Original articles

Pilot study of the impact sacroiliac joint manipulation has on walking kinematics using motion analysis technology

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Received 11 October 2012; received in revised form 10 May 2013; accepted 14 May 2013

Key indexing terms:

Manipulation;
chiropractic;
Gait;
Biomechanics;
Locomotion

Abstract

Objective: The purpose of this study was to evaluate the feasibility of engaging in a series of larger studies measuring the effect of sacroiliac joint manipulation on walking kinematics using motion analysis technology.

Methods: Twelve college students engaged in a baseline 90-second gait analysis at 1.5 mph using infrared VICON cameras. Following this, they underwent a prone heel comparison test for functional leg length inequality. Upon examination, participants were then classified as follows: left short leg, right short leg, or no short leg. Participants in each of the 2 short leg branches of this study were then randomized to receive either chiropractic manipulative therapy to the posterior superior iliac spine on the short limb side or no manipulation. Recruitment was ongoing for this pilot study until 1 participant was recruited in each of the following 5 comparative study groups: left short leg—manipulation, left short leg—no manipulation (control 1), right short leg—manipulation, right short leg—no manipulation (control 2), and no short leg (control 3). All participants then underwent another 90-second gait analysis. Data were then grouped and submitted to a blinded biomechanist to determine if there were any unique biomechanical differences between the groups.

Results: No statistically significant differences were measured because of this being a pilot study with a small sample size.

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Conclusions: The data from this study indicate that a series of larger studies with this design is feasible.

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Introduction

Two types of leg length inequality (LLI) exist: anatomical and functional LLI.^{1,2} A primary consequence of possessing a short lower limb is that it places abnormal mechanical stress on both lower limbs. For example, the longer limb often will develop greater foot pronation; and the shorter limb will be predisposed to degenerative joint changes.^{2,3}

An anatomically short lower limb occurs when someone is born with a smaller-than-normal bone affecting 1 lower limb.² This primarily occurs when individuals are born with a shorter than normal femur or tibia.

A consequence of an anatomically short lower limb is that the pelvis will undergo torsion to biomechanically adapt. This pelvic torsion can be corrected using a heel lift on the short limb side. Depending on the degree of short LLI, back pain and sometimes knee pain may develop.¹ Friberg et al⁴ found that there was a high correlation between low back pain and LLI if the inequality exceeded 15 mm. If untreated, the body quite obviously would have to adapt to the difference in limb length; and that could lead to the development of a functional adaptive scoliosis.¹

Another form of LLI is a functional LLI. This form of short lower limb is believed to be due to malposition of the innominate bone in relation to the sacrum, resulting in a limb that is shorter than normal.² One theory why this occurs is that there is greater-than-normal suprapelvic muscle hypertonicity that leads to an alteration in pelvic rotation, but additional subluxation-based theories have been proposed.^{5–8} Hip girdle malposition like this is thought to occur when the superior aspect of 1 innominate bone rotates posteriorly, resulting in the development of a functionally short lower limb.⁵

The long-term consequence of a functionally short lower limb is not clearly known.² If one limb is shorter than the other, the person will repeatedly exert lateral excursion forces to the short limb side as he or she walks just like he or she would with an anatomical LLI. This lateral force represents wasted momentum. Ideally, a person would be more biomechanically efficient if he or she was constantly moving forward instead of wasting some of his or her momentum by rocking laterally. If functional LLI could be reduced, that should have

implications in running sports, where forward momentum is critical. Additionally, over time, a short limb would likely result in more pressure being placed upon the articular surfaces of the short extremity during gait, similar to what would occur with an anatomical LLI. As a result, it is reasonable to suggest that this increased activity may result in greater wear and tear on the hip, knee, and ankle joints of the short limb if the malposition was not corrected. To corroborate this point, studies have shown that a leg length difference of as little as 3 cm has been correlated with a greater-than-normal risk of developing stress fractures and osteoarthritis on the affected side, as well as being correlated with lower back pain.^{4,9–13} The exact amount of LLI needed to cause gait asymmetry is not clearly known. Some authors have stated that the inequality must be over 2 cm to result in an asymmetrical gait,^{14,15} whereas others have stated it may be as little as 1 cm.¹⁶

Most chiropractic biomechanics studies have focused primarily on movement of the vertebral bodies and general spinal stability, and not on alterations in pelvis motion in response to LLI.^{17–23} A literature review on PubMed, Index to Chiropractic Literature, and Alt Health Watch using keywords *chiropractic*, *biomechanics*, and *gait* yielded only 2 applicable gait-related chiropractic manipulative therapy (CMT) articles. Sandell et al²⁴ found that, following CMT to the sacroiliac (SI) joint, runners improved their hip extension capabilities. This interesting change, however, did not materialize into any improvement in running velocity post-CMT on a 30-meter sprint ($P = .572$). Herzog,²⁵ in his CMT gait biomechanics article, described how hip CMT could cause direct biomechanical changes in the SI joint, as well as indirect changes through reflexive muscle relaxation pathways. He further went on to discuss how SI joint CMT increased gait support time and improved gait symmetry based on ground reaction force analysis using force plates. These findings add credibility to the belief that SI joint CMT may marginally alter the biomechanics of the lower limbs. Because of the limited research in this field, more studies are warranted, particularly studies utilizing state-of-the-art motion analysis technology.

Doctors of chiropractic often treat patients with functional LLI.^{26–28} The impact SI joint CMT has on LLI and gait kinematics should be studied further to

help chiropractors better understand how they may impact gait. The purpose of this pilot study was to determine the feasibility of engaging in a series of larger SI joint CMT gait studies.

Methods

This study was approved by the Texas Chiropractic College (TCC) Research and Human Subjects Committees.

Study design and setting

This was a single-blind, randomized, controlled pilot study of the immediate impact SI joint CMT had on functional LLI walking kinematics. Our specific aims were to determine if we could utilize advanced motion analysis technology and apply it to a chiropractic-related musculoskeletal research study, and to see if SI joint manipulation improved gait symmetry.

As shown in Fig 1A and B, 12 participants initially engaged in a 90-second baseline gait analysis test utilizing the VICON infrared camera imaging system (VICON, Centennial, CO). This is the same type of advanced motion capture imaging equipment that has been used in animated movies and video games.^{29,30} Following this, they all underwent a prone heel comparison test to observe for a functionally short lower limb. If the study participants possessed a short lower limb, they were then randomly subdivided into the 2 following groups: (1) posterior superior iliac spine (PSIS) CMT to the short leg side or (2) no CMT. Next, study participants underwent another 90-second gait analysis to determine if a change in gait was induced. The process of recruiting and testing participants continued over 1 month until there was at least 1 participant in each of the following 5 study subgroups of this pilot study: left (L) short leg—manipulation (manip), L short leg—no manip, right (R) short leg—manip, R short leg—no manip, or no short leg (Table 1). The L short leg—no manip, R short leg—no manip, and no short leg groups were intended to serve as controls for comparison purposes. The intent of this study was to collect pilot data that could be used to assess the feasibility of a series of larger studies and indicate possible data trends that should be monitored.

Randomization and blinding

After the baseline 90-second gait measurement, group assignment was determined by LLI examination.

Participants were initially subdivided into the 3 following groups based on the LLI test: left short leg, right short leg, and no short leg (as shown in Fig 1A). If a participant was in a short leg group, the treating chiropractor in this study then drew random slips of paper from a box that stated “manipulation” or “no manipulation.” By necessity, the doctor performing the SI joint CMT was aware of which group the study participant belonged to.

The external biomechanics data reviewer, however, was blinded as to group designation. He was only told that he would be provided with walking data from 5 distinct study groups and that he needed to determine if any unique differences existed between any of the groups’ pre- vs postwalking data. He was not told which groups underwent SI joint CMT.

Participants

Student volunteers were recruited with on-campus flyers and via word of mouth. All study applicants provided an informed written consent on college-approved documents. They were then screened against inclusion and exclusion criteria. Twelve apparently healthy individuals (range, 21–40 years of age) that met the inclusion/exclusion criteria participated in this 20-minute 1-visit study (Table 1). Three participants were excluded from this study because of violating the exclusionary criteria (2 had lower limb surgeries, and 1 exceeded the study age limit). Participants were given a study preparation handout of the exclusion criteria and reminded to avoid the following during the day that they tested for the study: caffeine, alcohol, and any outside source of CMT.

Inclusion/exclusion criteria

Inclusion criteria were as follows: (1) the participant had completed their TCC student physical and reported no contraindication to hip CMT, (2) between the ages of 20 and 45 years old, (3) answering “no” to all exercise contraindication sections on a Physical Activity Readiness Questionnaire, (4) they did not engage in strenuous exercise the day of the study, and (5) they provided their informed written consent. Study participants with any of the following were excluded from the study: (1) diagnosis of any lumbar, sacral, hip, or lower limb pathology that would prevent them from walking; (2) severe neurological conditions that would impact gait (eg, type II diabetes, Parkinson disease, traumatic brain

Fig 1. A, Experimental design. B, Illustration of a study participant and a sample computer model based on reflective marker data extraction using the VICON imaging system. Only the left side of the participant is marked in this diagram to avoid image clutter. *CMT*, chiropractic manipulative therapy; *L*, left; *LLI*, leg length inequality; *PSIS*, posterior superior iliac spine; *R*, right.

injury, dementia, stroke, epilepsy, multiple sclerosis, myasthenia gravis, Huntington disease); (3) history of alcohol abuse; (4) unstable medical conditions that would render exercise dangerous for them; (5) any health condition that would impair their ability to walk up to 3 mph; (6) visual impairment that would render walking on a treadmill dangerous for them; (7) hypertonia; (8) use of a cane or similar assistive walking device; (9) taking medications that alter motor function (eg, acetylcholine-esterase inhibitors, L-dopa agonists, dopa antagonists, or neuroleptics); (10) botulinum injection in their lower limb muscles within the past 6 months; (11) presence of severe pain in their lower limbs that they would rate greater than a 3 on a 1 to 10 visual analog scale; (12) vertigo or history of falls within the past 60 days; or (13) any bone or muscle-related surgeries ever.

Baseline preparation and kinematic recording

Participants were all given a verbal description of the walking study and LLI analysis prior to testing to reduce anxiety during the test. The study participants were scheduled to attend one 20-minute study session during their lunch hour. Upon arrival to the session, they changed into standardized black spandex shorts and dark shoes. All men wore new MX409 New Balance shoes, and women wore new WL574 New Balance shoes (New Balance, Brighton, MA). Prior to this study, researchers purchased 5 pairs of male (sizes 8-12) and female (sizes 5-9) shoes in common sizes. Standardized shoes were chosen as opposed to having participants walk barefoot to most closely emulate a real-world scenario. Any reflective logos on the shoes were spray-painted with nonreflective paint. The study participants additionally

Table 1 Baseline study participant attributes

	Group 1	Group 2	Group 3	Group 4	Group 5
	L short leg—manip	L short leg—no manip (control group 1)	R short leg—manip	R short leg—no manip (control group 2)	No short leg (control group 3)
Sex					
Male	2	2	1	2	4
Female	0	1	0	0	0
Age (y)	29.0 ± 7.1	29.3 ± 9.3	24.0 ± 0.0	22.0 ± 1.4	26.5 ± 3.7
Body mass (kg)	93.0 ± 22.5	75.3 ± 14.9	78.9 ± 0.0	72.8 ± 8.6	91.4 ± 31.0
Height (m)	1.72 ± 0.00	1.68 ± 0.14	1.73 ± 0.00	1.74 ± 0.01	1.77 ± 0.11
Body mass index (kg/m ²)	31.2 ± 7.5	26.3 ± 1.2	26.36 ± 0.0	24.0 ± 2.4	28.6 ± 6.2

Data listed as mean ± SD.

L, left; R, right.

rolled up and clipped the inferior aspect of their shirt near their xiphoid process to reduce the likelihood that their lower shirt would block the anterior superior iliac spine (ASIS) or PSIS reflective markers. Participants were asked to remove all shiny jewelry to decrease any chance that it might interfere with the VICON cameras during data collection. Next, trained research assistants placed 18 silver reflective markers on the participant's lower body using double-sided marker fixing tape and surgical tape. Reflective markers were placed on the following anatomic landmarks during this study bilaterally: ASIS, PSIS, greater trochanter, lateral epicondyle of the femur, tibial tuberosity, lateral malleolus, posterior calcaneus, top of the fifth metatarsal head, and top of the first metatarsal head (Fig 1B). Marker placement was double-checked by an anatomist with 10 years of teaching experience. Sixteen of the MoCap solutions reflective markers were 19 mm (MoCap solutions, Huntington Beach, CA). The 2 PSIS markers used in this study were slightly smaller, at 14 mm. This was done in an attempt to gain better resolution by reducing the likelihood that those markers would be merged together by the VICON cameras considering how close the PSISs were on smaller participants with narrow hips. Additionally, research participants were not allowed to wear regular socks during the study. They could wear ankle socks, but only if they did not reach their lateral malleolus.

Prior to the participant arriving at the laboratory each day, the VICON system was calibrated as suggested by the manufacturer. Once the participants were dressed properly and all of the reflective markers were in place, they stood on top of the 400 Pro series Keys treadmill (Keys Fitness Products, Inc, Dallas, TX). This treadmill had the side rails sawed off and the control panel fixed on the ground to ensure that they would not obscure vision of the reflective markers at any time during data collection. Next, the participants were instructed that

they would be walking as they normally would at a velocity of 1.5 mph. A research assistant started the treadmill at the same time as another researcher began recording data with the VICON system. The laboratory's VICON MX system consisted of 8 infrared Bonita 0.3-megapixel cameras. Kinematic data were recorded at 100 Hz. The displacement of the 18 reflective markers over time was measured. At the conclusion of 90 seconds, the researcher operating the VICON computer stopped the recording; and then the treadmill was stopped. The study participant was not given any indication of when the treadmill would be stopped prior to the examiner finishing his computer data recording. Following the baseline 90 seconds of data collection, the participant then carefully stepped off of the treadmill. After this, the research assistants took off the participant's shoes for him or her. They then removed the reflective markers on the 2 tibial tuberosity and 2 ASIS points. Prior to removing those 4 reflective markers, the research assistants made circular pen tracings around the markers on the participant's skin. This was done in an attempt to leave a guide that would aid in placing the markers back as closely as possible where they were for the 90-second postkinematic analysis.

LLI assessment

Leg length inequality assessment can be performed using magnetic resonance imaging, computed tomography, radiographs, or a tape measure or through manual assessment.^{2,8,9,26,31} Manual determination of LLI by chiropractors is commonly performed, but it has not been shown to be as accurate as more expensive imaging methods.^{8,31} When choosing an ideal method of measuring LLI we, similar to field practitioners, had to consider reliability, accuracy, magnification, radiation dose, cost, need for special equipment,

convenience, and the opportunity to image an entire extremity.⁹ In our study design, we opted to utilize a technique that we theorized would be more common among chiropractic general practitioners.³²

Study participants positioned themselves prone on a drop table with their shoes off. During study participant positioning for this LLI test, an effort was made to ensure that the participant's whole body was in a neutral position on the table without spinal or pelvic frontal plane distortion. The treating doctor then held the participant's ankles in a neutral position to prevent foot inversion or eversion. The leg length was visualized by comparing the inferior aspect of both compressed heels exclusively. This was chosen because of research suggesting that this form of LLI measurement demonstrated better interexaminer reliability,³¹ although LLI tests in general are not perfect.^{34–37} If the examining chiropractor found that the participant did have an LLI, he would reach into a box and draw out a random slip of paper that determined whether the participant would be manipulated or not. No attempt to measure an exact LLI distance was made. If hip CMT was in order, the short lower limb PSIS marker was also removed after a pen tracing was made around it on the skin. Following the intervention, or lack thereof, the study participant carefully stood up. The treating chiropractor made no attempt to recheck the LLI manually post-CMT to confirm that a change was induced. Next, the research assistants placed all of the reflective markers back where they were (the 2 tibial tuberosity markers, 2 ASIS markers, and 1 PSIS marker) and put the participant's standardized shoes back on him or her. The reason reflective markers had to be taken off was to prevent physically damaging them because of their delicate composition. After the intervention phase of the study, or lack thereof, the participants walked again for 90 seconds at 1.5 mph for their postkinematic analysis.

Intervention

The intervention phase of the study was performed by a chiropractor with 35 years of experience. The intervention involved either (1) a hypothenar ilium apex push to the PSIS on the short leg side³³ in an attempt to rotate the superior ilium anteriorly to elongate that lower limb or (2) no manipulation. The CMT consisted of a high-velocity, low-amplitude force delivered 3 times in a row over the PSIS using a drop table (Ergostyle 2000; Chattanooga Group Inc, Hixson, TX). The intent of the drop table was to try to keep the amount of force reasonably standardized. The drop table was used 3 times to ensure the joint was mobilized. This prone form of

CMT was selected to decrease the likelihood of making researchers remove more reflective surface markers than the 5 that were absolutely necessary to remove. No attempt to record an audible sound from SI joint CMT was made. One minute after receiving SI joint CMT or no CMT, the study participants engaged in their 90-second walking postkinematic analysis.

Kinematic post-data processing

The data were processed using a customized Matlab script (Mathworks, R2007a, Natick, MA). The kinematic data were analyzed to calculate characteristics of movement for each participant. In the current study, we investigated the changes in the functional active range of motion of the hip angle, knee angle, and ankle angle as a result of the intervention. In addition, the double support time, percentage double support time (duration both feet were on the ground in relation to the gait cycle), stance time, percentage stance time (duration 1 foot was on the ground in relation to the gait cycle), step length, and stride length bilaterally were calculated.

Approximate entropy (ApnEn), a measure of gait variability, was additionally determined for each joint. *Gait variability* is defined as the changes in the gait parameters between multiple cycles. In healthy individuals, there is a certain amount of acceptable variability that represents a normal (healthy) gait pattern. However, highly variable gait patterns are typically indicative of some type of pathology or loss of coordination,³⁸ which may render a person at risk for falling.³⁹ Gait variability has been identified by the application of a mathematical technique called *approximate entropy*. This technique has been shown to be responsive to the subtle changes in the movement pattern that might not be detected by traditional linear techniques. This is due to the fact that nonlinear approaches such as ApnEn use higher dimensional analysis techniques that may reveal small changes in the gait pattern.^{38,40,41}

Data were recorded for a period of 90 seconds, and the initial 10 seconds of the data was truncated to minimize the adaptation effects on their gait as they took their initial few steps on the treadmill. For each participant, the gait test was repeated posttreatment; and a similar data collection protocol was used.

Statistical analysis

Because of this being a pilot study with only a few participants, data were not analyzed using SPSS (Chicago, IL) or a similar statistics software package. Only descriptive statistics have been provided. Mean

values per group for each dependent variable over the 80-second analyzed time window was determined using Excel (Microsoft, Redmond, WA). Results were reported as mean values unless otherwise specified.

Results

Chiropractic manipulative therapy to the SI joint resulted in minimal change in joint angles and other parameters of gait (Tables 2A and 2B). This, however, was a pilot study with only a dozen participants. Three unique trends were noted after our data analysis. The R short leg—manip group increased its step length and stride length by approximately 17 mm (≈ 0.7 in) and 48.5 mm (≈ 2 in), respectively. Additionally, there

were changes in the percentage double support time for the R short leg—manip group of 1% to 2% in both limbs. Lastly, the R short leg—manip group had approximately a 4° decrease in its right hip angle post-SI joint manipulation.

Discussion

The changes in walking kinematics in response to CMT in this pilot study were small. These observations likely were the result of this experiment having a smaller sample size. This study intentionally was a pilot study with a small sample size within each group. Subsequent larger studies should follow a power analysis. Using G*Power version 3.1.3 (Universität

Table 2A Comparison of data collected

	Group 1 pre	Group 1 post	Group 2 pre	Group 2 post	Group 3 pre	Group 3 post
	L short leg—manip	L short leg—manip	L short leg—no manip (control group 1)	L short leg—no manip (control group 1)	R short leg—manip	R short leg—manip
Functional active						
Range of motion (°)						
L hip angle	38.2	37.6	39.2	39.2	42.8	38.9
L knee angle	57.9	58.7	59.1	59.5	62.7	60.6
L ankle angle	29.1	30.5	31.6	30.8	30.6	28.8
R hip angle	39.4	39.1	39.0	39.7	42.2	43.7
R knee angle	62.6	62.9	60.1	60.2	61.2	62.5
R ankle angle °	30.9	31.6	40.4	37.7	29.2	28.4
ApnEn						
L hip angle	0.20	0.17	0.19	0.18	0.21	0.21
L knee angle	0.30	0.25	0.28	0.26	0.25	0.27
L ankle angle	0.47	0.42	0.52	0.53	0.62	0.66
R hip angle	0.20	0.18	0.18	0.19	0.22	0.20
R knee angle	0.31	0.27	0.27	0.26	0.24	0.21
R ankle angle	0.51	0.45	0.52	0.50	0.69	0.67
Double support						
L double support (s)	0.33	0.34	0.33	0.32	0.33	0.33
% L double support	20.26	20.08	20.60	20.20	20.06	19.00
R double support (s)	0.31	0.32	0.33	0.32	0.29	0.33
% R double support	19.09	18.96	20.46	19.75	17.67	19.21
Stance time						
L stance time (s)	1.16	1.17	1.12	1.12	1.15	1.19
% L stance time	70.27	70.15	70.07	69.85	69.25	69.52
R stance time (s)	1.14	1.15	1.13	1.12	1.14	1.18
% R stance time	69.15	68.89	70.91	70.06	68.44	68.74
Step length						
L step length (mm)	445.03	450.70	453.59	460.86	453.75	468.70
R step length (mm)	442.07	448.46	430.23	429.78	439.65	458.96
Stride length						
L stride length (mm)	1132.43	1143.17	1117.74	1120.89	1128.55	1189.85
R stride length (mm)	1156.58	1163.15	1137.20	1131.04	1160.46	1196.12

Data listed as mean.

ApnEn, approximate entropy; L, left; R, right.

Table 2B Continuation of comparison of data collected

	Group 4 pre	Group 4 post	Group 5 pre	Group 5 post
	R short leg—no manip (control group 2)	R short leg—no manip (control group 2)	No short leg (control group 3)	No short leg (control group 3)
Functional active				
Range of motion (°)				
L hip angle	38.7	37.8	41.2	40.0
L knee angle	55.6	56.2	59.0	60.3
L ankle angle	34.7	38.1	32.7	31.8
R hip angle	39.6	39.7	40.9	39.6
R knee angle	58.3	57.4	58.4	58.1
R ankle angle	37.7	38.5	34.5	33.8
ApnEn				
L hip angle	0.21	0.20	0.21	0.23
L knee angle	0.33	0.34	0.31	0.30
L ankle angle	0.50	0.42	0.61	0.59
R hip angle	0.21	0.20	0.21	0.22
R knee angle	0.33	0.30	0.33	0.33
R ankle angle	0.44	0.37	0.64	0.60
Double support				
L double support (s)	0.33	0.34	0.35	0.35
% L double support	21.41	21.58	20.79	20.93
R double support (s)	0.32	0.33	0.34	0.34
% R double support	20.83	21.00	20.67	20.76
Stance time				
L stance time (s)	1.10	1.14	1.18	1.17
% L stance time	71.13	71.60	70.90	71.20
R stance time (s)	1.10	1.13	1.17	1.16
% R stance time	70.92	70.98	70.56	70.45
Step length				
L step length (mm)	434.21	445.10	457.25	457.03
R step length (mm)	440.40	444.33	447.43	438.91
Stride length				
L stride length (mm)	1090.30	1112.61	1157.34	1153.90
R stride length (mm)	1122.52	1147.15	1168.51	1162.37

Data listed as mean.

ApnEn, approximate entropy; L, left; R, right.

Kiel, Germany),^{42,43} we determined post hoc that future studies should have 34 participants per study group (experimental and control). This analysis was in accordance with a desired effect size of 0.25 (moderate), α of .05, and power of 0.8. We do feel that we would be capable of recruiting this number of student participants with future studies even with excluding participants who fail to meet the study inclusion/exclusion criteria. Recruiting outside nonstudent participants (general public) would be possible at our institution, but would require further resources.

Our 8-camera VICON motion analysis system (Oxford, UK) worked consistently in our study. No participants were injured at any point in this study. For safety reasons, following the completion of this experiment, we have installed thin side rails on the treadmill that provide a safety bar participants can grab

onto in case they lose their balance on the treadmill. We additionally recommend that future researchers consider using an overhead safety harness and pulley system as an extra precaution against falling.

Our method of using a blinded biomechanist appeared to be effective in this pilot study. One issue we did have was the transport of the large kinematic data files we were generating (approximately 82 MB per participant). As a result, it took our offsite biomechanist many hours to transfer all of the files from our laboratory computer to his computer for analysis using a trial version of TeamViewer 8 software (TeamViewer Inc, Tampa, FL). For future studies, we will need to purchase a more robust file transfer system to handle transferring large quantities of data.

The results of this study may also have been impacted by the fact that only the short limb side

underwent CMT. It is possible that manipulating the long-leg ischial tuberosity also through a posterior-to-anterior push may have had an additive effect in modifying functional LLI theoretically.⁵ By rotating the long-limb ischial tuberosity anteriorly, it should shorten the long-leg side. This action in addition to posterior-to-anterior CMT to the PSIS on the short leg side should be more effective at improving leg length symmetry than only manipulating 1 side. However, a study with a larger sample size will be needed to clearly determine if this hypothesis is correct. As a result, the subsequent larger follow-up studies after this one will involve corrective CMT to the long-leg ischial tuberosity in addition to the short-leg PSIS.

The experience we gained through this pilot study was invaluable for the generation of subsequent larger studies. If hip CMT improves gait symmetry, that may directly have implications on balance while walking. This may also have an impact on runner performance by reducing wasted energy expended through unnecessary lateral excursion forces to the short limb side due to functional LLI. Further study to determine the true physiological impact of SI joint manipulation on gait is required.

The main intent of this study was to determine if our design would be feasible to engage in a series of larger studies using advanced motion analysis technology. This was shown to be possible. This laboratory now intends to develop the 3 following walking studies involving SI joint and lumbar spine CMT over the course of September 2012 to September 2015 using large study groups: (1) normative data with healthy chiropractic college students, (2) normative data with healthy non-chiropractic student participants (mainstream public), (3) adult low back pain patient data (mainstream public), and (4) geriatric at-risk-for-fall data.

As this field is developed, further additional directions that should be explored would be running kinematic changes in response to hip and/or lumbar spine CMT and changes in gait that may be induced in ataxic special populations. Additionally, surface electromyography should be used to explore if any changes found in gait are induced by alterations in motor recruitment patterns of the lower limb muscles in response to CMT.

Limitations

This study only informs us as to the immediate impact SI joint CMT may have had on gait. It is possible that a CMT dose-response relationship may exist related to improvements in gait performance.

No radiograph or similar imaging lower limb test was used to ensure that participants truly had a func-

tionally short lower limb and not an anatomically short lower limb.^{2,44–48} This point likely is not as relevant considering that raw marginal change in kinematics pre- vs post-SI joint CMT was the major outcome we were interested in observing (eg, can SI joint CMT truly induce a subtle change in gait or not).

One issue this study must accept is the limitation on external validity. The population we sampled was composed of chiropractic students who regularly receive CMT. It is possible that the general public may react differently than individuals who receive CMT often. For example, the general population would be more likely to have joint fixations and thus benefit more from corrective hip CMT.

Lastly, our participants were reasonably healthy. The impact CMT may have had on older patients (eg, geriatric women at risk for falls) with various segmental hip-related joint fixations may have yielded different findings.

Conclusions

There is minimal research into how spinal manipulation may augment gait. The focus of this experiment was to determine if developing a series of larger hip CMT biomechanics studies using motion analysis technology was possible through our study design. The findings of our study suggest that larger studies are feasible, and we will proceed accordingly.

Funding sources and potential conflicts of interest

This study was supported by a grant from Dr SM Elliot, TCC President Emeritus. No conflicts of interest were reported for this study.

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