brown TW. Atraumatic osteolysis of the distal clavicle: histologic evidence of synovial pathogenesis. A case report. Orthopedics. 1986;9(4):557-559. doi:10.3928/0147-7447-19860401-15
6. Yu JS, Dardani M, Fischer RA. MR observations of posttraumatic osteolysis of the distal clavicle after traumatic separation of the acromioclavicular joint. J Comput Assist Tomogr. 2000;24(1):159-164. doi:10.1097/00004728-200001000-00028
7. Nuber GW, Bowen MK. Arthroscopic treatment of acromioclavicular joint injuries and results. Clin Sports Med. 2003;22(2):301-317. doi:10.1016/S0278-5919(03)00014-0
8. DeFroda SF, Nacccca C, Waryasz GR, Owens BD. Diagnosis and management of distal clavicle osteolysis. Orthopedics. 2017;40(2):119-124. doi:10.3928/01477447-20161128-03
9. Schwarzkopf R, Ishak C, Elman M, Gelber J, Strauss DN, Jazrawi LM. Distal clavicular osteolysis: a review of the literature. Bull NYU Hosp Jt Dis. 2008;66(2):94-101. Accessed August 19, 2020. https://pubmed.ncbi.nlm.nih.gov/18537776/
10. Cibulka MT, Hunter HC. Acromioclavicular joint arthritis treated by mobilizing the glenohumeral joint. A case report. Phys Ther. 1985;65(10):1514-1516. doi:10.1093/ptj/65.10.1514
11. Mestan MA, Bassano JM. Posttraumatic osteolysis of the distal clavicle: analysis of 7 cases and a review of the literature. J Manipulative Physiol Ther. 2001;24(5):356-361. doi:10.1067/mmt.2001.115260
12. Panagiotopoulos AC, Crowther IM. Scapular dyskinesia, the forgotten culprit of shoulder pain and how to rehabilitate. SICOT-J. 2019;5:29. doi:10.1051/sicotj/2019029
13. Cools AMJ, Struyf F, De Mey K, Maenhout A, Castelein B, Cagnie B. Rehabilitation of scapular dyskinesis: from the office worker to the elite overhead athlete. Br J Sports Med. 2014;48(8):692-697. doi:10.1136/bjsports-2013-092148
14. Davarian S, Maroufi N, Ebrahimi E, Parnianpour M, Farahmand F. Normal postural responses preceding shoulder flexion: co-activation or asymmetric activation of transverse abdominis? J Back Musculoskelet Rehabil. 2014;27(4):545-551. doi:10.3233/BMR-140480

15. Lee DR, Kim LJS. Effects of hand grip exercise on shoulder joint internal rotation and external rotation peak torque. J Back Musculoskelet Rehabil. 2016;29(3):521-525. doi:10.3233/BMR-150652
16. Cools AM, Witvrouw EE, Declercq GA, Vanderstraeten GG, Cambier DC. Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms. Br J Sports Med. 2004;38(1):64-68. doi:10.1136/bjsm.2003.004952
17. Cools AM, Declercq GA, Cambier DC, Mahieu NN, Witvrouw EE. Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. Scand J Med Sci Sport. 2007;17(1):25-33. doi:10.1111/j.1600-0838.2006.00570.x
18. Borstad JD, Ludewig PM. The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. J Orthop Sports Phys Ther. 2005;35(4):227-238. doi:10.2519/jospt.2005.35.4.227
19. Brantingham JW, Cassa TK, Bonnefin D, et al. Manipulative therapy for shoulder pain and disorders: expansion of a systematic review. J Manipulative Physiol Ther. 2011;34(5):314-346. doi:10.1016/j.jmpt.2011.04.002
20. Wainner RS, Whitman JM, Cleland JA, Flynn TW. Regional interdependence: a musculoskeletal examination model whose time has come. J Orthop Sports Phys Ther. 2007;37(11):658-660. doi:10.2519/jospt.2007.0110
21. Cisneros LN, Reiriz JS. Management of chronic unstable acromioclavicular joint injuries. J Orthop Traumatol. 2017;18(4):305-318. doi:10.1007/s10195-017-0452-0
22. Aliberti GM, Kraeutler MJ, Trojan JD, Mulcahey MK. Horizontal instability of the acromioclavicular joint: a systematic review. Am J Sports Med. 2020;48(2):504-510. doi:10.1177/0363546519831013