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The frictional properties at the thoracic skin–fascia interface: implications in spine manipulation

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Abstract

Objective. To assess the friction at the thoracic skin–fascia interface to determine the potential reaction force vectors during thoracic manual therapy.

Design. A basic in vivo study of human subjects, documenting the frictional properties at the interface between the thoracic skin and underlying fascia.

Background. Chiropractors, and other spine manipulative therapists, during thoracic manipulation have been attempting to apply force vectors to spine tissues in specific directions in addition to those applied normal to the skin. For obliquely applied forces to be directly transmitted to the underlying vertebrae, either friction is required at the skin–fascia interface or the applied force must "hook" on a bony process.

Methods. Subjects were placed in the prone position with the thoracic skin exposed. The posterior thoracic region was loaded with normal forces, incrementally from 125.3 to 392.9 N. The interface between the load and the skin was either a plexiglass plate or modelled hands. A force was then applied to either apparatus in the cephalad direction. The applied forces and corresponding displacements were measured using a load cell and an optoelectronic camera system, respectively. Chiropractors then performed actual thoracic manipulation to determine if they could maintain their location of contacts (spinous process/transverse process) on the underlying vertebra.

Results. Each of the subjects exhibited negligible friction between the thoracic skin and underlying fascia for both the plexiglass and modelled hand contacts. Furthermore, in each case, the apparatus travelled a distance greater than that between two transverse or spinous processes without showing an abrupt change in the slope of the force–displacement curves. The hands of chiropractors performing thoracic manipulation travelled a similar distance during the dynamic thrust.

Conclusions. The skin–fascia interface over the thoracic spine exhibits negligible friction. Therefore, the reaction force from a thoracic vertebra will be normal to the overlying skin. Furthermore, the data show that the ability to "hook" either a thoracic transverse or spinous process in the superior–inferior direction during a manipulative thrust may be greatly over-rated.

Relevance

During thoracic spinal manipulation, one cannot direct a force vector to a thoracic vertebra at a given angle by simply directing their thrust in that direction.

Keywords: Friction; Manipulation; Thoracic spine

1. Introduction

One of the basic assumptions of spinal manual therapy is that one can impart motion to a vertebra in a variety of directions. For example even as far back as the origins of chiropractic, students of spinal manipulation were instructed to apply a "thrust" in a direction to correct a "vertebral malposition". The "thrust" may be defined as the delivery of applied force to the vertebra. Although the concept of malposition is not given much credence anymore, the idea of correcting "abnormal" vertebral motion continues to be a common

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premise among spinal manipulators. A recently published text states that during thoracic spine manipulation, "the doctor commonly establishes contacts against the spinous process (SP) or transverse process (TP) of the superior vertebra and directs the adjustive vector anteriorly and superiorly to induce separation of the joint below the contact" [1]. A similar text emphasizes that during lower thoracic manipulation the student "thrust from inferior to superior" [2]. Finally, it has also been emphasized that it is important to thrust in a direction that is consistent with facet orientation to avoid imbricating these joint structures [3]. The common assumption of these stated opinions is that there is sufficient friction between the skin and the underlying vertebra to transmit non-normal forces. The purpose of this study was to determine the frictional properties that exist between the skin and underlying tissue interface, together with the ability to "hook" on a bony process.

Friction is a force acting parallel to the interface of two surfaces that are in contact during motion or impending motion of one surface moving over another. When friction exists between two surfaces, the magnitude of the frictional force (R_S) is directly proportional to the normal force (R_N) through the relationship $R_S = \mu R_N$, where μ is the friction coefficient. In Fig. 1 (top), when friction is present, the forces R_S and R_N are added generating a resultant force which will be capable of generating an equal and opposite reaction force by the underlying vertebra. However, the corollary of this argument, when friction is made negligible (Fig. 1, middle), the R_N component will be transmitted through the interface at that level to the underlying vertebra while the R_S component will not. Thus, the principle that we will use to determine if the aforementioned interface is frictionless is to incrementally increase R_N and then determine if the force required to shear the skin (R_S) along the fascia is related to R_N. Should friction exist between these surfaces, a direct relationship between R_N and R_S will emerge. In contrast, negligible friction will show R_S to be independent of R_N.

Should it be determined that this interface is frictionless, another possibility for the clinician to apply oblique forces to vertebrae is to "hook" on a spinous or transverse process (Fig. 1, bottom). This would require soft tissue under that hand to compress such that the shear component of the applied force would contact the bony surface. The question remains as to the existence of such a mechanism.

It is hypothesized that the skin–fascia interface is frictionless. If this is true, the clinical implication is that non-normal applied force components are ineffective at generating a shear force directly to the underlying vertebra. Furthermore, it is also hypothesized that a clinician's hand cannot "hook" on a bony vertebral prominence to apply an oblique force.

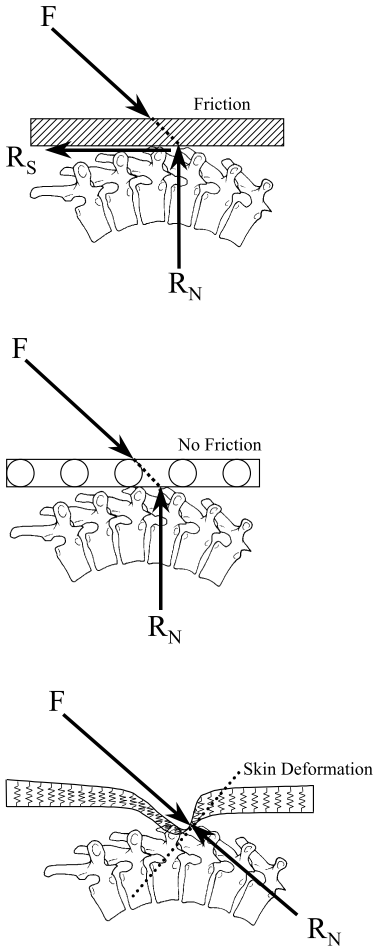

Fig. 1. The skin–fascia interface assuming friction is present (left) and friction is absent (middle). F represents applied force and R_S and R_N represent shear and normal reaction forces, respectively. The concept of "hooking" a bony prominence is represented by the diagram on the right. The dotted line represents the tangent to the contact surface.

2. Methods

2.1. Data collection

Three male subjects were chosen to represent each of the body types (ectomorph, mesomorph and endomorph). Each subject lay prone on a table with their thoracic skin exposed. A clear plexiglass plate ($40 \times 40 \times 1$ cm^3), instrumented with a load cell, was placed over the thoracic skin at the apex of the kyphosis. The cross-member was placed on top of this plate to apply varying normal loads to the torso. An infrared emitting diode (IRED) was placed on top of this cross-member acting as a marker for the high resolution displacement tracking system (Optotrak, Northern Digital, Waterloo, Canada) to measure displacement in all three axes (Fig. 2). The reference axis system was oriented with the x axis in the superior–inferior direction, y in the anterior–posterior direction and z in the medial–lateral direction. A force was applied through the load cell in the

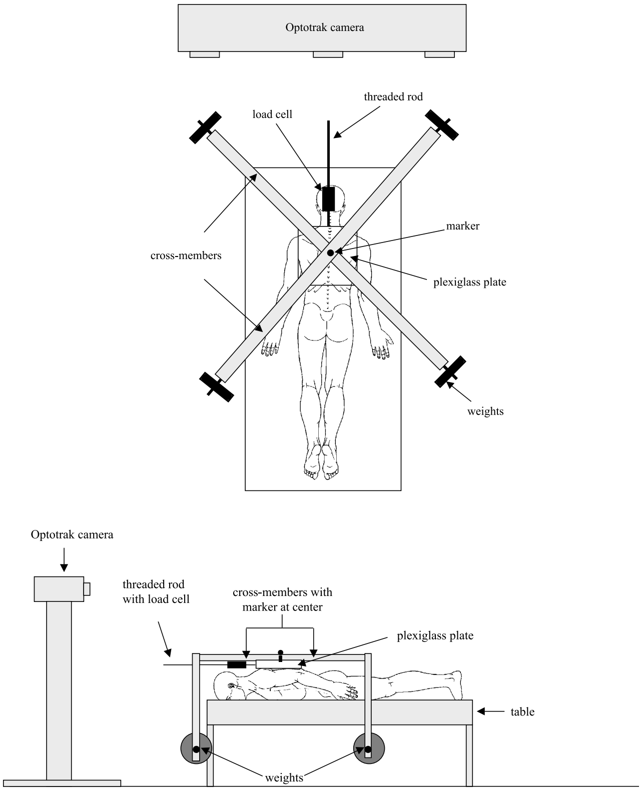

Fig. 2. Experimental setup.

cephalad direction causing the skin to slide over the underlying fascia. Since the apparatus (load cell, plate, cross-member and weights) had considerable mass, care was taken to minimize accelerations and thus inertial forces. Force and displacement data were collected and A/D converted at a sample rate of 64 Hz. The normal loads applied through the plate were 125.3, 147.6, 174.4, 214.5, 263.6, 303.7 and 392.9 N for subject #2. Subjects #1 and #3 went to a maximum of 303.7 N. The maximum value was chosen based on previous force measurements of 400 N during in vivo thoracic spinal manipulation [4,5]. This procedure was done purely to measure the frictional properties at the thoracic–fascia interface.

During manipulation, manipulative therapists claim to hook bony prominences of the vertebra. To determine if it was possible to hook onto a TP or SP, the aforementioned protocol was repeated using two sets of modelled hands of a chiropractor in place of the plate. The "carver bridge" and "knife edge" hands allegedly hook the TP and SP, respectively. The same normal loads were used for subject #2 for both modelled hands as described above. Subjects #1 and #3 both reached 214.5 and 303.7 N, respectively, for the "carver bridge" hands. Subjects #1 and #3, for the "knife edge" hands, both reached 174.4 and 214.5 N, respectively. In an attempt to monitor the skin displacement and thus load distribution within that tissue on each subject, 10 IREDs were placed over various regions (Fig. 3) on the thoracic skin. Lastly, displacement force data were collected using a surface known to exhibit friction (sandpaper, 320 grit Silicone carbide) for comparison to the biological skin–fascia interface. The normal loads used in this case were 25, 125.3, 147.6, 174.4, 214.5, 263.6, 303.7, 392.9, 482.1 N.

Construction of the loading apparatus (Fig. 2) required the threading of a 4 cm stud into one end of the load cell for its attachment to either the plexiglass plate or modelled hands. Threaded into the other end of the load cell was a 60 cm rod so that a pulling force could be applied to the transducer without the experimenter contacting the subject's back. The presence of this rod also eliminated the possibility of the experimenter covering displacement sensors seen by the optotrak tower housing three infrared cameras. The loading apparatus was constructed from two 2″ × 4″ wooden planks, 180 cm in length, attached at their centres to form a cross which was centred over either the plexiglass plate or modelled hands. The angle between these two planks was made adjustable. Attached at right angles to all four ends of this cross were 2″ × 4″ wooden members, 90 cm in length so that the applied weights were below the subject. In this way, the applied loads had a low centre of mass thus creating stability (Fig. 2).

The modelled chiropractor's hands were made from plaster impressions (biofoam) where the real clinician's hands were placed in the position required of a "carver bridge". This negative impression was filled with dental plaster and allowed to set. This resulting positive impression was then cleaned and attached to a wooded base that could be attached to the force transducer apparatus. This procedure was then repeated for the "knife edge" hand position. However, in the interest of comfort, these "knife edge" hands were covered with a simulated skin (thin foam).

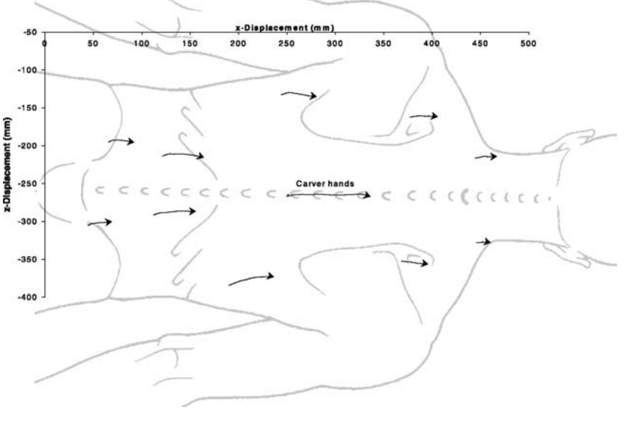

Fig. 3. Displacement (x, z) of skin markers using "carver bridge" hands in subject 3 (ectomorph).

To address the possible criticism that real "chiropractic hands" during actual thoracic manipulation were not used in this study, nine chiropractic faculty of the Canadian Memorial Chiropractic College with not less than 5 years of experience were instructed to thrust on one subject at the thoracic vertebra of their choice on a TP and then SP using the "carver bridge" and "knife edge" hand contact manipulative procedures, respectively. The goal of this exercise was to determine if the TP or SP contact could be maintained during the thrust. Five male subjects were used in this portion of the study. The chiropractors were instructed to direct their thrusts in the anterior-cephalad direction, as is standard protocol for these manipulative procedures, however, without taking a pre-manipulative pre-load in the cephalad direction (skin slack). Each chiropractor thrusts three times per contact. Each thrust was video taped and the resultant clips converted to digital format. The displacement of the chiropractors adjusting hand was measured by digitizing the hand displacement and converting to millimetres by using a calibration object in the field of view.

2.2. Data analysis

Since the purpose of this study was to determine the frictional properties between the skin and underlying thoracic fascia and vertebral processes among the three body types, a case study approach was required rather than collapsing the data from all subjects. To determine the frictional properties at the thoracic skin–fascia interface, x-displacement data were plotted against applied load data. To measure skin displacement, x-displacement data were plotted against z-displacement data.

3. Results

The applied force/displacement data demonstrate firstly, as one would expect with an interface that exhibits friction (sandpaper), that frictional force was directly proportional to normal force (inset Fig. 4). In contrast, this relationship was absent for all subjects when the skin–fascia interface was used for the same applied normal loads (Figs. 4–6). That is, as the normal loads were incrementally increased, the x-displacement–force relationship remained the same producing overlapping curves. Furthermore, the sandpaper surface demonstrated that no motion occurred until static friction was overcome. The static friction coefficient (μ) of this interface was calculated to be 0.893. In contrast, for the skin–fascia interface of all trials, there was immediate x-displacement with the onset of the applied pulling force. Therefore it appears that friction is negligible at this interface.

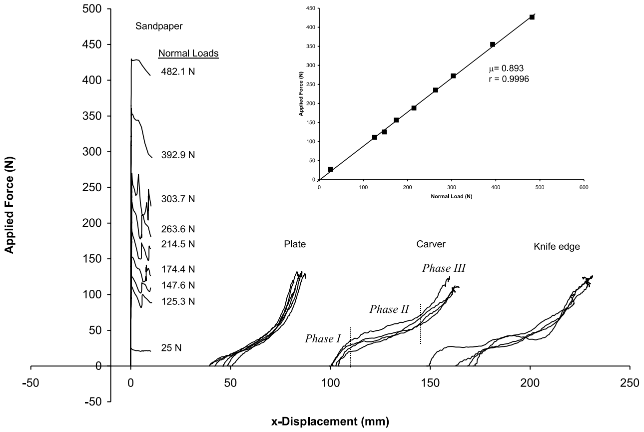

Fig. 4. x-displacement–force for sandpaper, plate, "carver bridge" and "knife edge" hands in subject 1 (mesomorph). Positive translation is in the cephalad direction. Inset shows relationship between applied and normal load for sandpaper where μ = static frictional coefficient and r = correlation coefficient.

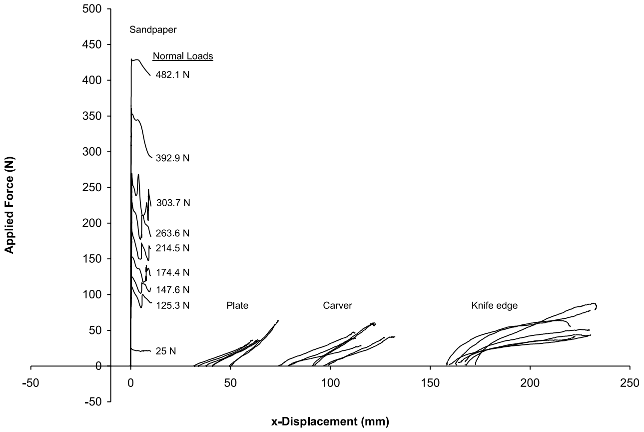

Fig. 5. x-displacement–force for sandpaper, plate, "carver bridge" and "knife edge" hands in subject 2 (endomorph). Positive translation is in the cephalad direction.

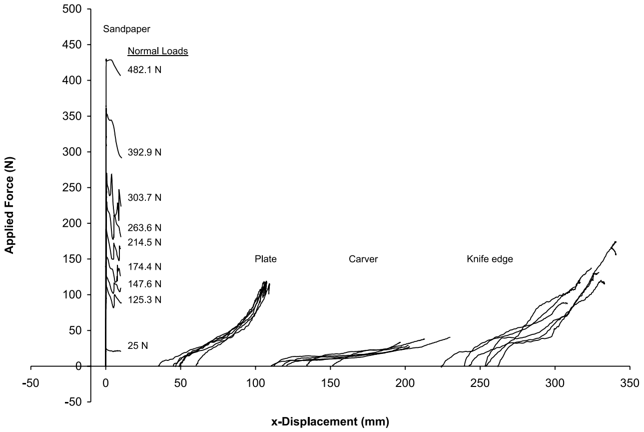

Fig. 6. x-displacement–force for sandpaper, plate, "carver bridge" and "knife edge" hands in subject 3 (ectomorph). Positive translation is in the cephalad direction.

In subjects #1 and #3, the curves for the "plate" displayed three regions (Fig. 4). The first region (phase I) is convex to the left. The second region (phase II) is linear and the last region (phase III) is concave to the left. Phase III was absent in subject #2. This is likely a result of insufficient skin displacement. In subjects #1, #2 and #3, the total mean x-displacement for the plate was 40.7 mm (SD 4.72), 26.26 mm (SD 3.00) and 60.95 mm (SD 6.32), respectively. On the contrary to what would be expected if hand contacts were hooking onto a TP or an SP, all curves for the "carver bridge" and "knife edge" modelled hands were smooth sloping despite travelling the aforementioned distances. Those distances would have ensured the travel over at least one SP or TP for subjects #1 and #3. Although subject #2 only traversed an average distance of 26.26 mm in any one trial, the total range covered over all trials was approximately 55 mm in which at least one SP or TP would have been encountered.

For the "carver bridge" hands, phases I and II were observed in all three subjects. However, phase III was only apparent in subject #1. Furthermore, it is of interest to note, in subject #3, that despite comparable x-displacements to the plate data, less than half of the force was required.

The "knife edge" hands showed phase I behaviour in all three subjects. Phase II behaviour was generally linear in subject #2 but was irregular in subjects #1 and #3. The "knife edge" hand contact generated substantial pressure, especially when using the greater normal loads. This was reported by subjects #1 and #3 as being quite painful. This may have been a contributing factor to the erratic movement of the torso observed in these two subjects as compared to the smooth movement as observed in subject #2. Phase III was difficult to distinguish in subjects #1 and #3 and was clearly absent in subject #2.

Our intent was to minimize the y and z displacements during this study. This was accomplished by choosing a relatively flat portion of the thoracic spine and minimizing the medial–lateral motion of the apparatus, respectively. A substantial y displacement would have meant that gravitation force would assist horizontal translation of either the plate or modelled hands. However, y displacement figures were insubstantial in that the maximum values for subjects #1, #2 and #3 were 6.77, 1.01 and 4.63 mm, respectively. The same was true of the z-displacement figures with maximum values for subjects #1, #2 and #3 of 4.17, 4.42 and 8.31 mm, respectively, indicating little medial–lateral motion.

Skin displacement monitored by 10 markers (x and z displacement) is illustrated in Fig. 3. It is evident that the skin was displaced with the greatest movement taking place near the modelled hands. The markers inferior to the hands exhibited greater displacement than the superior placed markers. The data shown in this figure were for the ectomorph using the "carver bridge" hands under a normal load of 174.4 N. Similar results were noted for other normal loads with both types of modelled hands in all three subjects.

When real "chiropractic hands" attempting to contact the TP were employed during actual thoracic manipulation, the average x-displacement was 38.75 mm (SD 12.3). When the chiropractors performed thoracic manipulation attempting to hook onto the SP, the average x-displacement was 33.25 mm (SD 8.5). The x-displacement range for the TP and SP contacts were 12.5–70.0 mm and 15.0–45.5 mm, respectively, clearly demonstrating that their hand passed over bony contacts failing to make a "hook".

4. Discussion

It appears that the skin–fascia interface over the thoracic spine exhibits negligible friction for all three body types. This is supported by the fact that the force required to cause a translation of the apparatus on the thoracic skin remained constant despite increases in the normal load and occurred the instant the pulling force was applied. In addition, there was no evidence for "hooking" on an SP or TP. These findings imply that when a clinician makes contact with the skin of the thoracic region of the body, the force crossing this thoracic skin–fascia interface would be dominated by normal force components, while the shear forces would be transmitted to the surrounding skin. Manipulative therapists may feel that friction is present when all skin slack has been removed. However, our data suggest that this perception is simply unyielding taut skin masquerading as friction between the skin and underlying vertebra.

A basic premise of health practitioners who practice soft tissue massage, joint mobilization and manipulation is that one alters the direction of the forces applied to provide the best possible therapeutic effect and hence alleviate the patient symptoms. In soft tissue massage, for example, the practitioner will, in some instances, determine the direction of muscle fibres and then apply a stripping type motion to stretch the origin of that muscle away from its insertion. In joint mobilization/manipulation procedures, the practitioner will commonly determine the direction of restriction of a bony segment, and then apply a force in a direction that will restore that motion. In the case of spinal manipulation, it is common to apply the force in a direction that is parallel to the zygapophyseal joint facings to avoid imbricating the cartilagenous surfaces. Although the intent of these procedures seems rational, the findings of this study indicate that they cannot be accomplished due to the frictionless nature of the skin–fascia interface. But the possibility remains that clinicians could "hook" onto a bony prominence and direct oblique forces. Specifically, one could argue that, since the force that crosses the interface is perpendicular to the surface, applying a force perpendicular to a curved component of a bony landmark may permit some control in altering the direction of the force acting on that bony element. In fact this has been the assumption in clinical teaching of manipulative techniques. The spinous and transverse processes of the thoracic vertebra are two such components. However in this study when contacts were made by the modelled hands on these two landmarks, no increase in force was observed. If these hands had hooked onto these bony prominences, a sharp rise in applied force would have been seen and motion would have ceased until the hands passed over these landmarks. No such observations were recorded. Furthermore, when real "chiropractic hands" were used to produce a dynamic thrust in the absence of removing skin slack, the average x-displacement was 38.75 and 33.25 mm for the TP and SP contact, respectively. It is not reasonable to believe that the vertebra moved this distance and thus, the contact on both of these bony landmarks was lost. In fact, all 54 thrusts performed showed this pattern of loosing the bony contact. Hence, this is further evidence that it is not possible to hook onto a component of a vertebra in this x direction, or at least did not occur in 54 clinical observations, during thoracic manipulation. If a sufficiently frictional surface was present between the thoracic skin and the underlying tissue, the taking up of skin slack prior to a manipulative thrust would not be necessary. The fact that spinal manipulators perform thoracic manipulation with the removal of skin slack supports the findings of this study. The taking up of skin slack limits the x-displacement excursion during manipulation allowing the therapist to maintain the original contact.

If forces crossing the skin to underlying structures are dominated by only normal components, what is the fate of any force component in a shearing direction? Obviously, since the contact is made with the skin, these shear forces must have initially been transmitted to this tissue. Our study supports this idea from two perspectives. Firstly, phase II and phase III of the force–displacement curves are remarkably similar to that which has been found in the literature when rabbit skin is stretched in vitro [6–8]. We would not expect to find phase I behaviour in this literature as phase I in our study was due to inertial forces resulting from the mass of the loading apparatus being set into motion. Secondly, examination of the movement of the skin markers reveals that skin, which was far from the apparatus, translated. The markers furthest away from the apparatus demonstrated the least translation. Future work must determine how these shear forces from the skin are transmitted to and affect the overall skeleton. This is critical in quantifying the mechanical effects of spinal manipulation onto the spine.

The main limitation of this study was that the force data were collected in a quasi-static manner. This would limit any viscous component of friction which is present in all biological systems and could be of some consequence during a dynamic "thrust" applied in a high velocity low amplitude (HVLA) manner. When force data were being collected, the "thrust" was of low velocity and hence the viscous component of friction would be negligible. This limitation was addressed by determining if the increased velocity associated with a real manipulative thrust produced enough viscous friction to alter the direction of the resultant force experienced by the vertebra. Typical HVLA thrusts were applied to the subjects and from which the viscous forces resisting the thrust were calculated. These data suggested that the velocity dependent viscous friction was insufficient to alter the direction of the applied force vector from the perpendicular given its small magnitude.

Caution should be used when applying the findings of this study to other areas of the spine or during other manipulative procedures. In the future, other manipulative procedures and other spinal regions will be examined. Finally, we were limited in the ability to compare these data to those of others as, to our knowledge, this is the first data set to examine the frictional characteristics of the skin–fascia interface anywhere in the body. Rather, the existing work addresses the frictional characteristics of skin with respect to the skin–external environment interface, not internal [9,10].

In summary, due to the negligible friction found at the thoracic skin–fascia interface, external forces being transmitted directly to the underlying vertebra are dominated by the normal components. This suggests that efforts to apply an oblique force during thoracic manipulation may be wasted effort. For example, applying a force on a 45° angle from normal to the skin will reduce the magnitude of the resultant force experienced by the underlying vertebra to 70.7% of the applied force. This has implications for manipulative technique when the smaller clinician is attempting to generate sufficient force to manipulate the vertebrae. This clinician would be spending 29.3% of their effort transmitting loads elsewhere creating deformation of the skin and producing a general translation of the entire patient along the table surface. We acknowledge that the component of the force producing this translation will affect the vertebra in question. However the resultant force direction experienced by that vertebra would not be predictable as intended by the clinician. These novel results then challenge the concept that directional specificity during spine manipulation is required to generate desirable therapeutic outcome.

Acknowledgements

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