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Posteroanterior movements in tender and less tender locations of the cervical spine

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Range of Motion, Articular

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ABSTRACT

In order to determine how posteroanterior movements (PAs) are related to tenderness and thus possibly symptom production, we measured PA movements to a force of 25 N on each side of the cervical spines of asymptomatic subjects. From ten subjects (six females and four males; mean age 37.2, range 21 to 50), ten locations with a difference in tenderness to pressure between sides were used for analysis. The force-displacement and stiffness-force curves for tender and control sides were compared in four ways: simultaneous confidence bands (SCBs) for each side; width of SCBs for each side; SCBs of the difference between pairs of the tender and control curves; and simultaneous prediction bands (SPBs) from the tender side were compared to individual curves of the controls. The tender side demonstrated greater variation of both displacement and stiffness. The tender sides demonstrated greater within subject stiffness for all force levels above 12 N. All individual stiffness-force curves of the tender sides were significantly different from the control side. Expected differences in single measures of either displacement or stiffness were not detected. The results suggest that the pattern of stiffness is a more effective method of characterizing PA mobility than single measures used in previous studies.

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INTRODUCTION

Musculoskeletal symptoms such as neck or back pain are amongst the most common reasons patients seek medical attention (Bogduk et al., 2003). Dysfunction of movement between individual intervertebral motion segments is considered to be a potential source of spinal musculoskeletal symptoms (Banks, 1998) and passive movement tests such as spinal posteroanterior movements (PAs) are intended to localize and assess the dysfunctional intervertebral movement (Maitland et al., 2005).

Although many authors advocate motion palpation as an important component of physical examination (Bullock-Saxton et al., 2002), the usefulness of passive movement tests such as spinal PAs has been brought into question by inconsistent repeatability (Pool et al., 2004; Smedmark et al., 2000). In spite of a lack of repeatability, manual assessment of passive movement has been shown to be useful clinically. For example, symptomatic locations (Jull et al., 1988) and the location of congenital fusion have been reliably detected by manual motion palpation (Humphreys et al., 2004). In a clinical study, the lumbar spines of patients were classified by findings on manual palpation as hypomobile or hypermobile. Patients who received corresponding treatment (manipulation to increase segmental mobility for the hypomobile group and stabilization exercises to counteract excessive mobility for the hypermobile group) had better treatment outcomes than those receiving randomly allocated treatment (Fritz et al., 2005).

Spinal PAs were previously thought to produce isolated movement between a target pair of vertebrae and the response felt by the therapist was considered to be a direct indicator of the local intervertebral movement (Grieve, 1981). It is now clear from both *in vivo* (Caling & Lee, 2001; Kulig et al., 2004; Lee & Evans, 1997; Lee et al., 2005)

and *in vitro* (Gal et al., 1997; Sran et al., 2005) studies that in addition to moving the target intervertebral segment, spinal PAs also move other structures including a number of intervertebral levels as well as extra-spinal structures.

In order to clarify the usefulness of spinal PAs, a number of investigators developed instrumented methods to objectively assess PA movements. Interpretation of data from studies discussed in a recent review (Shirley, 2004) relied on single scalar values of displacement or stiffness extracted from the force-displacement (FD) curves of spinal PAs to characterize the stiffness of the entire movement. Using these single values to assess stiffness, instrumented measures of spinal PAs have been successful in detecting differences occurring with segmental dysfunction. For example, differences have been demonstrated with reduction in symptoms in patients with low back pain (Latimer et al., 1996b), artificially induced disc degeneration in a porcine model (Kawchuk et al., 2001b), and local intervertebral stiffness *in vitro* in human thoracic spines (Sran et al., 2005). Using the same criteria for assessing stiffness, differences have been found also in relation to a wide variety of factors whose influence is extraneous to local intervertebral mobility (Kawchuk & Fauvel, 2001a) including subject position (Chansirinukor et al., 2001; Edmondston et al., 1998), stage of respiration (Shirley et al., 2003), size of the indenter (Squires et al., 2001), and muscle contraction (Colloca & Keller, 2004; Hodges et al., 2003). The methodologies used in these studies are able to detect altered stiffness of spinal PAs resulting from a variety of structures, but are unable to differentiate between alterations resulting from the targeted intervertebral segment and those resulting from extraneous factors.

We therefore set out to identify particular patterns of spinal PA stiffness associated specifically with intervertebral dysfunction (as indicated by local tenderness to pressure) using a protocol similar to that recommended for manual assessment of

unilateral PAs (Maitland et al., 2005). That is, we compared PA movements at tender and less tender locations that would otherwise be expected to be as similar as possible; i.e. side-to-side at the same spinal level. Rather than relying on single values of stiffness or displacement, we compared the patterns of displacement and stiffness throughout the PA movement using a bootstrapping method of calculating simultaneous confidence bands (SCBs) and simultaneous prediction bands (SPBs) to detect more specific differences. We hypothesized that, in addition to reduced displacement and an increase in single values of PA stiffness, more specific differences in the patterns of stiffness throughout the PA movement would correspond to differences in local tenderness to pressure.

By understanding the specific characteristics of PA stiffness related to tenderness (and presumably intervertebral dysfunction) we hope to enable more accurate interpretation of manual and instrumented assessment of PA movements.

METHODS

Subjects and experimental design

Asymptomatic subjects were recruited from university staff and students. Asymptomatic subjects were defined as participants with an absence of current neck symptoms, symptoms within the past six months that required treatment or contraindications or precautions to manual therapy treatment. Asymptomatic subjects as defined above are known to have a significant incidence of low-level symptoms (Lee et al., 2004). As tenderness to PA movements is considered to be an indicator of symptoms, it was expected that PAs to the cervical spine in this population would be tender to pressure at some locations.

Ten subjects (six females and four males; mean age 37.2 years, range 21 – 50 years; mean weight 72.7 kg, range 52 - 92 kg; mean height 169.9, range 155 - 179 cm) were recruited for the study. The experimental protocol was approved by the Griffith University Human Research Ethics Committee and all individuals provided written confirmation of their informed consent prior to participation.

Each subject participated in one session consisting of two trials. The procedures were explained and the subjects were familiarized with the equipment and operation of the pain indicator prior to the first trial. The subjects were instructed that they might experience some pressure pain during the procedures, but they could tell the operator to stop the trial at any time. For each trial, the subjects were prone on a standard treatment bed modified to ensure a reproducible position and on which the Passive Movement Assessment Device (PMAD) was mounted. Each trial consisted of the application of a unilateral PA force to a total of six locations: the right and left side at each of three levels separated by 12 mm. It is not possible to accurately locate specific anatomical levels without medical imaging so the three levels were repeatable positions in the mid cervical region that could be accessed by the PMAD (the therapist considered the highest level assessed for any subject to correspond to C2 and the lowest to C6) . After the first trial, the subject stood and walked a few steps before the second trial.

The assessment at each location consisted of five applications of force up to 25 N performed at a frequency of approximately 1 Hz which is within the range used in manual assessment of intervertebral movement (Snodgrass et al., 2006). The subject rated the maximum intensity of pressure pain experienced during any of the five repetitions and the operator was blind to their response. A single qualified Musculoskeletal Physiotherapist with over 30 years experience performed both trials.

Instrumentation and data collection protocol

The PMAD (Fig. 1) was designed to be capable of assessing unilateral PAs of the cervical spine in a manner as similar as possible to manual palpation. The PMAD consisted of an instrument for measuring the force and displacement that occurred when an indenter was applied to the subject. The indenter was a 25 mm length of 12 mm square aluminium section with edges rounded to a radius of approximately 1 mm. The operator applied a force through a thumb-hold above the indenter. A linear potentiometer (Hollywell LTS04N04KB5C) measured the displacement and a load cell (Transducer Technologies MLP-25) mounted between the thumb-hold and the indenter measured the force. The device was adjusted such that the medial edge of the indenter contacted the patient five to 15 mm from the midline and the movement was directed 10 degrees medially from the vertical. The sensors were connected to a PC through a USB DAQ card (NI 40006, National Instruments) and data were sampled at 100 Hz.

[Insert Fig. 1 about here]

The assembly could be fixed at 12 mm intervals along the long axis of the bed and be repositioned easily to a corresponding position on the contralateral side. A more complete description of the instrumentation and data collection protocol is described in our previous work along with repeatability data for the device (Tuttle et al., Under review).

The pain indicator was a linear array of 20 LEDs located under the bed not visible to the operator, but visible to the subject in the test position. The subject indicated the level of pain with the LEDs acting as a visual analogue scale. No LEDs represented no pain and all LEDs representing the worst pain imaginable. Data collection, storage and

operator feedback (an audible sound when the maximum force of 25 N was reached) were performed with custom software written in Labview Version 7.1 (National Instruments).

Data and statistical analysis

Data from test locations were used for further analysis if a difference in the pain rating of at least two LEDs (equivalent to one point on a ten point scale) was found to occur between sides at the same level during the same trial. In the event that both trials of the same location had a difference of greater than two LEDs, only the one with the greatest difference was used in further analysis. A total of ten pairs of locations from six subjects fulfilled the criteria and were used for further analysis. The median pain level on the tender side was 5.5 points (range 2.5 to 8.5) and for the less tender control side was 3.0 points (range 1.5 to 5.5).

Following data collection, the force and displacement data were processed with customized software using Matlab Version 7.04 (Mathworks, Inc.). Force and displacement values for each trial and each location were filtered using a second order low-pass Butterworth filter with a cut-off frequency of 2.5 Hz. The displacement at 0.5 N was assigned a value of zero to create a common origin for all curves and a single average curve was calculated for each test location. Displacement and stiffness values were extracted from the curves for 100 data points at 0.25 N intervals from 0.5 to 25 N of force (Tuttle et al., Under review).

Specialized methods of statistical analysis for assessing continuous (time series) data have been used in gait analysis but to our knowledge have not been applied previously to the assessment of passive movement. A detailed description of the type of analysis used in this study can be found in Lenhoff et al. (1999) and the application to the

current study is described more fully in Additional File 1. Briefly bootstrap resampling with PopTools (Hood, 2005) was used to calculate simultaneous confidence bands (SCBs) and simultaneous prediction bands (SPBs). SCBs define the band within which the entire mean curve of a group can be expected to lie while SPBs define the band which would be expected to fully enclose the entire length of a given proportion of individual curves from the population.

As it was not known beforehand how differences in spinal PAs between the tender and control sides might affect the FD or stiffness-force (SF) curves, four methods were used to compare the two sides for both types of curves. Firstly, the 95% SCBs were calculated for both the tender and control sides. Portions of the curves were considered to be significantly different when the SCBs for the tender and control sides did not overlap. Secondly, the 95% confidence intervals of the widths of the SCBs of the tender and control sides were compared to assess for differences in variability between sides. Thirdly, SCBs were calculated for the differences between the tender and control sides and where the bands did not contain zero, the result indicated a significant difference. Finally, the individual FD and SF curves from the tender sides were overlaid on the SPBs for the control side. Portions of the individual curves outside of the SPBs indicated the portion of the curve that was significantly different from the curves of the control side.

RESULTS

Representative data

The FD and SF curves for tender and control sides from two representative locations are shown in Fig. 2a and 2b, respectively. Although it could be considered to be the independent variable in this study, force is represented on the Y-axis of Fig. 2a as is

the convention for FD curves. The FD curves from the two subjects did not demonstrate consistent differences between the tender and control sides. The SF curves in Fig. 2b show comparisons of the stiffness data for tender and control sides with the independent variable (force) on the X-axis. The SF curves from the two tender sides shown in Fig. 2b each have characteristic portions that diverge from the control curves when the applied forces are in the mid and upper range of forces used in the current study.

[Insert Fig. 2 about here]

Comparisons of sides

The graphs in Fig. 3a - 3c compare characteristics of FD curves on the left and SF curves on the right. In Figs. 3a and 3b the SCBs of the FD and SF curves for the tender and control sides overlap throughout the curves demonstrating that no significant differences were detected between the means of either displacement or stiffness for the two sides at any level of force. The mean width of the SCB of the FD curves from the tender sides was wider than the control sides by 2.00 mm (CI = 1.90 to 2.12) and of the SF curves by 0.52 N/mm (CI = 0.44 to 0.60) demonstrating that there was greater variability of both displacement and stiffness on the tender sides. Figure 3c shows the SCBs of the difference in displacement (tender minus control) between the two sides for each level of force. The bands contain zero for all force values indicating the differences were not significant. Figure 3d shows that the difference in stiffness between the two sides was significant for all forces above 12 N.

[Insert Fig. 3 about here]

Comparisons of individual tender curves to control side

SPBs were plotted to determine if specific areas of individual curves of the tender sides differed from the control side. Fig. 3e shows that six out of the ten FD curves from the tender sides extended outside of the SPBs for the control sides indicating significant differences from the control sides. There did not appear to be a consistent pattern to the differences as four curves demonstrated less displacement throughout the force range, one less displacement in the latter half and one more displacement in the early half. In Fig. 3f, all of the SF curves from tender locations extended outside the SPB of the control sides indicating that all of the tender curves were significantly different from the control side. Eight of the tender curves were stiffer either between 12 and 16 N or above 20 N while two were less stiff below 12 N.

DISCUSSION

The current study set out to determine patterns of movement or stiffness associated with local tenderness during unilateral PAs of the cervical spine. We found several differences in the pattern of the tender sides compared to the less tender control sides. Specifically, the tender side demonstrated greater variation of both displacement and stiffness; the tender sides demonstrated greater within-subject stiffness for all force levels above 12 N; and all individual SF curves of the tender sides were significantly different from the control side. The expected differences between sides in single measures of either displacement or stiffness however were not detected.

The pattern of differences is illustrated by comparisons of the SF curves of the tender and control sides of the representative curves shown in Fig. 2b. The middle and latter thirds the curves from the tender side diverge from the corresponding control curve, reach a peak of maximum difference and then re-approach the control curve. The effects of a similar pattern can be seen in the shape of the mean SF curves in Fig. 3b,

the differences between tender and control sides in Fig. 3d and the areas where the individual tender SF curves are above the SPBs in Fig. 3f. Variations in the pattern (particularly variations in the force at which the stiffness of the painful side rises away from the control side) are likely to be responsible for single measures of displacement or stiffness as used in previous studies being unable to detect differences between sides in the current study.

Displacement has been used to assess PA mobility in previous studies but no differences in displacement were detected in the current study. The differences in displacement may have been too small to be detected by the methods used in the current study or unilateral PAs on the cervical spine may exhibit different behaviour than PAs applied to the midline of the lumbar or thoracic spines investigated in previous studies. Stiffness of Spinal PAs (slope of the latter portion of the FD curve) expressed as a constant is another parameter that has been used to characterize spinal PA stiffness. Although visual inspection of the FD curves from the current study may have suggested the stiffness approached a constant, the SF curves clearly indicated stiffness continued to change throughout the movement. The lack of constant stiffness in any region of the SF curves agreed with Nicholson et al. (2001) who found that a linear approximation of stiffness did not provide the best fit to FD curves from PAs to the lumbar spine. Variations in the force at which the stiffness of the tender side diverges from the control side may explain why single measures of displacement or stiffness were unable to detect differences between sides in the current study.

Clinical implications

The findings in the current study of significant differences in stiffness at forces starting at 12 N supports the assertion by experienced clinicians of being able to detect altered PA mobility well before the end of the PA movement. The method used in this study

may have in fact overestimated the minimum force necessary to manually detect differences. Clinicians will often displace overlying soft tissue to gain closer contact between their thumbs and the vertebrae being palpated. The indenter in the current study was applied in a predetermined linear direction without prior displacement of soft tissue which may have resulted in a thicker layer of soft tissue being compressed than occurs with manual palpation. A small amount of force being necessary to detect differences was also demonstrated by Marcotte et al. (2005) who found that the force used by clinicians varied from 1 N to 8 N, but the level of force did not affect the accuracy of detecting the location of a known intervertebral fusion. In light of differences being detectable at such low levels of force, it is interesting to note that many of the previous studies assessing central PA stiffness in the lumbar spine considered stiffness occurring only in the latter portion of the movement at forces above 30 N (Edmondston et al., 1998; Latimer et al., 1996a; Latimer et al., 1996b; Lee & Liversidge, 1994; Shirley et al., 2003).

Clinicians interpreting manual spinal PAs appear to consider aspects of the PA movements other than or in addition to the single values of displacement or stiffness previously used to describe instrumented assessments (Maher & Adams, 1995a; b). The findings of differences in patterns of stiffness throughout the PA movement may suggest some of the parameters that clinicians consider in their assessments of PA stiffness but the inferences that can be drawn from these findings are limited in several ways. Firstly, it is not known if the patterns of stiffness found in the current study could be differentiated from altered stiffness resulting from extraneous factors not addressed in this study but known to influence PA stiffness (e.g. position, respiration or regional muscle contraction). Secondly, despite the subjects being defined as asymptomatic, the control side could not be considered 'normal' but only less tender than the tender side. Both sides used for comparisons were tender to some extent and the sides only

differed in pain intensity by an average of 2.5 out of 10 on a visual analogue scale. Finally, although the analysis in the current study was more detailed than that used in previous studies, it may not have been sufficient to determine the essential characteristics of differences in spinal PAs related to altered segmental mobility.

It may be worth suggesting how clinicians' perceptions might relate to the patterns of stiffness described in the current study. Two common terms used to describe PA movements are R^1 (the point thought to correspond with the first onset of resistance) and endfeel. Petty et al. (2002) pointed out that there was resistance throughout the PA movement and suggested that R^1 did not correspond with a measurable point in PA movements. The point described as R^1 may, however correspond with the point where the rate of increase in stiffness changes rather than the point of first perceptible resistance. In the current study R^1 may therefore correspond with the point on the stiffness graphs where the tender side diverges from the control side. Likewise defining the physical equivalent of endfeel is problematic. There is no clear end of range of PA movements as displacement continues to increase with increasing force. The location, height and shape of portions of the SF curves diverging from the control sides may therefore be parameters of interest in assessing spinal PA stiffness. Additional research is necessary using symptomatic subjects to clarify the relationship between patterns of PA stiffness and symptom production. In addition, further studies relating clinician's perceptions with physical measurements may bring a greater objectivity to manual assessment of passive movements.

Conclusions

To our knowledge this is the first study to investigate differences in patterns of stiffness throughout PA movements to the cervical spine. The pattern of stiffness particularly from 12 to 16 N and 20 to 25 N is a more effective method of characterizing altered PA

mobility in the cervical spine related to intervertebral dysfunction than the single measures of displacement or stiffness used in previous studies. There was a small sample size in this study so the results can only be considered as preliminary but if confirmed, these findings will assist in determining more objective criteria for characterization of spinal PA mobility for research, teaching and clinical practice. Future studies investigating assessment and interpretation of spinal PAs may need to consider parameters other than the single values of displacement or stiffness used in previous studies.

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Competing interests

The authors declare that they have no competing interests.

CAPTIONS TO FIGURES

Fig. 1 Passive Movement Assessment Device (PMAD)

Fig. 2 Representative force-displacement (FD) and stiffness-force (SF) data from two subjects. Grey dashed lines represent tender sides; Black solid lines represent less tender sides.

Fig. 3 Simultaneous confidence and prediction bands comparing tender and less sides. Grey lines represent painful sides and black lines represent less tender sides. For solid lines, thick lines indicate means and thin lines indicate simultaneous prediction bands (SPBs). For dashed lines, thick lines indicate simultaneous confidence bands (SCBs) and thin lines indicate curves from individual locations.

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Tuttle, N, Barrett, R, Laakso, L. Postero-anterior movements of the cervical spine: repeatability of force displacement curves. *Manual Therapy* Under review.

Figure 1

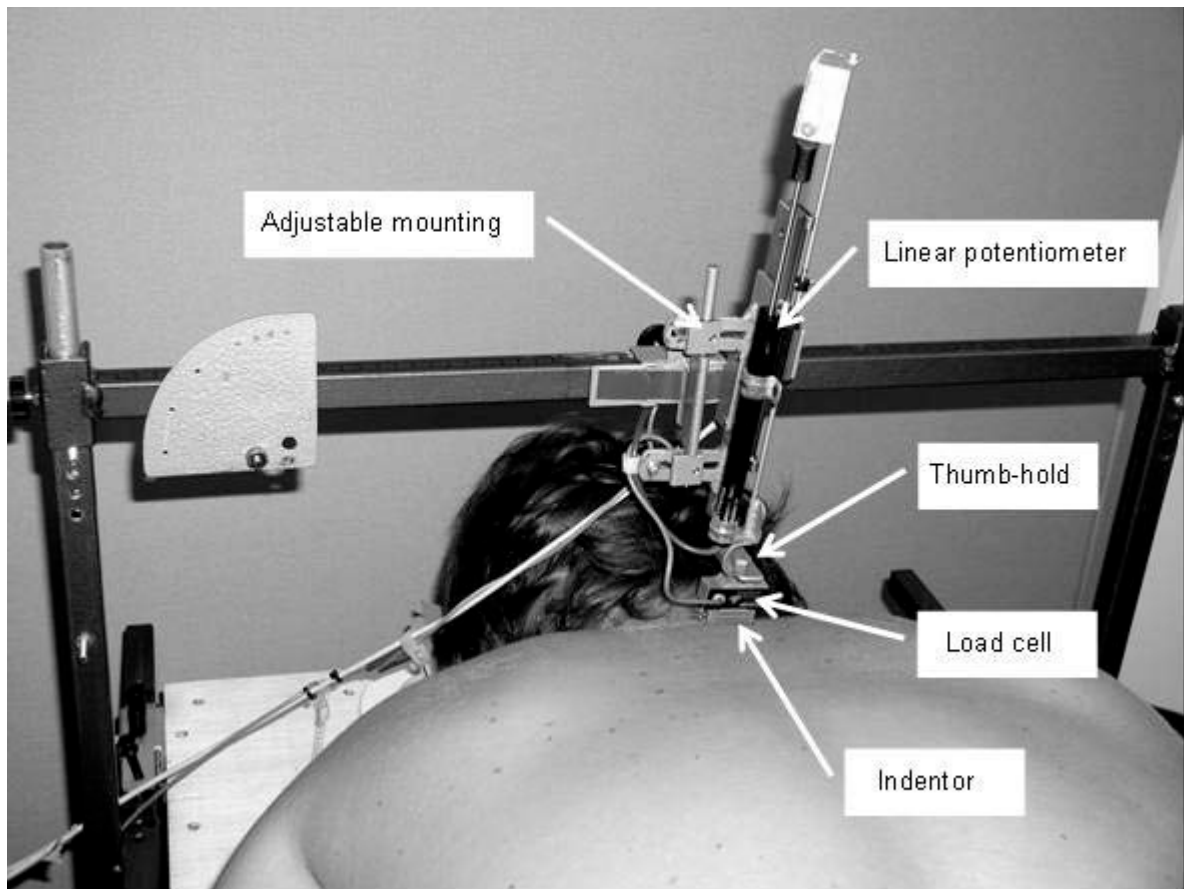


Figure 2

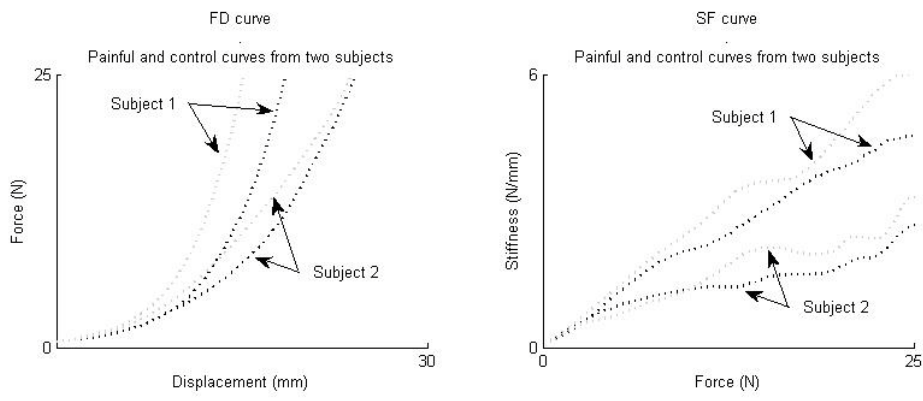
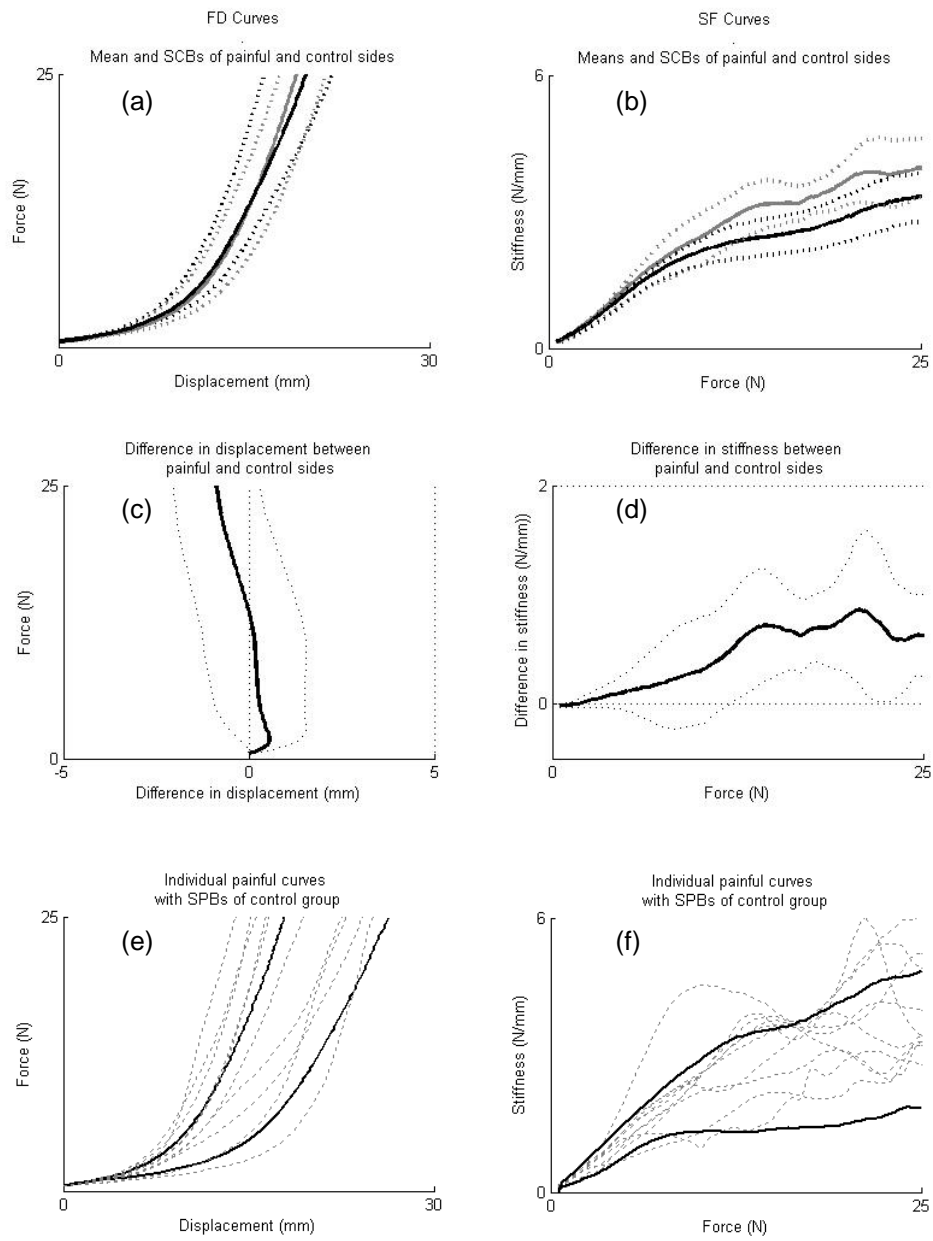


Figure 3



ADDITIONAL FILE 1

Calculation of simultaneous confidence and simultaneous prediction bands

Resampling methods such as bootstrapping overcome many of the difficulties resulting from small sample sizes. For this study, one thousand simultaneous bootstrap resamples (resampling entire curves) with replication were used for all analyses.

Simultaneous confidence bands (SCBs) enable the comparison of mean values by enclosing the area around the sample mean curve where, for a given probability, the entire length of the true mean curve can be expected to lie. To determine the SCBs, the sample mean curves from each of the bootstrap resamples for the tender side, the less tender side and pointwise difference between the two sides were calculated. The largest pointwise standardized deviation from the grand mean that occurred on each resample mean curve ($SD_{\max_{\text{resample}}}$) indicated the maximum distance (in standard deviations) from any point on that resample mean curve to the grand mean curve. The 95th percentile (50th largest) $SD_{\max_{\text{resample}}}$ ($SD_{95\%_{\text{resample}}}$) was therefore greater than the maximum distance (in standard deviations) between any point on the remaining 95% of the sample means and the grand mean. The width of the 95% SCB around the grand mean at each point was therefore $SD_{95\%_{\text{resample}}}$ multiplied by the pointwise standard deviation at that point. The difference between SCBs and point wise confidence intervals could be illustrated by probabilities related to the mean curve of any future resample of the original dataset. There would be only a five percent chance that any part of the curve would lay outside of a simultaneous confidence band, but as each curve would contain 100 data points one would expect an average of five data points to lie outside of a pointwise series of confidence intervals.

Plots of the SCBs of the tender and control sides were then be overlaid and any areas where the SCBs did not overlap represented areas of the curves with significantly different means. The mean and confidence intervals of the pointwise widths of the SCBs were calculated for the tender and control group as an indicator of the variance of the curves. The SCBs of the differences between the tender and control sides were graphed and if zero was not contained within the SCBs the difference was considered to be significantly different from zero.

Simultaneous prediction bands (SPBs) differ from SCBs in that, for a given probability, SCBs are expected to fully enclose the true mean curve of the population while SPBs are expected to enclose individual curves from the population. The usefulness of SPBs is that when future individual curves are co-plotted with the SPBs, if any part of the new curve is outside of the SPBs, then the individual curve can be considered to be significantly different from the population used to determine the prediction band. SPBs were also calculated using bootstrap resamples each containing ten curves. The maximum pointwise standardized deviation was calculated for each curve ($SD_{max_{curve}}$). The average of the 95th percentiles of $SD_{max_{curve}}$ from the bootstrap resamples ($SD_{95\%_{curve}}$) is therefore greater than the maximum distance (in standard deviations) between any point on 95% of the individual curves and the mean curve. The width of the 95% SPB of the control group around the grand mean at each point is therefore $SD_{95\%_{curve}}$ times the pointwise standard deviation at that point. Plots of individual curves of tender locations were overlaid on the SPBs of the control group. If any part of an individual curve from the tender side lies outside of the SPB of the control group, that curve can be considered to be significantly different from the control group.