EDUCATION
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ORIGINAL ARTICLE

Assessment of forces during side-posture adjustment with the use of a table-embedded force plate: Reference values for education

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ABSTRACT

Objective: Force-sensing treatment tables are becoming more commonly used by chiropractic educational institutions. However, when a table-embedded force platform is the sole measurement method, there is little information available about what force-time values instructors and students should expect for side-posture spinal manipulative thrusts. The purpose of this report is to provide force-time values recorded with such a system during side-posture manipulation with human recipients.
Methods: Student volunteers were examined by and received lumbar or pelvic side-posture manipulation from experienced chiropractors who were diplomates of the Gonstead Clinical Studies Society. Forces were recorded using proprietary software of a Bertec force platform; force and time data were analyzed with a custom-programmed software tool in Excel.
Results: Seven doctors of chiropractic performed 24 thrusts on 23 student recipients. Preload forces, averaging 69.7 N, and thrust loading duration, averaging 167 milliseconds, were similar to previous studies of side-posture manipulation. Peak loads were higher than previous studies, averaging 1010.9 N. Other variables included prethrust liftoff force, times from thrust onset to peak force and peak load to resolution of thrust, and average rates of force loading and unloading.
Conclusion: The values we found will be used for reference at our institution and may be useful to instructors at other chiropractic educational institutions, in the teaching of lumbar side-posture manipulation. A caveat is that the values of this study reflect multiple sources of applied force, not solely the force applied directly to the spine.

Key Indexing Terms: Manipulation, Chiropractic; Manipulation, Spinal; Force; Education; Motor Skills; Kinetics

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INTRODUCTION

Students in the doctor of chiropractic program (DCP) at our institution have in recent years experienced some technologic supplements to traditional teaching methods of chiropractic adjustment (or spinal manipulation) involving high velocity low amplitude (HVLA) thrusts. For example, we have implemented the use of mannequins specifically designed to mimic many relevant human characteristics.[1] The mannequins have pressure sensors at 64 important bony landmarks, which provide instant feedback to users about their palpatory locations; however, the pressure sensors are not programmed to quantify force applied during adjustments. For that purpose, we also have a force platform (or force plate) embedded in a treatment table. This system was developed by personnel at our institution and was originally used mainly for research purposes;[2–5] it has recently been installed in a classroom for use as part of our chiropractic technique courses.[1]

Instructors at our institution who use the force plate treatment table have found it convenient, in that adjustive procedures can be performed without special consideration for measurement equipment, aside from the computer and software needed. They also like that forces can be assessed 3-dimensionally (vertically downward, horizontally left-right, and horizontally cephalad-caudad), which is consistent with the way our students are taught. The plate does have a drawback of being an indirect method of force assessment, with a patient and table cushioning between the hand applying the force and the plate receiving it. And, side-posture thrusts typically have multiple points of contact between the practitioner and the patient; in addition to the contact hand, there is thigh-to-thigh contact, and the practitioner's other hand contacts the patient at the shoulder or arm, as well (Fig. 1). The plate may capture forces from these other locations, so there is a

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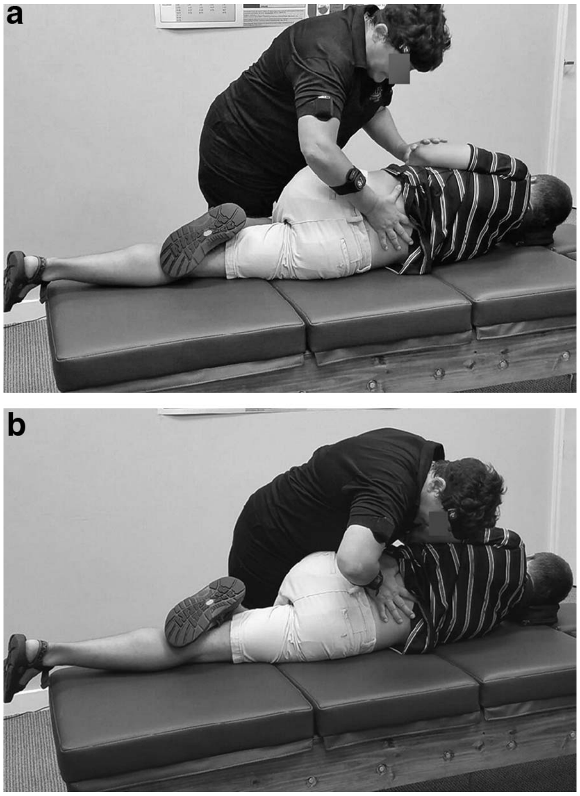


Figure 1 - Side-posture setup (a) and thrust (b), illustrating contacts of the doctor of chiropractic's right hand with the patient's spine, right thigh with the patient's left thigh, and left hand with the patient's upper left arm.

challenge to determine what amount of the measured force can be attributed to the thrust.

To place the role of a force-sensing chiropractic treatment table in the context of chiropractic education, one might consider a statement by Myers, "Competent delivery of [spinal manipulative therapy] requires the practitioner to be adept at modulating peak contact force and rate of force application." Myers commented that there are few opportunities for quantitative feedback.[6] There have been several studies involving force assessment of spinal manipulation with chiropractic students or otherwise in relationship to levels of education and experience. In an early example, Cohen et al[7] compared preload and peak forces of newly trained doctors of chiropractic (DCs) and experienced DCs, for thoracic thrusts to patients lying over a force plate embedded in a treatment table, finding no significant differences between the 2 groups. Descarreaux et al[8] examined repeated thrusts by students and experienced DCs on a mannequin outfitted with a strain gauge for measurement and with a spring to mimic the resistance of a thoracic spine. Some variables improved according to greater experience, including shorter time to peak force, lessened thrust-to-thrust variability, and faster rates of force production. Other studies have also found experience-related improvements in performance as measured by force-sensing systems[4,9–11] and that feedback with such systems contributed to improvement.[12,13] For instance, Snodgrass et al[14] found that physiotherapy students who received force feedback during mobilization were able to apply forces that closely matched those of an expert, more so than students who did not receive feedback.

Only a few studies involving students or comparisons of experience have examined force delivery to the lumbar or pelvic regions during side-posture adjustment. Triano et al[15] used a force plate embedded in a treatment table to compare peak forces delivered by experienced DCs to the forces of 2 groups of students with no previous training. Using a special apparatus to eliminate forces from any source other than the practitioner's thrusting hand, DCs averaged 488 N in peak forces, and students averaged 210 and 321 N (Table 1).[15] Later, Triano et al[16] assessed chiropractic students with no previous training as they learned lumbar side-posture manipulation and concluded that receiving force-time feedback resulted in "immediate and significant improvement in all measured parameters." Osterbauer and Katchmark[17] presented an examination of the effect of force feedback on students' ability to attain peak force and thrust speed targets while performing side-posture thrusts on a mannequin. Although students showed no statistically significant differences from the beginning to the end of a term of instruction, instructors received knowledge useful for refinement of their teaching methods.[17]

The studies by Triano and colleagues used straps and padded supports to prevent contact between the practitioner and recipient at any location other than the site of the

Table 1 - Force and Time Characteristics for Previous Studies of Side-Posture HVLA Thrusts on Humans[a]

	Triano and Schultz[18] 1997[b]	Triano et al[15] 2004[c]	Myers et al[6] 2012	Van Zoest and Gosselin[20] 2003[d]	Gudavalli et al[21] 2013[e]	Gudavalli and Rowell[22] 2014[e]
Preload, N	–	–	–	66, 83	106.3	98.7
Peak load, N	496, 516, 385	488; 210, 321	273–441	237, 241	327.6	340.3
Loading duration, ms	–	–	–	182, 166 ms	261 ms	164 ms
Rate of loading, N/s	2177, 2483, 1807	–	–	–	1077.6	1595

Abbreviation: HVLA, high velocity low amplitude.

[a] Not all studies reported all outcomes.

[b] Triano and Schultz[18]: for *mamillary push*, *hypothenar ischial*, and *long lever lumbar* thrusts, respectively.

[c] Triano et al[15]: experienced DCs; and 2 groups of untrained students, respectively.

[d] Van Zoest and Gosselin[20]: left and right sides, respectively.

[e] Gudavalli also reported unloading durations and unloading rates of 509 milliseconds and 683 N/s[21]; and 746 milliseconds and 523 N/s.[22]

thrusting hand and used an inverse dynamics transformation equation to predict the actual forces imparted to the spine or pelvis.[15,18,19] A different approach was used in a recent study by Myers et al,[6] in which uniaxial load cells were positioned where the practitioner was to place his left hand on the patient's left shoulder and where the practitioner's right thigh was to contact the patient's left thigh; another load cell, placed between the thrusting right hand and the participant's back, recorded forces of the first 5 thrusts applied to each participant; 5 additional thrusts were applied directly without the load cell; and the practitioner delivering the thrusts was outfitted with optical motion capture markers. Their algorithm combined measurements from the load cells and motion capture with the indirect measurements from the force platform.[6] Results from the studies by Triano and by Myers have been summarized in Table 1.

As used by Myers et al,[6] load cells placed between the practitioner's hand and the patient are an alternative method to a force plate. Studies by Van Zoest[20] and Gudavalli[21,22] have used this approach, and a summary of their results may be seen in Table 1. Like a force plate, load cells can measure forces in 3 dimensions, but they are inflexible and have some bulk, so there is less natural hand contact with the patient. Thin, flexible pressure pads also exist and have the advantage of less interference with contact of the patient, though their measurement is unidimensional; they have been used to measure thrust forces in several studies of manipulation,[23–30] though apparently not with side-posture HVLA.

The methods described in the studies by Triano and colleagues[15,18,19] and Myers et al[6] are not feasible for routine classroom use, and the 3D load cells used by Van Zoest and Gosselin[20] and Gudavalli[21,22] have a drawback of putting an object between the hand and the spine, which may not feel natural, especially to student chiropractors. Meanwhile, other chiropractic colleges also have treatment tables with embedded force platforms, most using the Force Sensing Table Technology system developed at Canadian Memorial Chiropractic College.[31] Instructors need technique-specific force targets for students to train toward. The purpose of the present report is to describe our assessments and present our findings of forces produced by side-posture thrusts delivered to human patients, as measured solely by the use of a table-embedded force plate. The results of this study will be useful to instructors at our university in chiropractic technique lab settings with mannequins and human patients and may inform others with similar equipment and educational needs.

METHODS

The force target values presented below have been derived from 2 related projects in which all doctors performing adjustments were diplomates of the Gonstead Clinical Studies Society. They were a relatively homogenous convenience sample of chiropractors who all have similar training and are certified as meeting a high standard. The characteristics of thrusts provided by experts in the Gonstead technique[32] have high relevance for our students and faculty members—our school teaches the Gonstead technique in the core curriculum, in addition to diversified technique,[33] and there is an active student Gonstead club.

Participants

In session 1, several DCs visited our campus for a symposium. Participants in the role of patients were all students enrolled in the DCP at the university, who had registered for the symposium and requested evaluation and care by the teaching chiropractors; the adjustments would have been performed independently of the investigation. Session 2 was planned specifically for investigational purposes, and all adjustments were provided by a single DC who was also a DCP faculty instructor and a project investigator. Session 2 students were invited by email—each had completed some technique classes in the DCP and had previously received adjustments from the treating DC or another faculty instructor. For both sessions, inclusion required that each student had an established patient file, previous experience with chiropractic adjustments, recent radiographs of the areas to be adjusted, and no known contraindications to receiving HVLA chiropractic care. Student volunteers were enrolled as participants only after examination by a participating doctor and a determination that side-posture adjustments of the lumbar region or pelvis were appropriate.

Procedures

The investigations of both sessions were approved by the Life University institutional review board. There was no funding specific to the study. Procedures were explained to all participants and signed consent was obtained. Investigators assigned randomized study ID numbers and recorded demographic information.

All adjustments were performed on a pelvic bench treatment table, as described above and in previous investigations,[2–4] with an embedded force plate (Bertec model FP4550-08, Bertec Corp, Columbus, OH, USA) positioned for lumbar or pelvic force assessment.

Our interest was limited to "push" type thrusts delivered through the doctor's pisiform or hypothenar eminence. In session 1, these could be to either side of the lumbar spine or pelvis; the DCs determined the details of site, thrust application, and patient positioning. In session 2, all thrusts were to be of the lumbar region, with patients positioned such that the DC could perform thrusts with the right hand. That constraint was related to use of an inertial measurement unit system for tracking the doctor's posture and movement patterns; those findings have been reported separately.[34]

Session 1 included an experimental procedure in which DCs wore a glove with an embedded thin flexible pressure-sensing pad (Tekscan model No. A401, Tekscan, Boston, MA, USA) placed between the doctor's hand and the patient. The pressure pad was intended to differentiate forces applied directly by the DC's hand from the indirect forces from multiple points of contact with the patient. However, the sensor proved to be too small, was difficult

Table 2 - Thrust Variables Defined

Variable	Unit	Description
Preload magnitude	N	Average magnitude of resultant force during first 20 ms of preload
Liftoff	N	Preload magnitude minus dip (valley) load
Thrust duration	seconds	Time from onset to peak of thrust
Average loading rate	N/ms	Average slope (dF/dT) over the middle third of the thrust
Peak magnitude	N	Maximum load
Unload duration	seconds	Time from peak to end time
Average unloading rate	N/ms	Average slope (dF/dT) over the middle third of the unloading

for the DCs to position precisely, and was prone to malposition problems owing to shearing. We have not included any data below and did not use the glove in session 2.

Data Reduction and Analysis

The investigators used the force plate manufacturer's proprietary software (Bertec Acquire, Bertec) to record data and export as Excel .csv files (Excel, Microsoft Corp, Redmond, WA, USA). Sampling is fixed at 1000 Hz, with a built-in anti-aliasing filter of 500 Hz; no additional filtering was added. A custom-programmed software tool, developed by 2 of the investigators using Excel, was used to extract time and force information for characteristic features.

We calculated the resultant force from the x, y, and z components of the 3D data and determined force and time values for the events of preload onset, thrust onset, peak load, and end of thrust; algorithms in the software tool could auto-detect many of these points but allowed for manual selection when force-time profiles were unusual. We then calculated the following thrust parameters: magnitude of preload force, prethrust liftoff force (a brief force decrease, or "valley" or "dip"), time from thrust onset to peak force, average rate of loading of force (linear regression analysis of the middle one-third of thrust), magnitude of peak load of the thrust, time from peak load to resolution of thrust, and average rate of unloading of force (linear regression analysis of the middle one-third of the thrust resolution phase); see Table 2 and Figure 2.

RESULTS

In session 1, 6 DCs performed 13 side-posture thrusts on 13 student recipients; 2 thrusts were delivered to L3, 6 thrusts to L5, 4 thrusts to either the left or right ilium (innominate), and 1 thrust to the sacral base. In session 2, the single DC performed 11 thrusts on 10 student recipients (1 thrust was repeated with mutual agreement of DC and patient); all thrusts were delivered to the L3, L4, or L5 levels, though the exact levels were not recorded.

Doctor of chiropractic participants had a mean (SD) age of 48.3 (8.7) years, height of 1.8 (0.1) m, and weight of 92.3 (10.3) kg; 6 were male, 1 was female, and they had been in practice a mean of 21.7 (10.0) years. Student participants had a mean age of 26.6 years (6.7) years, height of 1.7 m (8.7), and weight of 74.3 kg (13.9). There was no difference in age or weight between the 12 male and 11 female students (age: 26.7 vs 26.3 years, $p = .82$; weight: 77.3 vs 71.7 kg, $p = .28$), though the males were taller (height: 1.8 vs 1.6 m; $p < .001$).

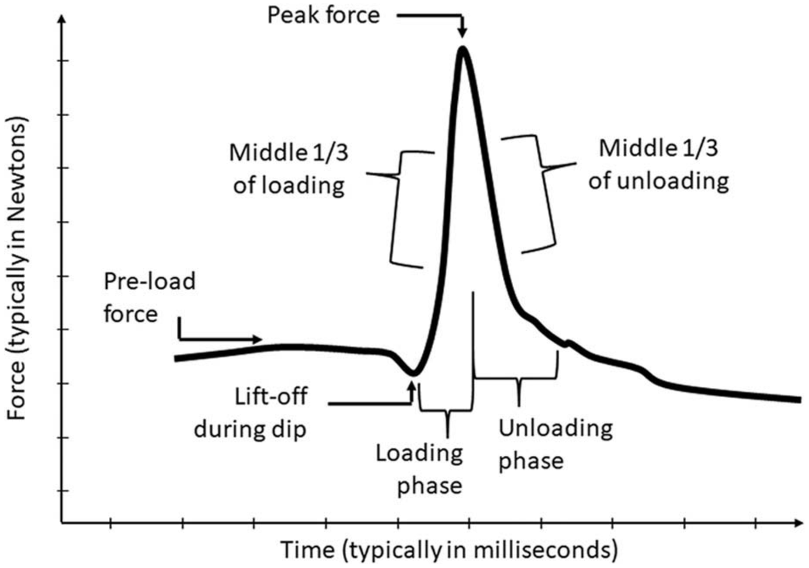


Figure 2 - Typical high velocity low amplitude (HVLA) thrust characteristics.

Table 3 - Force and Time Characteristics for the Present Study

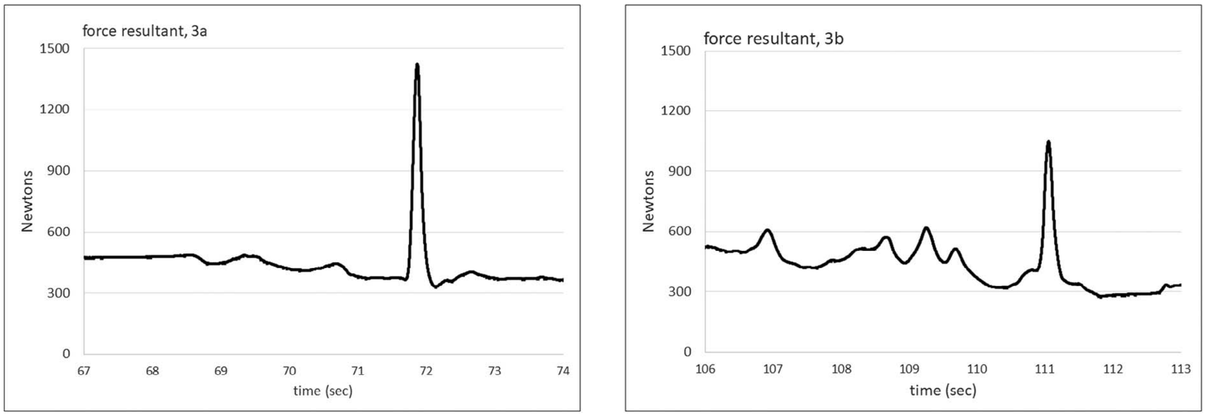
	Mean (SD)	Min–Max
Preload, N	69.7 (55.5)	11.2 to 203.8
Prethrust liftoff, N	14.8 (16.7)	0.5 to 58.9
Peak load, N	1010.9 (102.2)	846.2 to 1208.1
Thrust loading duration, ms	167 (25)	106 to 228
Mean rate of thrust loading, N/ms	8.2 (2.5)[a]	4.1 to 16.4[a]
Thrust unloading duration, ms	274 (75)	149 to 456
Mean rate of thrust unloading, N/ms	−3.5 (2.5)[a]	−0.5 to −8.8[a]

[a] If the mean rates are to be compared with those reported by Gudavalli et al[21] and Gudavalli and Rowell,[22] the equivalents would be 8200 N/s for thrust loading and −3500 N/s for unloading.

The force and time characteristics for the present study may be seen in Table 3. On average, the DCs applied a mean of 69.7 Newtons (N) of preload force during a setup phase, then lifted off by 14.8 N during a prethrust dip in force, before thrusting with a peak of 1010.9 N. The mean time required to move from the onset of the thrust to the peak was 167 milliseconds (ms), such that the load increased by 8.2 N per millisecond. Once the peak was reached, the force was unloaded over a 274-millisecond timespan, at a slower rate than it had been applied (3.5 N/ms.)

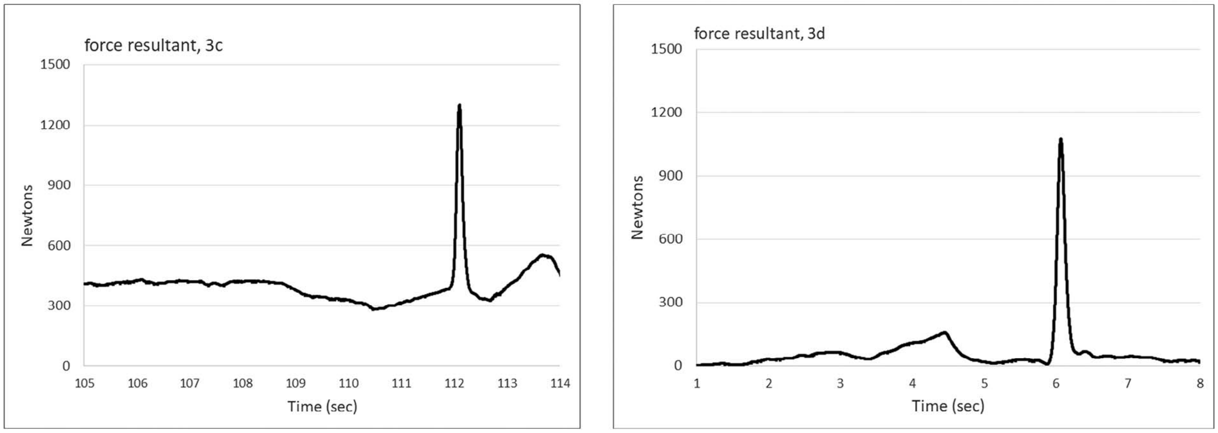
Figures 3a–3c depict 7-second periods of hand position refinement: preload, thrust, and immediate postthrust for recordings of 3 different DCs from session 1; Figure 3d depicts 1 thrust by the DC in session 2. Each graph covers approximately 5 seconds before the thrust and 2 seconds afterward; all 4 thrusts were directed at a lower lumbar vertebra. Small vertical oscillations represent prethrust hand positioning; thrust events are easily identifiable by the large upward deflections.

We used 2 different calibration methods. For session 2, the force plate was "zeroed" with the patient already on the table and the doctor's hand lightly touching the patient's back; the recordings and graphs represented only forces greater than that baseline level. However, in session 1, the force plate had been zeroed without the patient on the table, and the force recordings and graphs included a percentage of the patient's body weight corresponding to the pelvis and lumbar region lying over the force plate.



Calculated pre-load: 50.3 N, pre-thrust dip: 37.9 N, peak load: 1098.9 N

Calculated pre-load : 198.3 N, pre-thrust dip: 196.6 N, peak load: 846.2 N



Calculated pre-load: 107.8 N, pre-thrust dip: 107.3 N, peak load: 1043.5 N

Pre-load: 30.9 N, pre-thrust dip: 8.5 N, peak load: 1076.9 N

Figure 3 - 3a through 3c depict 7-second periods of setup refinement, preload, thrust, and immediate postthrust for recordings of 3 different doctors of chiropractic from session 1; the y-axis values include patient body weight. Figure 3d depicts 1 thrust by the doctor of chiropractic in session 2; the patient was already on the table when the force plate was calibrated.

Figure 4 - Demonstration of side-posture thrust as performed on the simple mannequin used in an earlier study (Owens et al[2]).

Body weights were subtracted in calculations, and the between-sessions differences have been accounted for in the results.

DISCUSSION

The force and time characteristics of the present study will enable students and faculty members to see whether their force delivery is far above or below those of a group of experts, even if they would not know exactly how much of the force is being imparted to the spine. Our instructors and students have access to our force plate and our mannequins during technique instruction and do not currently have access to another method of assessing forces (although our research group has a flexible pressure pad device in development.)

The preload values in the present study reflect contact by the doctor's thrusting hand only and are similar to the studies of Van Zoest[20] and Gudavalli.[21,22] The peak loads are large in comparison with all previous side-posture studies,[6,15,18,20–22] which should be expected—as discussed above, our peak loads likely include contributions by multiple points of contact—and thrust loading and unloading rates are similarly affected. In fact, judging by video recordings of the adjustments of the present study, in some cases the DC's upper torso may have come into contact with the patient during the thrust, which would also contribute to the recorded force. Thrust loading durations, averaging 167 milliseconds, were similar to those reported by Van Zoest[20] (182 and 166 milliseconds) and by Gudavalli and Rowell[22] in 2014 (164 milliseconds), but substantially shorter than reported by Gudavalli et al[21] in 2013 (261 milliseconds).

To try to get a sense of how much force might be imparted through shoulder and thigh contacts, 2 of the current authors informally recorded force measurements while performing side-posture thrusts on a mannequin: 5 customary thrusts (hand contacts on the spine, shoulder, and thigh), 5 shoulder-only contacts, and 5 thigh-only contacts. Our estimates suggest that contact at the shoulder might contribute only 3% to 15% of the total recorded force, but thigh contact could contribute as much as 60%. In comparison, for the more carefully calculated force values reported by Myers et al,[6] shoulder contacts appear to be in the range of 13% to 24% of the force recorded by the force plate, and thigh contact appears to be in the range of 19% to 31%.

Should forces recorded by a force plate be expected to have a valid relationship to the force applied to the patient, given that there is a patient and table upholstery between the hand applying the force and the plate receiving it? There is some disagreement. In a study of prone thoracic adjustment, Kirstukas and Backman[26] found the resultant forces measured by load cells mounted in a treatment table to have good peak load agreement with a flexible pressure sensor pad placed under the hands of 2 DCs. However, Mikhail et al[35] found that the forces measured by a Force Sensing Table Technology system,[31] for adults lying prone, were usually *greater* than the forces imparted to the T7 vertebrae by a servo-controlled linear actuator motor; the authors were unable to fully explain the seemingly counterintuitive finding.

That the DCs included in this study were all certified in the Gonstead technique is important as they have all been trained and tested to a common established standard, and their peak force and speed characteristics are similar. In contrast, a previous study from our center[2] featured experienced faculty DCs employing a mix of Gonstead and diversified style side-posture thrusts on a simple mannequin made from a plastic spine and pelvis model, enclosed within high-density foam padding cut roughly like a human torso (Fig. 4). Peak forces averaged between 350 and 580 N for thrusts intentionally delivered as either *light*, *normal*, or *heavy*.[2] They produced a wide range of peak loads: *normal* thrusts ranged from 175 to 885 N and *heavy* thrusts ranged from 244 to 1157 N, such that, for each category, the maximum force produced was approximately 5 times the minimum force. Loading rates ranged from 0.6 to 8.1 N/s for *normal* thrusts (maximum more than 13 times the minimum) and 1.3 to 10.5 N/s for *heavy* thrusts (maximum about 8 times the minimum).[2] The group of Gonstead practitioners in the present report was much more consistent, with the maximum peak force only 43% higher than the minimum. They delivered uniformly higher forces, averaging over 1000 N, with a small SD of 102 N. Similarly, their rates of force application were high and also more consistent than the results of the earlier study. However, some caution might be taken in comparison of the values of the present study (derived from human patients) with those of the earlier study (thrusts applied to a simple mannequin). And it is not known to what degree Gonstead-style side-posture thrusts might be different from other methods of side-posture thrusts. Finally, differences between individual DCs might also reflect personal and patient body morphology, patient presentations, perception of how force delivery produces the desired results, or even which educational institution or postgraduate seminars they have attended.

In our technique lab, when students perform thrusts on a mannequin, the instructors are able to project real-time graphs from the Bertec force plate's proprietary software to a classroom smartboard. They and the students currently use the visual feedback to make qualitative judgments of direction of force application (vector components in 3 dimensions), force level (height of the peak, as in Fig. 2), and thrust rate (slope of the line during loading phase, as in Fig. 2). Instructors have said that the visual feedback enhances students' abilities to make improvements. An effort is ongoing to advance faculty members' overall understanding of force-time characteristics, and the use of the system with side-posture thrusts will be enhanced with the values of this study. Unfortunately, the graphs they currently use are transient, unless a screenshot is made, and they do not have a way to obtain precise values or to quantitatively compare multiple thrusts. Efforts are underway to train faculty instructors on an app, written in Excel by 1 of the authors of the present study, that can report forces of preload, liftoff, and peak of thrust, as well as thrust duration of the loading phase, and thrust rate (Fig. 2) for up to 6 thrusts. Thus, our instructors will be able to capture, quantitatively analyze, and compare characteristics for multiple thrusts and display them together.

Future research will include our force plate but also an improved method of direct measurement with flexible pressure sensors. We aim to build a database of kinetic and kinematic characteristics of experienced DCs for educational comparisons.

A limitation of this study is that the force values stated above may not be directly applicable to other settings. They may be affected by the design of the table holding the force plate and the technical approach of the practitioners delivering the thrusts. A table with a force plate mounted in a different location or thrusts delivered by a substantially different method might yield dissimilar values. In addition, upholstery that is very soft or very hard may affect measured values.[36] Mikhail et al[35] additionally noted that individual instances of force measurement at the patient-table interface may be affected by factors such as the age, body mass index, overall morphology, and the degree of muscle activation at the time of thrust of the person receiving the thrust.

CONCLUSION

Our study of lumbar and pelvic HVLA side-posture thrusts found a range of 846 to 1208 N using a single force plate for assessment. These values reflect multiple sources of force applied to a patient, not the force applied directly to the spine. The methods and force levels described in this study will be useful to instructors at our institution, and perhaps to other chiropractic educators, in the teaching of lumbar side-posture adjustment or manipulation. Considerations need to be made for characteristics of other settings and how measured values may be affected.

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