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Canadian Chiropractic Association

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JCCA December 2023 Sports Chiropractic Special Issue: 15th Edition

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

(JCCA. 2023; 67(3):201)

KEY WORDS: sports, chiropractic, editorial

Éditorial
JCCA Décembre 2023 – Numéro spécial de la chiropratique sportive : 15e édition

MOTS CLÉS : sports, chiropratique, éditorial

As you may know, the JCCA's annual Sports Chiropractic issue is the only journal issue in the world dedicated to Sports Chiropractic research. Here we are with the 15th Sports Chiropractic issue of the JCCA. These 15 issues have only been possible with the ongoing support and dedication of the JCCA's Editorial Board, our esteemed peer reviewers, and the Canadian Chiropractic Association (CCA). I salute all the authors, past and present, for their efforts to further knowledge in Sports Chiropractic. Finally, thanks to you for taking time to read these important articles. I hope they bring you clarity, induce curiosity, and increase your appetite for evidence-based Sport Chiropractic.

As is our tradition, this year's issue includes impactful, interesting, and thought-provoking articles. In this issue you will find a couple of original research papers from exploring the validity of the Beighton score as a measure of generalized joint hypermobility to investigating the research capacity and productivity of Canadian sport chiropractors. There is also a systematic review about autonomic nervous system dysfunction in pediatric sport-related concussion and a mixed methods study about sport psychology in sport injury rehabilitation. Furthermore you will find couple of practical and rare case reports. I hope you find this issue informative and clinically applicable.

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).

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Investigating the research capacity and productivity of Canadian sports chiropractors

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Objectives: *To investigate the research capacity and productivity of Canadian sports chiropractors.*

Methods: *A cross-sectional survey (phase one) and scoping review (phase two) investigated the research capacity and productivity (from 2015-2020) of the Canadian sports chiropractic field.*

Results: *Most respondents (72%) reported obtaining research training from fellowship and master's programs, with only 2 (1%) PhD qualifications identified. Approximately, 30% reported active involvement in research, with 28% being part-time clinician researchers. Access to human and technological research resources were limited. We identified 67 publications and 16 conference*

Enquête sur la capacité de recherche et la productivité des chiropraticiens du sport canadiens

Objectifs: *Étudier la capacité de recherche et la productivité des chiropraticiens du sport Canadiens.*

Méthodes: *Une enquête transversale (première phase) et un examen de la portée (deuxième phase) ont permis d'étudier la capacité de recherche et la productivité (de 2015 à 2020) du domaine de la chiropratique sportive au Canada.*

Résultats: *La plupart des répondants (72 %) ont déclaré avoir obtenu une formation en recherche dans le cadre de programmes de bourses et de maîtrises, et seulement 2 (1 %) ont indiqué avoir obtenu un doctorat. Environ 30 % des répondants ont déclaré participer activement à la recherche, 28 % d'entre eux étant des cliniciens-chercheurs à temps partiel. L'accès aux ressources humaines et technologiques de la recherche était limité. Nous avons recensé 67 publications et 16 présentations de conférences sur une période de cinq*

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presentations within a five-year period, with clinical, population health, and basic science research as the areas most studied.

Conclusion: *The research effort of Canadian sports chiropractors is primarily conducted by clinicians involved in research on a part-time basis. Its research outputs predominantly reflect the research requirements of the RCCSS(C) Sports Sciences Residency Program, highlighting its contribution in developing capacity and producing research for the Canadian sports chiropractic field.*

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KEY WORDS: Research capacity, research productivity, research output, sports chiropractic, scoping review, survey

ans, les domaines les plus étudiés étant la recherche clinique, la recherche sur la santé des populations et la recherche en sciences fondamentales.

Conclusion: *L'effort de recherche des chiropraticiens du sport canadiens est principalement mené par des cliniciens impliqués dans la recherche à temps partiel. Leurs résultats de recherche reflètent surtout les exigences de recherche du programme de résidence en sciences du sport du Collège royal des sciences chiropratiques du sport du Canada (RCCSS(C)), soulignant leur contribution au développement des capacités et à la production de recherches pour le domaine de la chiropratique du sport au Canada.*

(JCCA. 2023;67(3):202-225)

MOTS CLÉS : Capacité de recherche, productivité de la recherche, résultats de la recherche, chiropratique sportive, examen approfondi, enquête

Introduction

In healthcare professions, research is vital not only to advance knowledge, but also to ensure evidence-informed, up-to-date, and safe patient care.[1,2] As research involving chiropractors has expanded, there have been efforts in North America[1,3,4], Australia[5], and Europe[6] to develop research agendas and evaluate the research capacity of the chiropractic profession.[7–11] Recently, a Delphi study[3] prioritized sports-focused research to inform research agenda development for Canadian sports chiropractors.[3] The top three research priorities were: effects of interventions on athletic outcomes, research about sports healthcare teams, and clinical research related to spinal manipulative and mobilization therapy. The three highest ranked conditions to research were low back pain, neck pain, and concussion. Collaborations with sports physicians, universities/colleges, and sports organizations were identified as important to pursue.[3] While many research priorities identified were specific to the sports chiropractic field, there was commonality among certain topics prioritized from Delphi studies conducted for general chiropractic practice[1,5,6], such as the integration of chiropractic care into multidisciplinary settings[1,3,5], effects of chiropractic care[1,3,5,6], spinal manipulation research[1,3,5,6], and the initiation of collaborative research activities[3,6].

While the development of a research agenda is an important step in advancing research efforts[1–3], its successful implementation is contingent on the available research resources (e.g. human and physical)[10] and the existing research environment (the academic, economic, social, political, technological and legal context in which the research is performed)[12]. Understanding the investigative capacity of the sports chiropractic field is necessary to recognize what research can be feasibly conducted, and what investments must be made to ensure a research agenda's success.[3] Moreover, once an agenda is implemented, methods must be put in place to evaluate the impact of this plan on the field's research capacity, productivity, and dissemination.

Research capacity is defined as "the ability to engage in, perform or carry out quality research."[13], where research productivity relates to the research output of a field of study.[14] Outputs of research are defined as an outcome of research that can take many forms, such as journal articles, conference publications, and patents, as examples.[15,16] Research capacity evaluations of a field of

study are important to conduct. They facilitate the oversight of the research infrastructure (including the human, physical and technological research resources available) and monitors research output.[17] With regular assessment of the research environment, a field of study can more easily conduct a needs analysis to determine what resources are required and how to allocate them responsibly to minimize research waste.[10,18] Regular monitoring can also allow organizations and researchers to navigate more swiftly and proactively when changes occur in the research environment.[10]

Previously, Stuber *et al*.[10] evaluated the research resource environment for the Canadian chiropractic profession by conducting a cross-sectional research capacity survey of members of the Canadian Chiropractic Association. These authors reported 93 full- and part-time chiropractic researchers in Canada who produced 530 authorships within a five-year period. Clinical research was the most common area of research, with systematic reviews representing the study type of the highest-level of evidence conducted. Office and laboratory space were reported as research facilities, and various collaborations were identified. While this information facilitates planning for the advancement of chiropractic research, these findings may not be fully transferrable to the sports chiropractic field, which may have its own unique research resource requirements. To our knowledge, the research capacity and output of the Canadian sports chiropractic field has not been studied.

The aim of this study is to investigate the Canadian sports chiropractic research resource environment by investigating its research capacity and productivity. This evaluation is part of a group of interrelated studies[3,4,19,20] conducted and planned to inform strategies to advance the research impact potential of the Canadian sports chiropractic field. Specifically, this present study will contribute the methods for an on-going research monitoring strategy that can be conducted every five-years to facilitate regular oversight of the Canadian sports chiropractic research effort.

Methods

Two phases were utilized to investigate the research capacity and productivity of the Canadian sports chiropractic field. Phase one involved a cross-sectional research capacity and productivity survey of all active fellows and residents of the Royal College of Chiropractic Sports Sciences (Canada) (RCCSS(C)). Phase two applied scoping review methodology to identify sports-focused chiropractic research outputs from January 17, 2015 to January 17, 2020. Since the intended outcome of this work is to create the methods for an on-going research monitoring strategy, a five-year period was chosen as it aligns with common timeframes for strategic planning cycles for organizations[21,22], such as the RCCSS(C). Additionally, a five-year interval facilitates the identification of research outputs from research occurring in the early to middle stages of an organization's strategic plan as it accounts for time lags from journal submission to publication that can range from a few months to up to two years.[23]

Phase one: *Research capacity and productivity survey*

The Consensus-Based Checklist for Reporting of Survey Studies (CROSS)[24] was used to report the methods of phase one of this study.

Survey content

A cross-sectional survey, the Sports Chiropractic Research Capacity and Productivity Survey (Sports Chiro ReCaP Survey), was developed by modifying an existing research capacity survey that collected data on the Canadian chiropractic research resource environment.[9–11] Modifications were made to adapt the survey to the sports chiropractic research context. Additional questions were added by consulting previous research capacity development studies[17,25] and a framework[26] that identified six principles for research capacity building: skills and confidence development, supporting linkages and partnerships, ensuring research is 'close to practice', facilitating appropriate dissemination, investing in infrastructure, and building sustainability and continuity.

The Sports Chiro ReCaP Survey (please contact corresponding author for details) is comprised of 38 questions covering eight themes: demographic characteristics (n=5), professional activities (n=2), research training (n=4), research roles/positions (n=5), research activity (n=4), research resources (n=6), collaborations (n=4), and research output (n=8). For this survey, "sports-focused research" was defined using the RCCSS(C) definition[27] (Appendix 1). Face validity of the survey was established by piloting and revising the survey with five content experts who are active contributors to sports-focused chiropractic

research. Of these experts, two have PhD qualifications, four are fellows of the RCCSS(C), four hold sports chiropractic leadership positions, and one is a coordinator of a sports chiropractic specialty training program. At the time of pilot testing, their mean ± SD clinical practice and research experience was 18 ± 5.9 and 15 ± 6.6 years, respectively.

Recruitment and survey administration

The target population for the cross-sectional survey were all active fellows and residents of the RCCSS(C). In Canada, the RCCSS(C) serves as the national governing organization for sports chiropractic, and RCCSS(C) members are considerable producers of sports-focused chiropractic research in Canada.[28] The majority of RCCSS(C) members have conducted sports-focused chiropractic research at some point in their careers, since a requirement of obtaining fellowship status from the RCCSS(C) involves completing research requirements.[27]

Self-selection sampling[29] was utilized by inviting all active fellows and residents of the RCCSS(C) (197 members) to participate in this online survey by direct recruitment at kiosks stationed at the RCCSS(C) Annual General Meeting (November 8, 2019), Annual Sports Conference (November 9-10, 2019), and by email invitations sent by the RCCSS(C) Office (weekly email invitations sent between November 12, 2019 to December 24, 2019). The Sports Chiro ReCaP Survey was administered electronically utilizing the SurveyMonkey platform (Momentive, San Mateo, California, USA).

To prevent multiple participation of the survey, participant names of those who completed the online survey at a kiosk stationed at the RCCSS(C) Annual General Meeting and Sports Conference were collected by a research assistant and placed in a secure document lockbox. At the completion of each day of kiosk data collection (November 8-10, 2019), the executive assistant of the RCCSS(C) accessed the lockbox to review the list of participants who completed the survey, removed their emails from the study email list for the email recruitment period of the survey, and then destroyed the list of participant names. SurveyMonkey uses cookies to determine if someone has previously taken a survey and provides options to permit single or multiple responses to an online survey.[30] To facilitate survey completion with tablets and laptops at the kiosks, the "multiple responses option" was enabled (November 8-10, 2019). Once kiosk collection was completed, the "multiple responses option" was disabled for the email invitation recruitment period of the survey (November 12, 2019 to December 24, 2019).

Data analysis - research capacity and productivity survey

Only fully completed surveys were included in the analysis. For calculating the survey response rate, fully completed surveys were included in the numerator and both respondents and non-respondents were included in the denominator.[31,32] All survey data were imported into Excel (Microsoft Corporation, USA), and analysed with descriptive statistics (frequencies, percentages and means).

Ethics

Phase one of this study received approval by the Canadian Memorial Chiropractic College (CMCC) Research Ethics Board (#1910B01, approval date 11/1/2019) prior to commencement. The online survey included a project information letter and informed consent form. Participants provided their informed consent to participate in the online survey by selecting the "accept" response at the end of the online informed consent form. No direct identifying information was collected in the survey.

Phase two: *Scoping review of sports-focused chiropractic research outputs (January 17, 2015 to January 17, 2020)*

Phase two applied scoping review methodology, guided by the framework outlined by Levac *et al*[33] and the PRISMA extension for scoping reviews[34]. Protocol registration was conducted at Open Science Framework (https://osf.io/bqahf/).

Identify the research question

We formulated the following research question: 'What is the research output (defined in this study as journal publications and conference presentations) of the Canadian sports chiropractic field from January 17, 2015 to January 17, 2020?' A five-year period was chosen, as this is a common time horizon utilized to set activities for achievement for strategic plans,[21,22] and is a reasonable period to account for the time lag of scholarly activity to lead to a research output (e.g. publication, grant obtainment, patent filing, etc.).[23]

Selection criteria

For inclusion, a research output met the following eligibility criteria: 1) it met the definition of sports-focused research as outlined by the RCCSS(C)[27] (Appendix 1), 2) at least one author was a Canadian chiropractor or a non-chiropractor faculty member of a Canadian chiropractic educational institution, 3) it was published in a peer reviewed journal or was listed as a conference presentation on research output lists obtained from the CMCC or Université du Québec à Trois-Rivières (UQTR) chiropractic training programs, and 4) it was published in either the English or French language. There were no limits on publication type or study design.

Information sources and search strategy

PubMed, MEDLINE (EBSCO), CINAHL, SPORTDiscus and the Index to Chiropractic Literature databases were searched on January 17, 2020. The search strategy was developed in consultation with an academic reference librarian. The search strategy was developed in MEDLINE and adapted to the other bibliographic databases. Search terms included subject headings (e.g., MeSH in MEDLINE) for each database and free text words for the key concepts of sports, chiropractic, and Canada (see Appendix 2 for the MEDLINE search strategy). Additionally, author searches of the studies retrieved from the literature search were cross-referenced using a Google search to confirm if authors were a Canadian chiropractor or a non-chiropractor faculty member of a Canadian chiropractic educational institution. Research output lists were obtained from the chiropractic research departments from CMCC (date range: January 2015 to January 2020) and UQTR (date range: January 2015 to January 2018) by email request. Search results from each database were imported and research output lists were manually entered into Endnote (Endnote X9 Version, Clarivate, Philadelphia, PA, 2013) for reference management. Duplicate citations were identified using the duplicate identifying functions in Endnote and were manually verified before removal.

Study selection

A two-phase (titles and abstracts; full-text articles) screening process was used to select eligible studies. In phase one screening, pairs of independent reviewers screened citation titles and abstracts to determine the eligibility of studies (categorizing studies as possibly relevant or irrelevant). Pairs of independent reviewers screened possibly relevant studies in full text during phase two screening to determine eligibility and documented reasons for exclusion. Reviewers met to discuss disagreements and reach consensus on study eligibility. A third reviewer was consulted in situations where consensus was not reached. Study authors were contacted for additional information as needed when screening and conducting data extraction.

Data extraction and synthesis

Extracted data from eligible studies was used to build key information tables. A second reviewer independently extracted study results and any disagreements were discussed to reach consensus. From each study, extracted data included author, year of publication/presentation, title, journal/conference, publication type, study design, area of research, and sport setting. Data were reported numerically and thematically. Descriptive statistics (frequency counts and percentages) were used to summarize the extracted data.

Results

Phase one: research capacity and productivity survey

Survey response and completion

Of the 197 active fellows and residents of the RCCSS(C), 47 participated in the online survey at a kiosk at the RCCSS(C) Annual General Meeting and Conference and 68 participated in response to email invitations sent by the RCCSS(C) Office. Of the 115 survey responses collected, 109 were fully completed surveys (55% response rate).

Participant demographics (Table 1)

Approximately 50% of respondents were between the ages of 31-50 and 72% of respondents were male. When asked about the number of years in active clinical practice, 36% of respondents practised 0-10 years, and 48% practised 11-30 years. Most respondents were graduates of the CMCC (80%). Approximately, 69% of respondents had obtained a chiropractic fellowship designation, 24% had a master's degree, and only 1.8% had a PhD degree. Additionally, 32% of respondents were currently in the process of completing a graduate training program with chiropractic fellowship being the most common. Nearly 27% of respondents held an academic position at a college or university as permanent or adjunct faculty.

Table 1.
Demographic analysis of survey participants (n=109)

Age	**Sample of Respondents, n (%)**
20-30	18 (16.5%)
31-40	27 (24.8%)
41-50	27 (24.8%)
51-60	23 (21.1%)
61+	14 (12.8%)
Gender	
Male	78 (71.6%)
Female	31 (28.4%)
How many years have you been in active clinical practice (active clinical practice is defined as practicing chiropractic either part- or full-time)?	
0-10 years	39 (35.8%)
11-20 years	23 (21.1%)
21-30 years	29 (26.6%)
31 + years	18 (16.5%)
Which chiropractic institution(s) did you graduate from?	
Canadian Memorial Chiropractic College	87 (79.8%)
Université du Québec à Trois-Rivières	5 (4.6%)
Western States Chiropractic College	5 (4.6%)
New York Chiropractic College	3 (2.6%)
Palmer Chiropractic College West	4 (3.7%)
Logan University	2 (1.8%)
Palmer Chiropractic College	1 (0.9%)
Los Angeles College of Chiropractic	1 (0.9%)
National University of Health Sciences	1 (0.9%)
Do you have a graduate degree (completed a university-based program) or a chiropractic specialty fellowship?	**Sample of Respondents, n (%)**
Master's Degree	27 (24.8%)
PhD Degree	2 (1.8%)
Chiropractic Fellowship	78 (69.0%)
No	22 (20.1%)
Are you in the process of completing a graduate degree (university-based) or a chiropractic fellowship?	
Master's Degree	8 (7.1%)
PhD Degree	2 (1.8%)
Chiropractic Fellowship	25 (23.0%)
No	80 (73.5%)
Are you interested in pursuing further graduate studies? Select all that apply.	
Master's Degree	16 (14.2%)
PhD Degree	16 (14.2%)
Chiropractic Fellowship	8 (7.1%)
No	66 (60.6%)
Other	8 (8.0%)
Do you currently hold an academic position at a university or college?	
Yes	30 (26.6%)
No	79 (72.3%)
What is the nature of your academic employment? (n=31)	
Tenured	1 (3.2%)
Tenure Track	0 (0.00%)
Permanent position no tenured track available at institution	13 (41.9%)
Contract	6 (19.4%)
Adjunct Faculty	9 (29.0%)
Other	2 (6.45%)

Professional activities, research training, areas of research, and roles

On average, survey respondents reported clinical practice consumed 66% of their professional workload, followed

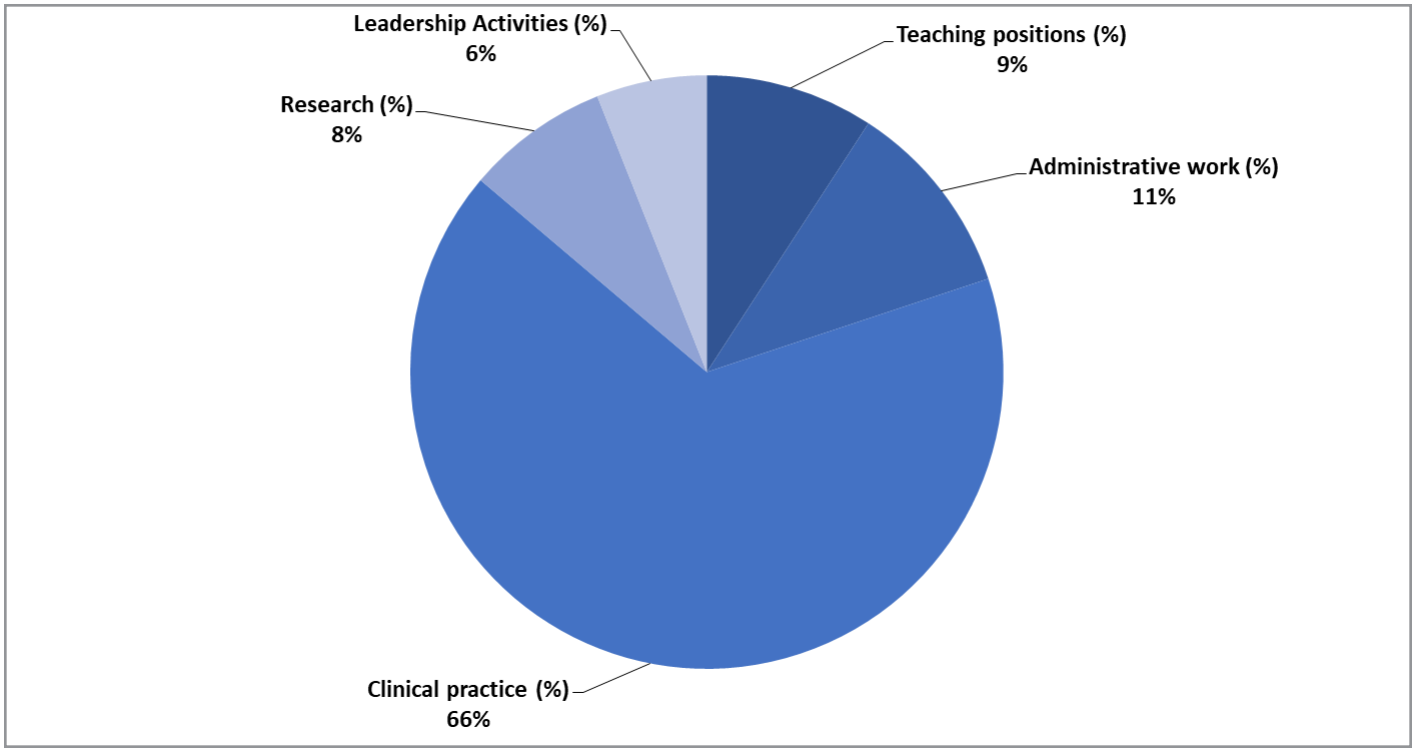

Figure 1.
Breakdown of professional activities

by administrative work (11%), teaching (9%), research (8%) and leadership activities (6%) (Figure 1). Of the 109 respondents, 33 (30%) identified themselves as an active chiropractic researcher. Within this subset, 31 were engaged in research in a part-time capacity, and only 2 respondents reported conducting research full-time. Only 14% of the 109 respondents reported protected time to conduct research. Most participants (72%) reported receiving formal training in research methodology. Of the participants involved in research, the largest categories of research focus (Figure 2) were basic science and mechanism (27%), clinical and epidemiology (25%), and health services and health policy research (21%). Sports-focused research (related to chiropractic practice applied to sport) and general sports-focused research were 10% and 9%, respectively. Sixty-six percent of respondents were involved in other professional activities such as leadership positions (board of directors, committee chair, or committee member). Within the past five years, 15% of respondents reported acting as a research mentor, 18% reported supervising a resident (or graduate student), and 15% reported supervising a chiropractic student research project. With respect to access to research mentorship and/or supervision, 69% reported having the ability to access a PhD supervisor or mentor.

Access to research resources

Survey respondents reported on their access to research-related resources in three domains with variable results (Table 2). Overall, respondents reported the highest access to reference librarians for human resources (46%), chiropractic table for physical resources (83%), and research databases for technological resources (65%). There were 45 (41%), 13 (12%), and 32 (29%) respondents who reported no access to human, physical, and technological research resources, respectively.

Collaboration

At the time of the survey, 18% were currently involved in a research collaboration outside of their academic institutions. When asked about professionals they collaborate with in research, respondents were most likely to collabor-

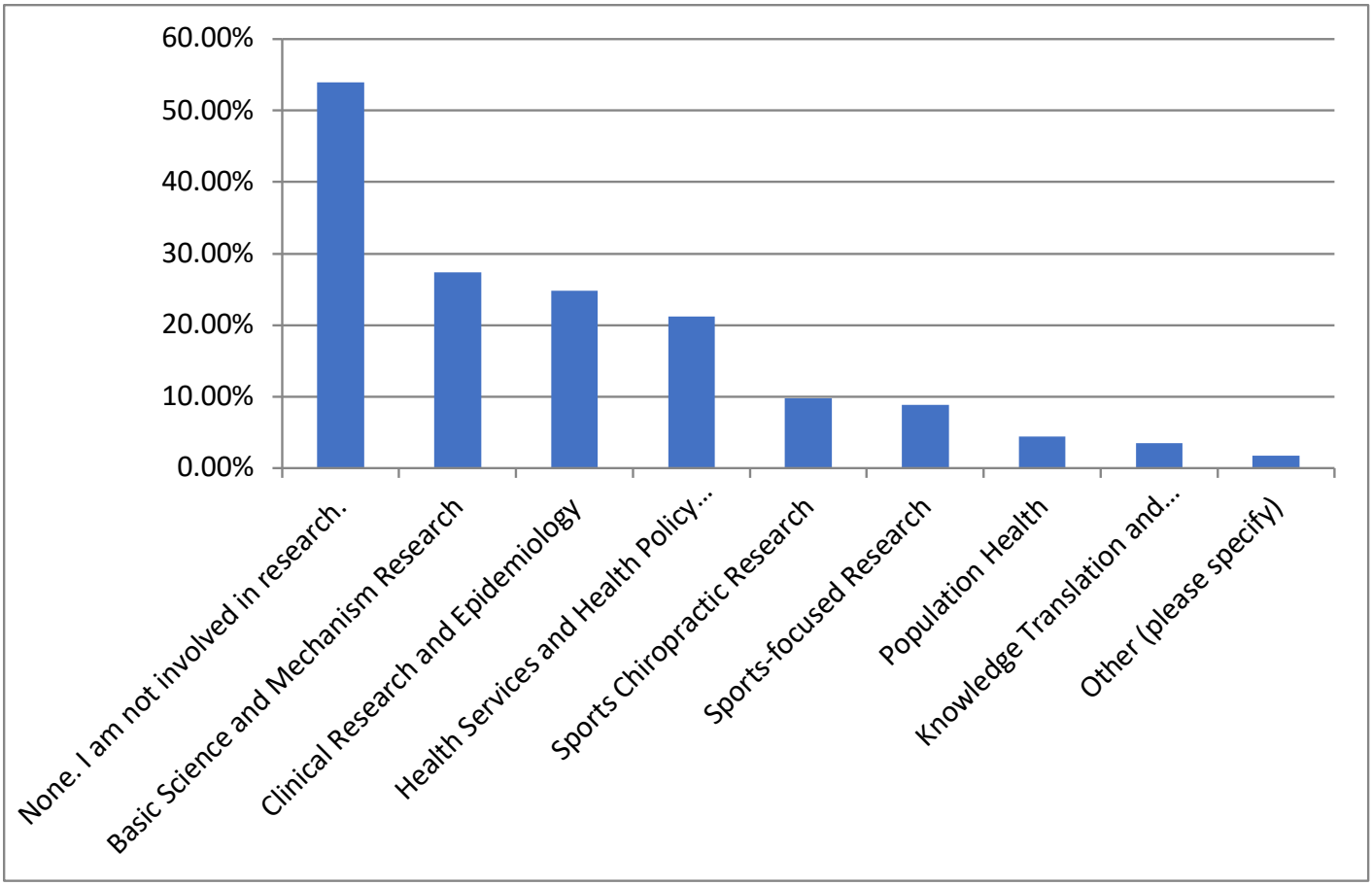

Figure 2.
Areas of research focus reported by Canadian sport chiropractors

ate intra-professionally (67%), with sport residents, sports chiropractic organisations, and the Canadian Chiropractic Research Foundation, provided as examples. Inter-professional collaboration was reported by 62% of respondents, and other areas of collaboration reported were with leading experts in the field (36%), funding agencies (7%), and industry (3%).

Research productivity

In the last 5 years, 29 (27%) respondents reported publishing a scientific paper as a primary author, with most of these respondents (76%) involved in publishing 1-2 articles. Similarly, 30 (28%) respondents reported publishing a scientific article as a secondary or co-author, with most of these respondents (77%) involved in 1-2 publications (Table 3). The top five study types that respondents participated in within the past 5 years were case reports (36%), systematic reviews/meta-analyses (28%), observational studies (20%), questionnaire/survey studies (14%), and narrative reviews/commentaries (12%). In total, 20 (18%) and 16 (15%) respondents reported conducting a scientific poster and platform presentation within the last 5 years, respectively. Forty-seven respondents (43%) reported current involvement in a sports-focused research project, with 17% as a primary investigator, 21% as a co-author, 3% as a research assistant, and 2% as a consultant. Within the past five years, 21 (19%) respondents reported receiving research grant funding, with one participant obtaining over 9 grants. As for participation in other scholarly activities within a five-year period, 27 (25%), 9 (8%), and 5 (5%) respondents reported serving as a peer reviewer for a journal, scientific conference, and granting agency,

respectively. A total of 6 respondents reported serving as a member of an editorial board of a journal, and 18 reported serving on a research committee.

Table 2.
Number of respondents with access to specific research resources (n=109)

Human Resources	**Respondents with Access**
Reference librarian	51 (46.4%)
Statistician	43 (39.1%)
Research Ethics Board	42 (38.2%)
Research methodologist	30 (27.3%)
Research assistants	27 (24.6%)
Laboratory technicians	25 (22.7%)
None of the above	45 (41.0%)
Other (please specify)	0
Physical Research Resources	**Respondents with Access**
Chiropractic table	91 (82.7%)
Office space	63 (57.3%)
Academic library	54 (49.1%)
Force plate	33 (30.0%)
Motion capture system	33 (30.0%)
Laboratory space/equipment	31 (28.2%)
Simulation lab	23 (20.9%)
Cadaver lab	22 (20.0%)
Electromyography system	21 (19.1%)
Biochemical resources	19 (17.3%)
None of the above	13 (11.8%)
Other (please specify)	3 (2.73%)
Technological Research Resources	**Respondents with Access**
Research databases (Eg. Medline, CINAHL, etc.)	72 (64.9%)
Bibliographic referencing software, such as Endnote, Mendeley, etc.	45 (40.5%)
Electronic journal holdings	44 (39.6%)
None of the above	32 (28.8%)
Statistical software	28 (25.2%)
Other (please specify)	1 (0.9%)

Table 3.
Research productivity of RCCSS(C) members over previous five years

Number of publications	0	1-2	3-4	5-6	7-8	9+
Sports-focused research paper in peer-reviewed journal as primary author (n=109)	80 (73.4%)	22 (20.2%)	5 (4.6%)	2 (1.8%)	0 (0.0%)	0 (0.0%)
Sports-focused research paper in peer-reviewed journal as co-author/ non-primary investigator (n=109)	79 (72.5%)	23 (21.1%)	3 (2.8%)	3 (2.8%)	0 (0.0%)	1 (0.9%)
Number of conference presentations	0	1-2	3-4	5-6	7-8	9+
Sports-focused research poster presentations (n=29)	9 (31.0%)	14 (48.3%)	5 (17.2%)	1 (3.5%)	0 (0.0%)	0 (0.0%)
Sports-focused research platform presentations (n=29)	13 (44.8%)	10 (34.5%)	4 (13.8%)	2 (6.9%)	0 (0.0%)	0 (0.0%)

Phase two: sports-focused chiropractic research outputs (January 17, 2015 to January 17, 2020)

Search results and study selection (Figure 3)
A total of 762 and 775 citations were identified through database searching and retrieval of research output lists (CMCC and UQTR), respectively. After removal of duplicates, 1105 citations were screened by reviewing titles and abstracts, of which 956 were excluded for not meeting the inclusion criteria. Of the 149 journal articles and conference presentations assessed for eligibility, 21 did not meet the sports-focused research definition, 35 did not include a Canadian chiropractor and/or Canadian chiropractic academic faculty, and 10 additional duplicates were identified. A total of 83 scientific works (67 journal publications[19,35–100] and 16 conference presentations[101–116]) were included in the qualitative synthesis (contact primary author for details).

Study design (Table 4)
Among the 67 journal publications, 34 (51%) were case reports/case series and 16 (24%) were original research studies. The most common original research study type was questionnaire/survey studies (10%). Of the higher level of evidence study types, only one systematic/scoping review and one randomized clinical trial were identified. Of the conference presentations, 12 (75%) were original research, two (13%) were systematic/scoping reviews, and none were case reports/case series.

Table 4.
Study design

Study Design	Journal publications[a], n (%)	Conference presentations[a], n (%)
Case reports/case series	34 (51%)	0
Original research (published)	16 (24%)	12 (75%)
Questionnaire/survey	7 (10%)	5 (31%)
Retrospective chart review	2 (3%)	0
Prospective cohort	2 (3%)	0
Quantitative text analysis	1 (1%)	1 (6%)
Computer simulation	1 (1%)	0
Randomized clinical trial	1 (1%)	0
Retrospective cohort	1 (1%)	1 (6%)
Laboratory study	1 (1%)	3 (19%)
Controlled trial	0	1 (6%)
Qualitative	0	1 (6%)
Editorials/commentaries	8 (12%)	1 (6%)
Book reviews	5 (7%)	0
Narrative reviews	2 (3%)	0
Systematic/scoping reviews	1 (1%)	2 (13%)
Historical paper	1 (1)%	0
Conference workshop presentation	0	1 (6%)
Total publications	67	16

a Due to rounding, may not add to 100%

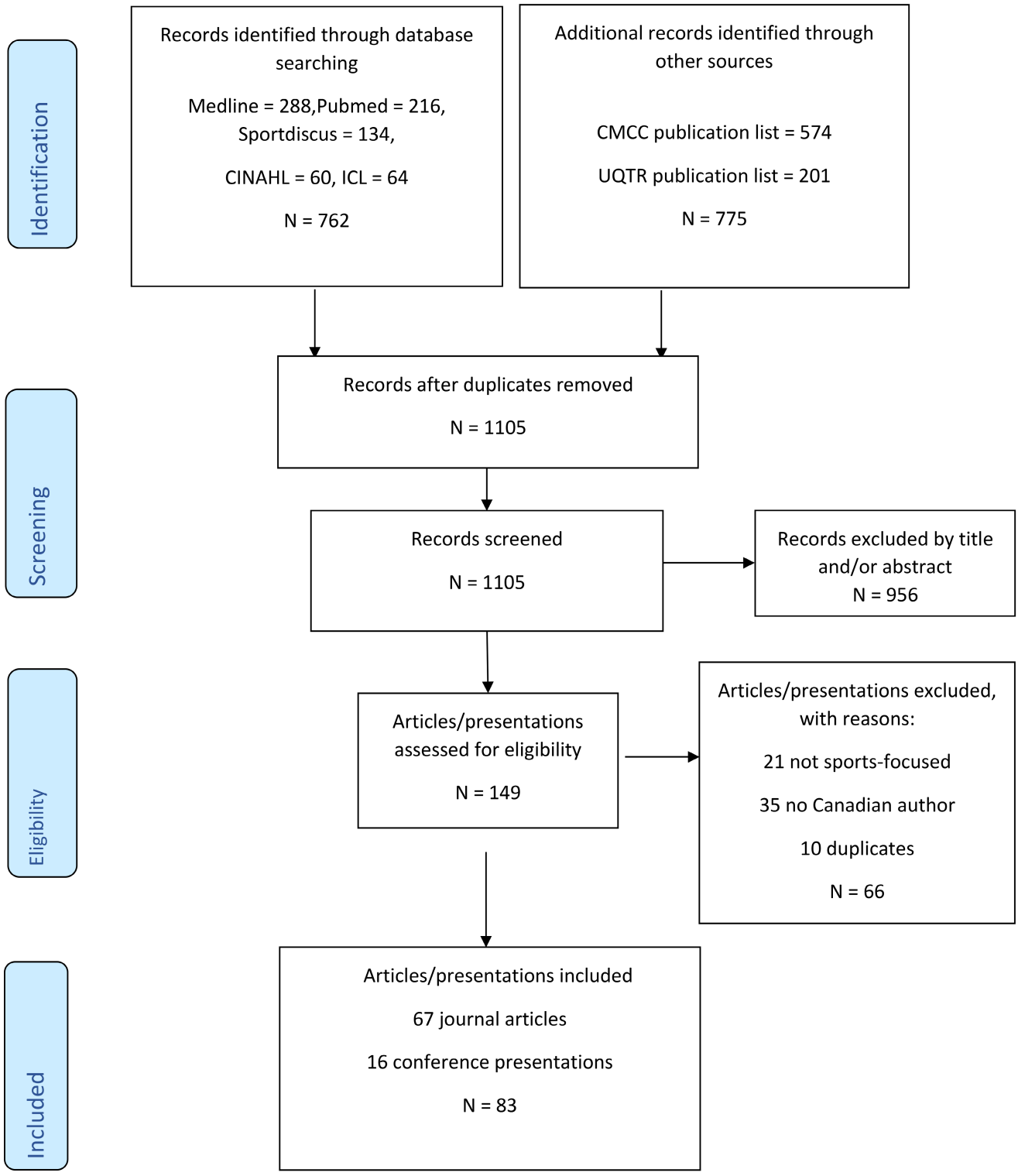

Figure 3.
Preferred Reporting Items for Systematic Reviews and MetaAnalyses Extension for Scoping Reviews flow diagram

Area of research (Table 5)
Clinical research was the most common area of research with 48 (91%) and 12 (75%) of journal publications and conference presentations contributing to this topic area, respectively. Population health and special populations was the second highest area of research for journal publications (25%) and third highest for conference presentations (13%). Basic science and mechanism research was third highest for journal publications (6%) and second highest for conference presentations (31%).

Table 5.
Area of research

Area of Research	Journal publications[b], n (%)	Conference presentations[b], n (%)
Clinical	48 (91%)	12 (75%)
Population health and special populations	13 (25%)	2 (13%)
Basic science and mechanism	3 (6%)	5 (31%)
Health services	1 (2%)	2 (13%)
Total publications/presentations contributing to the Area of Research Count[a]	53	16

[a] Certain publications & presentations contributed to more than one area of research. Editorials/commentaries, historical papers, and book reviews did not contribute to the area of research count
[b] Due to rounding, may not add to 100%

Journals, conferences, and specific sports
For journal publications, the majority (56 publications, 84%) were published in the Journal of the Canadian Chiropractic Association (JCCA), two (3%) were published in the Clinical Journal of Sport Medicine, and one each were published in Sports Health: A Multidisciplinary Approach, Journal of Orthopaedic & Sports Physical Therapy, The Physician and Sports Medicine, Journal of Martial Arts Anthropology, Journal of Back and Musculoskeletal Rehabilitation, Journal of Chiropractic Medicine, Chiropractic & Manual Therapies, Journal of Contemporary Chiropractic, and Journal of Bodywork and Movement Therapies. Most conference presentations were made at the World Federation of Chiropractic Biennial Conference (8 presentations, 50%), followed by the Association of Chiropractic Colleges Research Agenda Conference (2 presentations, 12.5%), and the International Symposium for Taekwondo Studies (2 presentations, 12.5%). Additionally, 45 scientific works (publications and/or conference presentations) conducted research on a specific sport, with the top five sports being hockey (10), soccer (7), taekwondo (5), baseball (4), and mixed-martial arts (3).

Discussion
To our knowledge, this is the first study to investigate the research capacity and productivity of the Canadian sports chiropractic field. Our findings revealed most RCCSS(C) survey respondents had formal research training, with the majority achieved through chiropractic fellowship programs, with a proportion attained from high degree research (HDR) training programs (28 master's and 2 PhD degrees). Approximately, 29% of survey respondents reported being active in chiropractic research, which represents 17% of RCCSS(C) members. The majority conduct research part-time with clinical duties making up the highest proportion of their professional workload. Access to research resources was varied across respondents. Human and technological research resources were areas where many reported not having access. Only 18% reported being actively involved in a research collaboration outside of their academic institution. We identified 67 publications and 16 conference presentations within a five-year period. Of the publications, the majority were case reports (34) with 16 being original research. The publications were in the areas of clinical, population health, basic science, and health services research.

Interpreting our results within the context of the most recent evaluation of the Canadian chiropractic research resource environment, Stuber *et al*.[10] identified 26 full-time and 67 part-time researchers, with 84 master's and 18 PhD qualifications. These researchers combined for a total of 530 authorships within a five-year period. The main areas of research reported were clinical, epidemiology, basic sciences, and health services research. Considering sports chiropractic is a small specialty within the Canadian chiropractic profession, the absolute number of researchers and research output identified from our study is smaller compared to that of Stuber *et al*.[10] due to its smaller relative size. However, at the time of our survey, 17% (33/197) of RCCSS(C) members reported being actively involved in research, which is larger than the 1.3% of Canadian chiropractors engaged in research as previously reported.[10]

At present, the Canadian Chiropractic Association report there are greater than 9,000 chiropractors licensed in Canada.[117] Applying our survey results to this national data, active researchers of the RCCSS(C) comprise approximately 0.37% (33/9000) of Canadian chiropractors engaged in research. The level of research engagement by RCCSS(C) members may be the result of its fellowship training program, where residents are required to conduct research as a part of their training, and fellows often mentor residents in this process.[27] With 18% of respondents in the present survey reporting involvement with research mentorship of a resident, mandatory research built into fellowship training programs is a mechanism that can stimulate research engagement.[118] To our knowledge, research capacity and productivity evaluations have not been published by other chiropractic fellowship programs, so it is not known if the level of research engagement within the RCCSS(C) is similar to other chiropractic specialties. With a "duty of care" of Canadian chiropractic specialty colleges to train its members and establish research as an important professional goal,[119] conducting such evaluations enables specialty colleges to monitor and evaluate their research activities to facilitate strategic planning to attain their research goals.

Investigating fellowship training programs in medicine, Cvetanovich *et al*.[120] evaluated the academic productivity of the orthopaedic sports medicine fellowship of the American Orthopaedic Society for Sports Medicine (AOSSM) and identified 610 faculty members representing 90 fellowship programs. Using the commercially available Scopus database, these authors identified 57 cumulative publications and 16 occurring within a three-year period. A similar study[118] of the American Orthopaedic Foot and Ankle Society (AOFAS) fellowship programs identified 187 faculty members from 48 fellowships programs and found the reported mean total number of publications per faculty member was 44.9 (SD=53.0; range 0-323; median=30). Interestingly, only 12 (2%) and 2 (1.1%) PhD qualifications were identified within the AOSSM and AOFAS samples, respectively.[118,120] A more recent study[121] that analyzed the American Medical Association's residency database and publicly available orthopaedic surgery residency programs identified 911 orthopaedic sports medicine faculty members and reported 38% master's and 23% PhD degrees. In comparison to these orthopedic fellowships, the research qualifications within our sample were lower at 24.8% and 1.8% for master's and PhD degrees, respectively. The lack of PhD qualifications within the RCCSS(C) represents a critical research capacity gap, since evidence indicates that researchers with advanced academic degrees contribute to greater engagement in research.[121]

At present, the Canadian sports chiropractic field does not have a financial support program for its clinicians to undertake HDR training (master's and PhD). Pursuing HDR studies requires significant investment and sacrifice for clinicians in practice (e.g., time away from practice, financial limitations, etc). These barriers may make such pursuits unfeasible for clinicians without formal support programs. An additional research capacity concern was the scarcity of full-time researchers. With only two survey respondents who reported conducting research full-time, the ability of the Canadian sports chiropractic field to increase its research output, maintain stakeholder collaborations, and sustain research leadership will be limited unless strategies are developed to fund full-time research opportunities. Additionally, many respondents to our survey reported limited access to research resources. With 80 (73.5%) respondents not presently enrolled in formal research training programs and 79 (72.3%) without an academic position, it is not surprising RCCSS(C) members without academic affiliation have difficulty accessing research resources. Strategies identified to build research capacity in allied health professions include creating pathways for HDR training, offering funding for research career opportunities, providing access to research resources, and establishing collaborations/partnerships with experienced research teams.[13] The Canadian sports chiropractic field should pursue and invest in these strategies.

When reviewing the study designs of the research outputs identified from our scoping review, the majority were case reports/case series (51%), which is reflective of the written requirements of the sports sciences residency training program of the RCCSS(C) (written requirements option 1: 4 case reports/case series, 1 literature review, 4 book reviews, and 1 original research study or option 2: 2 case reports/case series, 1 systematic review, and 1 original research study).[27] There was a paucity of research outputs from study designs of higher levels of evidence (e.g., randomized clinical trials, systematic reviews, large cohort studies). This is not surprising given only two full-time researchers and two PhD qualifications were identi-

fied. Complex study designs require advanced research expertise, supportive infrastructure, and adequate funding for successful execution. From our scoping review, the study designs with the highest frequency were those that are typically less resource intensive to conduct (e.g. questionnaires, retrospective chart reviews, case series, case reports). This finding likely reflects the current resource capability of the field. Should the Canadian sports chiropractic field aim to conduct more complex investigations, investments must be made to develop the human resources, infrastructure, and funding to support this work. An additional explanation for the limited RCTs and systematic reviews identified from our scoping review includes our selection criteria of only including research that met the definition of "sports-focused research"[27]. It is likely many researchers from the Canadian sports chiropractic field were involved in additional research that was not sports-focused. Our Sports Chiro ResCaP survey results support this supposition as 30 (28%) respondents reported being involved in conducting a systematic review within the investigated timeframe, which contrasts with our scoping review where one and two systematic/scoping reviews were identified as a publication and conference presentation, respectively.

With respect to the venue of publication, the JCCA published 84% of the sports-focused chiropractic research identified within the five-year review period of this study. Since 2009, the JCCA has published a special annual sports chiropractic issue, providing a publication setting to facilitate the dissemination of sports-focused chiropractic research.[122] This special sports edition along with offering open-access publication without a publication fee is likely a reason for the publication preference of Canadian sports chiropractic researchers. While the JCCA's special sports edition is an important publication venue for Canadian sports chiropractors, the high concentration of the field's research appearing in a single journal can potentially promote bias by engaging a smaller pool of peer reviewers in providing scholarly feedback. By concentrating publications within a single chiropractic journal, the dissemination of the work may be limited to a readership confined to the chiropractic profession. Submitting research for publication to various journals has benefits, especially if interdisciplinary journals are targeted. It can lead to broader diversity in the peer review process, providing researchers with valuable interdisciplinary insight to help shape their work. It can also increase the dissemination of research, permitting a broader reach to increase the diffusion of the field's research beyond the chiropractic profession.

The findings of this research capacity and productivity evaluation provide the data necessary to inform research strategy development for the Canadian sports chiropractic field. For the Canadian sports chiropractic field to conduct impactful research, investments in research capacity building interventions are required. The field of research capacity development (RCD) for health professions is an important area of study. A recent systematic review by Matus *et al*.[13] investigated research capacity building frameworks for allied health professions and identified three interconnected and interdependent themes essential for research capacity building that include 'supporting clinicians in research', 'working together' and 'valuing research for excellence'. These authors integrated these themes along with specific strategies to create a consolidated framework for RCD that can be applied at the individual, team, organization, and policy levels. In particular, the 'supporting clinicians in research' theme of this framework includes strategies of direct relevance to address areas of concern identified from our present research capacity and productivity evaluation. These strategies include education and training, opportunities to get involved, research friendly workplace, mentoring/coaching, access to resources, protected time and funding, reward and recognition, support to undertake post-graduate study including HDR, and skill mix of teams. Additionally, Cooke *et al*.[123] published a framework for research capacity development for impact that includes seven principles: skills and confidence building, co-production, actionable dissemination, infrastructure, linkages and collaborations, sustainability and leadership, and ownership and responsibilities. Similar to Matus *et al*.[13], this framework outlines the importance of RCD interventions working at and across individual, team, organization, and whole systems levels to foster RCD. In addition to this quantitative research capacity and productivity evaluation, our research group also conducted a qualitative study that interviewed sports chiropractic researchers and leaders to identify the challenges and opportunities for building research capacity in sports-focused research in the chiropractic profession. A manuscript reporting these results is forthcoming. It is our intention that the results of our qualitative and quantitative research capacity evaluations will

provide the data to apply RCD frameworks[13,123] to develop a RCD strategy for the Canadian sports chiropractic field. This RCD strategy will aim to develop the research resources and environment for the Canadian sports chiropractic field to conduct quality research that can make a positive impact to the health and well-being of Canadian society.

Strengths, limitations and future research

A strength of our study was our 55% survey response rate, which is larger than the 7.5% obtained from the research resource environment survey conducted for the Canadian chiropractic profession.[10] Previous research capacity survey studies utilizing email invitation for survey recruitment report response rates ranging from 7.5% to 48%.[10,124–126] A possible reason for our favourable response rate is likely the result of our recruitment approach that involved email invitation combined with in-person recruitment at a kiosk at the RCCSS(C) AGM and annual conference. However, it is possible our recruitment at these events may have introduced a biased sample as RCCSS(C) members who attended the AGM and annual conference may represent a more engaged sample compared to RCCSS(C) members who do not attend such events. Our results should be interpreted within this limitation.

Previous research capacity and productivity investigations have relied on self-report surveys[10,126] and conducting author searches of the Scopus database[118,120]. Self-report surveys are prone to recall bias and low response rates, influencing the accuracy of surveys to capture research output data. The Scopus database is a commercial database,[127] and not all journals are indexed in Scopus, potentially providing a limited view of research published. Since not all sports-focused chiropractic research in Canada is conducted by RCCSS(C) members, it was important to conduct a scoping review to supplement our survey results to capture research output data of sports-focused research conducted by Canadian chiropractors who are not RCCSS(C) members. We believe obtaining research output data from these two approaches has the benefit of providing a broader view of the research output of the Canadian sports chiropractic field by triangulating the results from both methods. The true research productivity likely falls between the results of both approaches. An advantage of our survey collection includes the capability to capture ongoing and unpublished research, which can be difficult for scoping reviews to identify.

A limitation of our scoping review approach was our inclusion of only publications or presentations that met the RCCSS(C) definition of being "sports-focused research"[27]. This likely underestimated the overall research output of the Canadian sports chiropractic field, as some of these researchers may be involved in research in other areas of study. However, the aim of the scoping review component of this study was to identify only "sports-focused" research outputs over a five-year period (January 17, 2015 to January 17, 2020), and we did not attempt to determine the field's cumulative publication output. Additionally, we only included journal publications and conference presentations, and other research outputs, such as policy documents or patent applications, were not included. It is possible our search strategy could have missed possible publications as our literature search was not peer reviewed by a second librarian utilizing the Peer Review of Electronic Search Strategies statement[128], and while we reviewed publication lists from CMCC and UQTR, we did not search other grey literature sources (e.g. thesis dissertations, unpublished repositories).

An additional limitation is the validity of the Sports Chiro ReCaP Survey. While the survey was developed by modifying an existing one that collected data on the Canadian chiropractic research resource environment,[9–11] the original survey was not evaluated for validity or reliability. Face validity of our survey was determined by five content experts, but a full validation study has not been conducted. Our survey findings should be interpreted within this limitation. Future research can conduct validity assessments of the Sports Chiro ReCaP Survey and investigate its test-retest reliability should the survey be used as an outcome measure to determine the effectiveness of RCD interventions. Additionally, the Sports Chiro ReCaP Survey did not capture data on research culture, which relates to how organisations value research.[17,129] To investigate research culture at the individual, team, and organizational levels, Holden *et al*.[130] developed and validated the Research Capacity and Culture (RCC) Tool. Future research can apply the RCC Tool to investigate the research culture of the Canadian sports chiropractic field. Readers should also be aware that our survey sample was members of the RCCSS(C), the official governing organization of sports chiropractic in Canada.[28] It is possible there are chiropractors in Canada who are members of sports chiropractic organizations from other countries or

internationally, such as the Diplomate American Chiropractic Board of Sports Physicians from the United States of America or the International Federation of Sports Chiropractic (FICS). RCCSS(C) members have affiliate membership with FICS and some may have dual membership with sports chiropractic organizations from other countries. Due to logistical challenges we chose to limit our survey sample to members of the RCCSS(C) but accounted for this limitation by adding a scoping review component to this study designed to identify sports-focused research outputs of Canadian chiropractors, irrespective of their memberships in various sports chiropractic organizations.

An intended application of our work is to implement these methods as an on-going research monitoring initiative. Repeating this evaluation in five-year intervals will provide serial data about the influence of the field's research strategy, investment, and capacity-building initiatives. Regular assessment will allow the field to adapt to changes in the research resource environment and adjust its research strategy accordingly.[10] While these methods provide useful quantitative research monitoring data, it does not provide evidence about the impact of the Canadian sports chiropractic research effort on Canadian society. To provide such investigations, research impact assessments (RIA) are required. RIA is a relatively new field of practice where a research enterprise is assessed using multiple methodologies to determine the value of research conducted in terms of its influence on stakeholders, government, and society.[18] Measuring and monitoring the impact of healthcare research is becoming increasingly common in government funding agencies and higher education institutions as part of a research quality assurance program to demonstrate accountability for research investment.[12,18] While conducting RIAs can be time consuming and resource heavy, a benefit to such an assessment is the ability to assign better judgement to the value of research conducted based on factors such as research quality and its impact on society. For example, our current evaluation identified that there were minimal RCTs conducted in the Canadian sports chiropractic field. While the field's current research resources do not permit these investigations, other study designs, such as descriptive healthcare utilization studies co-produced with stakeholders, may lead to a pathway for impact by stimulating stakeholder-led strategies to increase access to care to improve the health of Canadians. While RCTs have a high potential to influence healthcare decisions if conducted properly, other studies that require less monetary investment, may have reasonable impact potential if they are prospectively designed with the goal of attaining research impact. This can be enabled by applying research impact frameworks[18,131,132], such as the Canadian Academy of Health Sciences Impact Framework[15], in the planning process of a research endeavor to optimize a pathway to impact, such as co-producing research with key stakeholders to optimize research adoption. RIA will allow the Canadian sports chiropractic field to be better informed when pursuing research opportunities and prioritizing investment. To advance the research impact potential of the Canadian sports chiropractic field, we recommend future approaches to monitor its research resource environment to include an element of RIA.

Conclusion

This research capacity and productivity evaluation revealed that the current research effort of the Canadian sports chiropractic field is primarily conducted by part-time clinician researchers with limited protected time to conduct research. Many members of the RCCSS(C) report formal research training with the majority obtained through fellowship and master's training programs. There is a paucity of researchers with PhD qualifications, potentially limiting the field's ability to conduct investigations utilizing certain research designs. Despite its relative size, the Canadian sports chiropractic field has a reasonable level of engagement in research with many RCCSS(C) members involved in mentoring sports residents in research. The current research resource environment has produced research outputs that are consistent with the research requirements of the Sports Sciences Residency Program of the RCCSS(C), providing evidence of the importance of the RCCSS(C) fellowship training program in developing research capacity and producing research for the Canadian sports chiropractic field. Our results can be used to inform RCD strategies to advance the research impact potential of the Canadian sports chiropractic field.

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References

1. 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.
2. Eberman LE, Walker SE, Floyd RT, Covassin T, Nolton E, Snyder Valier AR, et al. The prioritized research agenda for the athletic training profession: a report from the Strategic Alliance Research Agenda Task Force. J Athl Train. 2019;54(3):237–244.
3. Lee A, DeGraauw L, Muir B, Belchos M, Oh D, Szabo K, et al. Identifying and prioritizing research to inform a research agenda for Canadian chiropractors working in sport – the Canadian sports chiropractic perspective. J Can Chiropr Assoc. 2022;66(3): 227–243.
4. Lee A, deGraauw L, Muir B, Belchos M, Szabo K, deGraauw C, et al. A qualitative study investigating research priorities and investigative capacity in sports-focused chiropractic research, part 1 - identifying research priorities to inform a Delphi study. J Can Chiropr Assoc. 2021;65(3): 292–317.
5. Amorin-Woods LG, Woods BL, Moore CS, Leach MJ, Kawchuk GN, Adams J. Research priorities of the Australian chiropractic profession: a cross-sectional survey of academics and practitioners. J Manipulative Physiol Ther. 2022;45(1): 73–89.
6. 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.
7. Adams J, Steel A, Chang S, Sibbritt D. Helping address the national research and research capacity needs of Australian chiropractic: introducing the Australian Chiropractic Research Network (ACORN) project. Chiropr Man Therap. 2015;23(12):1–6.
8. Adams J, Kawchuk G, Breen A, De Carvalho D, Eklund A, Fernandez M, et al. Leadership and capacity building in international chiropractic research: introducing the chiropractic academy for research leadership (CARL). Chiropr Man Therap. 2018;26(5):1–6.
9. Stuber K, Bussières A, Gotlib A. Chiropractic research capacity in Canada in 2008. J Can Chiropr Assoc. 2009;53(C): 227–230.
10. Stuber K, Kawchuk G. Research resource environment in Canada. Gathering knowledge in advance to inform chiropractic research priorities. J Can Chiropr Assoc. 2017;61(3): 178–183.
11. Stuber K, Bussières A, Gotlib A. Research consortium workshop III to advance the Canadian chiropractic research agenda. J Can Chiropr Assoc. 2009;53(1): 7–13.
12. Adam P, Ovseiko P V., Grant J, Graham KEA, Boukhris OF, Dowd AM, et al. ISRIA statement: ten-point guidelines for an effective process of research impact assessment. Health Res Policy Syst. 2018;16(1).
13. Matus J, Walker A, Mickan S. Research capacity building frameworks for allied health professionals: a systematic review. BMC Health Serv Res. 2018;18(1):716.
14. Abramo G, D'Angelo C. How do you define and measure research productivity? Scientometrics. 2014;101(2):1129–1144.
15. Frank C, Battista R, Butler L, Buxton M, Chappell N, Davies S, et al. Making an impact: a preferred framework and indicators to measure returns on investment in health research. Ottawa, ON: Canadian Academy of Health Sciences; 2009. Available from: https://cahs-acss.ca/making-an-impact-a-preferred-framework-and-indicators-to-measure-returns-on-investment-in-health-research/
16. Australian Research Council. State of Australian university research: volume 1, ERA national report. Canberra: ARC; 2015. Available from: https://www.arc.gov.au/sites/default/files/minisite/static/4551/ERA2015/downloads/ARC03966_ERA_ACCESS_151130.pdf
17. Wagner A, McElligott J, Wagner E, Gerber L. Measuring rehabilitation research capacity. Am J Phys Med Rehabil. 2005;84(12): 955–968.
18. Cruz Rivera S, Kyte DG, Aiyegbusi OL, Keeley TJ, Calvert MJ. Assessing the impact of healthcare research: a systematic review of methodological frameworks. PLoS Med. 2017;14(8).
19. 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.
20. Eindhoven E, Lee A, Stilwell P, Mior S. I expected to be pain free: a qualitative study exploring athletes' expectations and experiences of care received by sports chiropractors. Chiropr Man Therap. 2022;30(21):1–12.
21. Arnold E, Rush H, Bessant J, Hobday M. Strategic planning in research and technology institutes. R & D Management. 1998;28(2):89–100.
22. Lerner A. A strategic planning primer for higher education. Northridge, CA: California State University; 1999.
23. Andersen MZ, Fonnes S, Rosenberg J. Time from submission to publication varied widely for biomedical journals: a systematic review. Curr Med Res Opin. 2021;37(6): 985–993.
24. Sharma A, Minh Duc NT, Luu Lam Thang T, Nam NH, Ng SJ, Abbas KS, et al. A consensus-based checklist for reporting of survey studies (CROSS). J Gen Intern Med. 2021;36(10):3179–3187.
25. Sarre G, Cooke J. Developing indicators for measuring research capacity development in primary care organizations: a consensus approach using a nominal group technique. Health Soc Care Community. 2009;17(3) :244–253.
26. Cooke J. A framework to evaluate research capacity building in health care. BMC Fam Pract. 2005;6(44):1–11.

27. Royal College of Chiropractic Sports Sciences (Canada). Sports sciences residency program: supervisor handbook. Calgary, AB: RCCSS(C); 2018.
28. Royal College of Chiropractic Sports Sciences (Canada). Calgary, AB: RCCSS(C). Available from: http://rccssc.ca/. Accessed August 19, 2019.
29. Berndt AE. Sampling methods. J Hum Lact. 2020 May 1;36(2):224–226.
30. SurveyMonkey Inc. Allowing multiple responses. San Mateo, CA. Available from: https://help.surveymonkey.com/en/surveymonkey/send/allowing-multiple-responses/. Accessed April 1, 2023.
31. Phillips AW, Friedman BT, Durning SJ. How to calculate a survey response rate: best practices. Acad Med. 2017;92(2):269.
32. Phillips AW, Friedman BT, Utrankar A, Ta AQ, Reddy ST, Durning SJ. Surveys of health professions trainees: prevalence, response rates, and predictive factors to guide researchers. Acad Med. 2017;92(2): 222–228.
33. Levac D, Colquhoun H, O'brien KK. Scoping studies: advancing the methodology. Implement Sci. 2010;5:69.
34. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. Ann Intern Med. 2018;169(7):467–473.
35. Kazemi M. JCCA December 2019 sports chiropractic special issue: 11th edition. J Can Chiropr Assoc. 2019;63(3):143.
36. Kissel JA, Leonardelli C. Isolated musculocutaneous neuropathy: a case report. J Can Chiropr Assoc. 2019;63(3):162–170.
37. Marshall C, Gringmuth R. Pubic stress fracture presenting as a strain of adductor longus in a 16-year-old elite soccer player with Crohn's disease: a case report. J Can Chiropr Assoc. 2019;63(3):197–204.
38. Alikhani R, Shahrjerdi S, Golpaigany M, Kazemi M. The effect of a six-week plyometric training on dynamic balance and knee proprioception in female badminton players. J Can Chiropr Assoc. 2019;63(3):144–53.
39. Savic M, Lee A, Hook A. Clinical presentation of an adolescent female synchronized swimmer with a simple bone cyst in the proximal humerus: a case report. J Can Chiropr Assoc. 2019;63(3):171–177.
40. Savic M, D'Angelo K. Exploring the role of microinstability of the hip: an atypical presentation of femoroacetabular impingement (FAI) and labral tear in a collegiate endurance athlete: a case report. J Can Chiropr Assoc. 2019;63(3):187–196.
41. Renton T, Howitt S, Marshall C. Lifetime prevalence of concussion among Canadian ice hockey players aged 10 to 25 years old, 2014 to 2017. J Can Chiropr Assoc. 2019;63(2):80–91.
42. Corso M, Mior SA, Batley S, Tuff T, Da Silva-Oolup S, Howitt S, et al. The effects of spinal manipulation on performance-related outcomes in healthy asymptomatic adult population: a systematic review of best evidence. Chiropr Man Therap. 2019;27(1).
43. Karmali A, Walizada A, Stuber K. Knowledge and attitudes toward concussion among elite Canadian junior ice hockey players: an exploratory study. J Contemp Chiropr. 2019;2: 86–91.
44. Vander Doelen T, Manis A. Conservative management of Morel-Lavallée lesion: a case study. J Can Chiropr. 2019;63(3):178–186.
45. St-Onge E, Robb A, Beach T, Howarth S. A descriptive analysis of shoulder muscle activities during individual stages of the Turkish get-up exercise. J Bodyw Mov Ther. 2019;23(1):23–31.
46. Weis C, Baas E, Ciesla K, Kmpinski C, Landsman V. Ontario chiropractor's knowledge of exercise guidelines for pregnant patients. J Can Chiropr Assoc. 2019;63(1):5–17.
47. Cancelliere C, Mohammed R. Brain drain: psychosocial factors influence recovery following mild traumatic brain injury—3 recommendations for clinicians assessing psychosocial factors. J Orthop Sports Phys Ther. 2019;49(11):842–844.
48. Kazemi M. JCCA December 2018 Sports Chiropractic Special Issue: 10th Anniversary Edition. J Can Chiropr Assoc. 2018;62(3):149.
49. Marshall C. In response to: Googling concussion care. Clin J Sport Med. 2018;28(6):e99.
50. Wentzell M. Post-operative rehabilitation of a distal biceps brachii tendon reattachment in a weightlifter: a case report. J Can Chiropr Assoc. 2018;62(3):193–201.
51. Boroushak N, Eslami M, Kazemi J, Daneshmandy H, Johnson J. The dynamic response of the taekwondo roundhouse kick to head using computer simulation. Ido Movement Culture. 2018;18(2):54–60.
52. Grant C, Pajaczkowski J. Conservative management of femoral anterior glide syndrome: a case series. J Can Chiropr Assoc. 2018;62(3):182–192.
53. Corso M. Developmental changes in the youth athlete: implications for movement, skills acquisition, performance and injuries. J Can Chiropr Assoc. 2018;62(3):150–160.
54. Bell S, Borody C. Symptomatic os trigonum in national level javelin thrower: a case report. J Can Chiropr Assoc. 2018;62(3):202–210.
55. Corso M, Howitt S. Adolescent knee pain: fracture or normal? a case report. J Can Chiropr Assoc. 2018;62(2):105–110.
56. Lemoyne J, Poulin C, Richer N, Bussieres A. Analyzing injuries among university-level athletes: prevalence, patterns and risk factors. J Can Chiropr Assoc. 2017;61(2):88–95.
57. Kazemi M, Bogumil M, 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.

58. Emary PC, Watkins KM, Taylor JA. Grade V acromioclavicular joint separation in a 57-year-old mountain biker. J Can Chiropr Assoc. 2017;61(1):68–71.
59. Kazemi M. JCCA Special Issue December 2017 - Sports Chiropractic. J Can Chiropr Assoc. 2017;61(3):218.
60. Howitt S, Simpson K, Suderman D, Mercer A, Rutherford S, deGraauw C. Exercise as a vital sign: a preliminary pilot study in a chiropractic setting. J Can Chiropr Assoc. 2017;61(3):231–238.
61. Ko GD, Mindra S, Lawson GE, Whitmore S, Arseneau L. Case series of ultrasound-guided platelet-rich plasma injections for sacroiliac joint dysfunction. J Back Musculoskelet Rehabil. 2017;30(2):363–370.
62. Jacobs C, Cassidy J, Côté P, Boyle E, Ramel E, Ammendolia C, et al. Musculoskeletal injury in professional dancers: prevalence and associated factors: an international cross-sectional study. Clin J Sport Med. 2017;27(2):153–160.
63. Corso M, DeGraauw C, Hsu W. Osteochondral lesion of the distal tibial plafond in an adolescent soccer player: a case report. J Can Chiropr Assoc. 2017;61(3):261–268.
64. Kissel J, Wong C. Ganglion cyst of the wrist treated with electroacupuncture: a case report. J Can Chiropr Assoc. 2017;61(3):269–276.
65. Menta R, D'Angelo K. Challenges surrounding return-to-play (RTP) for the sports clinician: a case highlighting the need for a thorough three-step RTP model. J Can Chiropr Assoc. 2016;60(4):311–321.
66. Wentzell M. Book review - fascia in sport and movement. J Can Chiropr Assoc. 2016;60(1):123.
67. Wentzell M. Book review - faster, higher, stronger - how sports science is creating a new generation of superathletes and what we can learn from them. J Can Chiropr Assoc. 2016;60(1):124.
68. Wentzell M. Book review - fatigue in sport and exercise. J Can Chiropr Assoc. 2016;60(1):125.
69. Kazemi M. JCCA Special Issue December 2016 - Sports Chiropractic. J Can Chiropr Assoc. 2016;60(4):272.
70. De Finney J, Lawson G, Gryfe D, Gillis-Lawson S, Crawford J. History of the Royal College of Chiropractic Sports Sciences (Canada): the early years. J Can Chiropr Assoc. 2016;60(4):370–376.
71. Wasylynko D. A rare cause of chronic elbow pain in an adolescent baseball player: a case report. J Can Chiropr Assoc. 2016;60(3):226–232.
72. Tuff T, Chrobak K. Septic olecranon and prepatellar bursitis in hockey players: a report of three cases. J Can Chiropr Assoc. 2016;60(4):305–310.
73. Duquette S, Kazemi M. The use of spinal manipulation to treat an acute on field athletic injury: a case report. J Can Chiropr Assoc. 2016;60(2):158–163.
74. Howitt S, Brommer R, Fowler J, Gerwing L, Payne J, DeGraauw C. The utility of the King-Devick test as a sideline assessment tool for sport-related concussions: a narrative review. J Can Chiropr Assoc. 2016;60(4):322–329.
75. Kazemi M, Ingar A, Jaffery A. Injuries in elite taekwondo poomsae athletes. J Can Chiropr Assoc. 2016;60(4):330–341.
76. Karmali A, McLeod J. Identification and management of chronic shoulder pain in the presence of an MRA-confirmed humeral avulsion of the inferior glenohumeral ligament (HAGL) lesion. J Can Chiropr Assoc. 2016;60(2):175–181.
77. Welsh P, Gryfe D. Atypical presentation of axillary web syndrome (AWS) in a male squash player: a case report. J Can Chiropr Assoc. 2016;60(4):294–298.
78. 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.
79. Welsh P, DeGraauw C, Whitty D. Delayed diagnosis of an isolated posterolateral corner injury: a case report. J Can Chiropr Assoc. 2016;60(4):299–304.
80. Senécal I, Richer N. Conservative management of posterior ankle impingement: a case report. J Can Chiropr Assoc. 2016;60(2):164–174.
81. Howitt S, Ethridge E, Nelson E, Gotuaco M, Demello L. Exercise prescription: perceptions and physical activity habits in chiropractic students at CMCC. J Can Chiropr Assoc. 2016;60(4):286–293.
82. Kazemi M. JCCA Special Issue December 2015 – Sports Chiropractic. 2015;59:330–331.
83. Deleo T, Merotto S, Smith C, D'Angelo K. A posterior ring apophyseal fracture and disc herniation in a 21-year-old competitive basketball player: a case report. J Can Chiropr Assoc. 2015;59(4):373–382.
84. MacIntyre K, Gomes B, MacKenzie S, D'Angelo K. Conservative management of an elite ice hockey goaltender with femoroacetabular impingement (FAI): a case report. J Can Chiropr Assoc. 2015;59(4):398–409.
85. Marshall C. Book Review - Handbook of Neurological Sports Medicine. J Can Chiropr Assoc. 2015;59(2):193.
86. Hrkal P. Book Review - High Performance Training. J Can Chiropr Assoc. 2015;59(4):417.
87. Lee AD, Yu A, Young SB, Battaglia PJ, Ho CJ, Sport D, et al. Omohyoid muscle syndrome in a mixed martial arts athlete: a case report. Sports Health. 2015;7(5):458–462.
88. Wasylynko D. Chronic pain due to Little Leaguer's Shoulder in an adolescent baseball pitcher: a case report. J Can Chiropr Assoc. 2015;59(4):383–389.
89. Blanchette M, Pham A, Grenier J. Conservative treatment of a rock climber with a SLAP lesion: a case report. J Can Chiropr Assoc. 2015 ;59(3): 238–244.
90. Stobert J, Emary P, Taylor J. Femoroacetabular impingement: a retrospective case study with 8-Year follow-up. J Chiropr Med. 2015;14(4):290–296.
91. St-Onge E, MacIntyre I, Galea A. Multidisciplinary

approach to non-surgical management of inguinal disruption in a professional hockey player treated with platelet-rich plasma, manual therapy and exercise: a case report. J Can Chiropr Assoc. 2015;59(4):390–397.
92. Marshall C, Vernon H, Leddy J, Baldwin B. The role of the cervical spine in post-concussion syndrome. Phys Sportsmed. 2015;43(3):274–284.
93. Dossa K, Cashman G, Howitt S, West B, Murray N. Can injury in major junior hockey players be predicted by a pre-season functional movement screen - a prospective cohort study. J Can Chiropr Assoc. 2014;58(4):421–427.
94. Ferguson B, Stern P. A case of early sports specialization in an adolescent athlete. J Can Chiropr Assoc. 2014;58(4):377–383.
95. Mohib M, Moser N, Kim R, Thillai M, Gringmuth R. A four year prospective study of injuries in elite Ontario youth provincial and national soccer players during training and matchplay. J Can Chiropr Assoc. 2014;58(4):369–376.
96. Brown C, Stainsby B, Sovak G. Guyon Canal syndrome: lack of management in a case of unresolved handlebar palsy. J Can Chiropr Assoc. 2014;58(4):413–420.
97. D'Angelo K, Kim P, Murnaghan M. Juvenile osteochondritis dissecans in a 13-year-old male athlete: A case report. J Can Chiropr Assoc. 2014;58(4):384–94.
98. Menta R, Howitt S. Meniscal allograft transplant in a 16-year-old male soccer player: a case report. J Can Chiropr Assoc. 2014;58(4):436–443.
99. Kazemi M. JCCA Sports Chiropractic 6th Issue. J Can Chiropr Assoc. 2014;58(4):342.
100. Woitzik E, deGraauw C, Easter B. Ulnar impaction syndrome: a case series investigating the appropriate diagnosis, management, and post-operative considerations. J Can Chiropr Assoc. 2014;58(4):401–412.
101. Lee A, deGraauw L, Belchos M, Muir B, Szabo K, Howitt S, et al. A qualitative study investigating research directives for sports-focused chiropractic research: a second phase study to develop a sports-focused research agenda for Canadian sports chiropractors. In: EPIC World Federation of Chiropractic/ European Chiropractic Union Congress. 2019.
102. Kazemi M, Choi G, Millard F. The effects of spinal manipulative therapy on sports performance: a systematic review. In: EPIC World Federation of Chiropractic/ European Chiropractic Union Congress. 2019.
103. Corso M, Howitt S, Srbely J, Tran S, Liang C, Mior S. The immediate effect of spinal manipulation on ball velocity and neuromuscular function during an instep kick in former varsity soccer players: a feasibility study. In: EPIC World Federation of Chiropractic/ European Chiropractic Union Congress. 2019.
104. Kazemi M. Concussion Knowledge among sport chiropractors. In: 6th International Symposium for Taekwondo Studies. Seoul, South Korea: Kyung Hee University; 2018.
105. Kazemi M. Weight cycling: to be or not to be? . In: 6th International Symposium for Taekwondo Studies. Seoul, South Korea: Kyung Hee University; 2018.
106. Fowles J, Howitt S. Exercise is medicine in clinical care. In: Canadian Chiropractic Association National Convention and Tradeshow. 2018.
107. Kazemi M, Vora K, Bogumil. Concussion knowledge among sport chiropractors. In: International Sports Chiropractic Federation Assembly and Symposium. 2017.
108. Weis C, Baas E, Ciesla K, Kimpinski. Ontario chiropractors' knowledge of exercise guidelines for pregnant populations. In: DC 2017 World Federation of Chiropractic Congress. 2017.
109. Lee A, Szabo K, McDowell K, Granger K. 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. In: DC 2017 World Federation of Chiropractic Congress. 2017.
110. Stainsby B, Quattrocchi L, Turner C, Yaworski. Chiropractic utilization of exercise in the treatment plan: a cross-sectional study. In: DC 2017 World Federation of Chiropractic Congress. 2017.
111. Vernon H, Crawford J, Ercalao L. A controlled study of cervical dysfunction in concussion vs. whiplash patients. In: DC 2017 World Federation of Chiropractic Congress. 2017.
112. Vernon H, Crawford J, Ercalao L. A controlled study of the presence of upper cervical dysfunction in concussion and whiplash patients. In: The Canadian Pain Society Annual Scientific Meeting. 2017.
113. Stainsby B, Johnston C, Mayberry K, Mahony E, Okrainetz J, Rae. Conservative care of concussions: a systematic review. 2016 ACC-RAC conference proceedings. J Chiropr Educ. 2016;30(1):52-68.
114. Menta R, Beach T, Robb A, Howarth S. Relating lead hip internal rotation during the golf swing to passive capacity for joint movement. In: 63rd Annual Meeting of the American College of Sports Medicine. 2016.
115. Stainsby B, Dulay D, Brown P, Smith. The effects of spinal manipulation on vertical jump height - a pilot study. 2016 ACC-RAC conference proceedings. J Chiropr Educ. 2016;30(1):52-68.
116. Kazemi M, Hua G, Ingar A, Jaffery A, Huang G. Injuries in elite taekwondo poomsea athletes [abstract]. In WFC 13th Biennial Congress/ECU Annual Convention, Athens, Greece, May 13-16, 2015: proceedings. Toronto, ON: World Federation of Chiropractic; 2015. p. 149.
117. Canadian Chiropractic Association. About Canadian chiropractors. Toronto, ON: CCA. Available from:

https://chiropractic.ca/about-canadian-chiropractors/. Accessed Oct 6, 2023.
118. Sherman N, Bridge N, Khwaja A, Du P, Truchan L. Research Productivity of Foot and Ankle Fellowship Faculty. Foot Ankle Spec. 2022;15: 82–88.
119. The Federation of Canadian Chiropractic. Specialty Colleges. Halifax, NS: FCC; 2023. Available from: https://chirofed.ca/specialty-colleges/
120. Cvetanovich GL, Saltzman BM, Chalmers PN, Frank RM, Cole BJ, Bach BR. Research productivity of sports medicine fellowship faculty. Orthop J Sports Med. 2016;4(12).
121. Chen AZ, Greaves KM, Fortney TA, Ahmad CS, Levine WN, Trofa DP, et al. The role of advanced academic degrees in orthopaedic sports medicine faculty. Orthop J Sports Med. 2022;10(2).
122. Kazemi M. Sports chiropractic in Canada. J Can Chiropr Assoc. 2009;53(4):231-232.
123. Cooke J. Building research capacity for impact in applied health services research partnerships: comment on "Experience of health leadership in partnering with university-based researchers in Canada – a call to 're-imagine' research." Int J Health Policy Manag. 2021:10(2): 93–97.
124. Cordrey T, King E, Pilkington E, Gore K, Gustafson O. Exploring research capacity and culture of allied health professionals: a mixed methods evaluation. BMC Health Serv Res. 2022;22(1).
125. Palmer S, Coad J, Gamble J, Jones C, Lees-Deutsch L, McWilliams D, et al. Nursing, midwifery, and allied health professions research capacities and cultures: a survey of staff within a university and acute healthcare organisation. BMC Health Serv Res. 2023;23(1).
126. Frakking T, Craswell A, Clayton A, Waugh J. Evaluation of research capacity and culture of health professionals working with women, children and families at an Australian public hospital: a cross sectional observational study. J Multidiscip Healthc. 2021;14:2755–2766.
127. Scopus. Welcome to Scopus preview. Amsterdam: Elsevier. Available from: https://www.scopus.com/home.uri. Accessed July 8, 2023.
128. 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.
129. Robinson LR. Research culture, environment, and infrastructure. Am J Phys Med Rehabil. 2005;84(12):980–987.
130. Holden L, Pager S, Golenko X, Ware RS. Validation of the research capacity and culture (RCC) tool: measuring RCC at individual, team and organisation levels. Aust J Prim Health. 2012;18(1):62–67.
131. Kuruvilla S, Mays N, Pleasant A, Walt G. Describing the impact of health research: a research impact framework. BMC Health Serv Res. 2006;6:134
132. Reed MS, Ferré M, Martin-Ortega J, Blanche R, Lawford-Rolfe R, Dallimer M, et al. Evaluating impact from research: a methodological framework. Res Policy. 2021;50(4).

Appendix 1.
RCCSS(C) Sports-focused Research Definition[21]

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.

Appendix 2.
MEDLINE (EBSCO) Search Strategy

1. 1. NSO (1-63) AND Chiropract* AND (PL) Canada	Literature search using PubMed, MEDLINE (EBSCO), CINAHL, ICL, SportDiscus using (a) NSOs, (b) chiropractic, (c) location: Canada
2. (Sports Words) AND Chiropract* AND (PL) Canada	Literature search using PubMed, MEDLINE, CINAHL, ICL, SportDiscus using (a) sport terms, (b) chiropractic, (c) location: Canada. The sport terms identified include: athlete, performance, nutrition, athletic event coverage, team travel exercise physiology, sport psychology, sport, games, elite, Olympic, national, varsity
3. Author search	Authors identified from searches (1) and (2) will be cross-referenced using Google search to confirm they are a Canadian chiropractor involved in sport-focused research
Limiters: 1. (LA) - English and French language 2. (PT) - Peer reviewed publications including conference abstracts published in peer reviewed publications 3. (DP) - Publications with the last 5 years	

1. MH Sports+
2. MH Athletes
3. MH Athletic Performance
4. MH Games, Recreational
5. MH Psychology, Sports
6. MH Return to Sport
7. MH Sports Medicine
8. MH Sports Nutritional Physiological Phenomena
9. MH Sports Nutritional Sciences
10. TI athlet* or AB athlet*
11. TI competition or AB competition
12. TI competitive* or AB competitive*
13. TI elite* or AB elite*
14. TI game* or AB game*
15. TI olympi* or AB olympi*
16. TI recreational* or AB recreational*
17. TI return to play* or AB return to play*
18. TI sport* or AB sport*
19. TI varsity* or AB varsity*
20. 1-19/0R [***sports terms]
21. TI archery* or AB archery*
22. TI badminton* or AB badminton* or MH badminton
23. TI baseball* or AB baseball* or MH baseball*
24. TI basketball* or AB basketball* or MH basketball
25. TI biath* or AB biath*
26. TI bmx* or AB bmx*
27. TI bobsle* or AB bobsle*
28. TI boccia* or AB boccia*
29. TI boxing* or AB boxing* or TI boxer* or AB boxer*
30. TI bowling* or AB bowling* or TI bowler* or AB bowler*
31. TI broomball* or AB broomball*
32. TI canoe* or AB canoe* or MH water sports
33. TI cricket* or AB cricket*
34. TI curling* or AB curling*
35. TI cross country* or AB cross country* or TI cross-country or AB cross-country*
36. TI cycling* or AB cycling* or TI cyclist* or AB cyclist*

37. TI diving* or AB diving* or TI diver* or AB diver* or MH diving
38. TI equest* or AB equest*
39. TI fencing* or AB fencing* or TI fencer* or AB fencer*
40. TI field hockey* or AB field hockey* or MH hockey
41. TI figure skat* or AB figure skat*
42. TI football* or AB football* or MH football
43. TI golf* or AB golf* or MH golf
44. TI goalball* or AB goalball*
45. TI gymnast* or AB gymnast* or MH gymnastics
46. TI hockey* or AB hockey* or MH hockey*
47. TI judo* or AB judo* or MH martial arts
48. TI karate* or AB karate* or MH martial arts
49. TI kayak* or AB kayak* or MH water sports
50. TI lacrosse* or AB lacrosse* or MH racquet sports
51. TI lawn bowl* or AB lawn bowl
52. TI luge* or AB luge*
53. TI racquet* or AB racquet* or MH racquet sports
54. TI ringette* or AB ringette*
55. TI rower* or AB rower* or TI rowing* or AB rowing* or MH water sports
56. TI rugby* or AB rugby* or MH football
57. TI runner* or AB runner*
58. TI running* or AB running* or MH running
59. TI sailing* or AB sailing* or TI sailor* or AB sailor* or MH ships
60. TI soccer* or AB soccer* or MH soccer
61. TI skiing* or AB skiing* or TI skier* or AB skier* or MH skiiing
62. TI skating* or AB skating* or TI skater* or AB skater*
63. TI sledding* or AB sledding* or MH snow sports
64. TI snowboard* or AB snowboard* or MH skiing
65. TI softball* or AB softball* or MH baseball
66. TI speed-skat* or AB speed-skat* or MH skating
67. TI squash* or AB squash*
68. TI swim* or AB swim* or MH swimming
69. TI taekwondo* or AB taekwondo*
70. TI tennis* or AB tennis* or MH tennis
71. TI (track n2 field) or AB (track n2 field) or MH track and field
72. TI triath* or AB triath*
73. TI volleyball* or AB volleyball* or MH volleyball
74. TI wakeboard* or AB wakeboard*
75. TI water polo* or AB water polo* or water sports
76. TI wrestling* or AB wrestling* or TI wrestler* or AB wrestler* or MH wrestling
77. weightlift* or AB weightlift* or TI weight lift* or AB weight lift* or MH weight lifting
78. TI jiu jitsu* or AB jiu jitsu* or TI jiu-jitsu* or AB jiu-jitsu* or TI ju-jitsu* or AB ju-jitsu*
79. TI jogging* or AB jogging* or TI jogger* or AB jogger*
80. TI kendo* or AB kendo*
81. TI kung fu* or AB kung fu* OR TI kung-fu* or AB kung-fu*
82. TI mountaineer* or AB mountaineer*
83. TI qigong* or AB qigong*
84. 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*
85. TI walking* or AB walking*
86. 21-85/ OR [***National Sports Organizations]
87. MH Chiropractic
88. MH Manipulation, Chiropractic
89. MH Manipulation, Spinal
90. MH Musculoskeletal Manipulations

91. chiropra*
92. (spinal* or spine) n2 manip*
93. active* n2 releas*
94. Graston
95. instrument* n2 assist*
96. manip* n2 (cervical* or lumbar* or musculoskeletal* or thorac* or msk)
97. manip* n2 (therap* or treat* or manag* or intervention* or care)
98. mobilization* OR mobilisation*
99. musculoskeletal* n2 (therap* or treat* or manag* or intervention* or manip* or care*)
100. myofascial* n2 releas*
101. taping or kinesiotap*
102. 87-101/ OR [***chiropractic]
103. MH Canada +
104. Canad*
105. CMCC* or UQTR*
106. Alberta* or British Columbia* or Manitoba* or New Brunswick* or Newfoundland* or Nova Scotia* or Ontari* or Prince Edward Island* or Quebec* or Saskatchewan* or Nunavut* or Northwest Territor* or Yukon* or
107. Toronto* or Montreal* or Vancouver* or Edmonton* or Calgary* or Ottawa* or Waterloo* or Guelph* or Kingston* or Halifax* or Fredericton* or Hamilton* or Winnipeg* or Saskatoon* or St. John's or Thunder Bay or Regina* or Lethbridge* or Windsor*
108. Dalhousie* or UBC or mcgill* n2 universit* or mcmaster* n2 universit*
109. AF (ab or alta or qc or ont or bc or mb or sk or ns or nb or nf or nfld or pei
110. 103-109/ OR [***Canada]
111. 20 OR 88
112. 111 AND 102 AND 110
113. LIMIT 112 English OR French
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Canada-based sports chiropractors' attitudes, beliefs, and practical application of sport psychology in the injury rehabilitation process: a mixed-methods study

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Objective: *To understand Canada-based sports chiropractors' attitudes, beliefs, and practical application of sport psychology in the sports injury rehabilitation process.*

Methods: *A cross-sectional, mixed-methods study design was employed. A questionnaire was emailed to 144 eligible participants including Fellows and Residents of the Royal College of Chiropractic Sports Sciences (Canada) (RCCSS(C)). Fifty-two surveys were returned fully completed. Fifteen respondents completed semi-structured interviews to further examine attitudes and beliefs in sport psychology training, delivery, and referrals.*

Results: *Approximately two-thirds of Canada-based sports chiropractors felt that athletes were affected psychologically 100% of the time when injured. Sports*

Attitudes, croyances et application pratique de la psychologie du sport dans le processus de rééducation des blessures chez les chiropraticiens du sport basés au Canada : une étude à méthodes mixtes

Objectif: *Comprendre les attitudes, les croyances et l'application pratique de la psychologie du sport dans le processus de rééducation des blessures sportives des chiropraticiens du sport basés au Canada.*

Méthodes: *Une étude transversale à méthodes mixtes a été utilisée. Un questionnaire a été envoyé par courriel à 144 participants admissibles, dont des membres et des résidents du Collège royal des sciences chiropratiques du sport du Canada (RCCSS(C)). Cinquante-deux questionnaires ont été retournés dûment remplis. Quinze répondants ont participé à des entretiens semi-structurés afin d'examiner plus en détail les attitudes et les croyances relatives à la formation en psychologie du sport, à la prestation de services et à l'orientation des patients.*

Résultats: *Environ deux tiers des chiropraticiens du sport basés au Canada estiment que les athlètes sont affectés psychologiquement dans 100 % des cas*

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chiropractors reported using some basic psychological techniques during the sports injury rehab process and expressed interest in having more training in more advanced techniques and practical application of these skills, as well as developing a referral network with sport psychology professionals in Canada.

Conclusions: Sports chiropractors in Canada reported receiving entry level training in sports psychology and understood the importance of addressing the psychological aspects of sports injury. Further research is warranted to explore the effectiveness of current and future sports psychology education interventions for sports chiropractors.

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KEY WORDS: injury rehabilitation, mixed-methods study, sports chiropractic, sports injuries, sports psychology

lorsqu'ils se blessent. Les chiropraticiens du sport ont déclaré utiliser certaines techniques psychologiques de base au cours du processus de rééducation des blessures sportives et ont exprimé le souhait d'être formés à des techniques plus avancées et à l'application pratique de ces compétences, ainsi que de développer un réseau d'orientation avec des professionnels de la psychologie du sport au Canada.

Conclusions: *Les chiropraticiens du sport canadiens ont déclaré avoir reçu une formation initiale en psychologie du sport et comprendre l'importance d'aborder les aspects psychologiques des blessures sportives. Des recherches supplémentaires sont nécessaires pour explorer l'efficacité des interventions actuelles et futures de formation en psychologie du sport destinées aux chiropraticiens du sport.*

(JCCA. 2023;67(3):226-245)

MOTS CLÉS : rééducation post-traumatique, chiropratique sportive, blessures sportives, psychologie du sport, étude à méthodes mixtes

Introduction

Sport injuries are an unfortunate, but common, occurrence for those participating in sport. In 2009-10, an estimated 4.27 million Canadians aged 12 and older suffered an injury that limited their normal activities, and 35% of these were related to sport or physical activity.[1] The definition of "sport injury" varies in the literature, however typically it incorporates the following characteristics: (a) the injury occurred while in training or competition for a sport (b) medical attention was sought for the injury and (c) time was lost from training, practice and/or competition.[2–5] The etiology of sports injuries is complex, with many variables affecting response, recovery, and prevention. It is critical to examine sport injury while accounting for the biomedical, psychological, and social contributing factors, using a biopsychosocial model, to ensure recovery is optimized. Since Engel's introduction of the biopsychosocial (BPS) model in 1980[6], there has continued to be a shift in healthcare, away from a more traditional biomedical approach and towards the more comprehensive BPS model. The BPS approach has also been described in the context of sports injuries and rehabilitation.[7]

There has been an abundance of research in the past thirty years examining the importance of psychosocial factors related to sport injury and rehabilitation. Psychological interventions have been demonstrated to have a significant impact on the sport injury rehabilitation process.[8–10] There is some debate as to how these interventions should be delivered. In particular, there is a growing consensus that sport psychology consultants and/or mental health professionals may be best suited to deliver these interventions as they have the greatest level of expertise in this field.[11] However, not all athletes have access to these providers, especially outside of professional and collegiate level sports.[12–14] Sports psychology professionals are rarely fully integrated into a sport medicine team, perhaps due to limited access of healthcare systems, lack of understanding and procedures for referrals, and/or reluctance of athletes to participate.[15] Emerging literature suggests that it may be efficacious to utilize sport injury rehabilitation professionals (SIRPs) to help address the psychosocial aspects of the rehabilitation process.[16]

The involvement of SIRPs in the psychosocial aspect of the rehabilitation process has been studied extensive-

ly.[17] The literature in this domain is focused primarily on athletic therapists and physiotherapists, but can be extrapolated to any healthcare provider who provides sport injury rehabilitation as a service. For the purposes of this study, the term "sport injury rehabilitation professional" encompasses any healthcare or performance professional that is responsible for overseeing sport injury rehabilitation.

SIRPs are well-positioned to influence the psychological aspects of sport injury rehabilitation for many reasons.[15,18,19] First, SIRPs are often the initial point of contact for care when an injury occurs, they have regular contact with the injured athlete throughout the rehabilitation process and are able to assess, monitor, and intervene for both the physical and psychological aspects of the injury.[15,20–23] Physical and psychological issues are not mutually exclusive - they are often discussed in relation to one another.[20] In addition, SIRPs are an important source of emotional support during the recovery process as they have established rapport and trust with the athlete.[18,24,25] They may also be able to influence how receptive athletes are to using sports psychology to enhance rehabilitation.[22,25,26] As well, the act of physical touch during manual therapy may facilitate an athlete opening up about psychological struggles.[27] Finally, existing literature suggests that both athletes and SIRPs themselves feel SIRPs are in an ideal position to address psychological aspects of injury.[15,28–30] Some researchers and practitioners even argue that it is an absolute requirement for SIRPs to address psychosocial factors to some degree during the rehabilitation process if holistic recovery is to occur.[22] Without a doubt, effective injury management is enhanced by an understanding of the psychological aspects of injury.[31]

Competencies for many governing bodies of SIRPs in Canada, including athletic therapists, physiotherapists, and others, call for a baseline level of knowledge in psychosocial factors of healthcare.[32,33] There is a strong argument to be made for SIRPs having the knowledge and skillset to address these factors at an acceptable level.[22] This includes being able to recognize potential psychosocial reactions experienced by injured athletes, have the skillset to intervene when necessary, and be able to recognize the need for referral.[34] In practice, however, SIRPs may not feel confident in their knowledge and/or ability to deliver such interventions.

Training for SIRPs is focused mainly on the biological, orthopedic, biomechanical, and pathophysiological aspects of injury occurrence and recovery, and much less on the psychosocial aspects.[20] Many physical and manual therapy programs at the university/college level do incorporate some form of psychology training, however it is highly variable in context and depth.[20,35] Currently, the Royal College of Chiropractic Sports Specialists (Canada) (RCCSS(C)) post-graduate program for sport specialist chiropractor trainees includes one three credit course on sport psychology, and the format, content, and instructor of the course are not standardized across the program.[36] SIRPs in the field and researchers alike have called for additional post-graduate training in the field of sport psychology in order to gain the knowledge and skillset to be able to competently address some psychosocial aspects of sport injury rehab.[12,37,38] These practitioners also identified the need for a referral network of sport psychology professionals and had a preference to working in a multi-disciplinary environment with these professionals to ensure that the athletes' needs are met when the scope of the issue is beyond the skillset of the SIRP.[11,17]

To plan future changes in sports psychology training for SIRPs, it is important to have a better understanding of the current attitudes and beliefs surrounding the use of sport psychology by Canadian SIRPs. Post-graduate healthcare professional education and practice differs by country and region, and by profession. It is not sufficient to extrapolate data from previous research on athletic therapists and physiotherapists in the United States and United Kingdom to all other SIRPs. The purpose of this study is to examine Canada-based sports specialist chiropractors' attitudes, beliefs, and application of sports psychology principles during the sports injury rehabilitation process.

Methods

This study is a cross-sectional, convergent parallel mixed-methods design which included a quantitative survey questionnaire, followed by qualitative semi-structured interviews. Research ethics board approval was obtained from the Canadian Memorial Chiropractic College (REB Approval #2012B02).

Participants

To be eligible as a participant in the survey questionnaire and the semi-structured interview components of

this study, participants had to be Canada-based sport specialist chiropractors who are Fellows or Residents of the RCCSS(C), and who self-identify as utilizing sport injury rehabilitation as part of their practice.

Measures

Sports chiropractors' attitudes and beliefs around sports psychology in the sports injury rehabilitation process was measured using an adapted version of the Physiotherapist and Sport Psychology Questionnaire (PSPQ).[28] The PSPQ was originally adapted from the Athletic Training and Sport Psychology Questionnaire (ATSPQ).[15] Both the PSPQ and ATSPQ have been used in previous literature to measure attitudes and beliefs of sport psychology within injury rehabilitation for different SIRPs.[12,15,28,37] While neither original authors of the survey instruments report any validity or reliability data, Larson *et al*.[15] describe a pilot study that contributed to the development of the questionnaire where adjustments were made following feedback from 18 athletic therapists across five different institutions.

In the version used for the current study, the Sports Chiropractor and Sport Psychology Questionnaire (SCSPQ), the authors simply replaced "physiotherapists" with "sports chiropractors" and changed the demographic data to reflect typical education requirements and location for Canada-based sports chiropractors. The SCSPG includes 11 items, with a mixture of 5-point Likert-scale, open-ended, and closed-ended questions. Questions included how often participants encounter certain psychological conditions and identification of certain behaviours or characteristics that are present in athletes who do and do not successfully cope with injuries. The survey also included questions about referral practices and access to sports psychology professionals, as well as their education and training in sports psychology as a SIRP. Survey participants were also asked how often they practice certain psychological skills/techniques in the sports injury rehabilitation process. The questionnaire concluded with a comment box that allowed participants to provide any further comments or additional information.

The semi-structured interviews were conducted by one female member of the research team (CL) who is a sports chiropractor and mental performance consultant with Master's level training in qualitative research methods and applied sport psychology. The interviewer has a collegial relationship with many of the participants due to common inclusion in the same sports chiropractic organization. The semi-structured interview guide was adapted from a similar study by Heaney.[37] Heaney reported that the interview script had established face validity by sports psychologists, and pilot interviews were conducted in which feedback was provided and minor adjustments to the interview script were made.[37] The interview script included questions that covered three main areas: sports psychology content in sports chiropractors education / training, delivery of sport psychology support during the sport injury rehabilitation process, and sport psychology referral practices. See Appendix 1 for the interview script.

Data collection

Participants were recruited via email through the RCCSS(C) mailing list of members, including active Fellows and Residents of the organization. E-mails were sent out by an RCCSS(C) administrator twice weekly for a period of one month, which included a link to the questionnaire conducted on SurveyMonkey (SurveyMonkey Inc., USA). Response limits were set to ensure participants only responded once. Participants self-selected to complete the questionnaire, and participation was voluntary with no compensation provided. The project information letter and informed consent outlined the purpose of the study, procedures, benefits, risks, and confidentiality. Participants were able to withdraw their participation at any time during the questionnaire responses. At the completion of the questionnaire, participants had the opportunity to provide contact information if they wanted to participate in the semi-structured interviews.

For the semi-structured interviews, convenience sampling was conducted, and a member of the research team followed up with 21 individuals who expressed interest in participating. The follow up email included another copy of the project information letter and informed consent about the purposes, procedures, and confidentiality surrounding their responses. Fifteen of these individuals scheduled a meeting time. The semi-structured interviews were conducted by a secure online video platform (Zoom Video Communications, Inc., USA, Version 5.6) or telephone call, which was audio recorded using the Audacity application (Audacity, USA, Version 3.0). Only the interviewer and participant were present on each call, and none of the interviews were repeated. No field notes were

made during or after the interviews. Prior to initiating the interview, the participants were asked for consent to proceed. See Appendix 1 for consent script questions.

The interviews took approximately 20 to 30 minutes to complete. The audio recording was then auto-transcribed through NVivo™ software and checked for accuracy by two research assistants who de-identified the data. At the completion of this step, participants were emailed a copy of their transcript and had the opportunity to review the transcript to confirm, clarify, or withdraw any or all responses. When transcribing the interview data, one audio recording of one interview was not captured due to a technical error. This resulted in a total of 14 interviews to be analyzed.

Data analysis

All questionnaires which were fully completed (n=52) were included for analysis. The quantitative analysis was descriptive in nature. Analysis of questions that used Likert scales involved the calculation of mean score and standard deviations, and frequency calculations were used for any closed-ended (yes/no) questions. The open-ended questions were analyzed by one researcher (CL) and a simple content analysis was executed. Responses were categorized and grouped with similar answers to determine the frequency of each response, which is reported in the results section.

Two researchers (CL and LDG) completed the qualitative data analysis and followed a qualitative description approach.[39] Interview transcripts were entered into NVivo™ qualitative data analysis software, which was used to conduct a systematic thematic conventional content analysis.[40] Phases of thematic analysis were utilized, including familiarization of the manuscripts, generating an initial set of codes, searching for themes that were grouped together with similar ideas, reviewing and revising themes, defining and naming themes, and final analysis.[41]

Members of the research team (CL and LDG) coded each transcript independently and kept a reflexive journal. Codes were generated by reading the data, highlighting quotes that captured key concepts, and labelling groups of similar concepts and quotes within the same code.[40] Codes were then sorted into categories and organized into a code tree. All codes were given operational definitions.[40] Notes were taken to capture the researchers' thoughts, impressions, and initial analysis. All disagreements were discussed, and consensus reached during debriefing sessions. Key themes were identified and tested for rigor through constant comparison to ensure consistency between researchers. Searching for negative, atypical, or conflicting cases in code and themes enhanced analytic rigour.[42] Data saturation was defined as the point where the data produced little or no changes to the qualitative codes.[43]

The three main themes, *training*, *delivery*, and *referrals* were selected a priori as defined in the interview guide. From each of these main codes, secondary codes and tertiary codes were generated. Secondary and tertiary codes are reported within the results section of this paper.

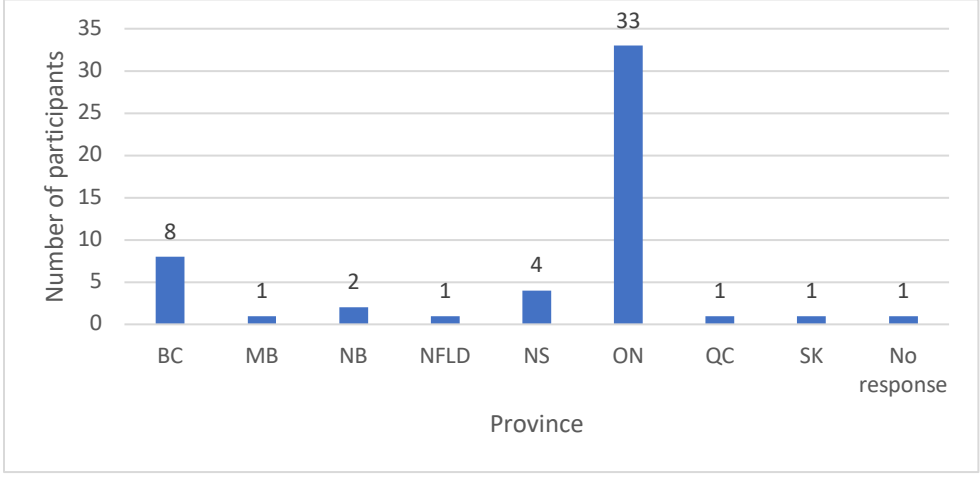

Figure 1.
Location of survey participants within Canada

Results

One hundred and seven (107) Fellows and 37 Residents of the RCCSS(C) were e-mailed the link to the questionnaire and a total of 52 surveys were submitted, fully complete, which is a response rate of 36%. The response rate was calculated as the number of respondents who submitted completed surveys (52) divided by the total number of eligible re-

spondents (144). Seven surveys were returned with only the demographic information completed, and no surveys were returned partially completed. A total of 21 respondents opted to also participate in the semi-structured interviews, and 15 of those respondents were interviewed.

Eleven (21%) identified as current Residents of the RCCSS(C) (21%), and 39 (75%) identified as current Fellows of the RCCSS(C). Two surveys were returned and did not indicate if the respondent was a Fellow or Resident. Figure 1 outlines the location of all respondents. Figure 2 outlines the educational and professional qualifications of the respondents. While post-graduate qualifications in sport injury / sport medicine and psychology differed across participants, the term "sports chiropractor" is used to refer to the participant group. Figure 3 outlines the number of years of experience of survey participants.

Quantitative results

The first part of the questionnaire investigated more general demographic characteristics of participants, as well as their utilization of sports injury rehabilitation in practice and the level of athletes they work with. One hundred percent (52/52) of participants reported that they utilize sports injury rehabilitation as part of their practice. The participants were asked to clarify further how many sports injury appointments or interactions they had per month (Figure 4). Sports injuries were characterized as the following: (1) the injury occurred while in training or competition for a sport (2) medical attention was sought for the injury (3) at least some time was lost from training or competition due to the injury. The participants were also asked about the level of competition of the athletes they treat (Table 1).

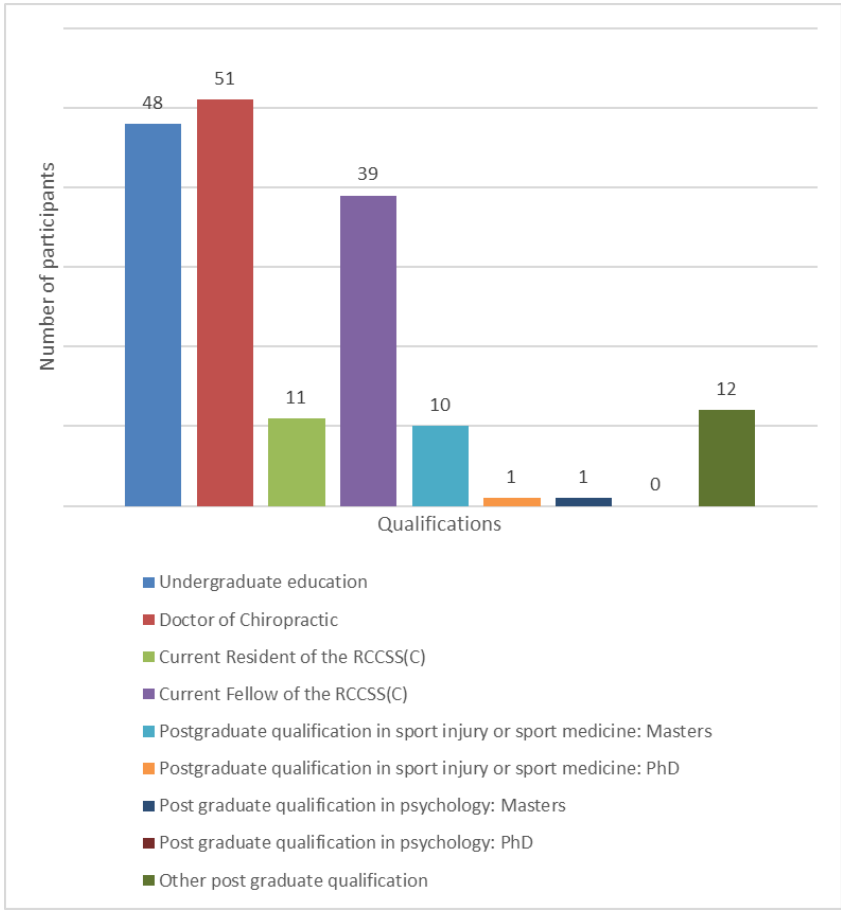

Figure 2.
Education and professional qualifications of participants

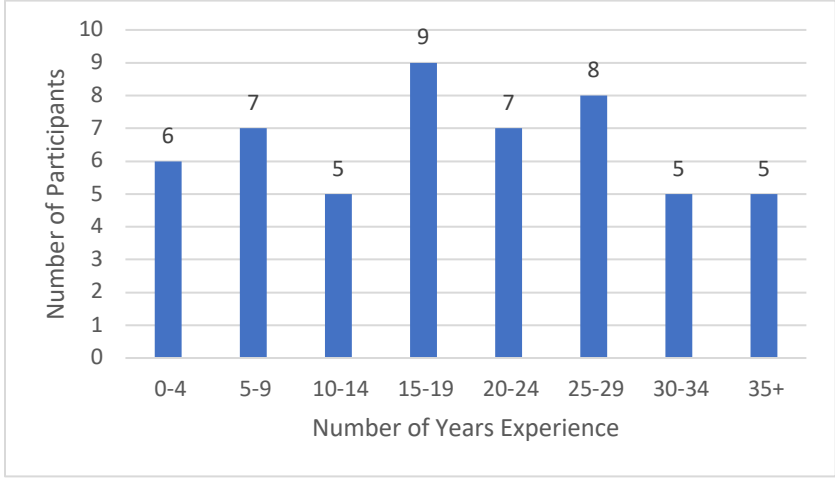

Figure 3.
Number of years experience as a chiropractor

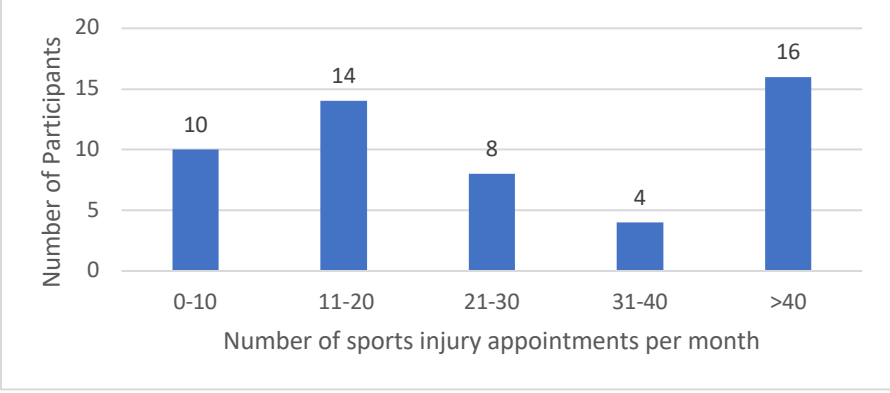

Figure 4.
Number of sports injury interactions or appointments per month

Table 1.
Level of competition of athletes treated

Level of Competition	% of participants who treat athletes at this level (n = 52)
Recreational	51 (98.1%)
Provincial	46 (88.5%)
National	34 (65.4%)
International	28 (53.8%)

Sixty-two percent (32/52) of sports chiropractors surveyed believe that athletes are affected psychologically by an injury 100% of the time, while 15% (8/52) of sports chiropractors believe that athletes are affected 75% of the time, and 19% (10/52) believe that athletes are affected psychologically 50% of the time (Q8). They reported encountering various psychological reactions or conditions associated with athletic injury, with stress/anxiety reported as the most common (Table 2).

Table 2.
Psychological reactions or conditions associated with sports injury.

CONDITION	MEAN	SD
Stress/anxiety	3.90	0.83
Exercise addiction	3.17	1.18
Fear avoidance	2.90	1.02
Depression	2.81	0.99
Treatment compliance problems	2.73	0.79
Anger	2.71	0.96
Cognitive overload	2.71	0.75
Problems with concentration/attention	2.56	0.85
1 = never encounter; 2 = rarely encounter; 3 = occasionally encounter; 4 =often encounter; 5 = very often encounter		

The practitioners also identified behaviours and characteristics between athletes who successfully cope with injury (Table 3) and those who do not (Table 4).

Table 3.
Behaviours/characteristics of athletes who successfully cope with injury

Behaviour/Characteristic	Frequency (%)
Positive outlook / attitude	38%
Compliance / commitment	36%
Resilience	31%
Intelligence / understanding of injury	31%
Social support	31%
Discipline / perseverance / dedication	23%
Determination / drive / work ethic	15%
Patience	13%
Motivation	12%
Goal-oriented	12%
Trust	12%
High self-confidence / esteem / belief	10%
Realistic / acceptance	10%

Thirty-nine of 52 of respondents (75%) have referred an injured athlete to counselling (including to a psychologist, mental performance consultant, social worker, etc.) for concerns related to their injuries. Thirty-two of 52 respondents (61.5%) refer directly to a specific mental performance consultant/coach and/or psychologist with a clinical focus on sport. Only twelve sports chiropractors surveyed (23%) use a specific written procedure when referring athletes for counselling services.

Table 4.
Behaviours/characteristics of athletes who do not successfully cope with injury

Behaviour/Characteristic	Frequency (%)
Stress / anxiety	42%
Fear / fear avoidance	33%
Poor compliance / commitment	23%
Poor social support	23%
Depression	19%
Hypercommitment / hyperfocus / overtraining	19%
Anger / aggression / frustration	17%
Poor intelligence / understanding of injury	17%
Poor lifestyle factors (i.e. nutrition, sleep, etc.)	15%
Negative / poor attitude	13%
Low confidence / esteem	12%
Loss of sport identity	12%
External stressors	8%
Poor concentration / focus	8%
Lack of trust	8%
Catastrophization	8%
Lack of acceptance	6%

The sports chiropractors surveyed indicated that they use a variety of psychological techniques during the sports injury rehabilitation process. Out of 13 suggested techniques, they utilized 8 of the techniques more than 60% of the time when working with injured athletes. The most used psychological technique was creating variety in rehab exercises, while the least used technique was reducing depression (Table 5).

Sixty-nine percent of sports chiropractors surveyed suggested that it was "very important" to address the psychological aspects of sports injury, and none of the participants suggested that it was "not important". In addition, 69% of respondents rated the importance of a course in sport psychology as "important" or "very important". Participants suggested that the top three most important skills a sports chiropractor could learn were "setting realistic goals", "understanding individual motivation", and "enhancing listening skills of the practitioner" (Table 6).

Table 5.
Psychological techniques used by sports chiropractors when working with injured athletes.

Technique	Mean	SD
Creating variety in rehab exercises	4.56	0.67
Using short-term goals	4.56	0.75
Encouraging effective communication skills	4.35	0.99
Encouraging positive self-talk / self-thoughts	4.25	1.12
Keeping athlete involved with the team	4.23	0.92
Enhancing self-confidence	3.85	1.14
Reducing stress or anxiety	3.40	1.16
Using relaxation techniques	3.00	1.28
Improving social support	2.90	1.26
Using mental rehearsal / visualization	2.79	1.33
Teaching muscular relaxation techniques	2.69	1.31
Teaching emotional control strategies	2.52	1.39
Reducing depression	2.10	1.24
1 = never use; 2 = use 25% of time; 3 = use 50% of time; 4 = use 75% of time; 5 = use 100% of time		

Table 6.
Reported important psychological skills / techniques for sports chiropractors to learn

Skill/Technique	Mean	SD
Setting realistic goals	4.38	0.89
Understanding individual motivation	4.37	0.89
Enhancing listening skills of practitioner	4.27	1.05
Using effective communication	4.19	1.05
Reducing depression	4.13	1.05
Creating variety in rehab exercises	4.13	1.07
Enhancing self-confidence of injured athlete	4.13	1.07
Reducing stress/anxiety	4.10	0.98
Encouraging positive self-talk / self-thoughts	4.06	1.02
Improving social support for the athlete	3.85	1.14
Teaching emotional control strategies	3.62	1.12
Teaching the use of mental imagery	3.60	0.99
Teaching muscular relaxation techniques	3.58	1.13
Teaching concentration skills	3.56	1.13
Note: 1 = not important; 2 = relatively important; 3 = important; 4= fairly important; 5 = very important		

Qualitative results

The qualitative results are presented as descriptions of the main themes and subthemes generated, with supporting quotes and statements that illustrate each theme. Representative quotes can be found in Tables 7 to 15. As a supplement to the qualitative data, numbers of statements related to the main issues are reported. Data saturation was reached at interview twelve, however the research team decided to continue to analyze the final two interviews to verify that data saturation had indeed been reached.

Main Theme 1: Training

Subtheme A: Type of training

Sports chiropractors described both structured and unstructured types of training. The majority of those interviewed (10/14) reported that they received training in sport psychology as part of their sports chiropractic residency program.

Half of the sports chiropractors interviewed (7/14) have attended a continuing education course or conference where sport psychology or mental health training was included. Many practitioners mentioned taking a mental health first aid course. Others described unstructured forms of training, including learning from experience in practice, and self-guided research through resources like books and podcasts. (Table 7).

Subtheme B: Content of training

Sports chiropractors reported a variety of topics that were covered in their sport psychology training. These included: recognition of symptoms/signs of mental health issues, psychology theory, general mental skills, mental skills for rehabilitation, and referral practices. Many of the interviewees reported that they gained a general "entry level knowledge" of sport psychology through their training. (Table 8).

Table 7.
Type of sport psychology training reported by sports chiropractors.

Code	Quote
Formal training in sport psychology	"I do remember that we did have a class in order. We have an academic requirement within the program in order to have to sit the exam, with specific hours that were involved, I think we needed 12 or maybe more than that. And I do remember going through things like visualization and guided imagery recognizing different types of athletes." (P1)
Continuing education courses and conferences	"Most of this would be through continuing education type, not specific courses on sports psychology, but in conferences and listening to speakers on the topic. I think there's a lot of that right now. So I've seen a handful of presentations on that in the last couple of years" (P4)
Unstructured training	"I've read a lot of books by a lot of different psychologists, lots of different approaches. And I think having known any of those things at that time would have been helpful, just to give athletes key points to think about, because sometimes they have access to professional sports psychologists and shockingly enough, some other really high-level people don't or they choose not to." (P11)

Table 8.
Content of sport psychology training reported by sports chiropractors

Code	Quote
Recognition	"It gives you the basic level of training to recognize when there are little things that you can help with that are sort of on the low end of the scale in terms of difficulty when it comes to dealing with the psychological aspects, with the athletes." (P1)
Entry level knowledge	"I do think that we have a good entry level knowledge on the topic, that we can start to address some of these issues with the athletes or patients that we're working with." (P3)
Theory of psychology	"I would say that we talked about more theoretical things than practical application. That's kind of what sticks out in my mind and thinking about general trends and acknowledging it more so than getting into the details." (P4)

Many sports chiropractors felt that the content of their training was lacking in some way. Areas that interviewees felt their training was lacking included: understanding scope of practice, sport psychology for injury rehabilitation, how to refer, and practical application of skills. (Table 9).

Subtheme C: Future training interests

When asked what areas of sport psychology they would like more training in at this point in their career, sports chiropractors had a variety of responses. Many (8/14) wanted additional training in mental skills, techniques and strategies, and in particular, the practical application of those strategies. Other topics of interest for future training included: understanding scope of practice, recognition of signs/symptoms of mental health issues, referral practices, research updates, experiences of athletes and professionals in the field, and more of a sports psychology for rehabilitation focus. (Table 10).

Main theme 2: Delivery

Subtheme D: Provider

Sports chiropractors believed that various professionals had a role to play in providing sport psychology support to an injured athlete (Table 11). Most commonly, they reported that the mental performance consultant (MPC) (11/14) should be providing this type of support, but also there was a role for the SIRP (8/14) to provide this support as well. They reported that other providers for support could be parents, coaches, physicians, and mental

Table 9.
Examples of aspects of sports psychology training that were lacking

Participant	Quote
Participant 3	"I think it gave me the ability to identify things, but not really the strengths to utilize it myself or I wouldn't say that I felt like I had a network afterwards to then refer people to. That was going to be working in that sports realm. I feel like that was lacking."
Participant 11	"I've been a fellow for over 20 years, and I don't specifically recall that we had any module or even discussion about sports psychology during our training. Like zero."

Table 10.
Future sports psychology training interests

Code	Quote
New mental skills and techniques	"I think in the fellowship training program, there should be a module, like when [mental performance consultant] was at our one conference. To have something consistently in there, for example, every injury rehab program, we talk about a technique or we talk about a modality or an approach for the mental side of that. You always have that little extra compliment there. I think it is that important." (P11)
Practical application of skills	"Practical applications and practical tools, case based scenarios, maybe even seeing - I don't love role playing necessarily - but seeing video or some sort of media that was created to show you these scenarios and give you examples would be helpful." (P4)
Referral practices	"I'm always trying to make myself that much more of a resourceful clinician for patients, and I think I really could build that list. Build the list of psychologists that… you need to go see this person if you're a team sport and you see this person if you're an individual sport and this person if you're athletic with, or an athlete with depression or an athlete with anxiety. I just want to know who to refer to." (P10)
Understanding scope of practice	"Knowing the scope of practice of those with a particular accreditation. What does a psychologist do or not do, or someone with a masters in social work. You can have a masters of psych or Ph.D. in psych and then you have a psychiatrist. Just knowing the scope of all of the different professionals that work within the mental health field would be helpful. How can they contribute differently than maybe someone else? And when and who should I refer there?" (P1)

health professionals (such as psychiatrists or psychologists). Many (8/14) indicated that there should be a team approach to providing psychological support to the injured athlete which could include any of the previously mentioned providers.

Subtheme E: Mental skills and strategies used in practice

Various mental skills and strategies are reported to be used in practice by sports chiropractors (Table 12). Most commonly, sports chiropractors used reassurance and education (10/14) with their athletes. Other mental skills and strategies include visualization, imagery, promoting social support, relaxation techniques, thought control strategies, active listening, communication, emotion management, goal-setting, return-to-play planning, and treating the person before the athlete.

Subtheme F: Integration Strategies

When asked how sports psychology can be integrated into

Table 11.
The professional whose role it is to provide psychological support to an injured athlete

Code	Quote
Team approach	"I think there's a collaborative effort. It's nice when the whole team is on the same page, and that means the whole thing, teammates, coaches. It means the practitioners that might be dealing with them, whether that's anyone doing any manual or physical therapy with them, their managing MD, all the way through to their psychological support team." (P1)
MPC / sports psych	"I think when you get to a certain level of sport, everybody needs to have some kind of sports psychology, whether it's goal setting, whether it's for coping with the stresses of losses or poor performances. I just think it's a really important component of sport that can't be ignored and pretending that it doesn't is necessary." (P11)
MPC / sports psych	"As far as the degree of the problem, a more significant, definable psychological issue should be dealt with by a sports psychology level person or someone with a reasonable amount of training." (P4)

Table 12.
Mental skills and strategies used in practice by sports chiropractors

Code	Quote
Reassurance and education	"I think engaging the athlete in their own recovery and in their own plan for recovery I think is really important. So having those skills to guide those conversations, I think is really useful. And explaining things in a way that makes it honest and clear what the expectations are." (P9)
Social support	"Depending on what kind of athlete, I think the athlete needs to make sure that they feel like they're still part of the team, that they're not like on an injured list and forgotten about." (P10)
Visualization	"I would say I do use visualization as well. So, like getting people to try to like, feel what they what they're going to feel in that scenario, think about like what it smells like when they're on the field and what they feel like when they're on the field and try to use some of those cues with people and get them to do that almost like a more of a meditative type approach." (P3)
Goal-setting	"I think goal setting is a big one. A lot of athletes are very goal oriented. So, you know, helping them set short term goals for the rehabilitation and then congratulating them when they get to those points so that they have some positive reassurance and then challenging them with future goals and achievements with respect to the rehabilitation process." (P7)
Emotion management	"The thing that gives them so much pleasure, that gives them their identity has been taken away from them temporarily, hopefully temporarily, and not permanently, to be able to deal with that loss for sure. And then to deal with the loss of the separation from their team or their sport or, you know, whatever is happening in their team or an individual athlete." (P11)
Active listening / communication	"Patients seem to like having the relationship, the conversations with them, the follow up with them. It is the village. You just listen and then you also make sure other people who work with them know your observations. Asking questions of colleagues often to confirm if they are seeing the same thing? They're always hard conversations to start." (P8)

the injury rehabilitation of athletes, sports chiropractors suggested the following strategies: selective integration, MPC fully integrated on support team, introduction at the community level, interprofessional collaboration, inherent within the rehab setting, role modelling of elite level athletes, and sharing of resources. (Table 13).

Main theme 3: Referrals

Subtheme G: Practitioner or resources for referral

Sports chiropractors utilize a variety of resources for referral for sports psychology issues. Most of the time (11/14), sports chiropractors are referring their athletes to mental health professionals (such as psychologists, psychiatrists, social workers, etc.) or mental performance consultants (MPCs). Occasionally, they are also referring their patients to physicians, school counsellors, coaches, or general web resources. (Table 14).

Subtheme H: Outcome of referral

The outcomes of the referral process were typically positive, where sports chiropractors felt that the athlete benefitted from the referral, or that collaboration occurred between practitioners. Occasionally, the outcome of the referral was unknown, as follow up did not occur. There was one instance where there was a negative outcome following referral.

Subtheme I: Barriers to referral

Sports chiropractors acknowledged many different barriers for referral (Table 15). The most common barriers reported by sports chiropractors were financial (10/14) and availability of practitioners for referral (13/14). Other reported barriers for referral included: time, stigma, scope of practice, laziness, athlete readiness/acceptance, and intra- and extra-professional perceptions of sports chiropractors.

Table 13.
Integration of sports psychology into injury rehabilitation of athletes

Code	Quote
Selective integration	"We need to be able to identify, though, when somebody needs some type of support. And we also need to know who to refer that person to because it might not be a regular psychologist. You might need somebody who's going to understand the level or what they're going through and be educated on what they're going through as an athlete, because not everybody can understand that and like why it's so important." (P15)
MPC fully integrated on integrated support team (IST)	"I've done a lot of work with the Olympic [sport] team… when we're actually at the worlds or at the Olympics, we have a morning meeting all the time with the physician, the chiro, the physio, the massage therapist, and sometimes [the mental performance consultant] would be involved. So we could mix up disciplines together for the benefit of the athlete." (P11)
Introduction at the community level	"It also has to come from grassroots level organizations saying, no, we need this, this is important… I think that organizations have to know a mental performance consultant / coach, and you start to get them at a younger age. So that way it becomes mainstream when they're older and they get into these higher levels of competition where these integrated health teams become very paramount to the success of that organization.. I think that has to be done and integrating that element in, similar to what they did with strength conditioning years ago, it wasn't mainstream, but they started to integrate it and showing the value to it." (P2)
Interprofessional collaboration	"I think having an open dialogue with I mean, with patient consent, obviously, with a psychologist, because I think an athlete might open up a little bit more to a psychologist or vice versa. And I would love tips from the psychologist, like make sure that you kind of hammer this home and mention this and stay away from this topic because it's triggering, but reinforce this topic and really have a team approach with the athlete in the center." (P10)
Inherent within rehab setting	"I think you can one hundred percent use it, with while we're having them do the rehab you can add the psychological component while they're doing that just to give more positive reinforcement, but also give them something that maybe they can do outside the clinic or if, let's say they're not ready to get back on their feet, something they can do while they're on crutches still or whatnot or even at practice, we can't physically participate, maybe there are some other type of drills they can do. I think that would be very beneficial." (P14)

Table 14.
Practitioner for referral for sports psychology

Code	Quote
Mental performance coach/ consultant	"Absolutely, and dealing with [major sport league] and a couple of teams that I've consulted with, they all have to see the mental performance specialist. That's what they're labeled as. It takes out some of the stigma and keeps in a realm that they can identify with. I think it's a great thing." (P2)
Sports physician	"My referrals being part of a multidisciplinary setting, a lot of times what I'll do is I'll send it to the sports physician. Right. So that way that direct referral could be made, so if there's an OHIP component to it, then that's an easier bridge to work through." (P2)
Mental performance coach/ consultant	"I think most often it's to a [mental performance consultant]. A lot of the work I do is quite often readily accessible. Our varsity team at [university], we send a bunch of people in there. Generally I'm finding the people on the spectrum that are having a difficult time with an injury, but we can actually see early signs of anxiety, depression, fear, avoidance or PTSD regarding injury. And like when I tend to find, like things are more severe, it's constantly on their mind, it's affecting their rehab, affecting their performance, those people we try really quickly, we try to get them out." (P6)

Table 15.
Barriers to referral

Code	Quote
Lack of network	"I don't have a network, so I don't know people I guess in my area. I find it really difficult to refer to people I don't personally know or don't have experience with." (P15)
Sport-specific expertise lacking	"These athletes in this day and age now know if it's going to resonate with them or if this is just generic. Athletes today are so highly specialized that referrals and the people that are working with them also have to be as specialized because they see that." (P2)
Financial	"The other problem, too, is always with the cost associated with it. In an ideal world, if you had people looking after their nutrition, you have the chiro and the physio that was looking after manual stuff, massage therapists, the psychological services, the naturopath, everyone. That could be helpful. But sometimes it does come down to cost. And so people will pick and choose what is maybe the best fit for them." (P1)
Scope of practice	"The uncertainty for me lies around the various types of mental health professionals. It's like choosing chiro, physio, athletic therapy when our patients say, well, do I physio or do I need chiro. So for me, how do I know, do I need a sports psychologist, a psychiatrist, a mental performance coach, a lifestyle coach? There are so many names now, just like in nutrition, like holistic nutritionist, dietitian, all these things. So not understanding the various qualifications and levels and sort of validity of each of these professions is a big concern for me, because I want to know that it's not, just it's above and beyond what I'm doing for them as someone who's just their advocate and someone they trust because they've been seeing me for a long time. What are these people saying and bringing from the practical side? So I want to know what they're doing and who they are basically to be succinct." (P4)
Perception of sports chiro	"I think that the psychology world also has to understand our competency with being able to identify athletes that have some profile, psychological profile that would warrant a referral, that our referral is actually respected and taken into consideration." (P2)

Discussion

The purpose of this study was to identify the attitudes, beliefs, and practical application of sport psychology interventions by Canada-based sports chiropractors in sports injury rehabilitation. Previous literature has explored this topic in athletic therapists and physiotherapists based in the United Kingdom and United States.[11–15,22,28–30,37,44–50] However to our knowledge, there have been no studies in Canadian sports chiropractors.

The literature has reported that SIRPs perceive that the psychological aspect of injury recovery is important and believe they have a role to play in addressing this aspect of recovery.[15,50] Forty seven percent (47%) of SIRPs surveyed by Larson and colleagues[15] and 62% of sports chiropractors surveyed in this study believed that every injured athlete suffers some sort of psychological issue related to their injury. The sports chiropractors in this study suggested that stress/anxiety was the most common psychological reaction to sports injury, along with exercise addiction, fear avoidance, depression, and treatment compliance problems. These findings are in line with the psychological issues reported by SIRPs in previous literature.[13,22,28,37,48]

Training / Education

Sports chiropractors in the present study seem to value sports psychology education, with more than two-thirds of sports chiropractors surveyed indicating that a course in sport psychology was "important" or "very important". While many of the interviewees who reported that their sport psychology training and education was part of their sports chiropractic graduate program, approximately half of the interview participants took a continuing education course that included sports psychology in some part. This may be due to the value they place on learning more about this topic. Among the interviewees having at least some exposure to sport psychology during their training, the overwhelming consensus was that their training was very basic in nature. General topics included recognition of signs/symptoms of mental health issues, psychology theory, and mental skills in general.

They felt that they lacked training in the practical application of skills. This finding aligns with previous literature where SIRPs indicated they were not receiving training in sport psychology theories and interventions, which resulted in a lack of confidence in implementing skills/techniques in practice.[48,49,51] Another common topic reported to be lacking in training of sports chiropractors was around referrals, including how, when, and who to refer to.[15,28,29,37,45,48,49]

Several studies noted that SIRPs expressed a desire to obtain more information about the psychology of injury and also a preference to learn about and apply mental skills to facilitate successful rehabilitation.[22] In other words, they wanted more education on both the theory and practical application of sport psychology specific to the sports injury rehabilitation process. While SIRPs recognize that additional knowledge is important, they also recognize that they currently lack the skills and/or competency to utilize these strategies with their clients.[22,46,50] Similarly, many of the sports chiropractors in the present study felt that their sports psychology training covered elements of performance psychology, however lacked a focus in sports psychology for injury rehabilitation, which is an important part of a holistic understanding of the recovery process.

Delivery / Practical application

The sports chiropractors surveyed in this study believed it was part of their role as practitioners to have the knowledge and skillset to address certain psychological aspects of rehab, with 69% of survey respondents acknowledging that it is "very important" to address the psychological aspects of sports injury. Many of these skills are woven organically into the clinical encounter and therapeutic alliance. Specifically, the most common skills identified as being important included setting realistic goals, understanding individual motivation, enhancing listening skills of the practitioner, creating variety in rehabilitation, and using effective communication.

Given that stress/anxiety and fear avoidance were two of the higher ranked psychological issues that SIRPs reported that their injured athletes experience, more advanced psychological techniques (such as using relaxation techniques, improving social support, using mental rehearsal/visualization, teaching emotional control strategies, etc.) were ranked lower as part of the sports chiropractors skillset, despite being recognized as beneficial by sports psychologists.[8] Previous research has suggested that this may be due to a lack of training in the practical application of these techniques, a lack of knowledge of these techniques to reduce stress/anxiety, or a belief that

it is not the role of the SIRP to implement such techniques.[29,37] This notion was supported by interviewees who reported that they felt competent in actively listening, and providing reassurance to injured athletes, but felt ill-equipped to provide further psychological support.

The sports chiropractors in this study identified several behaviours and characteristics displayed by their athletes who cope successfully and unsuccessfully with their injury. While it can be presumed that interventions designed to increase successful coping behaviours or decrease unsuccessful coping behaviours may be beneficial, no cause-and-effect relationship between coping and behaviour has been established.[37] The two characteristics that were identified as being associated with successful coping were "positive attitude" and "compliance / commitment", and the two characteristics that were identified as being associated with unsuccessful coping were "stress/anxiety" and "fear/fear avoidance". Interestingly, three previous studies in the literature by Heaney[37], Hemmings[28], and Larson15 each had "focus/concentration" and "poor focus/concentration" highly ranked on both lists, whereas participants in the present study did not identify those characteristics at all.

Some researchers identified that SIRPs do, in fact, feel underprepared to deal with issues related to motivation, counselling and social support, mental skills training, and psychosocial referral.[49] Gordon *et al*.[45] found that 84% of sports medicine professionals do not perceive themselves as competent in the use of sport psychology techniques.[45] Reasons for the lack of utilization of psychological strategies by SIRPs in the rehabilitation process may include: (a) SIRPs lack the confidence, knowledge, and/or training in integrating certain psychological techniques[15,38,48,50]; (b) SIRPs learn through experience and therefore favour more practical techniques[38]; (c) there is a lack of time in clinical practice already[15]; (d) the delivery of sport psychology techniques is beyond the role of the SIRP and may be better provided by a different professional[38,48]; (e) SIRPs are unfamiliar with the referral process or lack a network for referral[15]; and, (f) SIRPs believe that treating the physical complaint will result in a reduction of psychological symptoms[15]. Most of these sentiments were captured within the interviews of the present study. In general, it seems that sports chiropractors feel they have the knowledge, confidence, and skillset to implement basic psychological interventions such as goal-setting, self-talk, and imagery[22], but are less familiar with more advanced psychological skills that are better implemented by a specialized practitioner, such as a mental performance / sport psychology consultant[52]. Therefore, SIRPs must be competent in adequate referral practices, including who, when, and how to refer.

Referrals

Some concerns that athletes present with are beyond the scope of education and scope of practice of the SIRP. It is not always feasible or appropriate for SIRPs to be delivering these types of psychological interventions, and in these cases, a referral to an appropriately qualified healthcare professional is warranted.[29] Because of their proximity to, and frequency with which they attend to injured athletes, SIRPs may act as gatekeepers for athletes to access additional sports psychology services.[11] Therefore, they must have the knowledge to recognize a wide range of psychological reactions after injury, and have the skillset to intervene and refer when necessary.[11,16,22,34] This could be a number of concerns, including clinical mental health issues, performance-related psychological issues, and/or psychological intervention that is beyond what the SIRP is able to address. While clinical mental health issues are best addressed by a mental health professional such as a psychologist or psychiatrist, sports psychology consultants (SPCs), also known as mental performance consultants (MPCs), play an important role in assisting athletes in building psychological skills for rehabilitation or performance.[11]

In this study, 75% of sports chiropractors reported that they had referred an injured athlete to counseling for situations related to their injuries. This number was high in comparison to previous literature which reported referral rates between 9-54%.[15,28,37] Heaney[37] proposed that a higher rate of referral may suggest a greater appreciation for a sport psychology professional in providing support to an injured athlete, and/or a higher degree of access to sport psychology support. This may be related to the emergence of greater awareness of sports psychology in the past several years or the higher level of athletes that sports chiropractors are treating. Previous literature has suggested that a sports psychology professional is an integral member of a professional or elite sport medicine team, but is not as important at the lower levels.[53] In the present study, 56% of sports chiropractors work with

either a professional team or national sport organization, which may explain a greater access to sports psychology professionals for referrals. Interestingly, the semi-structured interviews revealed that many sports chiropractors lacked access to a sports psychology professional, however this may be more related to their work within the community, and less related to their work at the elite level. The interviews revealed several barriers that prevented sports chiropractors from referring their injured athletes to sports psychology professionals for sports injury rehabilitation. As previously mentioned, the availability of practitioners for referral was most cited. This may include lack of a referral network of sport psychology professionals, but also lack of sport-specific expertise within available mental health professionals. Previous studies have reported that only 10-25% of SIRPs who responded to surveys have access to a sport psychology consultant[12,15,28], whereas 27-46% of SIRPs surveyed in other studies actually referred athletes for sports psychology services[13,48]. Stigma attached to seeking sport psychology support was also considered a barrier, which aligns with previous literature.[37]

The literature supports the notion that SIRPs are able to recognize the signs and symptoms of a deeper psychological issue that warrants referral (i.e. when to refer), however they were uncomfortable in approaching the athlete to address their concerns and didn't know how to actually make the referral (i.e. how to refer).[12,44,49] Sports chiropractors in the present study reported similar concerns in lacking the ability to make an appropriate referral and expressed a desire for more training in this area. Other barriers to referral reported by sports chiropractors included cost of mental health services, athlete readiness/acceptance, and intra- and extra-professional perceptions of sports chiropractors.

Improved interaction and collaboration between SIRPs and sports psychology professionals is necessary in order to establish role clarity for psychological rehabilitation, clear boundaries of competence, and appropriate referral pathways to ensure a holistic approach to rehabilitation.[12,15,28,54,55] A number of strategies for fostering referral relationships have been suggested in the literature, including establishing written guidelines to standardize the referral process[54], informal meetings to develop open communication and share respective experiences[11], presentations from both SPC/MPCs and SIRPs to highlight their services, and specific training modules to equip SIRPs with strategies to utilize in clinical practice[11]. Future sports psychology education and training for sports chiropractors may include some of these strategies.

Limitations

The limitations of the current study include the possibility of selection bias. Participants self-selected to complete both the questionnaire and the semi-structured interviews. This could sway the sample toward individuals with interest in the subject matter, which may or may not exaggerate study findings. The lack of psychometric evaluation of the survey utilized in this study is a limitation. While the survey has been used in previous studies in similar populations, it has not undergone any reliability or validation testing which may introduce bias through measurement error. With respect to open-ended questions within the questionnaire, there may be some bias in interpretation when characterizing the responses. Another limitation of the present study is the distribution of geographical location of participants. Most participants are located in Ontario which may bias responses to practitioners working in this region.

Limitations of qualitative research in general may apply to this study. Schonfeld and Mazzola describe five potential limitations of qualitative research.[56] First, participants may change in the presence of an observer. The nature of their responses may change based on if they feel judgment, disrespect, or that their responses are not confidential. Second, there is a potential for the researchers to over-identify with study participants, which may affect the interpretation of the findings. In this study, the investigators know most of the study participants, given their inclusion in the same sports chiropractic organization. The participants may have also had previous knowledge of the interviewer which could affect their responses. Third, preconceived ideas from research or experience may influence the data naturally emerging from qualitative interpretation. Fourth, it is extremely difficult to draw causal inferences from qualitative data. This limitation is less prevalent in mixed-methods studies, given the corroboration that occurs with the quantitative data. Fifth, there is no statistical power analysis, such as in quantitative analysis, to determine when there is a sufficiently large and diverse sample. It is up to the interpretation of the researchers to determine if and when theoretical saturation has been reached.[56]

Future directions

The previous literature, as well as the findings of this study, have outlined the importance of sport psychology interventions in the sport injury rehabilitation process, as well as the attitudes and desires of SIRPs to have more knowledge and skills in delivering these interventions. There is a need for education for SIRPs to ensure that they have the knowledge, confidence, skills and competence to implement such interventions during the rehabilitation process.[46,54]

The limited body of evidence on specific sport psychology education interventions for SIRPs, and the questionable effectiveness of SIRPs sport psychology education, rationalizes a need for future research in this area. To our knowledge, there is no empirical data on sports psychology education interventions in sports chiropractors in Canada, despite a course requirement in the current graduate specialty program. Future studies could explore specific content to be included in a course curriculum, the method of delivery that is conducive to the learning style and time commitments of sports chiropractors in general, and how to measure the effectiveness of such a program to produce competency in this area.

Future collaborations or partnerships with stakeholder organizations including governing bodies of SIRPs, such as the RCCSS(C), with the Canadian Sport Psychology Association (CSPA), the governing body for mental performance consultants in Canada, may aid in the development of a network of professionals for sports chiropractors for the purposes of referral or consultation for sport psychology services. It may also be an opportunity to implement some of the collaboration strategies for the benefit of Canadian athletes.

Conclusion

Psychological responses are inextricably linked to physiological responses following an injury, and thus, psychological interventions should be considered as part of a comprehensive rehabilitation program. Sport injury rehabilitation professionals such as sport chiropractors are well-positioned to address and implement psychological strategies within rehabilitation and acknowledge the importance of doing so. However, they report that they require additional training in sport psychology theory and practical application beyond the basic educational curriculum. Few sport psychology education programs have been implemented and empirically evaluated with SIRP populations. Further research is warranted to establish an effective program design, and delivery method for a sport psychology education intervention for SIRPs.

References

1. Billette JM, Janz T. Injuries in Canada: Insights from the Canadian Community Health Survey. StatsCan. 2011; 82-624-X: 1-18.
2. Wiese-Bjornstal DM. Psychology and socioculture affect injury risk, response, and recovery in high-intensity athletes: a consensus statement: sport injury psychology consensus statement. Scand J Med Sci Sports. 2010;20:103–111.
3. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention Initiatives. J Athl Train. 2007;42(2):311–319.
4. Hagglund M. Methods for epidemiological study of injuries to professional football players: developing the UEFA model. Br J Sports Med. 2005;39(6):340–346.
5. Clarsen B, Bahr R. Matching the choice of injury/illness definition to study setting, purpose and design: one size does not fit all! Br J Sports Med. 2014;48(7):510–512.
6. Engel G. The clinical application of the biopsychosocial model. Am J Psychiatry. 1980;137(5):535–544.
7. Brewer BW, Andersen MB, Van Raalte JL. Psychological aspects of sport injury rehabilitation: Toward a biopsychosocial approach. In: Mostofsky DI, Zaichkowsky LD, editors. Medical Aspects of Sport and Exercise. Morgantown, WV: Fitness Information Technologies; 2002; 41–54.
8. Ievleva L, Orlick T. Mental links to enhanced healing: an exploratory study. Sport Psychol. 1991;5(1):25–40.
9. Brewer BW, Petitpas AJ, Sklar JH, Pohlman MH, Krushell RJ, Ditmar TD. Psychological factors, rehabilitation adherence, and rehabilitation outcome after anterior cruciate ligament reconstruction. Rehabilitation Psychol. 2000;45(1):20–37.
10. Brewer BW. Review and critique of models of psychological adjustment to athletic injury. J Appl Sport Psychol. 1994;6(1):87–100.
11. Zakrajsek RA, Martin SB, Wrisberg CA. National Collegiate Athletic Association Division I certified athletic trainers' perceptions of the benefits of sport psychology services. J Athl Train. 2016;51(5):398–405.
12. Arvinen-Barrow M, Hemmings B, Weigand D, Becker C, Booth L. Views of chartered physiotherapists on the psychological content of their practice: a follow-up survey in the UK. J Sport Rehabil. 2007;16(2):111–121.
13. Clement D, Granquist MD, Arvinen-Barrow MM. Psychosocial aspects of athletic injuries as perceived by athletic trainers. J Athl Train. 2013;48(4):512–521.

14. Lafferty ME, Kenyon R, Wright CJ. Club-based and non-club-based physiotherapists' views on the psychological content of their practice when treating sports injuries. Res Sports Med. 2008;16(4):295–306.
15. Larson GA, Starkey C, Zaichkowsky LD. Psychological aspects of athletic injuries as perceived by athletic trainers. Sport Psychol. 1996;10(1):37–47.
16. Clement D, Shannon V. The impact of a workshop on athletic training students' sport psychology behaviors. Sport Psychol. 2009;23(4):504–522.
17. Arvinen-Barrow M, Walker N. The psychology of sport injury and rehabilitation [Internet]. 1st ed. London, UK: Routledge; 2013 [cited 2020 Apr 14]. Available from: https://www.taylorfrancis.com/books/9780203552407
18. Ray R, Terrell T, Hough D. The role of the sports medicine professional in counseling athletes. In: Ray, R Wiese-Bjornstal DM, eds. Counseling in sports medicine. Champaign, IL: Human Kinetics; 1999. p. 3–21.
19. Scherzer CB, Williams JM. Bringing sport psychology into the athletic training room. Athl Ther Today. 2008;13(3):15–17.
20. Kolt G. Using psychology in the physical and manual therapies. In: Psychology in the physical and manual therapies [Internet]. Elsevier; 2004 [cited 2020 Apr 14]. p. 3–8. Available from: https://linkinghub.elsevier.com/retrieve/pii/B9780443073526500063
21. Wiese DM, Weiss MR. Psychological rehabilitation and physical injury: implications for the sportsmedicine team. Sport Psychol. 1987;1(4):318–330.
22. Ford IW, Gordon S. Perspectives of sport trainers and athletic therapists on the psychological content of their practice and training. J Sport Rehabil. 1998;7:79–94.
23. Gordon S, Potter M, Ford IW. Toward a psychoeducational curriculum for training sport-injury rehabilitation personnel. J Appl Sport Psychol. 1998;10(1):140–156.
24. Scherzer CB. Training athletic trainers in the delivery of sport psychology rehabilitation interventions. (Master's thesis). University of Arizona; 2004. Available from: http://hdl.handle.net/10150/280648
25. Zakrajsek RA, Fisher LA, Martin SB. Certified athletic trainers' experiences with and perceptions of sport psychology services for student-athletes. Sport Psychol. 2018 ;32(4):300–310.
26. Brewer BW, Jeffers KE, Petitpas AJ, Van Raalte JL. Perceptions of psychological interventions in the context of sport injury rehabilitation. Sport Psychol. 1994;8(2):176–188.
27. Nathan B. Touch and emotion in manual therapy. London: Churchill Livingstone; 1999.
28. Hemmings B. Views of chartered physiotherapists on the psychological content of their practice: a preliminary study in the United Kingdom. Br J Sports Med. 2002;36(1):61–64.
29. Wiese DM, Weiss MR, Yukelson DP. Sport psychology in the training room: a survey of athletic trainers. Sport Psychol. 1991;5(1):15–24.
30. Arvinen-Barrow M, Massey WV, Hemmings B. Role of sport medicine professionals in addressing psychosocial aspects of sport-injury rehabilitation: Professional athletes' views. J Athl Train. 2014;49(6):764–772.
31. Crossman J. Psychological rehabilitation from sports injuries: Sports Med. 1997;23(5):333–339.
32. Canadian Athletic Therapy Association. Canadian Athletic Therapists Association program accreditation manual: Competencies in athletic therapy. 2007; 1-20.
33. Bulley C, Donaghy M, Coppoolse R, Bizzini M, van Cingel R, DeCarlo M, Dekker L, Grant M, Meeusen R, Phillips N, Risberg M. Sports physiotherapy competencies and standards. Sports Physiotherapy For All Project [Internet]. 2004. Available from: www.SportsPhysiotherapyForAll.org/publications/
34. Harris LL. Perceptions and attitudes of athletic training students toward a course addressing psychological issues in rehabilitation. J Allied Health. 2005;34(2):9.
35. Heaney CA, Green AJK, Rostron CL, Walker NC. A qualitative and quantitative investigation of the psychology content of UK physiotherapy education programs. J Phys Ther Educ. 2012;26(3):48–56.
36. Royal College of Chiropractic Sports Sciences (Canada). Sports sciences residency program applicant information and application forms. 2016.
37. Heaney C. Physiotherapists' perceptions of sport psychology intervention in professional soccer. Int J Sport Exerc Psychol. 2006 Jan;4(1):73–86.
38. Heaney CA, Walker NC, Green AJK, Rostron CL. The impact of a sport psychology education intervention on physiotherapists. Eur J Physiother. 2017;19(2):97–103.
39. Sandelowski M. Whatever happened to qualitative description? Res Nurs Health. 2000;23(4):334–340.
40. Hsieh HF, Shannon SE. Three approaches to qualitative content analysis. Qual Health Res. 2005;15(9):1277–1288.
41. Braun V, Clarke V. Using thematic analysis in psychology. Qual Res Psychol. 2006 Jan;3(2):77–101.
42. Pope C. Qualitative research in health care: analysing qualitative data. BMJ. 2000;320(7227):114–116.
43. Guest G, Bunce A, Johnson L. 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.
44. Cormier ML, Zizzi SJ. Athletic trainers' skills in identifying and managing athletes experiencing psychological distress. J Athl Train. 2015 ;50(12):1267–1276.
45. Gordon S, Milios D, Grove J. Psychological aspects of the recovery process from sport injury: the perspective of sport physiotherapists. Aust J Sci Med Sport. 1991;25:53–60.
46. Hamson-Utley JJ, Martin S, Walters J. Athletic trainers' and physical therapists' perceptions of the effectiveness

of psychological skills within sport injury rehabilitation programs. J Athl Train. 2008;43(3):258–264.
47. Ninedek A, Kelt GS. Sport physiotherapists' perceptions of psychological strategies in sport injury rehabilitation. J Sport Rehabil. 2000;9(3):191–206.
48. Schult K. Using sport psychology in the athletic training room: perceptions and beliefs of certified athletic trainers. East Tennessee State University; 2002.
49. Stiller-Ostrowski JL, Ostrowski JA. Recently certified athletic trainers' undergraduate educational preparation in psychosocial intervention and referral. J Athl Train. 2009;44(1):67–75.
50. Tracey J. Inside the clinic: Health professionals' role in their clients' psychological rehabilitation. J Sport Rehabil. 2008;17(4):413–31.
51. Kamphoff C, Hamson-Utley JJ, Antoine B, Knutson R, Thomae J, Hoenig C. Athletic training students' perceptions of and academic preparation in the use of psychological skills in sport injury rehabilitation. Athl Train Educ J. 5(3):109–116.
52. Arvinen-Barrow M, Penny G, Hemmings B, Corr S. UK chartered physiotherapists' personal experiences in using psychological interventions with injured athletes: an interpretative phenomenological analysis. Psychol Sport Exerc. 2010;11(1):58–66.
53. Wiese-Bjornstal DM, Smith AM. Counseling strategies for enhanced recovery of injured athletes within a team approach. In: Pargman D, editor. Psychological bases of sport injuries. Morgantown, WV: Fitness Information Technologies; 1999. p. 125–155.
54. Heaney CA. Recommendations for successfully integrating sport psychology into athletic therapy. Wrisberg CA, Fisher LA, editors. Athl Ther Today. 2006;11(2):60–62.
55. Lynch GP. Athletic injuries and the practicing sport psychologist: practical guidelines for assisting athletes. Sport Psychol. 1988;2(2):161–167.
56. Schonfeld I, Mazzola J. Strengths and limitations of qualitative approaches to research in occupational health psychology. In: Sinclair RR, Wang M, Tetrick LE, editors. Research methods in occupational health psychology [Internet]. Routledge; 2012 [cited 2022 Jan 25]. p. 292–313. Available from: https://www.taylorfrancis.com/books/9781136212406/chapters/10.4324/9780203095249-27

Appendix 1.
Semi-Structured Interview Guide (Adapted from Heaney, 2006)

Pre-interview script:
We will now be initiating the semi-structured interviews. Your identity will not be disclosed at any point during the interview. Please answer to the best of your ability and knowledge. You can choose not to answer any question by saying "Choose not to answer" and you can opt to end the interview at any point. Do I have your consent to proceed?

The audio component of this interview will be recorded on an external audio recorder for the purposes of transcribing and later analyzing the data. Do I have your consent to record the audio of this interview?

1. TRAINING

(a) During your training to become a sports specialist chiropractor, did you receive any training on the psychological aspects of sports injury? (YES/NO + Comments) [If no go to question (e)]
(b) If yes, approximately how many course hours did this cover?
(c) Do you feel that this was enough? (YES/NO + Comments)
(d) What areas did you cover?
(e) If no, do you think it would have been beneficial to you to have covered this as part of your training? Why/Why not?
(f) Have you ever attended any training courses on the psychological aspects of sports injury? (YES/NO + Comments)
(g) Are there any areas of the psychological aspects of injury that you would like to receive training on at this stage of your career?

2. SPORT PSYCHOLOGY SUPPORT

(h) Have you ever referred an athlete to a mental performance consultant / sports psychologist or other mental health professional? (YES/NO)[If no go to question (m)]
(i) If yes, what professional did you refer to?
(j) If yes, why did you refer the athlete?
(k) Did you feel that the athlete benefitted from seeing this professional?
(l) How did you contact/find this mental performance consultant / sports psychologist?
(m) Would you consider referring any future players to a mental performance consultant / sports psychologist? Why/Why not?
(n) What barriers might prevent you from referring an athlete to a mental performance consultant / sports psychologist?

3. SPORT PSYCHOLOGY DELIVERY

(o) Whose role do you believe it to be to provide psychological support to an Injured or rehabilitating athlete?
(p) Do you believe that a mental performance consultant / sports psychologist should be a standard integral member of the rehabilitation team? Why/Why not?
(q) How do you believe sports psychology can be successfully integrated into the injury rehabilitation of athletes?

4. ANY ADDITIONAL COMMENTS

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Autonomic nervous system dysfunction in pediatric sport-related concussion: a systematic review

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Objective: *To identify, appraise and synthesize the evidence of autonomic nervous system (ANS) dysfunction following sport-related concussion in pediatric populations.*

Methods: *A literature search was conducted using MEDLINE (Ovid), SportDiscus (EBSCO), CINAHL (EBSCO), EMBASE (Ovid) and PsycINFO (Ovid). Studies were selected and appraised using the Joanna Briggs Institute (JBI) critical appraisal tools. Data was extracted from the included studies and qualitatively synthesized.*

Results: *Eleven studies were included in the synthesis. There was variability in the methods used to measure*

Dysfonctionnement du système nerveux végétatif dans les commotions cérébrales liées au sport chez l'enfant: une revue systématique

Objectif: *Identifier, évaluer et synthétiser les preuves du dysfonctionnement du système nerveux végétatif (SNV) à la suite d'une commotion cérébrale liée au sport dans les populations pédiatriques.*

Méthodes: *Une recherche documentaire a été effectuée sur MEDLINE (Ovid), SportDiscus (EBSCO), CINAHL (EBSCO), EMBASE (Ovid) et PsycINFO (Ovid). Les études ont été sélectionnées et évaluées à l'aide des outils d'évaluation critique du JBI (Joanna Briggs Institute). Les données ont été extraites des études incluses et ont fait l'objet d'une synthèse qualitative.*

Résultats: *Onze études ont été incluses dans la synthèse. Les méthodes utilisées pour mesurer la fonction du SNV varient d'une étude à l'autre, et*

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ANS function between studies, and sample populations and time to assessment following concussion varied considerably. There was also variability in the direction of change of ANS function between some studies.

Conclusion: *This systematic review identifies that concussion is associated with dysregulation of ANS function in pediatric athletes. We identified some weaknesses in the extant literature which may be due to existing logistical and financial barriers to implementing valid ANS measurements in clinical and sports settings.*

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KEY WORDS: sport-related concussion, concussion, mild traumatic brain injury, autonomic nervous system, dysautonomia, pediatric, athlete

les populations d'échantillons ainsi que le délai d'évaluation après une commotion cérébrale varient considérablement. La direction du changement de la fonction du SNV variait également d'une étude à l'autre.

Conclusion: *Cette étude systématique montre que les commotions cérébrales sont associées à une dysrégulation de la fonction du SNV chez les athlètes enfants. Nous avons identifié certaines faiblesses dans la littérature existante, qui peuvent être dues aux obstacles logistiques et financiers existants pour mettre en œuvre des mesures valides du SNV dans les environnements cliniques et sportifs.*

(JCCA. 2023;67(3):246-268)

MOTS CLÉS : commotion cérébrale associée au sport, commotion cérébrale, lésion cérébrale traumatique légère, système nerveux végétatif, dysautonomie, pédiatrie, athlète.

Introduction

Concussion, or mild traumatic brain injury (mTBI), is considered a subset of traumatic brain injury (TBI) that results from a direct or indirect biomechanical force transmitted to the head.[1] Concussion is described as a complex pathophysiological entity that results in functional, rather than structural disturbance to the nervous system including perturbations of normal cellular and physiological processes.[2]

Concussions account for 90% of all TBI's.[3, 4] Children have the highest incidence rate with 692 out of every 100,000 suffering a concussion at some point[3], with adolescent concussions accounting for 3% to 8% of all sport-related emergency department visits[5, 6]. As such, concussion remains a serious health concern for youth athletes, as estimates suggest that American children aged up to 18 years suffer between 1.1 to 1.9 million concussions per year in the context of sport and recreation, however this number may be an underestimation due to underreporting.[7-9]

Concussion is typically considered a self-limiting condition, with the majority resolving in 10-14 days, however up to 30% of individuals may experience persistent symptoms beyond four weeks.[10, 11] For youth, persistent symptoms may have significant impact on social, academic and sporting activities during critical stages of development.[10] Empirically, variability in the time to recovery has been observed between pediatric and adult populations[10] and the 2016 Consensus Statement on Concussion in Sport suggests that normal clinical recovery from concussion differs between pediatric individuals and adults.[1] Studies have also demonstrated that factors such as sex and age may influence concussion recovery, with females and adolescents exhibiting protracted recovery times.[12-16] Additionally, identification of TBI in pediatric individuals differs from that of adults due to developmental and physiological variances in the nervous system that exist during different stages of maturation.[17] One example of this includes pupil size and the pupillary light reflex (PLR), which provide insight into autonomic nervous system (ANS) activity.[18] Normative values for pupil size and the PLR have been described, with adults exhibiting decreased pupil size with increasing age[19, 20, 21], and adolescent boys showing slower maximum constriction velocities and smaller percent constriction compared to younger children[21, 22]. This is one example of a measurable physiological biomarker that allows us to quantify not only normal function, but also the variability we may

see following concussive injury across different age categories and throughout recovery.

It is well understood that concussion can cause symptoms of headache[23, 24], nausea[17, 23], balance difficulties[23, 25], light and noise sensitivity[23, 25], sleep disturbances[25], cognitive changes[23, 25-28], emotional disturbances[23, 29] and visual disturbances[30, 31] among others. The vast number of symptoms that may coexist following a concussion may highlight an intricate functional relationship between different areas of the nervous system, despite having anatomically distinct regions.[32-34] Thus, concussion should not be thought of as a focal or localized injury to the nervous system, but rather a diffuse injury that affects interneuronal communication.[2, 32]

An area of study that is of particular interest is the effect that concussion may have on the autonomic nervous system (ANS), as the ANS is intricately intertwined within the CNS and may be affected by head trauma.[33-35] A recent high quality systematic review by Pertab *et al*.[36] synthesized studies of individuals who had experienced a concussion and the resultant impacts on ANS functioning. The authors concluded that "it is likely that concussion causes anomalies in ANS functioning".[36] Due to the anatomical pervasiveness of the ANS within the central nervous system (CNS) it is reasonable to suggest that a concussive injury may contribute to the common symptomatology clinicians see via autonomic mechanisms, in certain individuals.

The autonomic nervous system (ANS):

The autonomic nervous system's role in human function includes involuntarily bodily monitoring to maintain a stable internal environment of the various organ systems. Within the CNS, there is extensive interconnectedness between cortical, subcortical and brainstem regions, many of which comprise the ANS and help us respond and cope with different internal and external environmental stressors.[33, 34] The efferent output of the ANS is largely mediated by autonomic reflexes. In the majority of these reflexes, afferent information is transmitted to homeostatic control centers located in the brainstem and hypothalamus.[33] Reciprocally connected nuclear areas such as the nucleus tractus solitarius, ventrolateral medulla, parabrachial nucleus, amygdala and thalamus play a major role in autonomic control.[33] Importantly, various supraspinal centers including the insula, anterior cingulate cortex, medial prefrontal cortices and portions of the limbic system control and modulate autonomic responses through various cognitive, behavioral and emotional mechanisms.[33] These areas remain salient as a concussion may influence the projection fibres connecting deep and superficial regions of the CNS through rotational and shearing mechanisms.[37-40] The widespread distribution of injury may result in common concussion symptoms including behavioral, emotional, cognitive and motor dysfunctions which may subsequently include dysregulation of ANS function.[26-29] Therefore, it is mechanistically plausible that concussion may result in ANS dysfunction, as suggested by existing preliminary studies and literature reviews.[35, 36, 41-44]

Some studies have demonstrated dysfunction in autonomic and neuroendrocrine systems across the entire spectrum of TBI.[41, 45-47] More recently, studies have measured ANS function and its integrity in concussed athletes, specifically.[21, 48-56] Physiologic measures of the ANS in the research and clinical setting include measures of heart rate variability (HRV)[54, 56-58], tilt table testing[59], baroreflex responsiveness[60], arterial pulse contour analysis[61], pupillometry[21, 62-65], exercise tolerance testing[66, 67], cerebrovascular reactivity[68], and cerebral blood flow[69]. However, the latter two markers are non-specific measures of ANS functioning, as there are complex arrays of local vascular mechanisms that influence a given hemodynamic response in brain tissue.[70-72]

There has been a surge of research into the effects of concussion on ANS functioning in the pediatric population. This is particularly important due to the aforementioned high incidence rates of concussion amongst youth and the considerable number of children participating in sports.[5-7, 14, 16] Comparable to studies that have defined age-specific features for concussion identification, symptom presentation, and recovery, it may be essential to compare the degree of ANS impairment following concussion in different age categories. Pertab *et al*.[36] conducted a systematic review, however included all ages and to our knowledge there has yet to be a systematic review of the literature on the pediatric population specifically.

McCrory *et al*.[1] state in the 2016 Consensus Statement on Concussion in Sport that child and adolescent (e.g., pediatric) guidelines for sport-related concussion should refer to individuals 18 years of age or less. Due to inconsistencies with the "pediatric" reference age range defin-

ition in the literature and between international health organizations, we decided to include studies of individuals aged 2-18 for the purpose of this systematic review.[73-75] Therefore, the objective of this review is to identify, appraise and synthesize the evidence of ANS dysfunction in a population aged 2-18 who have a history of a sport-related concussion.

Methods

This review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).[76] A full protocol for this systematic review was registered on Open Science Framework registries.[77]

Inclusion and exclusion criteria

To be included in the systematic review studies must have fulfilled the following criteria: 1) English language, 2) published in a peer-reviewed journal, 3) cohort studies, case-control studies, cross-sectional studies, other observational studies, 4) data includes analysis of individuals who have a history of concussion; when mixed brain injury samples are studied, it is required that results be separately specified for a subgroup of participants with concussion in order to be included (no mixed mild-moderate-severe groups), 5) participant ages 2-18 (inclusive), 6) data must have measured at least one variable of interest for ANS function. This outcome of interest was required to be primarily representative of an autonomic process. For the purpose of this review measures of cerebral blood flow, cerebral autoregulation and cerebral vasoreactivity were not used as proxies for ANS function due to factors independent of the ANS contributing to these processes.

Studies fulfilling any of the following criteria were excluded from the systematic review: 1) Publication types including: guidelines, letters, editorials, commentaries, unpublished manuscripts, dissertations, government reports, books and book chapters, conference proceedings, meeting abstracts, lectures and addresses, consensus development statements, guideline statements. 2) Study designs including case reports, case series, qualitative studies, non-systematic and systematic reviews, clinical practice guidelines, and studies not reporting on methodology. 3) animal or cadaveric studies, 4) studies of individuals with diagnoses of: Parkinson's disease, Alzheimer's disease, multiple systems atrophy, familial dysautonomia, multiple sclerosis, spinocerebellar ataxia (all types), severe traumatic brain injury, spinal cord injuries, ischemic brain injury, intracranial hemorrhage, autism-spectrum disorders and cerebral palsy.

Search methods

A search strategy was developed in consultation with a health sciences librarian, and reviewed by a second librarian using the Peer Review of Electronic Search Strategies (PRESS) checklist.[78] The following electronic databases were systematically searched from inception to May 30, 2021: MEDLINE (Ovid), SportDiscus (EBSCO), CINAHL (EBSCO), EMBASE (Ovid) and PsycINFO (Ovid). Search terms consisted of subject headings and text words relevant to 'concussion' and 'autonomic nervous system/autonomic nervous system dysfunction' and are included in Appendix I. Subject headings were specific to each database – e.g., MeSH in Medline. In addition to database searches, reference lists of included studies and previous systematic reviews on this topic were hand searched to ensure all relevant studies were identified. Authors' personal libraries were also hand searched for relevant studies that were not captured with the search strategy.

Data collection and analysis

Screening

The citations identified by the search strategy included as Appendix I were exported into EndNote X9 for reference management and tracking of the screening process. Pairs of reviewers screened articles in two phases (titles and abstracts; full text articles) using a standardized pre-piloted Excel spreadsheet. The first phase included screening of titles and abstracts for irrelevant and potentially relevant citations based on the outlined inclusion and exclusion criteria. Potentially relevant citations from the first phase were reviewed in the second phase using the full text article. At each phase of screening, consensus ratings were automatically populated within screening Excel spreadsheets for citations where there was agreement between reviewers. Any disagreement was resolved by discussion between the paired reviewers to reach consensus. According to the study protocol, if consensus could not be reached, a third reviewer would independently appraise the citation and discuss with the other two reviewers to reach consensus. However, this step was not utilized as it was not necessary during our screening process.

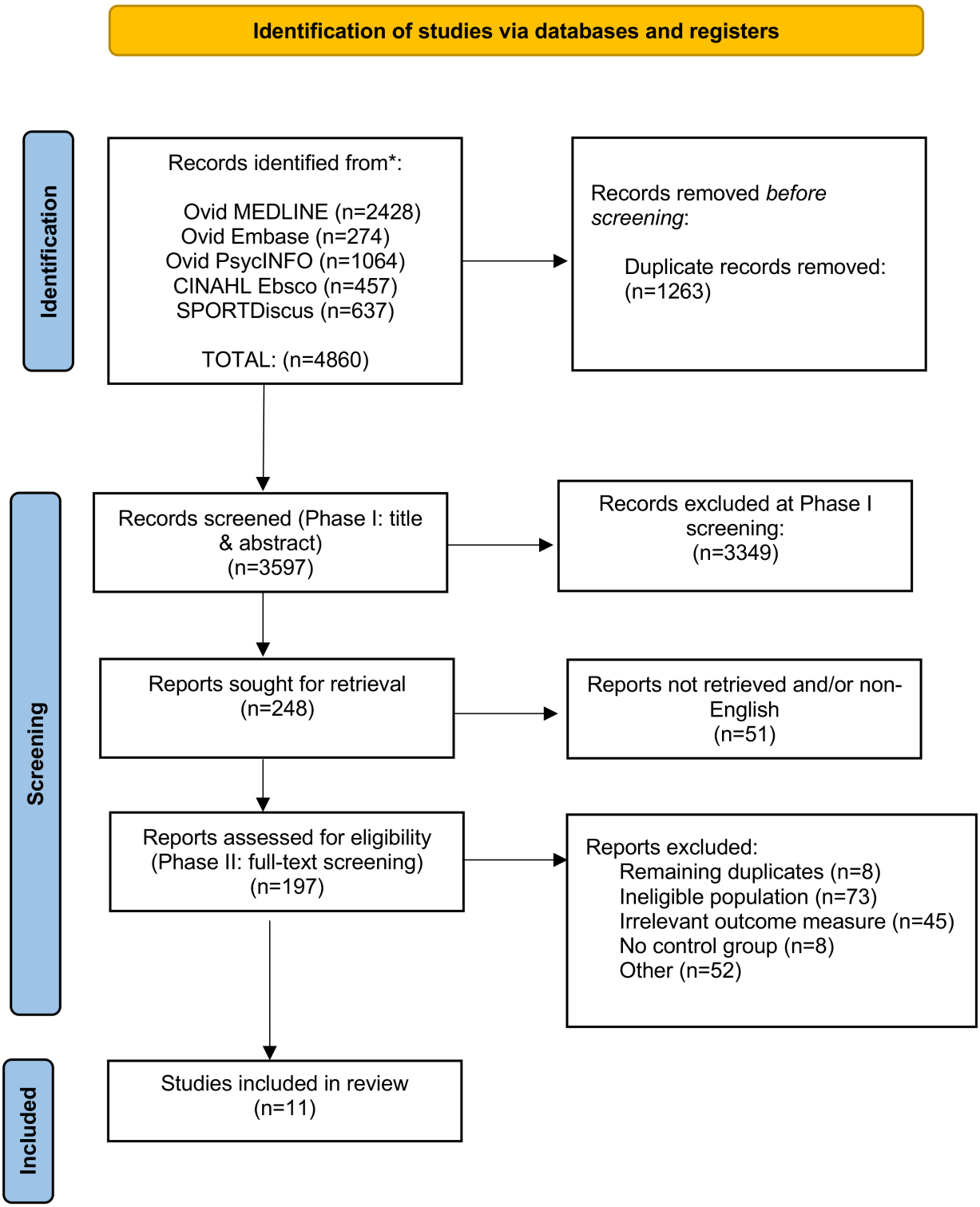

Figure 1.
PRISMA flow diagram

Critical appraisal

Critical appraisal of all articles that were deemed to be relevant was completed by pre-established pairs of reviewers, and consensus was reached through discussion. The internal validity of each study was assessed using the Joanna Briggs Institute (JBI) critical appraisal tools based on epidemiological study design.

Data extraction

The lead author (AP) extracted the data from studies with low risk of bias (n=11) and created evidence tables. A second reviewer (SHJ) checked the data extraction for accuracy and completeness. The research team used the results of the evidence tables to outline the evidence on each topic and to identify consistencies and limitations within the existing body of literature. Data tables describe the populations included in each study while also identifying the specific sport involved where applicable.

Statistical analysis

Ratings from the pairs of reviewers at phase 1 and phase 2 were compared and agreement was described using percent agreement and Kappa statistic with 95%CI. Results from low risk of bias studies were summarized in evidence tables and qualitatively described in text as we anticipated that data would not be able to be pooled for meta-analysis in any meaningful way, due to predicted heterogeneity in populations, ANS outcome measurements, time to assessment following concussion and study design.

Results

A total of 4860 citations were captured from database inception to May 2021 (Figure 1). Following removal of duplicates, we screened 3597 titles and abstracts in Phase I. The inter-rater percent agreement for Phase I screening between pairs of reviewers was 96.6% (95%CI – 96.0%-97.2%), kappa = 0.76 (95%CI – 0.72-0.80). Following Phase I screening, we sought 248 citations for full-text screening, however 51 articles could not be retrieved or were not obtainable in the English language. A total of 197 full-text articles were ultimately screened by the reviewers. The inter-rater percent agreement for Phase II screening between pairs of reviewers was 96.8% (95%CI – 93.7%-98.6%), kappa = 0.75 (95%CI – 0.58-0.92). In

Table 1.
Risk of Bias

Authors, Year	Research question	Criteria for inclusion	Subjects and setting	Matched controls	Valid exposure measurement	Valid measurement of outcome(s)	Confounding factors	Study taking place at multiple sites
Balestrini, 2021[48]	WC	AA	WC	Y	AA	Y	AA	N
Haider, 2021[52]	WC	WC	WC	Y	WC	Y	AA	Y
Hinds, 2016[53]	WC	AA	WC	Y, PA	AA	Y	AA	N
Memmini, 2021[50]	WC	WC	WC	Y	AA	Y	AA	N
Haider, 2020[51]	WC	AA	WC	Y	AA	Y	AA	N
Gall, 2004[55]	AA	WC	WC	Y	PA	Y	PA	N
Gall, 2004[54]	AA	WC	WC	Y	PA	Y	AA	N
Snyder, 2021[79]	WC	WC	WC	Y	AA	Y	AA	N
Woehrle, 2020[49]	WC	PA	AA	Y	AA	Y	AA	N
Paniccia, 2018[56]	WC	WC	WC	Y	WC	Y	WC	N
Master, 2020[21]	WC	WC	WC	Y	WC	WC	WC	N

Abbreviations: JBI, Joanna Briggs Institute; AA, adequately addressed; WC, well covered; NR, not reported, NAp, Not applicable; NAd, Not addressed; PA, poorly addressed; Y, Yes; N, No

total, 11 studies fulfilled the inclusion criteria and were deemed to be relevant for appraisal and synthesis.

Methodological quality

Risk of bias for each of the 11 studies was evaluated by pairs of reviewers using the JBI checklist for cross-sectional studies, and consensus was reached following discussion. All eleven relevant studies were deemed to be low risk of bias based on their methodological quality. A risk of bias table (Table 1) describes results from critical appraisal as well as other relevant information that may have been described in the included studies.

Study characteristics

As described above, the JBI critical appraisal checklist for analytical cross-sectional studies was used for all eleven studies. The authors of the majority of the eleven studies identified their study methodology as being case-control or cohort, however these study classifications were not consistent with their respective epidemiological study design definition. For example, the authors of five studies identified their respective study as using case-control methodology, however upon review, the presence or absence of an exposure (concussion or history of concussion) in all studies was used to dictate the grouping prior to measurement of the outcome of interest (ANS functioning).[49-51, 56, 79] Thus, the disease/outcome was identified after a known exposure. To be of case-control methodology, subjects would be sampled based on the outcome of interest (presence or absence of ANS dysfunction), with a historical observation determining those who had sustained a concussion and those who had not. Thus, the analytical cross-sectional critical appraisal tool was the best fit during appraisal. An additional four studies were identified as being prospective cohort studies, however most measurements took place within a short timeframe and not over the long term.[21, 48, 52, 53] Two studies did not state their proposed study design and were deemed to best fit a cross-sectional design.[54, 55] Upon appraisal we deemed all 11 studies to be low risk of bias and there is a more detailed description in Table 1.

Due to the variability and rapidly changing diagnostic criteria for concussion, different criteria were used for diagnosis or determination of past concussion between studies. Five studies stated clearly that concussion diagnosis was made by a physician.[21, 48, 52, 53, 56] Others stated that diagnosis was determined using combinations of medical history, reported mechanism of injury, medical chart review, or self-report of previous physician diagnosis.[49-51, 79] Two older studies utilized the Canadian Hockey Association guidelines to define concussion where diagnosis relied on team trainers and spectators to detect events suspicious of concussion while observing game play.[54, 55]

There was variability in how ANS function was measured in the eleven studies. Cardiovascular and cardioautonomic metrics such as blood pressure (BP), systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR), heart rate variability (HRV), and mean arterial pressure (MAP) were used.[48-56] Various combinations of these metrics were often included. The most common HRV sub-metric used was root mean square of successive RR interval differences (RMSSD)[48-51, 56], where the RR interval represents the time elapsed between two successive R-waves of the QRS signal of an electrocardiogram[80]. Studies also calculated the standard deviation of the NN intervals (SDNN)[50] and standard deviation of the RR intervals (SDRR)[54], where "NN" represents different nomenclature for "RR". However, the use of "NN" is used to distinguish that the RR interval of successive heart beats are "normal" and with the absence of artifacts.[80] Both of these sub-metrics are considered to be time domain measures of HRV, which quantify the inter-beat interval of a normal heart rhythm.[80] Other studies used frequency domain measures such as high frequency power (HF)[51, 54], low frequency power (LF)[51, 54], and the ratio of low frequency to high frequency power (LF:HF)[51, 54] as sub-metrics of HRV. Frequency domain measurements estimate the distribution of power (e.g., signal energy) into different frequency bands within the electrocardiogram.[80]

These cardioautonomic responses were commonly measured before, during or after various protocols of aerobic or isometric exercise.[49, 50, 53-55] Some studies examined cardioautonomic variables at rest, in different postures, or during autonomic reflex testing.[48, 51, 52] One study measured HRV over a 24-hour period during the participants' normal day-to-day activities.[56] A sole study evaluated cardiorespiratory function using respiratory rate, pulse-oximetry (SpO2), and end-tidal carbon dioxide (EtCO2).[79] Lastly, one study measured the multiple metrics of the autonomically controlled pupillary light reflex (PLR).[21]

Table 2.
Study location, sample populations and concussion diagnostic criteria.

Author(s), year	Location/setting	Sample and control population descriptions, number enrolled (n), age in years	Concussion diagnostic criteria used in study
Balestrini *et al*. 2021[48]	Sports medicine clinic, University of Western Ontario, Canada	Recreational and competitive adolescent athletes in a variety of sports from local adolescent sporting organizations. Concussed (mTBI) group and age and activity matched controls. mTBI: n = 65 (26M, 39F) age 15 +/- 1 yr CTRL: n= 54 (29M, 25F) age 14 +/- 1 yr	Diagnosed by a sports physician. Control participants with a previously diagnosed concussion were only included if they had not experienced symptoms in the 6-month period prior to testing (n=16).
Woehrle *et al*. 2018[49]	Sports medicine clinic, University of Western Ontario, Canada	Adolescents with sport-related concussion. Healthy, age and activity matched individuals recruited from community sports teams were used as controls. mTBI: n=19 (11M, 8F), age 15 +/- 2 yrs CTRL: n=16 (10M, 6F), age 15 +/- 2 yrs	Diagnosis was based on injury history, mechanism of injury and SCAT3 symptom score. The authors did not mention the presence or absence of a remote/resolved concussion history in the control population.
Memmini *et al*. 2021[50]	Recruitment from a minor hockey program. Quebec, Canada.	Asymptomatic Midget-AAA (age 15-18) male hockey players were divided into groups: concussion history (Chx) and no concussion history (CTRL). Chx group was divided further into those with 1 concussion (Chx1) and those with 2 or more concussions (Chx2). All groups were demographically matched. CTRL: n=18, age 16 +/- 1 Chx (total): n=16, age 16 +/- 1 Chx1: n=11, age 16 +/- 1 Chx2: n=5, age 16 +/- 1	Concussion history was determined by completion of a medical history and evaluation of de-identified health information. All concussion diagnoses were confirmed by medical records and by a resident neuropsychologist. Athletes who were currently experiencing persistent symptoms or those who sustained a concussion within 6-months of the assessment were excluded.

Author(s), year	Location/setting	Sample and control population descriptions, number enrolled (n), age in years	Concussion diagnostic criteria used in study
Haider *et al*. 2021[52]	University affiliated concussion management clinics in Buffalo, Philadelphia, and Albuquerque, USA.	Individuals presenting within 10 days of injury were considered for the concussion (mTBI) group. Healthy controls were age, activity, height, and weight matched and were obtained from regular pre-season health screening and examination. CTRL participants had no history of concussion within 12-months. mTBI: n=297 (174M, 124F), age 15.05 +/-1.7, prev. concussions 0.10 +/- 0.3, history of OH =1.4% (n=4) CTRL: n=214 (125M 89F), age 14.96 +/- 1.5, prev. concussions 0.62 +/- 1.0, history of OH = 0.5% (n=1) Sport related mTBI = 235/297 (79.4%)	Concussions were diagnosed according to international Concussion in Sport Group (CISG) guidelines by experienced clinicians based on history (including a standardized concussion symptom checklist) and clinical assessment. Diagnosis of concussion was standardized between all study physicians prior to enrollment. The CTRL group must not have been symptomatic or experienced a concussion within 12-months.
Hinds *et al*. 2016[53]	Concussion Clinic, Buffalo NY, USA	Recently symptomatic concussed (mTBI) patients with a mean time since injury of 5 days (n=40). Healthy, asymptomatic (n=30) athletes were selected as the control (CTRL) group. mTBI: n=40 (23M, 17F), age 15.5 (range 12-18) CTRL: n=30 (18M, 12F), age 15.9 (range 13-18)	Diagnosis based on physician evaluation and SCAT2. CTRL participants (no concussion) were selected if they were asymptomatic and had not experienced a concussion within 6-months prior to assessment. They also needed to be considered safe to exert themselves to exhaustion.
Haider *et al*. 2020[51]	University of Buffalo, New York, USA	Healthy, asymptomatic athlete participants. Included those with a remote concussion history >1 year ago (CH) and those without concussion history (CN). Age ranges in both groups were from 13-24 years. Individuals with >3 concussions were excluded. CH: n=9 (4M, 5F) age=18.3 +/-2.4 Prev. concussions (one=6, two=2, three=1) CN: n=21 (14M,7F), age=16.7 +/- 3.0	Self-reported concussion history. Only concussions that were recalled to be physician (or another relevant clinician) diagnosed, were included. However no comprehensive details of past concussion (loss of consciousness, recovery time, mechanism of sporting injury etc.) were collected. Those reporting no history of concussion diagnosis could be included in the CTRL group.

Author(s), year	Location/setting	Sample and control population descriptions, number enrolled (n), age in years	Concussion diagnostic criteria used in study
Gall *et al*. 2004 (BJSM)[55], 2004 (J. of ACSM)[54]	Simon Fraser University, British Columbia, Canada. Pacific International Junior B Hockey League (PIJHL)	Baseline data from 147 male Junior B players including a medical history and concussion (mTBI) history were obtained. Fourteen of 147 players sustained a concussion. Fourteen healthy non-concussed teammates (matched for position, playing time, body stature and team) served as the control group (CTRL). mTBI: n=14 (n=9 missed time, age=17.8 +/- 0.5) (n=5 did not miss time, age=18.8 +/- 0.8) CTRL: n=14 (n=9 matched controls for missed time group, age=18.7 +/- 0.4) (n=5 matched controls for no missed time group, age=19.0 +/-0.8)	Canadian Hockey Association concussion symptom guideline was used to diagnose a concussion, as applied through observation by team trainers and game attendees during game play.
Snyder *et al*. 2021[79]	University-Affiliated (UCLA) concussion clinics in Los Angeles, California	Individuals were part of a separate case-control study investigating the effect of psychological intervention in youth with persistent concussion symptoms. Controls were age-matched and recruited from local communities. PPCS: n=13 (4M, 9F), age = 16.15 (SD = 1.86), prev. concussions = 2 (SD = 1.08) CTRL: n=12 (6M, 6F), age=18.50 (SD=3.12), prev. concussions = 0.0	Concussion diagnosis by a medical provider within the past 2-16 months. Non-injured CTRL group could not be experiencing symptoms or have sustained a concussion within the 12-months prior to the study.
Master *et al*. 202021	Children's Hospital of Philadelphia, Pennsylvania, USA	Athletes aged 12-18 were prospectively enrolled. Healthy controls were athletes recruited from a local sub-urban high school with pupillometry measurements obtained prior to pre-season competition. mTBI: n=98 (43M, 55F), Age=15.7 (SD=1.54) CTRL: n=134 (56M, 78F), Age=15.3 (SD=1.61)	Concussion diagnosis was made by a sports medicine pediatrician according to the most recent consensus statement for concussion in sport. CTRL participants were healthy and had not sustained a concussion. Ten CTRL subjects subsequently sustained a concussion and thus were included in the concussed cohort.

Author(s), year	**Location/setting**	**Sample and control population descriptions, number enrolled (n), age in years**	**Concussion diagnostic criteria used in study**
Paniccia *et al*. 201856	Children's rehabilitation hospital, Toronto ON, Canada	Convenience sample of 553 youth athletes aged 13-18 was recruited from local sport organizations, as part of a larger pre-injury baseline testing study. Youth athletes who sustained concussion were placed in mTBI group and age/sex matched participants were then selected from the baseline cohort as the CTRL group. mTBI: n=29 (8M, 21F), Age=15 (SD=1.48) CTRL: n=15 (4M, 11F), Age=15 (SD=1.66)	Diagnosis of concussion was made by a physician. CTRL group consisted of those who did not sustain a concussion and who had undergone the same pre-injury baseline testing.

Abbreviations: M, male; F, female; mTBI, mild traumatic brain injury; n, number of participants; SCAT2/3, Sport Concussion Assessment Tool-2/3; CTRL, control group; CH, concussion history; CN, concussion naïve; SD, standard deviation; Chx, concussion history; Chx1, history of 1 concussion; Chx2, history of 2 or more concussions; PPCS, persistent post-concussion symptoms

Table 3.
Time to concussion evaluation, physiologic measurements, and findings.

Author(s), year	Time to assessment after concussion exposure	Specific ANS outcome measurements assessed	Key findings/conclusions
Balestrini *et al*. 2021[48]	When individuals pursued care at a sports medicine clinic (15 +/- 2 days after injury).	Heart rate variability (HRV, RMSSD), HR, and BP (MAP and DBP).	HR was greater in concussed group. HR in concussed group was also increased in each posture (supine vs. seated vs. standing). Smaller RMSSD values were observed in concussed females during seated posture compared to controls. Concussion may impair cardiovagal function in a sex- and posture-dependent manner. Cardiovagal dysfunction as measured by RMSSD persisted beyond clinical symptom resolution.
Woehrle *et al*. 2018[49]	12 +/- 10 days following concussion. Participants completed 2 separate testing sessions: immediately after diagnosis and at clinical discharge. The control group completed 2 test sessions separated by a minimum of 1 week.	HR, SBP, DBP, MAP, HRV (RMSSD) at rest and during 30% MVC isometric handgrip testing.	Change in HR was less in mTBI group during IHG test compared to CTRL ($p<0.05$). There is an impaired HR response at the onset of the IHG test in mTBI, which improved between the first and last visit.
Memmini *et al*. 2021[50]	Participants needed to be asymptomatic and have not sustained a concussion within 6-months of the assessment date.	Heart rate variability measures of mean N-N interval, RMSSD, and SDNN measured using ECG.	Pre-exercise: Mean RMSSD and SDNN were significantly higher for Chx2 than for Chx1. Post exercise: HR was higher for Chx compared to CTRL at all times points. Chx2 group differed significantly ($p<0.05$) from Cx1 and CTRL when measured 1-3min and 7-9min post exercise for recovery of NN/HR, SDNN and RMSSD. Elevated resting HR and longer return to baseline HRV was seen in concussed patients following exercise, when compared to controls. Having 2 or more concussions suppressed cardioautonomic function to a larger degree.

Author(s), year	Time to assessment after concussion exposure	Specific ANS outcome measurements assessed	Key findings/conclusions
Haider *et al*. 2021[52]	Concussed individuals who presented to the clinic within 10 days of the original injury.	BP, HR, PP using an automated BP cuff. Change in DBP, SBP and HR from supine to standing was calculated.	Concussed male and females experience symptoms of dysautonomia upon postural change more than healthy adolescents. These symptoms may have been due to cardioautonomic dysfunction as acutely injured adolescents with concussion had lower HRs and smaller changes in HR when moving from supine to standing, when compared to controls.
Hinds *et al*. 2016[53]	Concussed group was assessed within 5 days +/- 1.1 days, post-injury.	HR and RPE.	Concussed participants had lower HRs at the start of exercise compared to controls, but relative HR increase during each successive increase in exercise intensity was not significantly different between groups. RPE in the concussed group was higher for comparable workload when compared to controls. CTRL group exhibited no differences in HR or RPE between visits.
Haider *et al*. 2020[51]	Remote history of concussion of greater than 1-year	HRV metrics (HR, RMSSD, R-R interval were derived from the time-domain data and HF and LF HRV, and LF:HF were derived from the frequency domain data of HRV).	Athletes who reported a remote history of concussion showed a blunted cardiac parasympathetic response to a face cooling test compared to athletes without a reported history of concussion. There may also be a sympathetic predominance during face-cooling in athletes with history of concussion.
Gall *et al*. 2004 (BJSM)[55], 2004 (J. of ACSM)[54]	(BJSM, 2004) Exercise protocol completed within 72 hours of being asymptomatic at rest. Repeat protocol completed 5 days after initial assessment. (J. of ACSM, 2004) Baseline resting HRV measurement taken at 1.8 +/- 0.2 days following concussion injury. Exercise protocols completed once symptomatology has return to baseline.	(BJSM, 2004) HR and blood lactate. (J. of ACSM, 2004) HRV time domain measures (R-R interval means, SDRR). Estimation of LF power and HF power were calculated at rest and exercise. LF:HF ratio was also calculated.	(BJSM, 2004) Capacity to perform high intensity exercise did not seem to be influenced by concussion. However, although no detectable difference in symptoms from mTBI to control, the mTBI group did show an adverse CV response to steady state exercise. (J. of ACSM, 2004) No significant difference in any variable of HRV between concussed and controls while at rest, but there was difference during exercise.

Author(s), year	Time to assessment after concussion exposure	Specific ANS outcome measurements assessed	Key findings/conclusions
Snyder *et al*. 2021[79]	Within 2-16 months post-injury.	EtCO2 measured via capnometry. HR, RR, SpO2 also measured.	Baseline cardiorespiratory responses may be different in youth with PPCS compared to control participants and may be lower than normative ventilatory characteristics. These cardiorespiratory changes in the PPCS may be mediated by dysregulation in ANS functioning.
Master *et al*. 2020[21]	Measurements occurred within 28 days of injury (median 12 days, IQR 5-18 days). If injured participant had multiple assessments, the first assessment was used in the analysis.	Pupillometry. Eight pupillary dynamic metrics were quantified: maximum pupil diameter (steady-state pupil size before the light stimulus); minimum pupil diameter (pupil size after maximum constriction in response to the light stimulus); percentage pupil constriction; latency (time to maximum constriction in response to the light stimulus); peak and average constriction velocity; average dilation velocity; and T75 (time for pupil re-dilation from minimum diameter to 75%).	There were statistically significant differences in all PLR metrics between groups, except latency. Thus, testing the PLR identified a significant difference in pupillary autonomic control in concussed vs CTRL participants, and may serve as an objective biomarker of concussion.
Paniccia *et al*. 2018[56]	Concussed patients were followed weekly while symptomatic, and then at 1-, 3-, and 6-months following cessation of concussion symptoms. The same measures were collected for CTRL group.	HRV metrics: SDNN, RMSSD, pNN50, HF, HFnu. Mean HR was also calculated.	A decrease in RMSSD occurred in mTBI by day 15 and decreased until day 30, followed by levelling by day 50. mTBI were found to have increased HF and HFnu as days post-injury increased. Findings suggest an increasing trend of HRV along the recovery trajectory following concussion, although this recovery in physiology may be non-linear. There was a general increase in all HRV variables except SDNN, with increasing days post-injury.

Abbreviations: M, male; F, female; mTBI, mild traumatic brain injury; CTRL, control group; HR, Heart rate; RR, Respiratory rate; DBP, diastolic blood pressure; SBP, systolic blood pressure; MAP, mean arterial pressure; HRV, heart rate variability; RMSSD, root-mean square of successive N-N differences; SDNN, standard deviation of N-N intervals; SDRR, standard deviation of R-R intervals; CH, concussion history; CN, concussion naïve; Chx, concussion history; Chx1, history of 1 concussion; Chx2, history of 2 or more concussions; ECG, electrocardiogram; PP, pulse pressure; RPE, rating of perceived exertion; RRI, R-R interval; PPCS, persistent post-concussion symptoms; EtCO2, End-tidal carbon dioxide; SpO2, Blood oxygen saturation; PLR, pupillary light reflex; IQR, interquartile range; MVC, Maximum voluntary contraction; HF, high frequency power; HFnu, normalized power in HF band, LF, low frequency power; LF:HF, ratio of low frequency power to high frequency power; p, significance level

Summary of evidence

The eleven studies that were included in the data synthesis were heterogenous and could not be pooled for meta-analysis in any meaningful way as the methods of ANS measurement differed between studies. Additionally, sample populations, sample sizes, criteria for concussion diagnosis, time between concussion and initial ANS assessment, and number of repeat measures all varied between studies. Ten of the eleven studies clearly identified that the pediatric population studied were athletes. Three studies included ice hockey players[50, 54, 55], while another seven studies included "athletes from varying sports", or did not specify[21, 48, 49, 51-53, 56]. One study did not clearly state if participants were athletes, however the data collection took place at a university affiliated concussion clinic.[79]

Heart rate and blood pressure

Nine of eleven studies[48-55, 79] included measures of HR and/or BP. Measures of HR took place in different contexts, as some studies measured HR at rest and during or after exercise[50, 53, 55], while one study measured HR and BP responses to different postures[52]. One study measured heart rate and HRV during a 24-hour recording, but only reported on HRV.[56]

Hinds *et al*. suggest that resting HR is lower in concussed individuals versus controls (p=0.015), however the relative HR response to a standardized exercise-testing protocol is not significantly different between concussed athletes and controls.[53] Haider *et al*. found that concussed individuals had a statistically significant lower resting supine and standing HR, compared to controls (p<0.001; mTBI supine 66.9 +/- 12.2 bpm, standing 80.3 +/- 14.2 bpm; CTRL supine 71 +/- 12.9 bpm, standing 87.0 +/- 15.6 bpm). In this study, concussed individuals also had a smaller increase in HR compared to controls during a sit stand transition, however this was not statistically significant.[52] In contrast, Balestrini *et al*. found that HR was greater in concussed individuals in supine, seated and standing positions (supine p=0.03, seated p=0.006, standing p=0.009) compared to controls.[48] In this study, the concussed group also exhibited elevated DBP and MAP at their first visit, which was similar to controls by clinical discharge, however the elevated HR that was observed in concussed individuals did not recover by clinical discharge (p>0.5).[48] Memmini *et al*. also suggest that athletes with a history of concussion have higher resting HR, as well as higher post-exercise HR.[50] Lastly, although not statistically significant, Snyder *et al*. qualitatively identified a wider distribution of HR values amongst the participants in the concussed group when compared to the control group.[79]

In another study, there were smaller changes in HR within individuals in the concussed group during an isometric hand-grip exercise compared to controls (p<0.05; d=0.77, mTBI 95%CI 3.6-9.2 bpm, CTRL 95%CI 8.0-18.0 bpm).[49] Relative percentage change in HR was also less in the concussed group (% change in bpm; p=0.03; d=0.80, mTBI=9.5%; CTRL=20%).[49] During a different exercise task which involved steady-state aerobic exercise, Gall *et al*. reported that HR responses appeared to be greater in concussed individuals versus controls (p<0.05), with a significantly higher mean HR in the concussed group during an 8-minute aerobic test (mTBI, 126 bpm +/- 3.4 vs. CTRL, 116 bpm +/- 1.9, p<0.05).[55] However, the decreases in HR during a 5-minute recovery were not different between groups in this same study.

During cardioautonomic reflex testing (e.g., face cooling), individuals with a remote history of concussion (CH) showed overall positive changes in HR (% change in bpm), while control participants (CN) exhibited the expected negative change in HR at multiple timepoints of measurement (minute 1, CH +8.9% [−9.6, +27.4], CN −7.5% [−13.3, −1.7]; minute 2, CH +15.0% [−8.0, +38.1] CN −10.3% [−15.8, −4.7]; minute 3, CH +6.9% [−10.1, +24.4] CN −8.3% [−12.6, −4.1]).51 There was a difference over time between groups (p=0.021) that was not affected by sex (p=0.792) or age (p=0.097).

Heart rate variability

Six of the eleven studies[48-51, 54, 56] included HRV analysis. Like HR measurements, HRV was measured in different contexts and at different timepoints between the studies.

Balestrini *et al*. identified reduced RMSSD in concussed females while in a seated posture compared to controls (42 +/- 4ms vs. 61 +/- 7ms; p=0.01), which also correlated with their concussion symptom report (r2=0.07, p=0.005). In females, the RMSSD did not increase by clinical discharge (mean=37 days). This was the only study to identify a sex and posture dependent difference in HRV as a metric of cardioautonomic function.[48]

Woehrle *et al*. also identified reduced RMSSD in the concussed group compared to the control group at base-

line (72 +/- 58ms vs 82 +/- 53ms) and during isometric handgrip testing (IHG) (37 +/- 30ms vs 44 +/- 44ms). The group/time interaction was not statistically significant (p=0.824).[49] Isometric handgrip testing involves participants sustaining a brief isometric contraction (usually ~ 30% of maximal voluntary contraction) using a handheld dynamometer, however the intensity, duration and number of repetitions of IHG varies widely within the literature, and there is no agreed upon consensus as to the ideal duration of the test.[81, 82]

Memmini *et al*.[50] and Gall *et al*.[54] both measured HRV during five-minutes of resting, prior to having athletes exercise. Memmini *et al*. observed significantly higher mean RMSSD and SDNN in those with a history of two or more concussions (CHx2) compared to those with a history of only one concussion (CHx1) at rest (RMSSD, CHx2: 77+/- 17 vs CHx1: 49 +/- 13 ms; SDNN, CHx2: 92 +/- 197 vs CHx1: 66 +/- 14 ms). There was no comparison to concussion-free controls reported. Post-exercise, there were significant increases over time in RMSSD for both those with a history of one concussion and the concussion-free control group, but the groups were not statistically different.[50] Those with a history of two or more concussions had statistically significant differences in the recovery of RMSSD and SDNN after exercise when compared to those with a history of one concussion and the control group.[50] In contrast, Gall *et al*. reported no significant difference in concussed athletes and their matched controls in the RR interval or other parameters of HRV while at rest. However, during exercise the concussed group had significantly lower (p<0.01) mean RR intervals than matched controls (466.2 +/- 8.9 ms vs 508.1+/- 9.1 ms). The concussed group also displayed lower SDRR compared to controls at rest, but this failed to reach significance (10.7ms +/- 0.9 vs. 13.1ms +/- 0.9).54 Low and high frequency powers were also significantly reduced in the concussed versus control group across exercise protocols.

Haider *et al*. measured responses to face cooling in those with a remote history of concussion (CH) and those with no concussion history (CN). Face cooling has been shown to elicit transient but measurable increases in cardiac parasympathetic activity.[83] At baseline, the CH group had lower LF:HF ratios (p=0.050). During face cooling, there was no difference in RR interval over time between groups (p=0.161) and there was no effect of sex (p=0.582) or age (p=0.385). There was a difference in RMSSD over time between groups (p=0.048) that was not affected by sex (p=0.084) or age (p=0.597). Changes (% change in ms) were present at all minutes (Minute 1, CH +31.8% [-44.8, +109.4], CN +121.8% [+82.1, +161.5]; Minute 2, CH +23.4 [-56.1, +102.8], CN +167.7 [+88.7, +235.5]; Minute 3, CH +83.6 [+12.9, +154.2], CN +100.9 [+51.2, +150.7]).[51] There were no differences in other sub-metrics of HRV including HF, or LF:HF during face cooling.

Paniccia *et al*. was the only study to have pre-injury baseline HRV values for individuals who went on to sustain a concussion, as well as for the control group. All baseline measurements were taken prior to an athletic season. All HRV variables were similar at baseline between groups and there were no significant sex differences, with the exception of females having lower HF (normal units) compared to males. In the concussed group there was a decrease in RMSSD at 15 days post-injury that continued to decline until day 30. This decline subsequently levelled off at day 50 (p=0.02). Concussed participants also had increasing HF (p=0.005) and HF (normal units) (p<0.001) values with increasing days post-injury. The only variable that did not increase in the concussed group post-injury was SDNN. However, in the initial 30-40 days post injury, HRV in general was shown to decrease by 14-25%.[56]

Capnometry

One study used capnometry to measure various cardiorespiratory variables as a proxy of ANS regulation of respiration.[79] The authors found that there was no statistical differences in respiratory rate, HR or SpO2 between concussed and control groups, however there was a larger range of HR distribution values within the concussed group compared to controls. There was a significantly lower EtCO2 that was observed in the concussed group compared to the control group (mean=36.30 mmHg [SD=2.86] vs. 39.80 mmHg [SD=2.30], p=0.003). The control group demonstrated a strong negative correlation between EtCO2 and SpO2 using Spearman's rank correlation (r=-0.71, p=0.009), however no significant intercorrelations between EtCO2 and other cardiorespiratory variable existed in the persistent post-concussion symptom group.[79]

Pupillometry

A study by Master *et al*. utilized pupillometry to measure the ANS control of the PLR in concussed athletes and con-

trols.[21] Athletes with concussion had larger maximum pupil diameters (4.83 vs 4.01mm; difference, 0.82; 99.44% CI, 0.53-1.11), larger minimum pupil diameters (2.96 vs 2.63mm; difference, 0.33; 99.4% CI, 0.18-0.48), and greater percentage constriction following light stimulus (38.23 vs 33.66%; difference, 4.57; 99.4% CI, 2.60-6.55). Enhanced pupillometry metrics revealed faster average constriction velocity (3.08 vs 2.50mm/s; difference, 0.58; 99.4% CI, 0.36-0.81), faster peak constriction velocity (4.88 vs 3.91mm/s; difference, 0.97; 99.4% CI, 0.63-1.31), faster average dilation velocity (1.32 vs 1.22mm/s, difference, 0.10; 99.4% CI, 0.00- 0.20), faster peak dilation velocity (1.83 vs 1.64mm/s; difference, 0.19; 99.4% CI, 0.07-0.32), and faster time to 75% re-dilatation (1.81 vs 1.51s; difference, 0.30; 99.4% CI, 0.10-0.51) in concussed athletes compared to matched controls.[21]

Discussion

The purpose of this systematic review was to investigate if pediatric sport-related concussion is associated with dysfunction of the ANS when compared to healthy pediatric populations. In a previous systematic review, Pertab *et al*. identified that "it is likely that concussion causes anomalies in ANS function", however these authors synthesized data from all populations.[36] In our review, we were able to identify that there is evidence to support that sport-related concussion impairs various functions of the ANS in a pediatric population, specifically.

Monitoring following concussion has largely focussed on athletes' symptom levels during daily and athletic tasks, and has served as primary criteria for recovery and return to sport.[1, 84, 85] More recently, focus has been placed on objective biomarkers to detect concussion and to determine recovery in hopes of providing more accurate and safe return to sport.[30, 31, 86, 87] This focus has gained some acceptance as it is becoming apparent that subjective symptom reporting has its limitations, and can be readily modified by the reporting athlete. Concussion-like symptoms also exist in numerous conditions such as depression[88, 89], anxiety[90], chronic pain syndromes[88, 91], cervical spine injuries[92] and can also vary by sex[26, 93], making it challenging to determine the etiology of reported symptoms in the presence of co-existing conditions. Existing literature on moderate and severe TBI in pediatric populations suggest that injury results in profound negative influences on cardioautonomic functioning, respiratory function, cerebral oxygenation, and consciousness following injury, all of which that can be monitored objectively.[94-98] As concussions are considered a milder form of TBI, it behooves researchers and clinicians to understand the potential for these autonomic consequences to fall along a spectrum of dysfunction, similar to the already recognized spectrum of injury under the umbrella of TBI diagnosis.

In the studies we synthesized we identified that concussion is associated with dysregulation in cardioautonomic regulation and functioning in pediatric athletes. Haider *et al*.[42] and Hinds *et al*.[43] reported that concussed individuals exhibit lower resting HR and lower HR while in different postures at rest when compared to controls. These findings suggest that there may be a parasympathetic predominance of cardiovascular control in individuals following concussion. In contrast, Balestrini *et al*.[37] and Memmini *et al*.[39] found that concussed individuals have higher HR at rest suggesting the contrary – that there may be a sympathetic dominance following concussion. The latter is a generally accepted consequence following moderate and severe TBI, and mechanistically, increased sympathetic nervous system activity leads to neuroinflammation and oxidative stress, both of which are known to be present following concussion.[2, 94, 95] One potential contribution to the differences observed between studies is that the environmental context in which cardioautonomic measurements are taken may influence the results. This is important to recognize as exercise[99, 100], body temperature[101], time of day[102] and psychological state[89, 103] have all been shown to produce variations in cardioautonomic measurements. Nevertheless, despite the presence of positive and negative changes in resting HR, all the studies exhibited a measurable difference in the cardioautonomic control of HR when comparing concussed athletes to controls, thus suggesting some degree of dysregulation of the ANS following concussion.

There may also be different HR responses that occur when athletes are exposed to distinctive forms of exercise following concussion. Woehrle *et al*.[49] reported that concussed individuals have an impaired ability to elevate their HR at the onset of a dynamic IHG task. A brief IHG task and the concomitant HR response that should occur reflects a reduction in vagal inhibition on the heart.[104-106] This should result in a brief but measurable increase in HR upon the onset of the exercise. The authors hypothesized that because concussed individuals have an im-

paired response to an IHG task it may suggest that they have a reduced ability to withdraw cardiovagal control of the heart as a result of disrupted ANS function.[49] Cardiovagal withdrawal is largely dictated by supratentorial and brainstem regions of the ANS, which may be susceptible to concussive impacts. During an aerobic exercise task, Gall *et al*.[55] reported that the HR response in concussed athletes is larger resulting in a higher mean HR. Unfortunately, due to the mechanistic complexity of cardioautonomic and cardiovagal control under different conditions, the responses observed in these two studies cannot be directly compared with confidence. Different exercise paradigms (e.g., dynamic exercise vs steady-state aerobic activity) produce different physiological effects.[104-106] Thus, it is not surprising that these authors observed different autonomic responses in their respective populations, as the environmental context of testing and measurement was different.

Another form of physiological monitoring following concussion that is also objective is autonomic reflex testing.[107] Autonomic reflexes are largely responsible for the maintenance of homeostasis within an organism while providing ongoing adaptation to both internal and external environmental stressors, and reflect reflexive activity of the sympathetic or parasympathetic components of the ANS.[33, 107] Technically, the ANS as a whole is reflexive in nature, as it automatically responds to perturbations in pre-established physiological set points. Still, there are specific reflexes within the ANS that can be isolated, measured and compared to their expected normal values. In humans these reflexes are innate, thus, dysregulation can lead to aberrant physiology, illness, and somatic symptoms.[108-110]

Two studies assessed the integrity of autonomic reflexes in individuals who had sustained a concussion. Haider *et al*.[51] evaluated the cardioautonomic response to a face-cooling procedure which is based on the mammalian dive reflex physiology. The dive reflex triggers bradycardia in order to conserve oxygen stores which is a protective response to cold water submersion.[83] The authors observed a profound reduction in the reflexive bradycardia that was expected during face-cooling in the group with a remote history of concussion, as they exhibited the contrary – a profound and measurable increase in HR during all timepoints of the procedure. The control group exhibited the expected bradycardia at all timepoints, which reflects an appropriate parasympathetic response to face cooling. These results provide evidence that there may be persistent deficits in reflexive ANS control in asymptomatic individuals who report a history of concussion, that are not present in those without a history of concussion. These findings may suggest the importance of having objective clinical measures to assess ANS integrity and athletic readiness for return to sport, in hopes of preventing return prior to full physiological recovery.

Master *et al*.[21] evaluated the utility of the PLR, which has been shown to be adversely affected by concussion in previous studies.[18, 111] Resting pupil size, responsiveness to light, and re-dilatation of the pupils are mediated by regions of the ANS and they are readily measurable by technologies such as pupillometry.[112-114] Pupillary defects and aberrant responsiveness to light stimuli are well documented in all forms of TBI[64, 65, 115] which has led to increasing utility of pupillometry in the diagnosis and management of concussion. Master *et al*.[21] found that all advanced pupillometry metrics were different in a concussed pediatric population compared to controls. Specific findings such as larger resting maximum pupil diameter and larger minimum pupil diameter suggest a sympathetic predominance while greater constriction and dilation velocities may suggest an aberrant and exaggerated response to a light stimulus. Areas of the CNS including the superior colliculus, pretectal olivary nucleus, locus coeruleus and the Edinger-Westphal nucleus all modulate the PLR with the help of higher cognitive brain centres.[116] Thus, an injury to any combination of these areas may lead to an aberrant PLR through disruption of communication between these modulatory regions.

Collectively in the studies we synthesized, we identified significant heterogeneity in study methodology which made it impossible to perform a meta-analysis of the results. However, upon qualitative synthesis it became apparent that the ANS may be disrupted in some way following concussion – a concept that is already generally accepted in existing literature.[35, 43, 44, 117]

Our systematic review identified weaknesses in the existing literature which include but are not limited to small sample sizes, lack of baseline ANS measurements, variability in the concussion diagnostic criteria used, and variability between times to assessment post-injury. Some studies examined concussed individuals as acutely as 1.8 days following injury[54, 55] while others examined

individuals who were asymptomatic and only reported a history of concussion[51], or reported ongoing post-concussion symptomatology up to 16-months after injury[79]. This limits our ability to compare these studies with certainty as asymptomatic individuals may differ substantially from individuals still suffering from post-concussive symptoms when considering psychological state[88, 90] and aerobic capacity[118], both of which may confound ANS measurement.

Additionally, having strict age criteria in our methodology ended up being a limitation of our review as there were multiple relevant studies that were not included due to sample population age.[61, 119-122] A large proportion of studies in the existing literature include college and university aged participants, as institutions may have access to varsity athletes for data collection. Unfortunately, most of these studies had populations with mean ages of 19-22 years of age, which falls outside of our pre-established pediatric definition. So, although the methodology of such studies was generally acceptable and included concussed and non-concussed populations along with valid measures of ANS function, they could not be included in our review. Widening the scope of a future review to include individuals up to the age of 25 may result in more sound conclusions due to more potential studies being included in the synthesis.

Lastly, the pervasive lack of baseline ANS data in the existing literature is a major limitation and impairs our ability to make conclusions with directional certainty. Improving pre-season ANS measurement and including repeated measurement at regular intervals throughout the season will substantially improve the validity of making post-injury comparisons within individuals in future studies. Repeated measurements during a sporting season would likely be necessary to maintain the validity of the comparison as the improved fitness and aerobic capacity that one may gain throughout a season may increase an individual's HRV and decrease their resting HR and BP.[118, 123] Thus, even a single pre-season measurement may not be a valid comparator following injury, especially if an injury occurs in the peak of an athletic season.

Conclusion

In conclusion, our systematic review identified evidence to support that concussion likely leads to dysfunction of the ANS in pediatric athletes. This is in line with another recent systematic review of all ages and populations.[36] We identified some significant limitations in the methodology of the existing literature. Additionally, certain measurements of ANS function can be cumbersome and expensive, which is a barrier to widespread adoption in the sporting community particularly at the grassroots level. Future studies should focus on standardization of measurement methods, gathering baseline data, and performing repeat measurements of athletes throughout an athletic season. Implementation of these methods may lead to more accurate descriptions and quantification of the influence that concussion has on the ANS and may improve diagnosis and management of concussion in sport.

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References

1. McCrory P, Meeuwisse W, Dvorak J, Aubry M, Bailes J, Broglio S, et al. Consensus statement on concussion in sport-the 5(th) international conference on concussion in sport held in Berlin, October 2016. Br J Sports Med. 2017;51(11):838-847.
2. Giza C, Hovda D. The neurometabolic cascade of concussion. J Athl Train. 2001;36(3):228-235.
3. Guerrero JL, Thurman DJ, Sniezek JE. Emergency department visits associated with traumatic brain injury: United States, 1995–1996. Brain Inj. 2012;14(2):181-186.
4. Howell DR, Brilliant AN, Storey EP, Podolak OE, Meehan WP, 3rd, Master CL. Objective eye tracking deficits following concussion for youth seen in a sports medicine setting. J Child Neurol. 2018;33(12):794-800.
5. Boyce S, Quigley M. An audit of sports injuries in children attending an accident & emergency department. Scot Med J. 2003;48:088-90.
6. Kelly K, Lissel H, Rowe B, Vincenten J, Voaklander D. Sport and recreation-related head injuries treated in the emergency department. Clin J Sport Med. 2001;11:77-81.
7. Bryan MA, Rowhani-Rahbar A, Comstock RD, Rivara F, Seattle sports concussion research C. Sports- and recreation-related concussions in US youth. Pediatrics. 2016;138(1).
8. Kroshus E, Garnett B, Hawrilenko M, Baugh CM, Calzo JP. Concussion under-reporting and pressure from coaches,

teammates, fans, and parents. Soc Sci Med. 2015;134:66-75.
9. Williamson IJ, Goodman D. Converging evidence for the under-reporting of concussions in youth ice hockey. Br J Sports Med. 2006;40(2):128-32.
10. Zuckerman SL, Brett BL, Jeckell AS, Yengo-Kahn AM, Solomon GS. Prognostic factors in pediatric sport-related concussion. Curr Neurol Neurosci Rep. 2018;18(12):104.
11. Zemek R, Barrowman N, Freedman S, Gravel J, Gagnon I, McGahern C, et al. Clinical risk score for persistent postconcussion symptoms among children with acute concussion in the ED. JAMA. 2016;315(10):1014-1025.
12. Broshek D, Kaushik T, Freeman J, Erlanger D, Webbe F, Barth J. Sex differences in outcome following sports-related concussion. J Neurosurg. 2005;102:856-863.
13. Colvin AC, Mullen J, Lovell MR, West RV, Collins MW, Groh M. The role of concussion history and gender in recovery from soccer-related concussion. Am J Sports Med. 2009;37(9):1699-1704.
14. Halstead ME, Walter KD, Moffatt K, Council On Sports M, Fitness. Sport-related concussion in children and adolescents. Pediatrics. 2018;142(6).
15. McClincy MP, Lovell MR, Pardini J, Collins MW, Spore MK. Recovery from sports concussion in high school and collegiate athletes. Brain Inj. 2006;20(1):33-39.
16. Meehan WP, d'Hemecourt P, Comstock RD. High school concussions in the 2008-2009 academic year. Am J Sports Med. 2010;38(12): 2405-2409.
17. Araki T, Yokota H, Morita A. Pediatric traumatic brain injury: characteristic features, diagnosis, and management. Neurol Med Chir (Tokyo). 2017;57(2):82-93.
18. Ciuffreda K, Joshi N, Truong J. Understanding the effects of mild trauatic brain injury on the pupillary light reflex. Concussion. 2017;2(3).
19. Winston M, Zhou A, Rand C, Dunne E, Warner J, Volpe L, et al. Pupillometry measures of autonomic nervous system regulation with advancing age in a healthy pediatric cohort. Clinical Autonom Res. 2020;30(1):43-51.
20. Rickmann A, Waizel M, Kazerounian S, Szurman P, Wilhelm H, Boden KT. Digital pupillometry in normal subjects. Neuroophthalmol. 2017;41(1):12-18.
21. Master CL, Podolak OE, Ciuffreda KJ, Metzger KB, Joshi NR, McDonald CC, Margulies SS, Grady MF, Arbogast KB. Utility of pupillary light reflex metrics as a physiologic biomarker for adolescent sport-related concussion. JAMA Ophthalmol. 2020;138(11):1135-1141.
22. Boev A, Fountas K, Karampelas I, Boev C, Machinis T, Feltes C, et al. Quantitative pupillometry: normative data in healthy pediatric volunteers. J Neurosurg. 2005;103:496-500.
23. de Guise E, Lepage JF, Tinawi S, LeBlanc J, Dagher J, Lamoureux J, et al. Comprehensive clinical picture of patients with complicated vs uncomplicated mild traumatic brain injury. Clin Neuropsychol. 2010;24(7):1113-1130.
24. van Ierssel JJ, Tang K, Beauchamp M, Bresee N, Cortel-LeBlanc A, Craig W, et al. Association of posttraumatic headache with symptom burden after concussion in children. JAMA Netw Open. 2023;6(3):e231993.
25. Elbin RJ, Knox J, Kegel N, Schatz P, Lowder HB, French J, et al. Assessing symptoms in adolescents following sport-related concussion: a comparison of four different approaches. Appl Neuropsychol Child. 2016;5(4):294-302.
26. Covassin T, Elbin RJ, Bleecker A, Lipchik A, Kontos AP. Are there differences in neurocognitive function and symptoms between male and female soccer players after concussions? Am J Sports Med. 2013;41(12):2890-2895.
27. Landre N, Poppe CJ, Davis N, Schmaus B, Hobbs SE. Cognitive functioning and postconcussive symptoms in trauma patients with and without mild TBI. Arch Clin Neuropsychol. 2006;21(4):255-273.
28. Oldenburg C, Lundin A, Edman G, Nygren-de Boussard C, Bartfai A. Cognitive reserve and persistent post-concussion symptoms--a prospective mild traumatic brain injury (mTBI) cohort study. Brain Inj. 2016;30(2): 146-155.
29. Macartney G, Woodfield M, Terekhov I, Vassilyadi M, Goulet K. Anxiety, depression, and symptom experience in concussed children and youth. JSPN. 2021;26(1):e12310.
30. Hunfalvay M, Murray NP, Roberts CM, Tyagi A, Barclay KW, Carrick FR. Oculomotor behavior as a biomarker for differentiating pediatric patients with mild traumatic brain injury and age matched controls. Front Behav Neurosci. 2020;14:581819.
31. Hunfalvay M, Roberts C, Murray NP, Tyagi A, Barclay KW, Bolte T, et al. Vertical smooth pursuits as a diagnostic marker of traumatic brain injury. Concussion. 2019;5(1).
32. Iverson G. Network analysis and precision rehabilitation for the post-concussion syndrome. Front Neurol. 2019;10:489.
33. McCorry L. Physiology of the autonomic nervous system. Am J Pharm Educ. 2007;71(4).
34. Cramer G, Darby S. Clinical Anatomy of the Spine, Spinal Cord and Autonnomic Nervous System - Chapter 10: Neuroanatomy of the Autonomic Nervous System. 3rd ed. St. Louis: Elsevier; 2014.
35. Purkayastha S, Stokes M, Bell KR. Autonomic nervous system dysfunction in mild traumatic brain injury: a review of related pathophysiology and symptoms. Brain Inj. 2019;33(9):1129-36.
36. Pertab JL, Merkley TL, Cramond AJ, Cramond K, Paxton H, Wu T. Concussion and the autonomic nervous system: an introduction to the field and the results of a systematic review. NeuroRehabil. 2018;42(4):397-427.
37. Holbourn A. Mechanics of head injuries. Lancet. 1943;242(6267):438-441.
38. Gennarelli T, Thibault L, Tomei G, Wiser R, Graham D, Adams J. Directional dependence of axonal brain injury

due to centroidal and non-centroidal acceleration. SAE technical paper series. 1987.
39. Post A, Hoshizacki TB. Rotational acceleration, brain tissue strain, and the relationship to concussion. J Biomech Eng. 2015;137(3).
40. Meaney D, Smith D. Biomechanics of concussion. Clin Sports Med. 2011;30(1):19-31, vii.
41. Esterov DG, Brian D. Autonomic dysfunction after mild traumatic brain injury. Brain Sci. 2017;7(8).
42. La Fountaine M. An anatomical and physiological basis for the cardiovascular autonomic nervous system consequences of sport-related brain injury. Intl J Psychophysiol. 2018;132(Part A):155-166.
43. Callaway CCM, Kosofsky BE. Autonomic dysfunction following mild traumatic brain injury. Curr Opin Neurol. 2019;32(6):802-807.
44. Bishop S, Neary JP. Autonomic, cerebrovascular and mild traumatic brain injury physiology: linkages and future applications. Curr Res Concussion. 2015;2(2):49-58.
45. Bondanelli M, De Marinis L, Ambrosio M, Monesi M, Valle D, Zatelli M, et al. Occurence of pituitary dysfunction following traumatic brain injury. J Neurotrauma. 2004;21:685-696.
46. Tanriverdi F, Unluhizarci K, Kelestimur F. Pituitary function in subjects with mild traumatic brain injury: a review of literature and proposal of a screening strategy. Pituitary. 2010;13(2):146-153.
47. Keshavarzi Z, Afshari AR, Mohammadzadeh N, Mohebbi M, Mohebbi M, Mollazadeh H. Traumatic brain injury and the gastrointestinal tract: the role of female sexual hormones. J Endocrinol Metabolism. 2017;7(6):163-171.
48. Balestrini CS, Moir ME, Abbott KC, Klassen SA, Fischer LK, Fraser DD, Shoemaker JK. Autonomic dysregulation in adolescent concussion is sex-and posture-dependent. Clin J Sports Med. 2021;31(3):257-265.
49. Woehrle EH, Harriss AB, Abbott KC, Moir ME, Balestrini CS, Fischer LK, Fraser DD, Shoemaker JK. Concussion in adolescents impairs heart rate response to brief handgrip exercise. Clin J Sports Med. 2020;30(5):e130-e133.
50. Memmini AK, La Fountaine MF, Broglio SP, Moore RD. Long-term influence of concussion on cardio-autonomic function in adolescent hockey players. J Athl Train. 2021;56(2):141-147.
51. Haider M, Johnson B, Horn E, Leddy J, Wilber C, Reed E, et al. Blunted cardiac parasympathetic activation in student athletes with a remote history of concussion: a pilot study. Front Neurol. 2020;11:547126.
52. Haider M, Patel K, Willer B, Videira V, Wilber C, Mayer A, et al. Symptoms upon postural change and orthostatic hypotension in adolescents with concussion. Brain inj. 2021;35(2):226-32.
53. Hinds A, Leddy J, Freitas M, Czuczman N, Willer B. The effect of exertion on heart rate and rating of perceived exertion in acutely concussed individuals. J Neurol Neurophyisol. 2016;7(4).
54. Gall BP, Parkhouse W, Goodman D. Heart rate variability of recently concussed athletes at rest and exercise. Med Sci Sports Exerc. 2004;36(8):1269-1274.
55. Gall BP, Parkhouse W, Goodman D. Exercise following a sport induced concussion. BJSM. 2004;38(6):773-777.
56. Paniccia M, Verweel L, Thomas S, Taha T, Keightley M, Wilson K, et al. Heart rate variability following youth concussion: how do autonomic regulation and concussion symptoms differ over time postinjury? BMJ Open Sport Exerc Med. 2018;4(1):e000355.
57. Taralov ZZ, Terziyski KV, Kostianev SS. Heart rate variability as a method for assessment of the autonomic nervous system and the adaptations to different physiological and pathological conditions. Folia Med (Plovdiv). 2015;57(3-4):173-180.
58. Bishop SA, Dech RT, Guzik P, Neary JP. Heart rate variability and implication for sport concussion. Clin Physiol Funct Imaging. 2018;38(5):733-742.
59. Heyer G, Fischer A, Wilson J, MacDonald J, Cribbs S, Ravindran R, et al. Orthostatic intolerance and autonomic dysfunction in youth with persistent postconcussion symptoms: a head-upright tilt table study. Clin J Sport Med. 2016;26(1):40-45.
60. Bishop S, Dech R, Baker T, Butz M, Aravinthan K, Neary JP. Parasympathetic baroreflexes and heart rate variability during acute stage of sport concussion recovery. Brain Inj. 2017;31(2):247-259.
61. La Fountaine M, Hill-Lombardi V, Toda M, Testa A. Autonomic nervous system responses to concussion: arterial pulse contour analysis. Front Neurol. 2016;7:13.
62. Truong JQC, Kenneth J. Comparison of pupillary dynamics to light in the mild traumatic brain injury (mTBI) and normal populations. Brain Inj. 2016;30(11):1378-1389.
63. Truong JQ, Joshi NR, Ciuffreda KJ. Influence of refractive error on pupillary dynamics in the normal and mild traumatic brain injury (mTBI) populations. J Optom. 2018;11(2):93-102.
64. Truong JQ, Kenneth J. Objective Pupillary Correlates of photosensitivity in the normal and mild traumatic brain injury populations. Mil. Med. 2016;181(10):1382-1390.
65. Truong JQ, Kenneth J. Quantifying pupillary asymmetry through objective binocular pupillometry in the normal and mild traumatic brain injury (mTBI) populations. Brain Inj. 2016;30(11):1372-1377.
66. Kozlowski KF. Exercise and concussion, part 1: local and systemic alterations in normal function. IJATT. 2014;19(2):23-27.
67. Kozlowski KF, Graham J, Leddy JJ, Devinney-Boymel L, Willer BS. Exercise intolerance in individuals with postconcussion syndrome. J Athl Train. 2013;48(5):627-635.

68. Churchill NW, Hutchison MG, Graham SJ, Schweizer TA. Cerebrovascular reactivity after sport concussion: from acute injury to 1 year after medical clearance. Front Neurol. 2020;11:558.
69. Wang Y, Nelson LD, LaRoche AA, Pfaller AY, Nencka AS, Koch KM, et al. Cerebral blood flow alterations in acute sport-related concussion. J Neurotrauma. 2016;33(13):1227-1236.
70. Doshi HW, Wiseman N, Liu J, Wang W, Welch RD, O'Neil BJ, Zuk C, Wang X, Mika V, Szaflarski JP, Haacke EM, Kou Z. Cerebral hemodynamic changes of mild traumatic brain injury at the acute stage. PloS one. 2015;10(2):e0118061.
71. Papadaki EK, Kavroulakis E, Manolitsi K, Makrakis D, Papastefanakis E, Tsagaraki P, Papadopoulou S, Zampetakis A, Malliou M, Vakis A, Simos P. Cerebral perfusion disturbances in chronic mild traumatic brain injury correlate with psychoemotional outcomes. Brain Imaging Behav. 2021;15(3):1438-1449.
72. Chen JJ, Johnston KM, Ptito A. Altered hemodynamic response function immediately after concussion. An ongoing serial functional magnetic resonance imaging study. CJSM. 2008;18(2):191
73. Hestbaek L, Jorgensen A, Hartvigsen J. A description of children and adolescents in Danish chiropractic practice: results from a nationwide survey. J Manipulative Physiol Ther. 2009;32(8):607-615.
74. NICHD. Pediatric Terminology [cited 2023 January 3]. Available from: http://bioportal bioontology org/ ontologies/ 45989?p=terms.
75. Centers for disease control and prevention. Child Development 2021 [cited 2023 January 3]. Available from: https://www.cdc.gov/ncbddd/childdevelopment/ positiveparenting/toddlers.html.
76. Page M, McKenzie J, Bossuyt P, Boutron I, Hoffmann T, Mulrow C, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71.
77. Parks A. Autonomic nervous system dysfunction in pediatric mild traumatic brain injury: a systematic review: Open Science Framework Registries; 2021 [cited 2023 February 8]. Available from: https://osf.io/qtsz8.
78. McGowan J, Sampson M, Salzwedel D, Cogo E, Foerster V, Lefebvre C. PRESS peer review of electronic search strategies: 2015 guideline statement. J Clin Epidemiol. 2016;75:40-46.
79. Snyder AS, Sheridan C, Tanner A, Bickart K, Sullan M, Craske M, Choe M, Babikian T, Giza C, Asarnow R. Cardiorespiratory functioning in youth with persistent post-concussion symptoms: a pilot study. J. Clin. Med. 2021;10(4).
80. Shaffer F, Ginsberg JP. An overview of heart rate variability metrics and norms. Front Public Health. 2017;5:258.
81. Petrofsky J, Prowse M, Remigio W, Raju C, Salcedo S, Sirichotiratana M, et al. The use of an isometric handgrip test to show autonomic damage in people with diabetes. Diabetes Technol Ther. 2009;11(6):361-368.
82. Nielsen SE, Mather M. Comparison of two isometric handgrip protocols on sympathetic arousal in women. Physiol Behav. 2015;142:5-13.
83. Godek D, Freeman A. Physiology, diving reflex. StatPearls Publishing; 2022 [cited 2023 February 10] Available from: https://www.ncbi.nlm.nih.gov/books/NBK538245/
84. DeMatteo C, Randall S, Falla K, Lin C, Giglia L, Mazurek M, et al. Concussion management for children has changed: new pediatric protocols using the latest evidence. Clin Pediatr. 2020;59(1):5-20.
85. Provance AJ, Engelman GH, Terhune EB, Coel RA. Management of sport-related concussion in the pediatric and adolescent population. Orthopedics. 2016;39(1):24-30.
86. Meier TB, Huber DL, Bohorquez-Montoya L, Nitta ME, Savitz J, Teague TK, et al. A prospective study of acute blood-based biomarkers for sport-related concussion. Ann Neurol. 2020;87(6):907-920.
87. Capo-Aponte JEB, Beltran TA, Walsh DV, Cole WR, Dumayas JY. Validation of visual objective biomarkers for acute concussion. Mil Med. 2018;183(suppl1):9-17.
88. Snell DL, Martin R, Macleod AD, Surgenor LJ, Siegert RJ, Hay-Smith EJC, et al. Untangling chronic pain and post-concussion symptoms: the significance of depression. Brain Inj. 2018;32(5):583-592.
89. Hartmann R, Schmidt FM, Sander C, Hegerl U. Heart rate variability as indicator of clinical state in depression. Front Psychiatry. 2018;9:735.
90. Iverson GL, Greenberg J, Cook NE. Anxiety is associated with diverse physical and cognitive symptoms in youth presenting to a multidisciplinary concussion clinic. Front Neurol. 2021;12:811462.
91. Stalnacke BM. Postconcussion symptoms in patients with injury-related chronic pain. Rehabil Res Pract. 2012;2012:528265.
92. Reneker JC, Moughiman MC, Cook CE. The diagnostic utility of clinical tests for differentiating between cervicogenic and other causes of dizziness after a sports-related concussion: an international Delphi study. JSAMS. 2015;18(4):366-372.
93. Brown DA, Elsass JA, Miller AJ, Reed LE, Reneker JC. Differences in symptom reporting between males and females at baseline and after a sports-related concussion: a systematic review and meta-analysis. Sports Med. 2015;45(7):1027-1040.
94. Kim SW, Jeon HR, Kim JY, Kim Y. Heart rate variability among children with acquired brain injury. Ann Rehabil Med. 2017;41(6):951-960.
95. Baguley I, Nicholls J, Felmingham K, Crooks J, Gurka J, Wade L. Dysautonomia after traumatic brain injury:

a forgotten syndrome? J Neurol Neurosurg Psychiatry. 1999;67:39-43.
96. Wright DK, O'Brien TJ, Shultz SR. Sub-acute changes on MRI measures of cerebral blood flow and venous oxygen saturation in concussed Australian rules footballers. Sports Med Open. 2022;8(1):45.
97. Wright AD, Smirl JD, Bryk K, Fraser S, Jakovac M, van Donkelaar P. Sport-related concussion alters indices of dynamic cerebral autoregulation. Front Neurol.. 2018;9:196.
98. Verweij BH, Amelink GJ, Muizelaar JP. Current concepts of cerebral oxygen transport and energy metabolism after severe traumatic brain injury. Prog Brain Res. 2007;161:111-124.
99. Kingsley JD, Figueroa A. Acute and training effects of resistance exercise on heart rate variability. Clin Physiol Funct Imaging. 2016;36(3):179-187.
100. Freeman JV, Dewey FE, Hadley DM, Myers J, Froelicher VF. Autonomic nervous system interaction with the cardiovascular system during exercise. Prog Cardiovasc Dis. 2006;48(5):342-362.
101. Davies P, Maconochie I. The relationship between body temperature, heart rate and respiratory rate in children. Emerg Med J. 2009;26(9):641-643.
102. Black N, D'Souza A, Wang Y, Piggins H, Dobrzynski H, Morris G, et al. Circadian rhythm of cardiac electrophysiology, arrhythmogenesis, and the underlying mechanisms. Heart Rhythm. 2019;16(2):298-307.
103. Koch C, Wilhelm M, Salzmann S, Rief W, Euteneuer F. A meta-analysis of heart rate variability in major depression. Psychol Med. 2019;49(12):1948-1957.
104. Maciel B, Gallo L, Marin Neto J, Lima Filho E, Martins L. Autonomic nervous control of the heart rate during dynamic exercise in normal man. Clin Sci. 1986;71:457-460.
105. Martin C, Shaver J, Leon D, Thompson M, Reddy P, Leonard J. Autonomic mechanisms in hemodynamic responses to isometric exercise. J Clin Invest. 1974;54:104-115.
106. Victor R, Seals D, Mark A. Differential control of heart rate and sympathetic nerve activity during dynamic exercise: insights from intraneural recordings in humans. J Clin Invest. 1987;79:508-516.
107. Zygmunt A, Stanczyk J. Methods of evaluation of autonomic nervous system function. Arch Med Sci. 2010;6(1):11-18.
108. Wig R, Oakley CB. Dysautonomia and headache in the pediatric population. Headache. 2019;59(9):1582-1588.
109. Olshansky B, Cannom D, Fedorowski A, Stewart J, Gibbons C, Sutton R, et al. Postural orthostatic tachycardia syndrome (POTS): a critical assessment. Prog Cardiovasc Dis. 2020;63(3):263-170.
110. Burton JM, Morozova OM. Calming the storm: dysautonomia for the pediatrician. Curr Probl Pediatr Adolesc Health Care. 2017;47(7):145-150.
111. Carrick F, Azzolino S, Hunfalvay M, Pagnacco G, Oggero E, D'Arcy R, et al. The pupillary light reflex as a biomarker of concussion. Life (Basel). 2021;11(10).
112. Boulter J, Shields M, Meister M, Murtha G, Curry B, Dengler B. The expanding role of quantitative pupillometry in the evaluation and management of traumatic brain injury. Front Neurol. 2021;12:685313.
113. Mathot S. Pupillometry: psychology, physiology, and function. J Cogn. 2018;1(1):16.
114. Luz Teixeira T, Peluso L, Banco P, Njimi H, Abi-Khalil L, Chanchay Pillajo M, et al. Early pupillometry assessment in traumatic brain injury patients: a retrospective study. Brain Sci. 2021;11(12).
115. Adoni A, McNett M. The pupillary response in traumatic brain injury: a guide for trauma nurses. J Trauma Nurs. 2007;14(4):191-196.
116. Ettinger E, Wyatt H, London R. Anisocoria. Variation and clinical observation with different conditions of illumination and accommodation. IOVS. 1991;32(3):501-509.
117. Bishop SA, Dech RT, Guzik P, Neary JP, Heart rate variability and implication for sport concussion. Clin Physiol Funct Imaging. 2018;38(5):733-742.
118. Souza HCD, Philbois SV, Veiga AC, Aguilar BA. Heart rate variability and cardiovascular fitness: what we know so far. Vasc Health Risk Manag. 2021;17:701-711.
119. La Fountaine MF, Hohn AN, Testa AJ, Weir JP. Attenuation of spontaneous baroreceptor sensitivity after concussion. MSSE. 2019;51(4):792-797.
120. Huang M, Frantz J, Moralez G, Sabo T, Davis PF, Davis SL, Bell KR, Purkayastha S.Reduced resting and increased elevation of heart rate variability with cognitive task performance in concussed athletes. J Head Trauma Rehabil. 2019;34(1):45-51.
121. Dobson JL, Yarbrough MB, Perez J, Evans K, Buckley T. Sport-related concussion induces transient cardiovascular autonomic dysfunction. Am J Physiol Regul Integr Comp Physiol. 2017;312(4):R575-R84.
122. Worley ML, O'Leart MC, Sackett JR, Schlader ZJ, Willer B, Leddy JJ, Johnson BD. Preliminary evidence of orthostatic intolerance and altered cerebral vascular control following sport-related concussion. Front Neurol. 2021;12:620757.
123. Cornelissen VA, Verheyden B, Aubert AE, Fagard RH. Effects of aerobic training intensity on resting, exercise and post-exercise blood pressure, heart rate and heart-rate variability. J Hum Hypertens. 2010;24(3):175-182.

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Assessing construct validity of the Beighton Score as a measure of generalized joint hypermobility in varsity athletes

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The Beighton Score (BS) is a tool that dichotomizes those who have generalized joint hypermobility (GJH) and those who do not. Unfortunately, the BS is often used in populations that it was not originally developed for, including athletes for screening purposes. The construct validity of the BS remains unknown in this population. This secondary analysis investigated the construct validity of the BS by comparing varsity athletes' passive shoulder and hip ranges of motion (ROMs) to their respective BS and individual forward bend tests (FBTs). There were statistically significant but weak correlations between shoulder ROMs and the BS (r=0.142, p=0.021). Mean hip ROMs were greater by 5-degrees in those with positive FBTs compared to those with negative FBTs. This difference falls within typical measurement errors that occur in practice. Therefore, our results do not

Évaluation de la validité de construction du score de Beighton en tant que mesure de l'hypermobilité articulaire généralisée chez les athlètes de haut niveau.

Le score de Beighton (BS) est un outil qui permet de distinguer les personnes souffrant d'hypermobilité articulaire généralisée de celles qui n'en souffrent pas. Malheureusement, le score de Beighton est souvent utilisé dans des populations pour lesquelles il n'a pas été conçu à l'origine, notamment les athlètes, à des fins de dépistage. La validité de construit du score de Beighton reste inconnue dans cette population. Cette analyse secondaire a étudié la validité conceptuelle du score de Beighton en comparant les amplitudes de mouvement passives de l'épaule et de la hanche des athlètes universitaires à leur score de Beighton et à leurs tests individuels de flexion avant. Des corrélations statistiquement significatives mais faibles ont été observées entre les amplitudes de mouvement des épaules et le score de Beighton (r=0,142, p=0,021). Les amplitudes moyennes de flexion de la hanche étaient supérieures de 5 degrés chez les personnes ayant subi un test de flexion avant positif par rapport à celles ayant subi un test de flexion avant négatif. Cette

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support the construct validity of the BS as a measure of GJH in healthy athletes.

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KEY WORDS: Beighton Score, construct validity, generalized joint hypermobility, hypermobility, range of motion, sport

différence s'inscrit dans le cadre des erreurs de mesure typiques qui se produisent au cours de la pratique. Par conséquent, nos résultats ne confirment pas la validité conceptuelle du score de Beighton en tant que mesure de l'hypermobilité articulaire généralisée chez les athlètes en bonne santé.

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MOTS CLÉS : Score de Beighton, validité de construit, hypermobilité articulaire généralisée, hypermobilité, amplitude de mouvement, sport

Introduction

Joint hypermobility is a trait of an individual who exhibits joint ranges of motion (ROMs) that exceed an accepted normal ROM for a particular joint.[1] Joint hypermobility may be localized to a single joint or occur at several joints in the body, which is referred to as generalized joint hypermobility (GJH). GJH is a trait of certain connective tissue disorders, such as Ehlers Danlos Syndrome (EDS) however it may also exist to a lesser degree in those without pathology.[2] Existing literature supports that GJH may predispose one to musculoskeletal pain[2-4], proprioceptive deficits[5], and injury[2,6-9]. In contrast, there is literature to suggest GJH may actually be advantageous in certain sports[10, 11] while possibly decreasing the likelihood of joint and ligament injury[10, 12]. Despite these conflicting observations, the identification of GJH in athletes may still be important.[13] Thus, it is necessary to evaluate the properties of measurement tools that operationalize the construct of GJH.

While there are different approaches used to detect GJH, the Beighton Score (BS) is the most commonly used tool in both research and clinical settings.[6, 14, 15] The current version of the BS is a 9-point scoring tool that was intended to be used for epidemiological screening and includes four bilateral joint measurements and one sagittal plane multi-joint measurement (full forward flexion of the trunk and hips).[16, 17]

The BS has been incorporated into the more comprehensive Brighton Criteria, which serves as the diagnostic criteria for benign joint hypermobility syndrome (BJHS) and the hypermobile subtype of EDS.[14, 18] Previous work has validated the BS as a measure of GJH in children[19]; however, literature reveals discrepancies in the ideal cut-off values that should be used in adults of different ages, sexes and ethnicities, which questions the validity of the BS as a measure of GJH in select populations.[20] Additionally, Malek *et al*.[1] suggest that the joints within the scoring system do not accurately represent the definition of GJH, and thus cannot be used as a direct indicator of GJH. These authors also propose that the BS cannot be used as an indirect indicator of GJH, as a positive BS value is unable to identify all presentations of GJH, including those with hypermobility at joints outside those that are measured in the BS.[1] Thus, false-negative outcomes become possible as individuals may receive a negative BS outcome, despite exhibiting hypermobility at joints outside the scoring system and a clinical presentation that raises suspicion of disease.[1]

Nevertheless, the BS has been widely adopted in the clinical setting. This includes its use as a screening tool for GJH in sports medicine and athletic settings; however, the use of the BS in this context has not been validated. Validity is one of three fundamental properties for a measurement tool and is comprised of several subtypes. Construct validity is one subtype that can be evaluated on the strength of relationships between measurements obtained using the tool and measurements of other variables that are theoretically connected to the construct.[21] Regarding the BS, construct validity refers to its ability to operationalize the construct of GJH. The construct of GJH is theoretically related to ROM measurements at joints that are, and are not, represented within the BS. Thus, construct

validity for using the BS in a specific population may be assessed by investigating the strength of its relationships with measurements of joint ROM.

To our knowledge, no previous study has investigated the construct validity of the BS as a measure of GJH in a sample of healthy adult athletes. Thus, the objective of this study was to investigate for construct validity of the BS in healthy adult athletes in two ways. First, we investigated for correlation between participants' BS and their passive flexion ROM at the femoroacetabular and glenohumeral joints. We hypothesized that if the BS exhibits construct validity as a measure of GJH, those with higher scores should exhibit greater ROMs at joints not included in the BS. Second, we compared the joint ROMs of those who scored positive on the forward bend test (FBT) to those participants who scored negative, as the FBT is the only component of the BS that requires motion at the shoulder and hip joints. Therefore, we hypothesized that those with a positive FBT would exhibit larger ROMs.

Methods

Design

This was an exploratory secondary analysis of pre-season screening data from male and female varsity athletes of various sports. All protocols for the original data collection were approved by the research ethics board at the University of Toronto (Protocol #33327). Data used for the current investigation was a subset of a larger database.[22] Deidentified data were electronically transferred from the University of Toronto to the Canadian Memorial Chiropractic College in accordance with an established data transfer agreement between the institutions. The protocols for this secondary analysis were approved by the Canadian Memorial Chiropractic College's research ethics board (REB #2201X02).

Participants

The sample comprised 266 uninjured male (n=169) and female (n=97) athletes from the University of Toronto. Inclusion criteria included sport participation on a varsity athletic team at the time of data collection. Exclusion criteria included the presence of a known injury at the time of data collection that limited involvement in practice or competition. Prior to their participation in data collection, all athletes provided their written informed consent.

Data collection and quality assurance

The original dataset included measurements of active and passive ROMs at various joints, Functional Movement Screen® scores, anthropometric measurements of the upper and lower extremities and BS outcomes. For our study, we used BS data and hip and shoulder flexion ROMs measured in degrees using manual goniometry.

Bilateral passive hip and shoulder flexion ROMs were measured while supine and seated, respectively. Each measurement was obtained with and without multiarticular restraint; however, for the purpose of this study, only measurements without multiarticular restraint were used (e.g., hip flexion with the knee flexed and shoulder flexion with the elbow extended) in hopes of reducing the influence from surrounding biarticular musculature on ROM measurements. Two measurements were recorded for each joint and the mean was calculated for the left and right side separately, which were further combined as an average. This yielded one hip and one shoulder ROM value per participant that was used in the statistical analysis.

The BS was measured using a standardized protocol as described by Juul-Kristensen *et al*.[23], where test component positivity was determined using visual observation and manual goniometry[16, 17, 23] and scored 0 when negative and 1 when positive. Following completion of all nine measurements, the total BS was calculated as an integer value ranging from 0 to 9. For our study, the integer value of the BS and the outcomes of the individual FBT for each participant were used (e.g., positive FBT versus negative FBT).

Prior to secondary analysis, the original measurement data was reviewed by a single investigator (AP) for the presence of missing data, as well as any identifiable data entry or measurement errors. Consensus on the handling of identified errors in the data was achieved through discussion with a second investigator (SH). Participants were eliminated from the analysis for either the shoulder or hip if they were missing both measurements for either the left or right side for the respective joint.

Statistical analysis

All statistical analyses were performed using R (Version 4.2.1).[24] Two analyses were conducted to assess for construct validity. First, the relationship between the overall integer value of the BS and the hip and shoulder flexion ROMs (left and right combined) were evaluated with Spear-

man's rank correlations. Second, mean hip and shoulder ROMs, standard deviations and 95% confidence intervals were calculated separately for those who scored positive on the FBT and those who did not. Welch's 2-sample t-test was used to compare hip and shoulder ROMs between athletes of these two groups. Effect sizes were determined using Cohen's d.[25] Statistical significance was achieved for all analyses when the p-value was less than 0.05.

Results

Participants

Participant demographics are described in Table 1. There was a disproportionate number of male athletes (n=169) in comparison to female athletes (n=97). There were three sports that contained only male athletes (e.g., football = 86 males, baseball = 7 males, ice hockey = 7 males). There was one sport that contained only female athletes (e.g., field hockey = 7 females).

Data quality

Two-hundred sixty-three shoulder flexion ROM data points were used in the analysis (Table 2). Three male football players were missing all ROM measurements for one or both sides for the shoulder and one erroneous shoulder ROM value was identified in a fourth football player. Two-hundred sixty-six hip flexion ROM data points were in used in the analysis. BS data was complete for all participants, and there were no identified data entry errors.

Beighton Scores

One-hundred twenty-six of two-hundred sixty-six athletes (47%) scored 0/9 on the BS (Figure 1a.). Only 25/266 athletes (9%) scored at least 4/9 on the BS (Figure 1a.). The FBT was the most frequently scored positive component of the BS (Figure 1b.).

Table 1.
Participant demographics

Sport	Sex	Height (m)	Mass (Kg)
All	Total (n=266)	1.77 (0.09)	81.3 (18.4)
All	M (n=169) F (n=97)	1.82 (0.07) 1.69 (0.08)	89.6 (17.3) 66.8 (8.9)
Football	M (n=86) F (n=0)	1.82 (0.06) --	96.6 (17.2) --
Soccer	M (n=21) F (n=26)	1.80 (0.05) 1.67 (0.06)	77.1 (6.6) 65.4 (9.3)
Rugby	M (n=18) F (n=19)	1.77 (0.07) 1.64 (0.05)	87.9 (17.9) 67.7 (11.3)
Volleyball	M (n=10) F (n=14)	1.88 (0.05) 1.78 (0.06)	82.3 (5.4) 66.6 (4.4)
Lacrosse	M (n=13) F (n=11)	1.80 (0.07) 1.67 (0.05)	84.8 (24.1) 68.0 (8.2)
Basketball	M (n=7) F (n=14)	1.87 (0.08) 1.74 (0.07)	84.5 (6.6) 69.1 (9.4)
Field Hockey	M (n=0) F (n=13)	-- 1.64 (0.05)	-- 64.6 (8.3)
Baseball	M (n=7) F (n=0)	1.78 (0.06) --	76.2 (10.1) --
Ice Hockey	M (n=7) F (n=0)	1.84 (0.08) --	87.4 (10.3) --

Abbreviations: m, meters; Kg, Kilogram; n, number of participants; M, Male; F, Female

Table 2.
Descriptive measures of hip and shoulder flexion ranges of motion (degrees) for each sex within each sport. Standard deviations are reported in parentheses.

		Hip				Shoulder			
Sport	**Sex**	**Mean**	**SD**	**CI-LL**	**CI-UL**	**Mean**	**SD**	**CI-LL**	**CI-UL**
All	All	115	(11)	114	117	167	(10)	166	168
All	M	112	(10)	110	113	165	(9)	164	166
	F	121	(11)	119	123	171	(11)	169	173
Football	M	113	(11)	111	115	166	(9)	164	167
	F	--	--	--	--	--	--	--	--
Soccer	M	109	(9)	105	112	163	(9)	159	167
	F	118	(10)	114	122	172	(11)	168	176
Rugby	M	113	(7)	109	116	166	(10)	161	170
	F	117	(11)	113	122	171	(10)	167	176
Volleyball	M	110	(9)	104	115	165	(12)	157	172
	F	125	(9)	120	129	174	(8)	169	178
Lacrosse	M	109	(13)	102	116	163	(7)	159	167
	F	125	(8)	120	130	170	(13)	163	178
Basketball	M	120	(4)	116	123	166	(10)	158	174
	F	122	(12)	116	128	169	(14)	162	177
Field Hockey	M	--	--	--	--	--	--	--	--
	F	125	(11)	119	131	168	(11)	162	174
Baseball	M	112	(10)	104	119	169	(6)	162	171
	F	--	--	--	--	--	--	--	--
Ice Hockey	M	110	(9)	103	117	159	(4)	156	163
	F	--	--	--	--	--	--	--	--

Abbreviations: SD, Standard Deviation; CI-LL, confidence interval-lower limit; CI-UL, confidence interval-upper limit; M, Male; F, Female

Assessment of construct validity

A weak, yet statistically significant, correlation was observed between passive shoulder flexion ROM and the BS (Figure 2a. ρ=0.142, p=0.021). The correlation between passive hip flexion ROM and the BS was also weak, and not statistically significant (Figure 2b. ρ=0.111, p=0.070).

Mean hip flexion ROM was greater by 5 degrees amongst those who scored positive on the FBT (Table 3. p=0.002, d=0.44). Mean shoulder flexion ROM was 2 degrees higher amongst those who scored positive on the FBT (Table 3. p=0.084, d=0.20).

Table 3.
Hip and shoulder ranges of motion for those who scored positive and those who scored negative on the forward bend test component of the Beighton Score. Means, standard deviations, confidence interval (CI) limits, p-values and effect sizes are reported.

	Hip					**Shoulder**				
	n	Mean (95%CI) (degrees)	Standard Deviation	p	d	n	Mean (95%CI) (degrees)	Standard Deviation	p	d
FB +ve	191	119 (116, 121)	12	0.002	0.44	188	168 (166, 171)	11	0.084	0.20
FB -ve	75	114 (112, 115)	10			75	166 (165, 168)	10		

Abbreviations: n, number of participants; p, significance value; d, Cohen's d effect size; FB, forward bend test; +ve, positive test; -ve, negative test

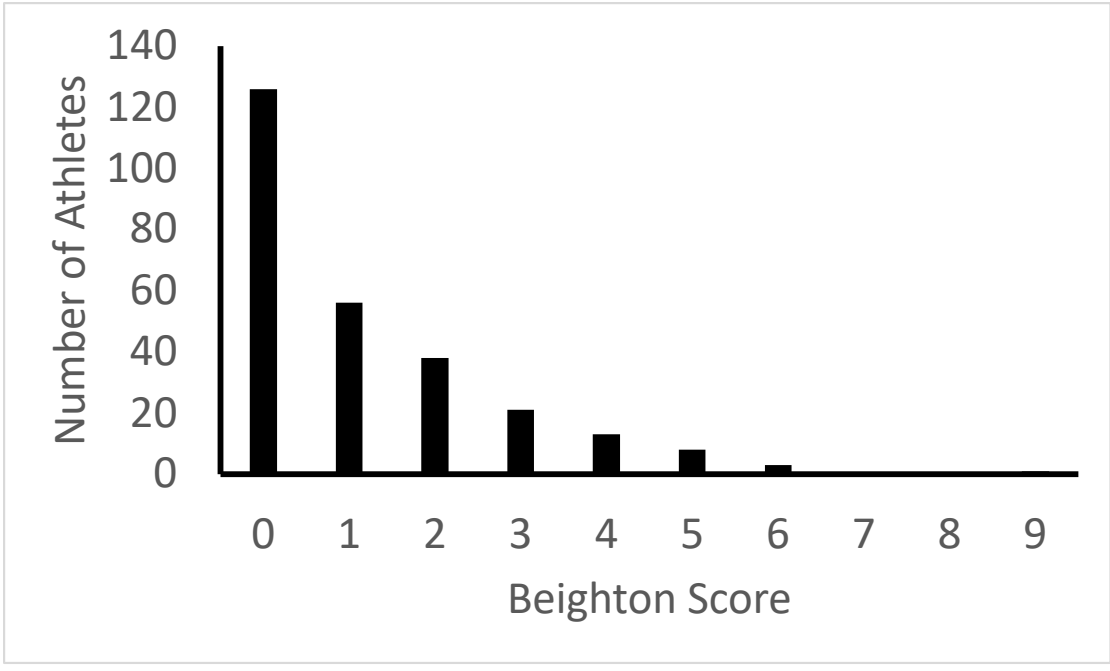

Figure 1a.
Distribution of Beighton Scores amongst athletes.

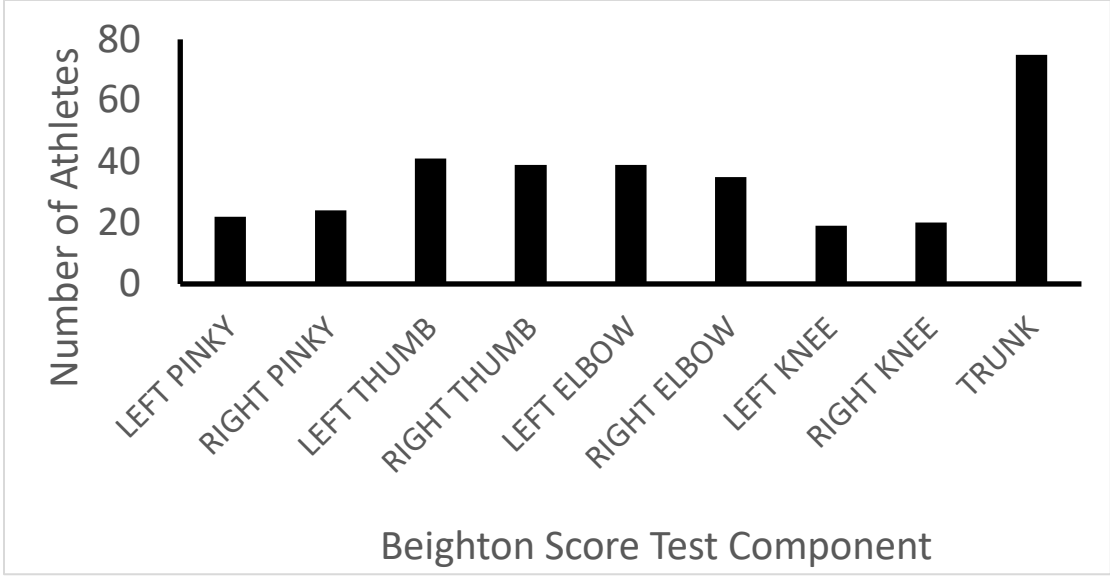

Figure 1b.
Number of athletes scoring positive in each component of Beighton Score.

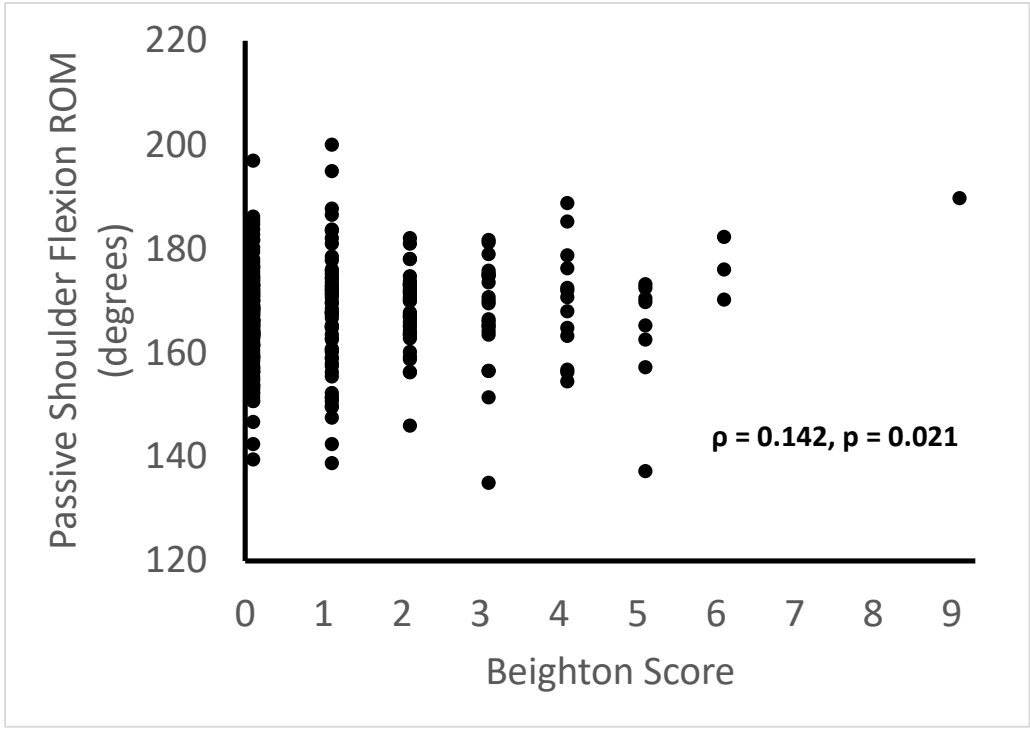

Figure 2a.
Beighton Score versus passive shoulder flexion range of motion.

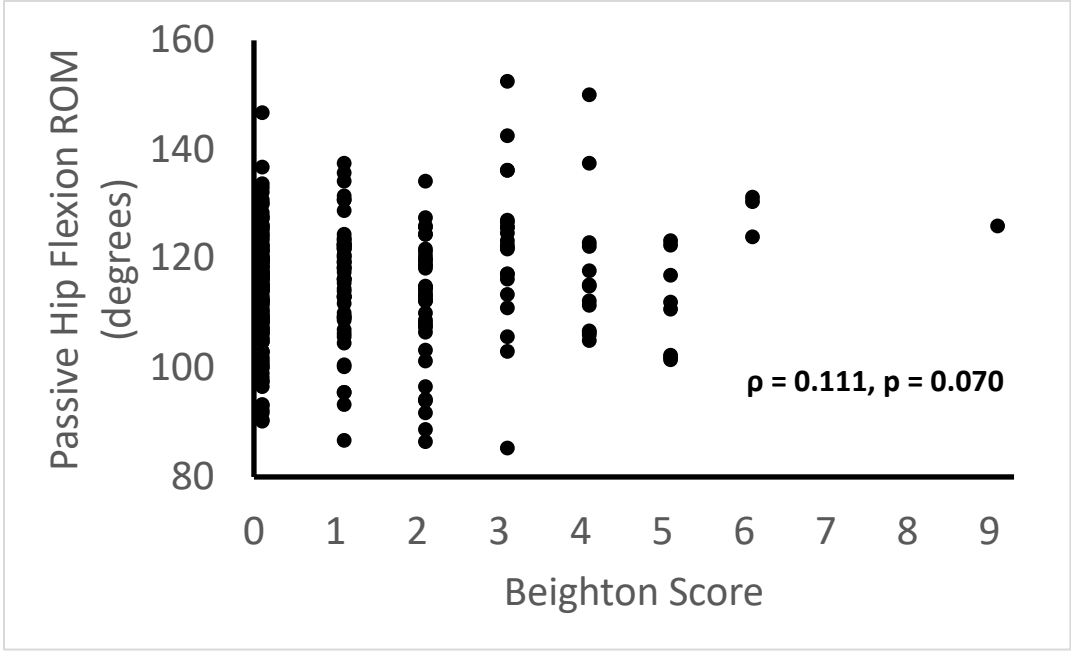

Figure 2b.
Beighton Score versus passive hip flexion range of motion.

Discussion

There remains conflict in the existing GJH literature as some authors suggest that ligament laxity may contribute to musculoskeletal injury[2, 6-9] and pain[2-4], while others suggest it is an asset in certain sports[10, 11] and may prevent ligament and soft tissue injury[10, 12]. Despite these conflicting findings, detection of GJH in athletes may still be important.[13] This relevance has been recognized by clinicians and has resulted in the widespread use of the BS in sport[4, 12, 26-29], clinical[1,18, 30] and research settings[1, 16] without adequate consideration for the validity of the BS as a measure of GJH in these populations. The current study questions the appropriateness of these applications as the results fail to support the construct validity of the BS as a measure of GJH in healthy adult athletes.

Construct validity is determined by relationships between the measurement and other variables/measurements that are associated (either known or theoretical) with the construct.[21] We chose to assess for the construct validity of the BS in two ways. The first was by assessing the strength of an association between the overall BS and ROMs at two large multiaxial joints that are not directly measured in the existing BS. The current assumptions of the BS are that it can be used to operationalize GJH, thus detecting widespread hypermobility even at joints that are not included within the scoring tool.[1, 16, 31] If this is true, one would expect that individuals with a larger BS would exhibit greater ROMs at most, if not all, major joints in the body.

Ultimately, our statistical analyses did not support the construct validity of the BS in our sample population. Although there was a statistically significant correlation between shoulder flexion ROM and the BS, the strength of the correlation was weak and likely a consequence of the study's sample size. Similarly, a statistically significant difference in hip flexion ROMs was observed between those who scored positive on the FBT and those who did not; however, the effect size was small and the 5-degree difference that was identified is within the standard measurement error ranges for manual goniometers[32-34]. For these reasons, we do not believe these results are practically meaningful.

Using the overall BS to assess the association with hip and shoulder ROM is different from the clinical approach that uses standardized cut-off points for the BS to identify people as being hypermobile or not. In conflict with

KEY POINTS

Findings

Our results do not support construct validity of the Beighton Score as a measure of generalized joint hypermobility in healthy adult athletes. Weak correlations exist between passive shoulder and hip ranges of motion and integer values of the Beighton Score in this population. Statistically significant differences exist in mean hip flexion ranges of motion in those with a positive versus negative forward bend test, however the differences fall within standard measurement errors of manual goniometry.

Implications

Statistically significant results may not translate to practical significance when considering range of motion measurement errors that occur in clinical practice. Additionally, the Beighton Score may have little practical use for the screening of generalized joint hypermobility in healthy athletes, as the measurements included in the Beighton Score have been previously described as arbitrary and do not include large multiaxial joints that have high injury prevalence in sport.

Caution

Our study was a secondary analysis of an existing dataset composed of healthy athletes from a limited number of varsity sports with limited joint range of motion measurements. The sample may not have been representative of athletes who are more likely to exhibit joint hypermobility, such as ballet and artistic dancers.

this dichotomous approach suggesting that GJH is an all-or-none phenomena, it is well understood that the hypermobility associated with various hereditable connective tissue disorders falls along a continuum and is not, in fact, simply present or absent.[1] Furthermore, there is no consensus on the ideal cut-off value that should be used to determine the presence or absence of GJH. Existing literature has revealed that mobility status is significantly affected by age, sex and ethnicity[20] and the most used cut-off value for all populations is ≥4/9[1, 20]. However, it has been proposed that a value of ≥7/9 be used for Caucasian children aged 6-12[19], suggesting that the scoring criteria could change throughout one's life. It is for these reasons that the overall BS was used in our study, instead of mobility classification.

The current study being a secondary analysis is its main limitation. This means that we were unable to control what ROMs were collected. For example, data for internal and external rotation ROM values at these joints may have highlighted potential exposure dependent ROM differences in certain athletes, as this has been observed in various sports.[10, 29, 35]

Our sample population was also not representative of certain sports that have been shown to have a high prevalence of hypermobility, such as ballet and artistic gymnastics.[10, 29, 35] This may have resulted in the large number of athletes who scored low on the BS, and therefore our results should not be generalized to all athletic populations. The inclusion of a wider variety of sports to include those that have a higher prevalence of hypermobility may help to further assess for construct validity of the BS as a tool for classifying GJH, as these populations may be unique. We suggest that future works address these limitations.

Conclusion

In conclusion, our results do not support the construct validity of the BS as a measure of GJH in healthy adult athletes. While shoulder ROM was very weakly associated with the integer value of the BS and hip flexion ROM was greater in those who scored positive on the FBT, it is important to consider that reaching statistical significance does not always equal practical significance. These findings question the ability of the BS to serve as an indicator for future injury risk or performance in athletic populations, a purpose it is often used for. Although we did not measure this, we believe it may be inappropriate to use the tool in this context.

References

1. Malek S, Reinhold EJ, Pearce GS. The Beighton Score as a measure of generalised joint hypermobility. Rheumatol Int. 2021;41(10):1707-1716.
2. Wolf JM, Cameron KL, Owens BD. Impact of joint laxity and hypermobility on the musculoskeletal system. J Am Acad Orthop Surg. 2011;19:462-471.
3. Kirk JA, Ansell BM, Bywaters EGL. The hypermobility syndrome: musculoskeletal complaints associated with generalized joint hypermobility. Ann Rheum Dis. 1967;26:419-425.
4. Scheper MC, de Vries JE, de Vos R, Verbunt J, Nollet F, Engelbert RH. Generalized joint hypermobility in professional dancers: a sign of talent or vulnerability? Rheumatol. 2013;52(4):651-658.
5. Smith TO, Jerman E, Easton V, Bacon H, Armon K, Poland F, et al. Do people with benign joint hypermobility syndrome (BJHS) have reduced joint proprioception? A systematic review and meta-analysis. Rheumatol Int. 2013;33(11):2709-2716.
6. Pacey V, Nicholson LL, Adams RD, Munn J, Munns CF. Generalized joint hypermobility and risk of lower limb joint injury during sport: a systematic review with meta-analysis. Am J Sports Med. 2010;38(7):1487-1497.
7. Briggs J, McCormack M, Hakim AJ, Grahame R. Injury and joint hypermobility syndrome in ballet dancers: a 5-year follow-up. Rheumatol. 2009;48(12):1613-1614.
8. Sundemo D, Hamrin Senorski E, Karlsson L, Horvath A, Juul-Kristensen B, Karlsson J, et al. Generalised joint hypermobility increases ACL injury risk and is associated with inferior outcome after ACL reconstruction: a systematic review. BMJ Open Sp Ex Med. 2019;5:e000620:1-14.
9. Liaghat B, Pedersen JR, Young JJ, Thorlund JB, Juul-Kristensen B, Juhl CB. Joint hypermobility in athletes is associated with shoulder injuries: a systematic review and meta-analysis. BMC Musculoskelet Disord. 2021;22(1):389.
10. Baeza-Velasco C, Gely-Nargeot MC, Pailhez G, Vilarrasa AB. Joint hypermobility and sport: a review of advantages and disadvantages. Cur Sports Med Rep. 2013;12(5): 291-295.
11. McCormack M, Briggs J, Hakim A, Grahame R. Joint laxity and the benign joint hypermobility syndrome in student and professional ballet dancers. J Rheumatol. 2004;31:173-178.
12. Nathan JA, Davies K, Swaine I. Hypermobility and sports injury. BMJ Open Sport Exerc Med. 2018;4:e000366:1-6.
13. Oddy C, Johnson MI, Jones G. The effect of generalised joint hypermobility on rate, risk and frequency of injury in

male university-level rugby league players: a prospective cohort study. BMJ Open Sp Ex Med. 2016;2:e000177:1-6.
14. Klemp P. Hypermobility. Ann Rheum Dis. 1997;56:573-575.
15. Sendur OF, Odabasi BB, Turan Y. An overlooked diagnosis in rheumatology: benign joint hypermobility syndrome. J Musculoskelet Pain. 2010;18(3):277-287.
16. Beighton P, Solomon L, Soskolne CL. Articular mobility in an African population. Ann Rheum Dis. 1973;32:413-418.
17. Keer R, Grahame R. Hypermobility syndrome: recognition and management for physiotherapists. Edinburgh: Butterworth Heinemann; 2003.
18. Grahame R, Bird HA, Child A. The revised (Brighton 1998) criteria for the diagnosis of benign joint hypermobility syndrome (BJHS). J Rheumatol. 2000;27(7):1777-1779.
19. Smits-Engelsman B, Klerks M, Kirby A. Beighton score: a valid measure for generalized hypermobility in children. J Pediatr. 2011;158(1):119-123, 23 e1-4.
20. Singh H, McKay M, Baldwin J, Nicholson L, Chan C, Burns J, et al. Beighton scores and cut-offs across the lifespan: cross-sectional study of an Australian population. Rheumatol. 2017;56(11):1857-1864.
21. Kimberlin CL, Winterstein AG. Validity and reliability of measurement instruments used in research. Am J Health Syst Pharm. 2008;65(23):2276-2284.
22. Poulos C. Exploring the relationship between performance on a series of squat-based movement tasks and passive range of motion capacity - Is successful performance a valid method of ruling out range of motion restrictions? [thesis]. Toronto, Canada: University of Toronto; 2019.
23. Juul-Kristensen B, Rogind H, Jensen DV, Remvig L. Inter-examiner reproducibility of tests and criteria for generalized joint hypermobility and benign joint hypermobility syndrome. Rheumatol. 2007;46(12):1835-1841.
24. R. Core Team. R: a language and environment for statistical computing. 4.2.1 ed. Vienna, Austria: R Foundation for Statistical Computing; 2022.
25. Torchiano M. Effsize: efficient effect size computation. 2020.
26. Schmidt H, Pedersen TL, Junge T, Engelbert R, Juul-Kristensen B. Hypermobility in adolescent athletes: pain, functional ability, quality of life and musculoskeletal injuries. J Orthop Sports Phys Ther. 2017;47(10):792-800.
27. Smith R, Damodaran AK, Swaminathan S, Campbell R, Barnsley L. Hypermobility and sports injuries in junior netball players. Br J Sports Med. 2005;39(9):628-631.
28. Rejeb A, Fourchet F, Materne O, Johnson A, Horobeanu C, Farooq A, et al. Beighton scoring of joint laxity and injury incidence in Middle Eastern male youth athletes: a cohort study. BMJ Open Sport Exerc Med. 2019;5:e000482:1-5.
29. Grahame R, Jenkins JM. Joint hypermobility - asset or liability? A study of joint mobility in ballet dancers Ann Rheum Dis. 1972;31:109-111.
30. Beighton P, De Paepe A, Steinmann B, Tsipouras P, Wenstrup RJ. Ehlers-Danlos syndromes: revised nosology, Villefranche, 1997. Am J Med Genet. 1998;77(1):31-37.
31. Remvig L, Jensen DV, Ward RC. Are diagnostic criteria for general joint hypermobility and benign joint hypermobility syndrome based on reproducible and valid tests? A review of the literature. J Rheumatol. 2007;34:798-803.
32. van Rijn SF, Zwerus EL, Koenraadt KL, Jacobs WC, van den Bekerom MP, Eygendaal D. The reliability and validity of goniometric elbow measurements in adults: a systematic review of the literature. Shoulder Elbow. 2018;10(4):274-284.
33. Shamsi M, Mirzaei M, Khabiri SS. Universal goniometer and electro-goniometer intra-examiner reliability in measuring the knee range of motion during active knee extension test in patients with chronic low back pain with short hamstring muscle. BMC Sports Sci Med Rehabil. 2019;11:1-5.
34. Harris JD, Mather RC, Nho SJ, Salvo JP, Stubbs AJ, Van Thiel GS, et al. Reliability of hip range of motion measurement among experienced arthroscopic hip preservation surgeons. J Hip Preserv Surg. 2020;7(1):77-84.
35. Klemp P, Chalton D. Articular mobility in ballet dancers: a follow-up study after four years. Am J Sports Med. 1989;17:72-75.

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Risk factors of multiple pulmonary emboli in an elite Ironman triathlete: a case report

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Objective: *To present a unique case of pulmonary embolism (PE) in an elite-Ironman triathlete and review athlete-specific risk factors associated with venous thromboembolism (VTE).*

Case presentation: *A 57-year-old male triathlete presented for chiropractic care of midback pain and dyspnea one day before competition. During competition, he was removed and unable to complete the event with dyspnea, chest, and midback pain. Vitals revealed prolonged elevated resting heart rate. He was triaged to the hospital with a high index of suspicion for PE. He was diagnosed with multiple PE in both lungs.*

Facteurs de risque d'embolies pulmonaires multiples chez un triathlète Ironman d'élite : un rapport de cas

Objectif: *Présenter un cas unique d'embolie pulmonaire (EP) chez un triathlète Ironman d'élite et passer en revue les facteurs de risque spécifiques aux athlètes associés à la thrombo-embolie veineuse.*

Présentation du cas: *Un triathlète de 57 ans s'est présenté pour des soins chiropratiques en raison de douleurs au milieu du dos et de dyspnée un jour avant la compétition. Pendant la compétition, il a été évacué et incapable de terminer l'épreuve en raison d'une dyspnée, d'une douleur thoracique et d'une douleur lombaire. Les signes vitaux ont révélé une élévation prolongée de la fréquence cardiaque au repos. Il a été transféré à l'hôpital avec une forte suspicion d'EP. On lui a diagnostiqué une EP multiple dans les deux poumons.*

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Summary: *VTE is not normally considered in athletes. A combination of athlete-specific risk factors may predispose athletes to a higher propensity of VTE. Due to life-threatening consequences, it is important to include a differential diagnosis of VTE in patients presenting with midback pain and dyspnea.*

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KEY WORDS: triathlete, pulmonary embolism, deep vein thrombosis, venous thromboembolism, endurance sport

Synthèse: *La thrombo-embolie veineuse n'est normalement pas envisagée chez les athlètes. Une combinaison de facteurs de risque spécifiques aux athlètes peut les prédisposer à une plus grande propension à la thrombo-embolie veineuse. En raison des conséquences potentiellement mortelles, il est important d'inclure un diagnostic différentiel de la thrombo-embolie veineuse chez les patients souffrant de douleurs lombaires et de dyspnée.*

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MOTS CLÉS : triathlète, embolie pulmonaire, thrombose veineuse profonde, thrombo-embolie veineuse, sport d'endurance, chiropratique

Introduction

Venous thromboembolism (VTE) encompasses both deep vein thrombosis (DVT) and pulmonary embolism (PE).[1] The pathogenesis of DVT begins with thrombogenesis, of which nearly 80% are accounted for in the lower extremity.[2,3] The most common site for a thrombus is in the valves and cusps of the superficial veins of the calf. However, they have also been reported in the femoral, popliteal, and iliac veins with the risk of PE increasing if the thrombus is located more proximally.[2] The thrombus will break off and ascend as an embolus along the venous pathway into the inferior vena cava into the right side of the heart and then pass through the pulmonary arteries into either the left or right lung.[3] The embolus will typically descend to the lower lobes of the lung due to gravity.[2] Consequently, the embolus will create increased pulmonary vascular resistance due to mechanical obstruction leading to the release of neurohormonal factors including serotonin, thrombin, and histamine.[3] This can lead to back-flow of blood to the right ventricle along with dilation and thinning of the right ventricular wall and higher perfusion demands from the right ventricle.[3] Subsequently, higher pressure from the right ventricle can lead to less distensibility and filling of the left ventricle and lower overall stroke volume.[3] Ultimately, this leads to tachycardia due to impaired systemic perfusion. In severe cases, lead to right-sided heart failure, lung infarctions, and sudden death.[3,4]

DVT and PE are typically considered health conditions that are associated with prolonged physical immobility, physical inactivity, and poorer metabolic health.[1,5,6] For instance, hospitalized residents account for nearly 60% of cases of VTE in the community.[6] Overall, the age-adjusted incidence rate is higher for men (130 per 100,000) compared to women (110 per 100,000) with the male to female reported as 1.2:1 historically.[5,6] Additionally, recent epidemiological data has reported a higher incidence of VTE due to an aging population and more specific and sensitive diagnostic tests.[5,6]

One classic triad of risk factors, Virchow's Triad (circa 1854) has been taught historically as factors associated with developing VTE.[1] The three pillars of risk factors in Virchow's Triad includes prolonged venous stasis, increased hypercoagulability, and endothelial injury.[1] Cardiovascular exercise, however, is believed to be a gold-standard preventative measure for VTE.[1,7] However, there are several case reports of DVT and PE in elite endurance athletes that are initially misdiagnosed as musculoskeletal sprain or strain-type injuries.[8] This can unfortunately lead to higher diagnostic lag time and potentially athletic career or life-altering health consequences.[1,6,8] While it is unknown the proportion of patients with VTE who present to a chiropractor for care, several published case reports stress the potential for patients with vascular pathologies that can present for care with musculoskeletal-like symptoms.[9-12] Vascular diseases, such as DVT

and PE are not often considered in the differential diagnosis process for conditions with musculoskeletal manifestations. This is due in part to the fact that pathology associated with these conditions are not commonly seen by physical therapists and chiropractors.[13] As such, the purpose of this case report is to highlight the unique risk factors and presentation of VTE in endurance athletes and to report a case of multiple PE that was suspected in an elite Ironman triathlete during competition.

Case presentation

The information from this case report is based on clinical documentation obtained during the patient's sideline evaluation and hospital records.

Pre-competition: travel, symptoms, and chiropractic management

A 57-year-old male elite-level Ironman triathlete travelled seven hours by car five days prior to the triathlon. He reported that he previously competed in a marathon two weeks prior to the triathlon.

One day prior to competition, he presented to a nearby community chiropractor for management of new-onset left-sided thoracic spine and chest pain and attributed to his long drive. He reported that his chest pain worsened with deep inspiration. While the details and clinical notes of the assessment were not obtained, he reported to received spinal manipulative therapy and taping to the thoracic spine. He reported that his pain reduced following treatment, but he had difficulty sleeping the night before the triathlon due to his thoracic spine and chest pain.

Competition day: sideline evaluation

The average air and water temperature on the day of competition were recorded at 26°C and 20°C, respectively. During the swimming component of the triathlon, he was removed by rescue kayaks for shoreside medical evaluation as he was reportedly struggling to swim and became presyncopal. His chief complaint included intermittent pleuritic chest pain, left periscapular and thoracic spine pain, and worsening exertional dyspnea. On observation by the side-line sport medicine physician, he was alert but appeared uncomfortable. Visual inspection revealed no gross abnormalities, with the exception of slight pallor in his face. His initial resting heart rate (RHR) was recorded at 98 bpm and blood pressure was recorded at 128/78 mmHg. Respiratory rate was 14 breaths per minute. Palpation of his radial pulses were strong bilaterally. Oxygen saturation levels were recorded at 98% SpO_2 with a pulse oximeter. Auscultatory examination of the lung fields were unremarkable bilaterally.

His medical history included a previous DVT three years ago and benign prostate hyperplasia which was well managed with finasteride. His previous DVT occurred following a long duration of travel and was managed with Warfarin and Heparin for three months. His family medical history included a myocardial infarction that his mother suffered at the age of 63. He denied any family history of clotting disorders.

After continued monitoring of the patient for 20-minutes, he reported a complete resolution of chest pain, and he felt ready to complete the triathlon. Sustained measurement of his heart rate remained elevated at 98 bpm and he reported that his normal RHR was historically between 54-56 bpm. Due to a strong suspicion for serious cardiovascular or cardiorespiratory pathology, the side-line sport medicine physician removed him from competition, and he was transported to a local hospital via ambulance.

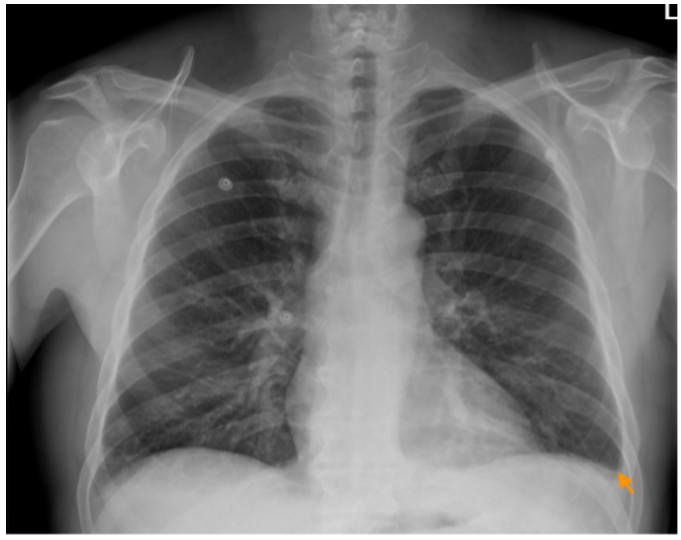

Figure 1a.

X-ray examination of the chest reported as normal. In retrospect there is questionable increased opacity of the basilar zones of the lungs bilaterally, as well as minimal blunting of the left costophrenic angle (yellow arrow). However, none of the classic radiographic findings such as "Westermark" or "Hampton Hump" signs are seen.

Triage and hospital management

Electrocardiography (ECG) in the ambulance revealed a normal sinus rhythm and heart rate of 98 bpm. At the hospital, a chest X-ray was reported as normal (Figure 1a). However, upon retrospective evaluation, there was questionable increased opacity of the basilar zones of the lungs bilaterally, as well as minimal blunting of the left costophrenic angle. A Computed Tomography Pulmonary Angiography (CTPA) confirmed multiple pulmonary emboli in both lungs (Figure 1b). A D-dimer test was over 5000µg/L. Rivaroxaban (15 mg twice daily) was started immediately. The patient was admitted to the hospital overnight and discharged the next day. He was prescribed Rivaroxaban for one month and instructed to follow up with his Family Physician and a Hematologist. Furthermore, he was restricted by the attending physician to participate in sub-symptom threshold exercise and instructed to present to emergency if he continued to experience any exercise-induced dyspnea.

Discussion

The incidence of DVT and PE has not been investigated in the athletic population.[14] Taylor *et al*.[8] published a case report of approximately 50 professional and elite-level

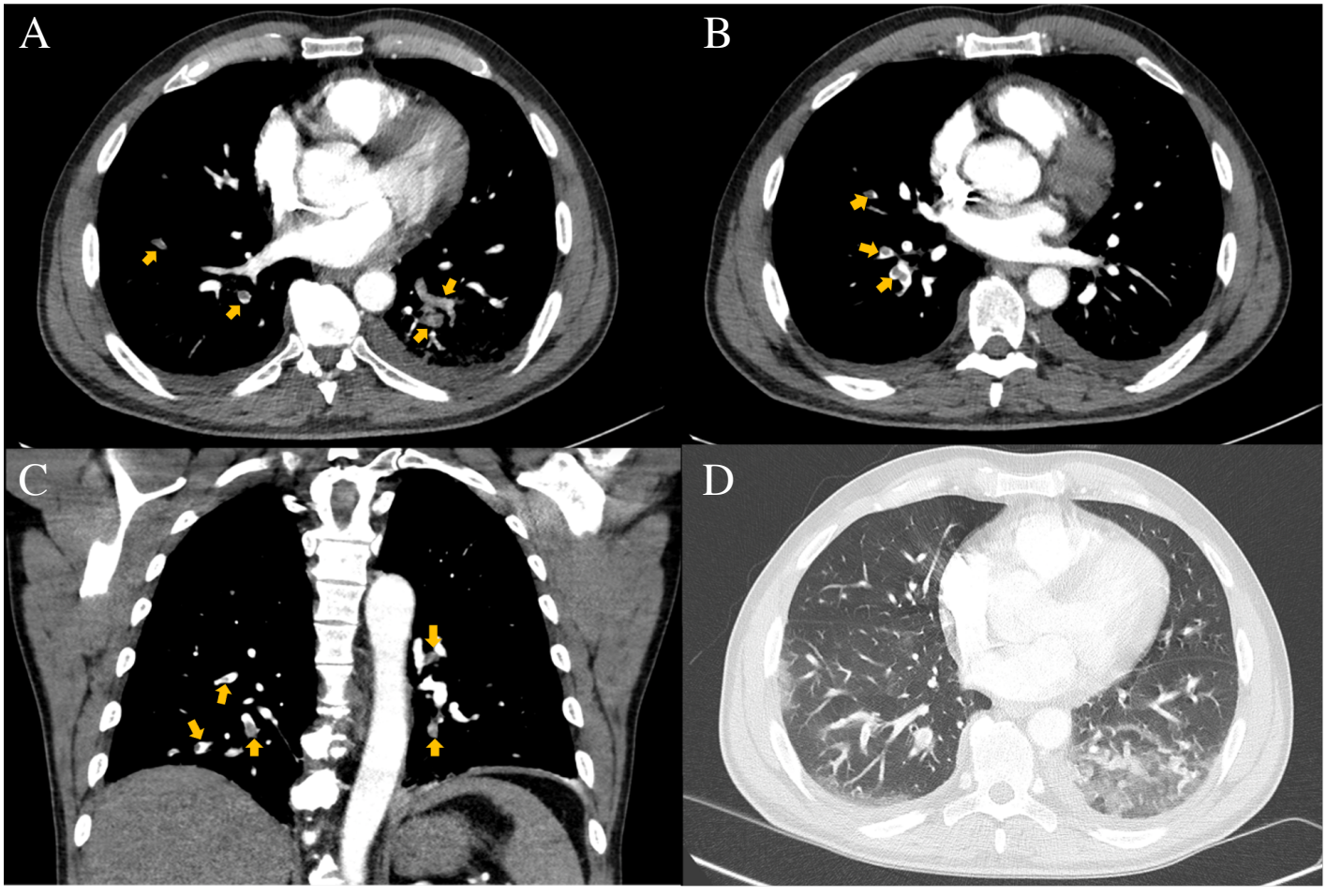

Figure 1b.

Axial and Coronal CTPA, soft tissue windows (A,B,C) demonstrates multiple pulmonary emboli bilaterally in segmental and sub-segmental arteries of the lower, middle and upper lobes. These present as central filling defects in the contrast filled arterial system (yellow arrows). Axial CTPA, lung window (D) demonstrates the resulting consequence to the lung parenchyma; bilateral basilar subsegmental atelectasis with a mild bilateral pleural effusion.

Table 1.
Overview of risk factors for VTE in endurance athletes

Hypercoagulability	Venous stasis	Endothelial injury
• Inherited thrombophilia[15] • Oral contraceptive use[15,16] • Hemoconcentration (prolonged exercise + dehydration + heat)[8,14,15]	• Long duration of travel[18,19] • Athlete's heart (bradycardia + hypotension)[14,20]	• Post-exercise inflammation[14,21] • Repetitive microvascular damage from sport[8]

athletes who experienced PE acutely following exercise. Importantly, over 50% of athletes were initially misdiagnosed, leading to an average diagnostic lag time of greater than one month and return to play times ranging from two to eight months.[8] It is critical for clinicians in sport to understand athlete-specific risk factors from Virchow's triad that can ultimately lead to improved VTE screening and identification (Table 1). This section will dive into the three pillars of Virchow's triad and highlight key areas for clinician awareness.

Hypercoagulability

Previous literature has reported conflicting conclusions on oral contraceptive (OC) use and increased risk of VTE.[15,16] A systematic review by de Bastos *et al*.[16] reported a two-fold increase of risk of thrombosis from all individual types of combined (estrogen with progesterone) OCs and upwards of a fourfold increase in contraceptives with an estrogen dosage greater than 30 μg. It is unclear whether progesterone-based oral contraceptives may be protective against VTE.[16] While the use of OCs in athletes has been reported as similar compared to the non-athletic population, OCs have been shown to decrease the fibrinolytic response and increase coagulative factors during exercise.[15] Taylor *et al*.[8] also reported that nearly 74% of female athletes with VTE reported OC use at the time of diagnosis or symptom presentation with PE. Endurance athletes are also susceptible to other physiological changes in blood that occur after acute exercise. For instance, El-Sayed *et al*.[17] reported that prolonged high-intensity exercise leads to an increase in platelet aggregation and increases in both coagulatory and fibrinolytic factors. Hemoconcentration can be further exacerbated in endurance athletes due to dehydration and prolonged heat exposure from their sport-related demands, but the combined relationship of all these variables for VTE risk has yet to be investigated in endurance athletes.[8,14,15] Another important risk factor to consider are athletes with hereditary thrombophilia.[14] Reportedly, the prevalence of hereditary thrombophilia is similar in the athletic and non-athletic population.[15] Taylor *et al*.[8] reported that 25.5% of athletes were found to have some form of inherited thrombophilia that was later diagnosed following a DVT or PE. While the types of prothrombotic mutations were not disclosed, this is an important consideration as more common heredity mutations including Factor V Leiden or prothrombin deficiencies can put patients at a higher risk of a VTE event between two-to-eighty times greater.[15]

Venous stasis

Long duration of travel (e.g., car or flight) has classically been associated with increased VTE risk.[18] Philbrick *et al*.[18] reported the incidence of VTE at 4.7 per one million travelers with an average flight duration of greater than hours in the general population. Only one observation study in athletes investigated travel of greater than four hours compared to less than two hours in trained marathon athletes and thrombogenic risk.[19] They reported that athletes that traveled greater than four hours had a statistically significant increase in serum coagulatory factors, however, one limitation is that the long-travel group was on average, 10-years-older than the short-travel group.[19] One additional factor for increased circulatory stasis includes characteristic structural, functional, and electrical remodeling associated with regular athletic training, otherwise known as athlete's heart.[20] High-level endurance athletes commonly show greater left ventricular hypertrophy, increased stroke volume and parasympathetic tone, leading to an average resting heart rate of less than 50 bpm and hypotensive blood pressure measurements compared to the general population.[20] This slower circulatory flow has been postulated to increased venous stasis

and the potential for DVT formation in the athletic population.[14]

Endothelial injury

Taylor *et al*.[8] reported that approximately 15% of athletes were diagnosed with a recent lower limb strain or sprain injury prior to experiencing a PE. Additionally, the pathogenesis of upper extremity DVTs including Paget-Schroetter syndrome have been associated with repetitive arm use and injury to the axillary and/or subclavian vein.[8] While previous literature has shown a transient increase in inflammatory and muscle injury biomarkers peaking 24-48 hours post-marathon, it is hypothesized that this leads to a period of susceptibility within the vascular endothelium for developing a VTE following aerobic exercise.[14,21]

Recognition

Reflecting on the patient in this case, there are several factors of Virchow's Triad that can be considered. Our patient did not have any family history of clotting disorders or oral contraceptive use. Second, his medical documentation reported that his previous DVT was attributed to traveling on a very long trip. He subsequently developed symptoms of DVT within one week of his travel. Similarly, prior to this triathlon, our patient had a history of long duration of travel and developed symptoms of VTE within one week of his travel. Next, our patient was an experienced endurance athlete that understood his normal RHR range around 54-56 bpm. After 20-minutes of resting for sideline medical evaluation, his RHR continued to be sustained at 98 bpm. Lastly, while this patient's hydration status at the triathlon and previous strenuous training was unclear, it is possible that these factors could contribute to higher hemoconcentration and aggregation of coagulatory factors.[17,21]

Currently, there is no gold-standard for the sideline assessment of VTE in endurance athletes. Historically, the Wells score, a clinical prediction score criteria, is the most widely used tool for risk stratification of DVT or PE in the general population due to its high sensitivity (0.92).[22] The Wells score consists of a diagnostic, point-based algorithm for patients with suspected DVT/PE that is calculated based on specific patient history or physical examination findings that are present.[22] For instance, patients with a RHR of >100 bpm would receive a +1 score indicating a higher suspicion for PE based on the Wells score. However, when tested retrospectively in athletes who developed a DVT or PE, the Wells score had a 100% failure rate for correctly identifying athletes with known VTE.[22] Furthermore, the patient in our case would have a total score indicating DVT or PE is unlikely according to the Wells score criteria. As such, clinicians may be challenged when screening and identifying VTE in athletes when non-athletic interventions are applied.

Additional testing including ECG, D-dimer, or diagnostic imaging is often required for the diagnosis of PE.[23,24] Sinus tachycardia, a non-specific finding, is the most common abnormality observed on ECG.[2] D-dimer, a commonly investigated biological marker, is the product of breakdown of the fibrous mesh of a blood clot.[24] High levels of D-dimer (>5,000 μg/L) are another non-specific marker associated with several severe diseases including malignancy, sepsis, VTE, trauma, and aortic aneurysm as examples.[25] Lastly, characteristic signs of VTE observed on X-ray include Westermark sign, a focal area of hyperlucency in the vessels distal to the site of occlusion, and Hampton Hump, a dome-shaped pleural opacity in the lung.[23] The sensitivity and specificity for PE of Westermark sign is 14% and 92%, and the Hampton Hump is 22% and 82%, respectively.[23] Chest radiographs are often the first-line imaging modality used to assess differential diagnoses for pleuritic chest pain including pneumonia, pneumothorax, and PE.[23] CT pulmonary angiography is the gold-standard for the diagnosis of PE.[24] This involves injecting the patient with contrast and examining sequential axial images to identify 'filling defects' in the pulmonary artery vasculature.[26] Filling defects refers to areas where the normal opacification (of contrast) in the lumen of the pulmonary arteries is disrupted.[26] This is clearly observed by the yellow arrows in Figure 1b. Our patient was treated with an anti-coagulant Rivaroxaban, an oral direct Factor Xa inhibitor in the coagulation cascade.[27] Common side effects include bleeding complications, cough, vomiting, and gasteroenteritis.[27]

We believe clinicians should focus on obtaining a thorough health history and a sustained vitals examination of athletes presenting with thoracic pain and exercise-induced dyspnea both in office and on the sideline. Specifically, clinicians should ask about family history of clotting disorders. Additionally, clinicians should ask athletes about type and usage of OC, if applicable. Secondly, clinicians should anticipate that vitals measurements for elite-

level endurance athletes may be significantly lower due to physiological adaptations to exercise. As such, when observing normal ranges in the general population in an athlete with symptoms of DVT or PE, clinicians should have a high index of suspicion of VTE when faced with clinical uncertainty. Typically, the symptoms of PE include tachycardia and hypoxemia.[2] Clinicians should also consider the combined risks of dehydration, high-intensity exercise, OC use, and heat exposure on VTE risk to educate athletes potentially better on heat-reduction strategies, hydration frequency, and the symptoms of VTE.

Summary

This case report details a unique case of VTE that presented in an elite 57-year-old Ironman triathlete following a long duration of travel. This patient was treated by a chiropractor one day prior to competition with symptoms of mechanical thoracic spine pain. During the swimming component of the triathlon, he was rescued, triaged, and transported to a nearby hospital and later diagnosed with multiple PE. This case report describes the unique risk factors of VTE in athletes for clinicians to consider along with the conditions of a non-musculoskeletal origin that can present with musculoskeletal manifestations. This case posed a diagnostic challenge from a clinical perspective as traditional risk stratification criteria may not be applicable to an athletic population. In summary, this case highlights the importance of a thorough health history, sustained vitals, and performing a cardiorespiratory examination that proved timely in assisting with this patient's pre-hospital management. While rare, VTE is a condition that can appear in athletes and should be considered as a differential diagnosis in athletes with exertional dyspnea, chest pain, and thoracic spine pain.

References

1. Hull CM, Harris JA. Venous thromboembolism and marathon athletes. Circulation. 2013;128(25): e469-471.
2. Tapson VF. Acute pulmonary embolism. New Engl J Med. 2008;358(10): 1037-1052.
3. Turetz M, Sideris AT, Friedman OA, Triphathi N, Horowitz JM. Epidemiology, pathophysiology, and natural history of pulmonary embolism. Sem Intervention Radiol. 2018; 35(2): 92-98.
4. Goldhaber SZ, Elliott CG. Acute pulmonary embolism: part I: epidemiology, pathophysiology, and diagnosis. Circulation. 2003;108(22): 2726-2729.
5. Tritschler T, Kraaijpoel N, Le Gal G, Wells PS. Venous thromboembolism: advances in diagnosis and treatment. J Am Med Assoc. 2018;320(15):1583-1594.
6. Heit JA. Epidemiology of venous thromboembolism. Nature Rev Cardiol. 2015;12(8):464-474.
7. Yung LM, Yung M, Yao X, Chen ZY, Huang Y, Leung FP. Exercise, vascular wall and cardiovascular diseases. Sports Med. 2009;39(1):45-63.
8. Taylor BA, Parducci PM, Zaleski AL, Panza GA, Pescatello LS, Thompson PD. Venous thromboemboli associated with acute aerobic exercise: a review of case report commonalities. Scand J Med Sci Sports. 2019;29(11): 1749-1754.
9. Stainsby BE, Muir BJ, Miners AL. Upper extremity deep vein thrombosis presenting to a chiropractic clinic: a description of 2 cases. J Chiropr Med. 2012;11(4): 286-292.
10. Fernandez M, Pollard H, McHardy A. A patient with deep vein thrombosis presenting to a chiropractic clinic: a case report. J Manip Physiol Ther. 2007;30(2): 144-151.
11. Kopansky-Giles DR, Grod JP, Crowther ER. Acute proximal deep vein thrombosis: presentation in a chiropractic office. J Can Chiropr Assooc. 1995;39(4): 205-209.
12. Mastragostino P, Chung C. Superficial venous thrombosis of the upper limb presenting to a chiropractic clinic: a case report. J Can Chiropr Assoc. 2020;64(1): 76-81.
13. Christensen MG, Hyland JK, Goertz CM, Kollasch MW, Shotts BL, Blumlein NL, Johnson JM, Day AA, Smith MM. Practice analysis of Chiropractic 2015: a project report, survey analysis, and summary of chiropractic practice in the United States. National Board of Chiropractic Examiners; 2015.
14. Hull CM, Harris JA. Venous thromboembolism in physically active people: considerations for risk assessment, mainstream awareness and future research. Sports Med. 2015;45(10):1365-1372.
15. Grabowski G, Whiteside WK, Kanwisher M. Venous thrombosis in athletes. J Am Acad Orthopaed Surg. 2013;21(2): 108-117.
16. de Bastos M, Stegeman BH, Rosendaal FR, Vlieg AV, Helmerhorst FM, Stijnen T, Dekkers OM. Combined oral contraceptives: venous thrombosis. Cochrane Database of Systematic Reviews. 2014(3).
17. El-Sayed MS, Ali ZE, Ahmadizad S. Exercise and training effects on blood haemostasis in health and disease. Sports Med. 2004;34(3): 181-200.
18. Philbrick JT, Shumate R, Siadaty MS, Becker DM. Air travel and venous thromboembolism: a systematic review. J Gen Intern Med. 2007;22(1):107-114.
19. Parker B, Augeri A, Capizzi J, Troyanos C, Kriz P, D'Hemecourt P, Thompson P. Effect of air travel on exercise-induced coagulatory and fibrinolytic activation in marathon runners. Clin J Sports Med. 2011;21(2): 126-130.

20. Doyen B, Matelot D, Carré F. Asymptomatic bradycardia amongst endurance athletes. The Phys Sportsmed. 2019;47(3): 249-252.
21. Bernat-Adell MD, Collado-Boira EJ, Moles-Julio P, Panizo-González N, Martínez-Navarro I, Hernando-Fuster B, Hernando-Domingo C. Recovery of inflammation, cardiac, and muscle damage biomarkers after running a marathon. J Strength Condition Res. 2021;35(3): 626-632.
22. Zaleski AL, Taylor BA, Pescatello LS, Thompson PD, Denegar C. Performance of wells score to predict deep vein thrombosis and pulmonary embolism in endurance athletes. Phys Sportsmed. 2017;45(4): 358-364.
23. Worsley DF, Alavi A, Aronchick JM, Chen JT, Greenspan RH, Ravin CE. Chest radiographic findings in patients with acute pulmonary embolism: observations from the PIOPED Study. Radiol. 1993;189(1):133-136.
24. Corwin MT, Donohoo JH, Partridge R, Egglin TK, Mayo-Smith WW. Do emergency physicians use serum D-dimer effectively to determine the need for CT when evaluating patients for pulmonary embolism? Review of 5,344 consecutive patients. Am J Roentgenol. 2009;192(5): 1319-1323.
25. Baxevanos G, Tzimas T, Pappas G, Akritidis N. A series of 22 patients with adult-onset Still's disease presenting with fever of unknown origin. A difficult diagnosis?. Clinical Rheumatol. 2012;31:49-53.
26. Wittram C. How I do it: CT pulmonary angiography. Am J Roentgenol. 2007;188(5): 1255-1261.
27. Mueck W, Stampfuss J, Kubitza D, Becka M. Clinical pharmacokinetic and pharmacodynamic profile of rivaroxaban. Clinical Pharmacokin. 2014;53:1-6.

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Interval return to play for a wrist fracture in a hockey player: a case report

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Distal radius fractures are a common sports injury, often managed with reduction, immobilization, and rehabilitation. However, structured sport specific return to play protocols have yet to be developed, specifically within hockey. This case report reviews the various factors to consider when managing an athlete's recovery from a radius fracture, and objective measures to aid with return to play decision making when managing a hockey player.

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KEY WORDS: radius, fracture, return to play, hockey, athlete, chiropractic, rehabilitation

Retour au jeu dans l'intervalle pour une fracture du poignet chez un joueur de hockey: un cas concret

Les fractures du radius distal sont des blessures sportives courantes, souvent traitées par réduction, immobilisation et rééducation. Cependant, des protocoles de retour au jeu structurés et spécifiques au sport n'ont pas encore été mis au point, en particulier pour le hockey. Ce rapport de cas examine les différents facteurs à considérer lors de la gestion de la récupération d'un athlète après une fracture du radius, et les mesures objectives visant à faciliter la prise de décision concernant le retour au jeu lors de la gestion d'un joueur de hockey.

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MOTS CLÉS : radius, fracture, retour au jeu, hockey, athlète, chiropratique, rééducation

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The involved patient provided consent for case publication.

Introduction

Injuries are common amongst athletes, most notably within contact sports such as hockey, due to the nature of play. In the United States, it is estimated that the emergency department sees 18,000 hockey related injuries per year with over 90% of these patients being males, and 50% between the ages of 9-18 years old.[1] Elbow, wrist, and hand injuries account for 14.1% of all hockey related visits to the emergency department.[1] The most common upper extremity mechanism of injuries in hockey players are falls, collisions with other players, or contact with another stick or the boards. Defensemen are susceptible to these mechanisms of injury through their sport-specific demands and have been shown to comprise 40.1% of all wrist and forearm hockey related injuries.[2] To the authors' knowledge, a formal return to play protocol for hockey players following a distal radius fracture has yet to be developed. General principles of fracture management include reduction, immobilization, and rehabilitation.[3] Athletes' sport, position, and timing of injury within season all need to be considered for optimal fracture management.[3] For example, the demands placed through a wrist will vary between sports and sport specific roles, as well the frequency and intensity of practice and game play throughout a season. This case report reviews the various factors to consider for a return to play following a wrist fracture, and objective measures that a clinician can use to aid in their decision making.

Case presentation

A left-handed, 18-year-old male Junior A hockey defenseman, was playing in an exhibition game on August 30, 2019. Holding his stick with both hands, he pushed an opposing player across their back and felt a snap sensation in his left wrist. A "fork deformity" was observed by the team therapist as the player used his right arm to help hold his hand stationary. The player was removed from the ice and brought directly to the dressing room. The arm was stabilized in a splint by the team therapist, and they were transported to the hospital by ambulance.

At the hospital, radiographs confirmed a displaced left distal radius fracture (Figures 1a and 1b). External reduction was completed, and further radiographic imaging confirmed appropriate bone alignment (Figure 2). The player was released with a referral to follow up with an orthopaedic surgeon who recommended surgery. Open reduction with internal fixation surgery with follow-up radiographs took place a week and half later (Figure 3).

The player's left wrist was splinted in a hard plaster cast following their surgery. The plaster cast was removed

a) Left PA wrist radiograph.

b) Left lateral wrist radiograph.

Figure 1.
Initial left PA wrist (a) and lateral wrist (b) radiographs taken at the emergency department.

Figure 2.
Follow up left PA wrist radiograph taken post-external reduction to confirm proper bone alignment.

Figure 3.
Follow up left PA wrist radiograph taken after open reduction with internal fixation surgery, one and a half weeks post-injury.

three weeks post-surgery and replaced with a removable splint to be worn 24-hours a day, except while doing rehabilitation. With guidance from the orthopaedic surgeon, a goal was set with the team therapist and player to prepare for a full return to play (RTP) thirteen weeks after the initial injury.

A full rehabilitation schedule with pre-established outcome measures including wrist range of motion, shot speed, and hockey specific wrist strength, was developed based on the proposed RTP plan (see Table 1). Measured wrist ranges of motion included wrist flexion (flex), extension (ext), ulnar deviation (ulnar dev) and radial deviation (rad dev). Range of motion was measured to the nearest degree using a goniometer. Shot speed was assessed using a radar gun (km/hour) while shooting on ice with different variations of a shot including wrist shot, snap-shot, and slap shot (See Figure 4a and 4b, and Table 2). Lastly, hockey specific wrist strength was assessed using a weight scale objective measurement by determining the maximum weighted force (lbs.) a player could flex through their stick onto a weight scale off ice (See Figure 5). Two measurements were taken per player and the average was used. To determine if the player's outcome measures of shot speed (km/hour) and hockey specific wrist strength (lbs) were an accurate representation of a Junior A hockey player of similar weight (within 10lbs) and height, data was collected from three teammates (see Table 1).

Table 1.

Rehabilitation Weekly Plan and Measured Outcomes Pre/Post Treatment. Following the rehabilitation plan, prescribed exercises were progressed using load management concepts to gradually increase repetitions, sets, and resistance, in accordance with the player's symptoms, objective measures, and daily load.

WEEK	Rehabilitation Plan	Outcome Measures
Week 1 Sept. 25 to Oct. 3	• Finger Movements/ROM • Pinch grip • Resisted finger extension with elastic band • On ice skating, no stick/puck	Oct 3 (Day 1 cast off) ***Range of Motion*** / **Pre Treatment** / **Post Treatment** *Flex* 10° 13° *Ext* 25° 25° *Radial Dev* 15° 15° *Ulnar Dev* 15° 18°
Week 2 Oct. 3 to Oct. 9	• **Cast removed Oct. 3, 2019 (5 weeks post injury, 3 weeks post-surgery)** • Active wrist and finger ROM • Full hand grip squeezes with ball • Soft tissue therapy of associated muscles APCF • Mobilization of carpal joints • Acupuncture of associated muscles	Oct 8 ***Range of Motion*** / **Pre Treatment** / **Post Treatment** *Flex* 45° 60° *Ext* 30° 43° *Radial Dev* 15° 15° *Ulnar Dev* 20° 20°
Week 3 Oct. 10 to Oct. 16	• Resisted wrist ROM (isometric) • Resisted wrist flexion/extension with TheraBand's • Wrist ROM with stick • Soft tissue therapy of associated muscles APCF • Mobilization of carpal joints • Acupuncture of associated muscles	Oct 10 ***Motion*** / **Treatment** / **Treatment** *Flex* 46° 60° *Ext* 20° 30° *Radial Dev* 20° 20° *Ulnar Dev* 20° 20° Oct 15 ***Motion*** / **Treatment** / **Treatment** *Flex* 30° 35° *Ext* 65° 73° *Radial Dev* 25° 30° *Ulnar Dev* 25° 25°
Week 4 Oct. 17 to Oct. 23	• Active wrist ROM • Stick work (No ball/ puck) • Strength Training of wrist/hand/elbow with added resistance • Soft tissue therapy of associated muscles APCF • Mobilization of carpal joints • Acupuncture of associated muscles	Oct 19 ***Motion*** / **Treatment** / **Treatment** *Flex* 73° NA* *Ext* 35° NA* *Radial Dev* NA* NA* *Ulnar Dev* NA* NA* Oct 22 ***Motion*** / **Treatment** / **Treatment** *Flex* 75° NA* *Ext* 40° NA* *Radial Dev* 30° NA* *Ulnar Dev* 25° NA* Weight Scale of stick flex was 25lbs

WEEK	Rehabilitation Plan	Outcome Measures
Week 5 Oct. 24 to Oct. 30	• Stick work with ball off ice • Continue with Strength Training of upper extremity • Soft tissue therapy of associated muscles APCF • Mobilization of carpal joints • Acupuncture of associated muscles	No data collected
Week 6 Oct. 31 to Nov. 6	• On ice individual stick handling drills • Individual shooting off ice with ball • Begin single player passing drills • Continue with Strength Training of upper extremity • Soft tissue therapy of associated muscles APCF • Mobilization of carpal joints • Acupuncture of associated muscles	Nov 4 Weight Scale comparison to teammates • Player 1, R handed forward: 50lbs • Player 2, L handed Defence: 50.5lbs • Player 3, L handed Defence: 66.5lbs • Injured Player: 35 lbs
Week 7 Nov. 7 to Nov. 13	• Non-contact practice focusing on multi-athlete drills • Shooting drills with other players and goalie • Full body strength training • Soft tissue therapy of associated muscles APCF • Mobilization of carpal joints • Acupuncture of associated muscles	No data collection
Week 8 & 9 Nov. 14 to Nov. 28	• Return to Full practice with battling drills • Continue Off ice cross training • Soft tissue therapy of associated muscles APCF • Mobilization of carpal joints • Acupuncture of associated muscles	Nov 16 Weight Scale of injured player 41lbs

* ROM was measured using a goniometer during the days the player received treatment
** A weight scale was placed on the floor with players putting their strength through their flexed stick, 2 measurements were taken per player and the numbers averaged. Players compared were the closest in weight and height of the injured player.
***APCF – As per clinical findings
**** N/A – Data was not collected at this time

a) Slap Shot

b) Wrist Shot

Figure 4.
Demonstration of speed of shot Measurements (km/hour). Used to determine hockey player's shot speed on ice using a radar gun. The radar gun is placed behind the net and the player is asked to shoot either a slap shot, or wrist shot from the hashmarks, approximately 22 feet away from the goal line.

Table 2.
Speed of shot measurements for teammates (km/hour)

Player Handedness and Position	Wrist Shot	Slap Shot	Snap Shot
Left-handed Defenseman	71.17	80	70
Right-Handed Defenseman	71	79.33	70
Left-Handed Forward	70.56	77.98	71.94
Right-Handed Forward	69	76.25	69.3
Injured Player Nov 19	61.67	Unable due to pain	64
Injured Player Dec 13	65.5	55	66

*Teammates were measured taking the shots in a stationary position from the hash marks in front of the goal. Players who took multiple shots were averaged to get their speed. Players were grouped into their shot handedness and position for comparison

The player followed the structured RTP plan with weekly treatments. Updates to the team therapist were incorporated into the rehabilitation program (see Table 1). The player returned for a seven-week follow-up appointment with the orthopaedic surgeon, where wrist strength was tested and found to be 5/5 with no pain, and the incision was determined to be healing appropriately. The surgeon recommended discontinuous use of the splint and cleared him to begin sport specific conditioning. However, it was advised that the player not return to game play for the remainder of the season due to the extent of the initial injury. Following this appointment, the player began sport specific rehabilitation on-ice in non-contact conditions only.

The player requested a second opinion and scheduled an appointment with a sports medicine physician with

Figure 5.
Hockey Specific Wrist Strength - Weight Scale Objective Measure (lbs.). Intended to measure wrist strength for hockey players. With a weight scale placed on the floor, the player was instructed to put as much force through the stick as possible to flex their stick.

hockey specific knowledge to consult on his RTP plan. Upon evaluation, the sports physician was satisfied with the completed rehabilitation, along with the player's strength and capabilities to perform sport specific tasks. Due to the extent of the initial injury and the full contact nature of hockey, the player was not cleared for a full RTP by the proposed deadline and was advised to wait four additional weeks before returning to games to ensure adequate bone healing.

During the additional four weeks, the player continued to follow the rehabilitation plan set forth to enhance strength, while participating in full contact practices with no pain or reinjury. Objective measures continued to be collected, which showed ongoing improvement in each variation of shooting. He returned to play a full game without incident eighteen weeks from the date of injury.

Discussion

This case study highlights the various factors associated with return to play decisions following a distal radius fracture in a hockey player including bone healing, range of motion, strength, ability to meet position-specific demands of their sport, and timing within a sport season. The main goal when managing an acute intra-articular fracture is to restore the articular surfaces.[4] Internal fixation (the surgical approach used with this case) generally provides an earlier return to sport at six to twelve weeks compared to a pin fixation or wrist spanning procedure, with fewer complications.[4] Management of fractures in athletes varies significantly from the general population as their course of action may be chosen for a specific return to sport outcome.[3] In this case, the surgeon decided to remove the splint and advise rehabilitation three weeks after surgery. Open reduction and internal fixation are common for the management of distal radial fractures as it allows for early mobilization and strengthening, supporting positive outcomes with athletes returning to play.[5] Quadlbauer *et al*.[6] compared the functional results between early mobilization immediately following surgery and five weeks of immobilization after surgery. The early mobilization group was placed in a removable splint and were encouraged to start rehabilitation in the first week post-operatively. They concluded that the early mobilization group had increased ROM and grip strength as well as better outcome scores compared to the immobilization group.[6] Additionally, Brehmer *et al*.[5] compared an accelerated rehabilitation program with a standard protocol after surgical fixation. The accelerated program began passive ROM and strengthening at two weeks compared to six weeks in the standard program. At zero to eight weeks the accelerated program showed better mobility, strength, and outcome scores with earlier return to function com-

pared to the standard group.[5] This data supports the decision to begin passive range of motion and strengthening exercises in week one and two.

For athletes who require a full functioning wrist for their sport and cannot continue to play with a cast, it is recommended that they only consider returning to play after the fracture has fully healed.[1] In preparation for sport, gradual progressions are recommended to ensure the wrist is capable of functioning comfortably for daily activities, followed by sport specific drills, practice and the final step of game play.[1] Henn and Wolfe recommend at least 80% of baseline ROM and strength should be demonstrated, as well as radiographic healing of the bone prior to returning to play.[4] These principles were foundational for this athlete's structured RTP plan and the sports medicine physician's decision to allow game play eighteen weeks following the initial injury. The timing of the injury also influenced the athlete's decision to seek out a second opinion for RTP clearance. As an influential player on the team's success, along with significant scouting opportunities to impact his future hockey career, he was eager to return for playoffs. Although athletes may disagree with the timeline and would prefer a quicker return to play process, it may not always be the appropriate decision for that case. The athlete's health and injury recovery should always be the main priority regardless of level of competition.

To the best of the authors' knowledge, there currently is not a collection of pre-established objective measures to help with clinical decisions when guiding an athlete, specifically a defenseman, back to hockey following a wrist injury. Wrist range of motion, shot speed, and hockey specific wrist strength were selected as objective measures for this case as range of motion is a standard measurement with fracture recovery,[2] and shot speed and wrist strength (measured through a player's ability to flex their stick) are skills required for role-specific success as a defenseman. Although further investigation is required to validate the objective measured used here, this case study can act as a foundation for developing hockey sport specific objective measures to help guide clinical decisions with distal radial fractures.

Limitations

The authors acknowledge the limitations of this case study including a small amount of data collected, lack of generalizability, lack of a control group, and a small sample size when comparing the athlete to his teammates. The athlete was also provided with specific exercises, where other exercises could have been more effective. Lastly, our suggested outcome measures of using a weighted scale and speed of shot are unvalidated and need to be further investigated.

Summary

This case report described the occurrence and management of a distal radius fracture in a defensive hockey player. It highlights the unique clinical considerations as an athlete progresses through this injury, while demonstrating the importance of objective measures within a structured, sport-specific return to play.

References

1. Tedesco L, Swindell H, Anderson F, Jang E, Wong T, Kazam J, Kadiyala R, Popkin C. Evaluation and management of hand, wrist, and elbow injuries in ice hockey. Open Access J Sports Med. 2020:11: 93-103.
2. Gotlin M, Minhas S, Buchalter D, Feder I, Alaia M, Jazrawi L. Performance and return to sport after hand, wrist, and forearm fractures in the National Hockey League. J Arthroscop Sports Med Rehabil. 2020;2(5): 505-510.
3. Robertson, G., Wood, A. Fractures in sport: optimising their management and outcome. World J Orthoped. 2015;6(11): 850-863.
4. Beleckas C, Calfee R. Distal radius fractures in the athlete. Curr Rev Musculoskeletal Med. 2017. 10: 62-71. DOI: 10.1007/s12178-017-9385-8.
5. Brehmer J, Husband J. Accelerated rehabilitation compared with standard protocol after distal radial fractures treated with volar open reduction and internal fixation: a prospective, randomized, controlled study. J Bone Joint Surg. 2014; 96:1621-1630.
6. Quadlbauer S, Pezzei C, Jurkowitsch J, Kolmayr B, Keuchel T, Sminon T, Hausner T, Leixnering M. Early rehabilitation of distal radius fractures stabilized by volar locking plate: a prospective randomized pilot study. J Wrist Surg. 2016;6(2):102-112.