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Commentary

The role of force-sensing devices in spinal manipulative therapy research, education, and clinical practice

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Spinal manipulative therapy (SMT) is commonly used by chiropractors, and much attention has been given to teaching students how to master it. Currently, over 20 chiropractic educational institutions use some type of force-sensing device (FSD) to teach students how to modulate their SMT force-time characteristics. Modulating SMT forces is believed to improve SMT's effectiveness, increase comfort during SMT, and reduce adverse events, contributing to improved clinical outcomes. In this commentary, we highlight

Le rôle des appareils de mesure de force dans la recherche sur la thérapie par manipulation vertébrale, son enseignement et sa mise en œuvre en pratique clinique

La thérapie par manipulation vertébrale est très utilisée par les chiropraticiens et on accorde une attention particulière à l'enseignement offert aux étudiants sur la façon de maîtriser cette thérapie. Actuellement, plus de 20 établissements d'enseignement de la chiropratique utilisent un type d'appareil de mesure de force (AMF)

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Conflicts of Interest:
The Canadian Memorial Chiropractic College (CMCC) commercializes the Force Sensing Table Technology (FSTT®) system, which was mentioned in this commentary. None of the authors received any compensation related to the sale of FSTT® units, and CMCC, as an institution, did not have any influence in designing or writing this commentary. The authors declare no other conflicts of interest. No funding was received in preparation of this manuscript.

the transition we are currently living in and discuss the strengths, uncertainties and opportunities of using FSDs to modulate SMT force-time characteristics within research, education, and clinical practice. Given that additional high-quality research is needed to determine if the ability to modulate SMT force-time characteristics indeed influences clinical effectiveness, increases patient comfort, and reduces adverse events, a collaborative effort is needed to address these critical research gaps. Specifically, having similar FSDs across educational institutions allows the collection of multicenter data, sharing research findings across different settings, and provides a unique opportunity for advancing educational and clinical research.

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pour enseigner aux étudiants la manière de moduler leurs caractéristiques forcetemps dans le cadre de la thérapie par manipulation vertébrale. La modulation des forces dans le cadre de la thérapie par manipulation vertébrale est censée améliorer l'efficacité de cette thérapie, améliorer le confort pendant cette phase et réduire les effets secondaires, contribuant ainsi à l'obtention de meilleurs résultats cliniques. Dans ce commentaire, l'accent est mis sur la transition que l'on vit actuellement et on discute des forces, des incertitudes et des possibilités d'utiliser les AMF en ce qui a trait à la modulation des caractéristiques forcetemps dans le cadre de la thérapie par manipulation vertébrale dans la recherche, l'éducation et la pratique clinique. Étant donné qu'une recherche complémentaire de meilleure qualité est nécessaire pour déterminer si la capacité à moduler les caractéristiques forcetemps dans le cadre de la thérapie par manipulation vertébrale a effectivement une incidence sur l'efficacité clinique, augmente le confort des patients et réduit les effets secondaires, un effort de collaboration est nécessaire pour combler ces lacunes en matière de recherche critique. En particulier, avoir des AMF semblables dans les établissements d'enseignement favorise la collecte de données multicentriques, la communication des résultats de recherche dans différents contextes et offre une occasion unique de faire progresser la recherche éducative et clinique.

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MOTS CLÉS : chiropratique, modulation de la force, dispositifs de mesure de force, thérapie manuelle, habiletés motrices, manipulation vertébrale

Background

Manual therapy and force-time characteristics

Manual therapy is a conservative intervention commonly used by healthcare professionals, including chiropractors, physiotherapists, and osteopaths, among others.[1,2] It encompasses several techniques (such as joint manipulation and mobilization) that apply mechanical forces with unique characteristics to the patient's body.[3,4] These characteristics include force magnitude (i.e., how much force is applied), speed (i.e., how fast the force is applied), and loading rate (i.e., the ratio of force application over the time it is applied). These force characteristics are often dynamic and vary over time and with the chosen technique. Therefore, they are often measured and interpreted in relation to the specific time frame of their application, with each manual therapy technique having its unique set of force-time characteristics.[5–8] Specifically, joint manipulation usually includes the application of a preload

force immediately followed by a single high-velocity, low-amplitude impulse force. Joint mobilization applies a rhythmic cyclic, low-velocity, variable-amplitude series of forces. Spinal manipulative therapy (SMT) is a type of joint manipulation extensively used to treat spinal pain.[9,10] However, SMT is a challenging and complex motor skill that likely requires extensive training to fully comprehend and master it. Therefore, several teaching and learning strategies have been investigated and implemented in SMT training, including visual feedback.[11–14]

Force Sensing Devices

Force-sensing devices (FSDs) were originally implemented in chiropractic education as a training tool to quantify the forces applied during manual therapy, including SMT, and provide students with immediate visual feedback regarding their force-time characteristics.[13–15] An example of a commonly used FSD is the Force Sensing Table Technology (FSTT®, Toronto, Ontario, Canada), which is composed of a treatment table with an embedded force plate that measures the forces in all three axes of motion at the interface between the subject receiving the SMT and the table, at a rate of up to 2000 Hz.[16] The chiropractic profession has used and popularized SMT throughout the last century,[1] and it is now often related to the use of SMT. Specifically, SMT is applied in nearly all chiropractic consultations[2,17,18] and taught at every chiropractic educational institution[19,20]. Thus, it is natural for these institutions to attempt to optimize teaching strategies regarding students' SMT skills. Consequently, several chiropractic educational institutions worldwide have integrated FSDs into their curriculum in various fashions intending to facilitate and support the development of SMT motor skills.

The goal of incorporating FSDs into education is to provide objective feedback to learners so they can replicate the force-time characteristics of experienced field practitioners. Specifically for SMT, educational institutions use FSDs to teach students how to modulate the SMT force-time characteristics and to adapt it to suit each unique patient.[21,22] Practical experiences and observations from the educators in our team indicate that combining the objective feedback from FSDs with individualized guidance on motor skills strategies may facilitate trainees to better modulate their SMT force-time characteristics and reduce variability in SMT performance when compared to observation alone. From a theoretical standpoint, modulating SMT force-time characteristics is believed to optimize clinical outcomes by 1) improving SMT effectiveness, 2) increasing patient comfort, and 3) minimizing potential adverse events.[22–24] In this commentary, the term "adverse events" is used as a broad term that encompass the wide range of adverse events following SMT described in the literature.[25,26]

The purpose of this commentary

As more chiropractic students are being trained using FSDs, it is essential for users to be aware of strengths, uncertainties, and opportunities regarding modulation of SMT force-time characteristics and the role of FSDs in investigating how SMT force-time characteristics may influence clinical outcomes. The discussion is focused on SMT clinical effectiveness, patient comfort, and adverse events when modulating force-time characteristics within the context of research, education, and clinical practice. This commentary was framed based on discussions during the FSTT® workshop at the Chiropractic Australia's Research Foundation (CARF) Researchers' Day 2023, and includes expert opinions from workshop participants, key stakeholders (researchers and educators) from institutions that have utilized FSDs in the last decade and a student representative with vast experience with FSTT®.

Do SMT force-time characteristics matter? The rationale for using FSDs

The clinical effectiveness of SMT is believed to be associated with neuromechanical responses observed following SMT applications. Notably, associations between SMT force-time characteristics (e.g., preload force, peak impulse force, impulse duration, location, technique) and neuromechanical responses (e.g., spinal tissue loading, muscle spindle activity, muscle activation) have been shown consistently.[27–36] While it remains unknown how the underlying mechanisms of SMT influence clinical outcomes, the use of FSDs could potentially facilitate the modulation of SMT force-time characteristics, which, in turn, may contribute to improving clinical effectiveness.
Patient comfort during SMT has been identified as a critical component when teaching SMT.[23,37] From the perspectives of the authors, who all have been the recipients of SMTs from students and practitioners, there appear to be differences in comfort depending on the SMT force-time

characteristics. Additionally, comfort has been associated with improvements in pain and global perceived change.[38] Thus, comfort may influence clinical outcomes and the ability to modulate SMT force-time characteristics may improve patient comfort.

From a safety perspective, SMT is perceived to have added risks of injury due to the application of forces that are perceived to have higher magnitudes and speeds than other types of manual therapies.[39–41] Therefore, applying SMT with lower forces has been recommended to specific populations (e.g., older adults and children[24,42]) as well as to prevent specific adverse events (e.g., costal and vertebral fractures[43,44]). Although no studies have quantified the SMT force-time characteristics required to create tissue injuries, the ability to modulate SMT force-time characteristics in a clinical setting may contribute to preventing adverse events and improving its safety.

What do we know about SMT force-time characteristics? Strengths and uncertainties in using FSDs

Force sensing devices provide students with visual feedback on their SMT force-time characteristics. Feedback can facilitate the development of specific motor skills and optimize motor learning and performance.[45] Current SMT educational approaches focus on training students to consistently modulate their SMT force-time characteristics to deliver SMT with a wide spectrum of forces and speed. The combination of FSDs' visual feedback with tailored instructions can facilitate the development of individual motor skill strategies, allowing each student to modulate SMT force-time characteristics most suited for their individual attributes as well as the patients (e.g., sex, height, weight, strength). Although field chiropractors present a large variability in the characteristics of SMT forces used in clinical practice,[46] previous studies showed that both, students and practitioners reduced the variability of their SMT forces immediately after a training session using FSDs[12,47]. Additionally, a previous pre-post study suggests that students can retain their ability to modulate SMT forces after a 12-week detraining period.[48]

Currently, we are living in a transition period moving from "is force modulation possible?" towards "is force modulation important?". Similar to every research area, the limited capacity and resources "force" researchers to approach one question at a time. In the case of FSDs, investigations to date have focused on determining if force modulation was even possible. With several studies demonstrating that force modulation is indeed possible,[11–15,37,47,48,66,68,72] the focus can now shift towards investigating the clinical relevance of force modulation. Whether this was the best approach or not is beyond the scope of this commentary. Nevertheless, had the focus to date been the importance and clinical relevance of force modulation first, maybe instead of asking "why are we teaching force modulation, if we do not know if it makes a difference clinically?", we would be asking "why are we looking into the clinical effects of force modulation if we do not even know if it is possible to control and modulate forces? People might just apply whatever they feel is needed". Regardless of that, it is unquestionable that the time has come, and future efforts must now focus on investigating the importance and relevance of force modulation on clinical outcomes.

A great example of something similar has recently been demonstrated. Specifically, recent advances related to the non-specific effects of physical treatments for low back pain,[49] including SMT, suggest that the specific site or region of SMT application has limited impact on clinical outcomes[50,51]. Force sensing devices may provide educators with an opportunity to shift their focus towards a more modern and nuanced understanding of SMT,[52] which involves the potential relationship between force-time parameters and clinical outcomes, including clinical effectiveness, patient comfort and safety.

Clinical effectiveness of SMT

The distinct physiological responses elicited by different SMT force-time characteristics suggest that a dose-response relationship between SMT force-time characteristics and clinical outcomes may exist.[27–36] However, it remains unknown if 1) such relationship actually exists,[53] 2) the specific SMT force-time characteristics that should be targeted and 3) the specific provider or patient characteristics that dictates the choice of such characteristics.

Force sensing devices can be easily implemented in clinical settings by embedding it in a regular treatment table, thereby allowing the measurement of SMT force-time characteristics in a clinical setting without significantly disrupting the patient encounter.[54] Such implementation would allow for correlations to be drawn between SMT force-time characteristics and clinical outcomes

(including adverse event). If clinical outcomes are associated with specific SMT force-time characteristics, future research, education, and practice can focus on the specific characteristics that influence clinical outcomes, potentially enhancing the clinical effectiveness of SMT. Specifically, further investigations on the best strategies for developing the motor skills needed to apply such characteristics could be conducted, as well as how to tailor them to specific patient attributes. On the other hand, if SMT force-time characteristics are not associated with clinical outcomes or adverse events, future research, education, and practice can shift their focus away from specific force-time characteristics for clinical effectiveness to a broader focus on other aspects of SMT or perhaps use educational credits on other aspects of clinical practice (e.g., patient education and self-management strategies).[55]

There are, however, some important limitations to currently available FSDs[56] that should be considered. For example, previous studies have shown that forces measured by FSDs embedded in treatment tables are different than the ones applied by the provider[57–60] and, as such, cannot be used as a proxy to the forces being applied to the patient. However, currently available FSDs to measure forces directly applied to patients (such as flexible pressure mats and finger sensors) are limited in terms of maximum force capability, sampling rate, measurement error, number and type of sensors, uniaxial force measurement, and design, significantly limiting its application and implementation in clinical SMT investigations.[56] Additionally, costs of FSDs and their respective software can vary significantly, as well as costs related to training personnel on how to use FSDs and interpret the data, especially in the research context. Most investigations have used FSDs integrated into treatment tables focused on prone thoracic SMT.[38,54,58,60–62] While this was an important start, fewer people suffer from thoracic spinal pain compared to cervical and lumbar spinal pain.[63] The force-time characteristics of side-posture lumbar and supine cervical SMT are not simple to quantify as they involve coupled-motions and the impulse vector is not directed perpendicular to the table. While FSDs at the clinician-patient interface would provide a more appropriate quantification of applied forces during SMT to these regions, not only the devices' limitations mentioned above, but also the combination with rotational movements, would still make the interpretation and application of cervical and lumbar SMT force measurement in a clinical setting challenging. Therefore, force-time characteristics of cervical and lumbar techniques remain uncertain as they cannot be accurately quantified in a clinical setting with current FSDs with the required rigour for research.

Comfort of SMT

Currently, the limited available evidence does not support the idea that SMT force-time characteristics are related to comfort.[37] Specifically, perceived SMT impulse duration, but not objectively measured SMT impulse duration, was observed to be associated with the comfort experienced by students following SMT.[37] However, findings obtained from students familiar with SMT applied with limited force-time characteristics variability limits the generalizability of these results to people not trained in SMT and suffering from pain. Despite that, comfort has been associated with improvements in pain and global perceived change.[38] Therefore, it remains unknown if using modulated SMT force-time characteristics tailored to specific patient characteristics may influence patient comfort.[38]

Adverse events of SMT

Adverse events have been suggested to be associated with SMT force-time characteristics, particularly with the total peak impulse force and, potentially, the loading rate.[39–41,60] Although previous investigations suggest that SMT force magnitudes are below the magnitudes described in the literature to cause tissue damage,[60,64,65] the potential relationship between SMT force-time characteristics extending beyond just peak forces and injuries remains unknown.

Based on the rationale that SMT force magnitudes may be associated with adverse events, some teaching institutions focus on training students to modulate their SMT force-time characteristics so that lower forces are applied first and subsequently gradually increased. This training is greatly facilitated by FSDs' visual feedback and students and practitioners are indeed able to better modulate their SMT force-time characteristics immediately after a training session using FSDs.[12,47] However, it remains unknown if such an approach is maintained in clinical practice and if it, indeed, prevents the occurrence of adverse events. Additionally, it also remains unclear if feedback specifically from FSDs are necessary or if traditional verbal feedback are just as effective in developing force modulation skills. Importantly, adverse events are broad in nature and

can affect not only physical aspects (e.g., tissue damage), but also psychological and social aspects of the patient (e.g., mental health and participation). Therefore, SMT force-time characteristics may not be the only factor contributing to adverse events.

Where to next? Opportunities in using FSDs

Research and clinical practice

Specific FSDs have been reported to have excellent within-patient reliability in measuring SMT force-time characteristics at the patient-table interface.[16,21] Several FSDs have been used in numerous studies focusing on motor skills development, student training in force modulation using manikins,[11,13,66–68] and characterizing SMT's forces, loading, and dynamic behavior with the human body[5,7,57,60,62,69]. These have significantly advanced our knowledge of SMT kinetics to date. Combined with integrating into a standard treatment table, this allows FSDs to easily replicate real-life scenarios, supporting the generalizability of investigations using it.

Since many chiropractic educational institutions worldwide have FSDs, there is an opportunity to foster international research collaborations. Recently, a consortium using the FSTT® was developed to bring together institutions interested in jointly conducting collaborative research investigating all aspects of SMT force-time characteristics and their modulation. Specifically, the FSTT® consortium has to date held two formal in-person meetings with representatives from 13 institutions (with additional institutions attending virtually). At these meetings, pedagogical approaches to delivery of SMT and best-practice approaches to training in force-modulation were debated, along with challenges/opportunities to integrating FSD technology into both lab- and clinically-based research. The FSTT® consortium is currently finalizing its inaugural collaborative research project and has fostered many additional international educational and research collaborations using a variety of FSDs, including FSTT®, load cells, finger pressure sensors and pressure mats. While not aspiring to fill all the gaps, the consortium has the potential to advance this field by standardizing methodologies across studies ensuring greater external validity. Through standardization and resource pooling across institutions, the consortium is well positioned to investigate the value of FSDs in this field, whilst supporting institutions with smaller research capacities, enabling them to benefit from the expertise and support of more established and experienced researchers. Such multisite, international collaborations foster high quality research and educational opportunities, paving the way for more consistent and impactful advancements in SMT research and education.

Additionally, the quantification and reporting of SMT force-time characteristics used in previous clinical trials is nearly nonexistent, as most studies quantifying the SMT force-time characteristics have been conducted on asymptomatic participants or manikins.[5,37,57,67] Consequently, the characteristics of the SMT forces being applied in clinical settings, to real patients, remains under-investigated.[38,54] A recent observational study found no associations between specific SMT force-time characteristics (measured at the patient-table interface) and pain, disability, and global perceived change.[38] While this challenges the potential dose-response relationship between SMT force-time characteristics and clinical outcomes, there is a significant paucity of evidence related to this topic.[53] Although FSDs are currently being used in clinical investigations within real-world clinical settings, a joined international multisite collaborative approach would have a greater impact and generalizability. It is important to note, however, that the overall effects of SMT have been observed to be small compared to no treatment or sham SMT,[70,71] leaving little variance for SMT force-time characteristics to potentially explain. Still, there is also the possibility that the effects are small, with wide confidence intervals, and present substantial heterogeneity exactly because neither the SMT force-time characteristics, its customization to specific patient characteristics or the ability to modulate it were taken into account within clinical trials.

Education and clinical practice

The goal of chiropractic education is ultimately focused on clinical practice and its curriculum allows students to develop skills to treat patients with spinal pain. For SMT, this includes applying a wide range of force-time characteristics, mimicking the forces reported in the literature and those applied by experienced practitioners.[5,7] The use of FSDs not only assists students and clinicians to better modulate SMT force-time characteristics,[12,13,47] but also provides the opportunity for quality assurance in standardizing skill development (by providing visual quantitative feedback) and establishing minimal competencies required for entering clinical practice. However,

while better modulation of SMT force-time characteristics has been anecdotally observed in teaching institutions using FSDs, additional high-quality, rigorous investigations are crucial to demonstrate that 1) trainees can indeed better modulate their SMT forces-time characteristics in comparison to those who do not use FSDs, and 2) if such modulation skills are transferable to clinical practice. Importantly, similar to any other intervention, evidence on its benefits is fundamental prior to further incorporating FSDs into more formal standards, such as professional regulations or accreditation requirements.

In educational settings, FSDs have mainly been used for training modulation of SMT force-time characteristics of the thoracic spine.[13,48,61,66,72] Using FSDs is a good pedagogical approach for students to understand the kinetic components of SMT and receive visual feedback when learning to modulate their forces so they can modify their motor strategies accordingly. Therefore, there is the opportunity for more complex SMT techniques (e.g., side-posture lumbar SMT) to also be accurately quantified through FSDs. Additionally, the use of FSDs can be expanded as they can provide force-time feedback on any manual therapy technique that involves the application of forces, such as muscle energy technique and mobilization with movement. Finally, using FSDs may support complementary learning strategies, such as students' self-assessment and peer-mentoring by trained and experienced student mentors, particularly when time, resources, and faculty availability is limited.[73]

Considering the current uncertainties surrounding the clinical value of modulating SMT force-time characteristics and the lack of high-quality evidence on the impact of using FSDs in SMT training, we strongly recommend educators who use FSDs in education to keep their mind open to the possibility of adapting their teaching focus and approach as higher-quality evidence becomes available. We plead educators to play an active role in contributing to make such evidence become available. Specifically, while several previous studies[11–15,37,47,48,66,68,72] have been instrumental in providing the current foundational knowledge, further advancement is needed and high-quality trials are imperative. An international collaborative effort, such as the FSTT® consortium, presents a unique opportunity to make significant contributions in this area. By involving multiple institutions in collaborative initiatives, funding options are also broadened, including external and internal funding – from institutional and research grants to governmental educational organizations and beyond. It is fundamental that educational institutions who use FSDs in their curricula to conduct rigorous and systematic investigations on its impact and report their findings regardless of if they are supportive of FSDs use or not. The researchers in this commentary make themselves available to help and support such endeavour (MF, ASD, FCKD, IP, CAM, CN).

Next steps

It is time to shift the focus of SMT forces-time characteristics investigations. More high-quality research is urgently needed regarding whether the ability to modulate SMT force-time characteristics actually influences clinical effectiveness, increases patient comfort, and reduces adverse events. These would inform whether educational settings should continue to focus on modulating SMT force-time characteristics using FSDs. Thus, several questions remain:

- What are the SMT force-time characteristics currently used in the real-world clinical practice with real patients?
- Does the modulation of force-time characteristics enhance the clinical effectiveness?
- Does the modulation of force-time characteristics tailored to the patient attributes increase comfort or patient satisfaction with care?
- What are the patient attributes that dictate what SMT force-time characteristics should be used?
- Does using lower SMT forces prevent adverse events?
- How can cervical and lumbar SMT force-time characteristics be appropriately quantified and interpreted?

Conclusion

We have discussed the strengths of modulating SMT force-time characteristics using FSDs. The ability to modulate SMT force-time characteristics could potentially improve clinical outcomes by improving SMT effectiveness and comfort, and reducing adverse events. However, additional high-quality research is needed to confirm or refute this. While FSDs are being rapidly included in SMT curricula in chiropractic education, the uncertainties discussed should not be ignored. So far, research has yet to keep up with the educational implementation of FSDs.

We have identified several opportunities for future clinical and educational research using FSDs to increase the knowledge that will help advance the field and elucidate its impact.

List of abbreviations

SMT = Spinal manipulative therapy
FSD = Force sensing device
FSTT® = Force Sensing Table Technology

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