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Corresponding Author	Isabelle Pagé
Corresponding Author's Institution	Université du Québec à Trois-Rivières
Order of Authors	Isabelle Pagé, Michael Swain, Arnold Wong, Alexander Breen, Diana De Carvalho, Martin Descarreaux, Martha Funabashi, Gregory Kawchuk
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Abstract

Objective: Spinal stiffness assessments are commonly used by manual therapists. Although devices have been developed to objectively measure spinal stiffness, individual characteristics (i.e., sex, age, weight, height) may affect the measurement results. Therefore, this study aimed to describe the correlations between individual characteristics and spinal stiffness.

Methods: A secondary analysis of three adult datasets using three different devices, in two spinal regions, from a total of five separate cross-sectional studies was conducted. Differences in spinal stiffness between males and females and the strength of correlation between spinal stiffness and age, and anthropometric characteristics were evaluated using either t-test for independent samples, Pearson or Kendall's Tau rank correlation coefficient.

Results: As expected, results varied between datasets, however, few factors displayed consistent correlations. Specifically, spinal stiffness was significantly lower in females than males in all three datasets. Height was positively correlated to spinal stiffness across all datasets. While weight was correlated to thoracic stiffness, it presented varied correlation with lumbar stiffness. Two datasets showed BMI was inversely associated with lumbar spinal stiffness, whereas results from the thoracic spine region showed a positive correlation. The results of one dataset suggest that physiological measurement evaluating body weight distribution may also affect spinal stiffness, however the specific correlation remains unclear.

Conclusion: Despite of dataset differences, significant correlations were observed indicating that participant characteristics appear to affect spinal stiffness measurement. Therefore, future studies assessing spinal stiffness should report and control for individual characteristics. Moreover, a standardised testing protocol for spine stiffness measures remains to be developed.

1. Introduction

Low back pain (LBP) and neck pain have been the number one cause of disability globally since 1990.(1) Although the causes of spinal pain are largely unknown, it is believed that most are mechanical in nature.(2, 3) As such, clinicians typically use physical assessments to categorise patients with different biomechanical dysfunctions in order to inform their clinical decision process.(4)

Spinal stiffness assessments are one of the most commonly investigated biomechanical properties of the spine used in the prognosis or treatment decision-making pathways of manual therapy practitioners. It is thought that spinal stiffness may be related to pain and/or be altered by treatments.(5) To assess the spinal stiffness of a patient, a clinician usually applies manual posteroanterior force to a spinal region (e.g. thoracic region) or to individual spinal landmarks along the spine (e.g. spinal processes) and subjectively judges the corresponding spinal movement or stiffness. Based on the clinician's experience, spinal movement can be perceived as normal, hypermobile or hypomobile which is used to guide treatment. Although manual spinal stiffness assessments have traditionally been included in the clinical evaluation of spinal biomechanics, the reliability of these manual assessments have been found to be limited.(5) Accordingly, various spinal stiffness testing devices have been developed to quantify the procedure and have been shown to improve accuracy and reliability.(6) As a result of these improvements, a number of studies have now been conducted with these devices and demonstrate the responsiveness of spinal stiffness to various interventions or treatment.(7, 8)

While the design of spinal stiffness devices varies, the basic principles of instrumented spinal stiffness measurement are similar. A typical spinal stiffness device is comprised of a motor to control the movement of an indenter which loads the spine of a prone participant, a load cell to measure the loading force, and a displacement sensor to measure the displacement of the indenter (indirect displacement of the spine) in response to the indentation.(6) Importantly, the device is anchored to a stable reference point and is not a handheld device. Using the collected force and displacement data,

two spinal stiffness coefficients (global and terminal) can be calculated from the force-displacement (F-D) curve (Figure 1). For both coefficients, an increase in magnitude implies an increase in spine stiffness.

Figure 1

Although the overarching goal of any spinal stiffness testing device is to objectively measure spinal stiffness, characteristics of the individual being assessed, such as sex, age, weight, height, body mass index (BMI) and back pain symptoms may affect the measurement results.(9-13) However, the relation between these variables and spinal stiffness as measured by different devices remains unknown.(9, 11, 14-18) Given that different clinicians or researchers may use different devices for clinical assessments or research, it is paramount to understand the impact of different devices as well as testing protocols in moderating the relations between individuals' characteristics and spinal stiffness. The findings can ultimately help interpret and compare spinal stiffness values between studies and clinical conditions. Unfortunately, no studies have been conducted to evaluate the effects of different devices, participants' characteristics, and testing protocols on the measured spinal stiffness.

The purpose of this study was to describe the correlations between individual characteristics (i.e. anthropometric data, sex and age) and spinal stiffness as measured by different spinal stiffness measurement devices in individuals with and without LBP. This goal was achieved by conducting secondary analyses of three datasets collected previously using three different devices, in two spinal regions, in a total of five separate cross-sectional studies. It was hypothesised that the correlation between individual characteristics and spinal stiffness would vary greatly between datasets, while potentially important individual characteristics would be identified. Given the increasing usage of instrumented spinal stiffness measurement in research and its potential as an objective outcome in clinical settings, understanding its variations and/or similarities would be of great importance to develop standardized protocols and testing recommendations.

2. Methods

2.1 Datasets presentation

Secondary analyses of data from five independent cross-sectional studies were conducted. Datasets A and B originated from two separate studies whereas Dataset C was comprised of three studies that were conducted using the same protocol. Details for each dataset are presented in Table 1 and pictures of each testing device are included in Figure 2. Scientific and/or ethical review for each original study was approved by the respective University's Human Research Ethics Committee and approval for secondary analyses was obtained when required (Table 1). Individual studies were conducted in accordance with the Helsinki Declaration of 1975. All participants provided their informed and written consent at the stage of the original study according to the ethics approval. These studies were similar in that they all investigated adults, with and without back pain using a load-controlled indenter device to objectively measure spinal stiffness. Individuals' characteristics (weight, height, BMI, age and sex) were included in each study and Dataset A also included physiological measurements (free-standing height, sitting height, waist circumference, waist-to-height ratio, and waist posteroanterior diameter). The spinal levels assessed landmark identification procedure and the applied load and velocity used to assess spinal stiffness varied between studies (Table 1). While the theoretical definitions for global and terminal spinal stiffness were the same across the studies, the exact calculation was specific to each dataset.

Figure 2

Table 1

2.2 Statistical analysis

A standardized analysis protocol was established whereby datasets were initially checked for pertinent assumptions that included normality, outliers, and linearity, at the individual variable level. A

descriptive analysis was first conducted including means and standard deviation (SD) for parametric data or median and interquartile range (IQR) for non-parametric data. Statistical comparison between datasets were not conducted since ethics certifications did not allow sharing of data between institutions.

Since spinal stiffness in males and females where normally distributed in all datasets, *t*-tests for independent samples were conducted to compare spinal stiffness between males and females. Pearson correlation coefficients (r) or its estimated value (r_e) from Kendall's tau rank correlation coefficients (for non-parametric data) were computed to quantify the strength of correlation between spinal stiffness and participants' characteristics (anthropometric, age, and sex). The strength of the correlations was evaluated as being "strong" ($r \geq 0.70$), "good" ($0.50 \leq r < 0.70$), "moderate" ($0.30 \leq r < 0.50$) or "poor" ($r < 0.30$).(19) Bias-corrected bootstrapping (1,000 bootstrap samples) was used to construct 95% confidence intervals for all correlation coefficients. IBM SPSS Statistics for Windows (Armonk, NY, IBM Corp) was used for all analyses and statistical significance was set at $p \leq 0.05$.

3. Results

3.1 Participants' characteristics descriptive analysis

Participant characteristics for each dataset are reported in Table 2. The three datasets included participants reporting and not reporting back pain. While Datasets A and C compared participants reporting at least one day of LBP in the past week versus participants not reporting a LBP episode within the past week, Dataset B compared participants reporting constant or recurrent thoracic pain for at least the past three months (with or without an episode in the past week) and participants without significant pain in the thoracic region for at least the past 3 months. A total of 288 (146 female, 140 male) participants were included across the three study sites. Age and sex ratios differed across the datasets, and this disparity was pronounced when participants were categorized based on the presence or absence of back pain. Anthropometric characteristics (weight, height and BMI) were consistent among the three datasets.

Table 2

3.2 Spinal stiffness: descriptive analysis

Table 3 presents the global and terminal spinal stiffness for each spinal level evaluated in the three datasets. Although comparisons between datasets could not be conducted using statistical analyses due to differences in protocols, it can be observed that spinal stiffness values varied greatly between studies. Complete analyses, including effects of spinal levels and back pain on spinal stiffness value, can be found elsewhere for Dataset A (20), Dataset B (paper currently under review), and Dataset C (7, 8, 15).

Table 3

3.3 Correlations between spinal stiffness and individual characteristics

Tables 4 and 5 present the correlations between individual characteristics with terminal and global spinal stiffness respectively. Overall, terminal and global spinal stiffness at specific levels of the spine appears to be correlated to some individual characteristics, however, pattern of correlations is rarely consistent among the three datasets.

3.3.1 Age

No significant correlation between both terminal and global stiffness and age was shown in any of the three datasets (all p values > 0.05).

3.3.2 Sex

T-tests revealed significant lower spinal stiffness (global and terminal spinal stiffness coefficient) in females compared to males in the thoracic spine (Dataset B). This analysis was significant for all spinal levels (T5 to T8) in participants with chronic thoracic pain (p values ≤ 0.04) and when all participants were grouped (p values ≤ 0.01). The mean difference of spinal stiffness between females and males ranged between 0.88 and 1.41 N/mm. Regarding the lumbar spine, Dataset A revealed significant lower global spinal stiffness in females at L3 and L5 but not at L1. This analysis was

significant when all participants were grouped and when only participants with ≥ 1 day of LBP in the past week were evaluated (p values < 0.05). No significant difference was observed for the global spinal stiffness in participants without LBP in the past week and for the terminal spinal stiffness (all p values > 0.05). Females had a mean difference in spinal stiffness with males ranging between 0.09 and 0.12 N/mm. Similar to Dataset A, Dataset C showed significant lower spinal stiffness at L3 in females compared to males when all participants were grouped (terminal stiffness : t(127) = 2.98, p = 0.04; global stiffness : t(127) = 3.05 p = 0.03) and when only participants with ≥ 1 day of LBP in the past week (terminal stiffness : t(42) = 3.00 p = 0.01; global stiffness : t(42) = 2.94 p = 0.01) were evaluated. The mean difference in spinal stiffness between females and males

3.3.3 Height

Dataset C showed significant but poor correlations between L3 spinal stiffness and height (terminal stiffness r = 0.18 [0.01, 0.34]; global stiffness r = 0.21 [0.04, 0.37]) among all participants. The correlation was of moderate strength when only participants with ≥ 1 day of LBP in the past week were evaluated (terminal stiffness r = 0.33 [0.04, 0.57]; global stiffness r = 0.37 [0.08, 0.60]). In Dataset A, height was only significantly correlated with terminal spinal stiffness at L5 in participants without LBP (r = 0.49 [0.15, 0.78]) and to global spinal stiffness at L3 when all participants were grouped regardless of pain status (r = 0.22 [-0.01, 0.40]). Overall, height was moderately to strongly correlated with thoracic terminal and global spinal stiffness. Specifically, except for T6 in individuals with and without chronic thoracic pain, terminal spinal stiffness was significantly correlated to height at all spinal levels ($0.18 \leq r_e \leq 0.58$). Similarly, height was moderately correlated with global spinal stiffness at all spinal levels when all participants were grouped ($0.31 \leq r \leq 0.33$), and in individuals without chronic thoracic pain ($0.45 \leq r \leq 0.55$). In participants with chronic thoracic pain, only T5 was significantly correlated to the global spinal stiffness (r = 0.33 [0.02, 0.61]). Overall, these correlations indicate that an increase in spinal stiffness value is associated with an increase in body height.

3.3.4 Weight

Weight was significantly correlated (poor to moderate strength) with spinal stiffness at all spinal levels when all participants were grouped in Dataset B ($0.26 \leq r \leq 0.41$). In participants without

chronic thoracic pain, these variables were moderately to strongly correlated at three of the four spinal levels ($0.41 \leq r \leq 0.56$). In individuals with chronic thoracic pain, significant correlations were only observed at T5 and T6 ($0.37 \leq r \leq 0.41$). For the lumbar spine, while Dataset C did not show any significant correlation (all p values > 0.05), Dataset A only revealed a poor inverse correlation between weight and L5 terminal stiffness in participants with ≥ 1 day of LBP in the past week (r = -0.26 [-0.46, 0.01]), indicating that heavier individuals with ≥ 1 day of LBP in the past week seem to present lower values of L5 lumbar terminal stiffness.

3.3.5 Body Mass Index

Dataset C showed a poor negative correlation between L3 spinal stiffness and BMI: all (terminal stiffness r = -0.24 [-0.40, -0.08]; global stiffness r = -0.25 [-0.39, 0.07]), participants without LBP in the past week (terminal stiffness r = -0.22 [-0.44, -0.04]; global stiffness r = -0.25 [-0.41, -0.01]) or participants with ≥ 1 day of LBP in the past week (terminal stiffness r = -0.22 [-0.68, -0.11]; global stiffness r = -0.39 [-0.49, -0.08]). In Dataset A, L5 spinal stiffness was poorly to moderately correlated with terminal and global spinal stiffness when all participants were grouped (terminal stiffness r = -0.35 [-0.54, -0.14]; global stiffness r = -0.25 [-0.41, -0.07]) and when only individuals reporting ≥ 1 day of LBP in the past week were evaluated (terminal stiffness r = -0.37 [-0.57, -0.13]; global stiffness r = -0.27 [-0.45, -0.08]). For the thoracic spine, correlations were inconsistent. T6 was moderately correlated with global (r = 0.34 [0.05, 0.58]) and terminal (r = 0.34 [0.01, 0.58]) spinal stiffness in participants reporting chronic thoracic pain, and poorly with global spinal stiffness when all participants were grouped (r = 0.25 [0.00, 0.48]). Moreover, T8 global spinal stiffness was moderately correlated to BMI in healthy participants only (r = 0.47 [0.17, 0.68]).

3.3.6 Other anthropometric characteristics

Dataset A also included other anthropometric measures and some presented significant correlations with spinal stiffness (Table 5). Interestingly all significant correlations were observed either when all participants were grouped or when only individuals with ≥ 1 day of LBP in the past week were evaluated. Waist circumference presented significant reverse correlations with the terminal spinal stiffness of L5 when all participants were grouped (r = -0.22 [-0.44, -0.04]), and among individuals with ≥ 1 day of LBP in the past week (r = -0.28 [-0.48, -0.05]). Waist postero-anterior diameter

revealed a significant and inverse correlation of moderate strength with L5 terminal spinal stiffness in participants with ≥ 1 day of LBP in the past week (r = -0.32 [-0.54, -0.03]). L5 global and terminal spinal stiffness was significantly correlated (moderate strength) with the waist to height ratio when all participants were grouped (terminal coefficient = -0.29 [-0.51, -0.06]; global coefficient = -0.26 [-0.41, -0.06]) as well as when only individuals with ≥ 1 day of LBP in the past week were evaluated (terminal coefficient = -0.33 [-0.55, -0.07]; global coefficient = -0.31 [-0.48, -0.31]). Sitting height was not significantly correlated with spinal stiffness, and waist circumference and waist postero-anterior diameter were not significantly correlated to the global spinal stiffness at any of the lumbar spinal levels (all p values > 0.05).

Table 4

Table 5

4. Discussion

This secondary analysis of three datasets independently collected at different Universities was conducted to identify whether individuals' characteristics (including anthropometric, age and sex) are associated with spinal stiffness values. Like this investigation, prior studies have reported heterogeneous findings using different devices, protocols, in different settings. As a result, while some studies report significant correlations between spinal stiffness and participant age (9), sex (9-11), weight (10-12), skin fold (12) and BMI (10, 12, 13), others have found no correlation between spinal stiffness and similar individual characteristics, such as age (9, 11, 14-17), sex (14, 16, 17), weight (9, 14, 16, 17), height (11, 14-17) and BMI (18). The current study is the first to conduct identical statistical analyses on data acquired using different testing protocols and devices. Height and BMI presented significant correlations with spinal stiffness in two or three of the datasets and the latter was significantly different between sex. Our explanation of why some studies may have failed to identify

these correlations/differences as well as the reasons why other individual characteristics (e.g. weight and age) presented inconsistent or nonsignificant correlations will be discussed below.

Similar to previous studies (10-13), Dataset A reported a significant negative relationship between spinal stiffness and weight and between spinal stiffness and BMI. Dataset C also revealed a significant negative correlation with BMI but not with weight, which has also been previously reported.(11, 14-17) Higher body weight and BMI may indicate a thicker layer of subcutaneous tissue and soft tissues at the abdominal and/or dorsal lumbar region that may increase the compliance of tissue during indentation, yielding lower measured spinal stiffness. This idea is further supported by the negative correlations between waist circumference or waist-to-height ratio, and spinal stiffness observed in Dataset A. Viner et al. (1997) observed negative correlations between skinfold thickness and spinal stiffness, which were significant from L3 to S1 ($-0.53 \leq r \leq -0.71$) but not at L1 and L2. (12) They suggested that participants with greater BMI and skinfold values might have a greater extent of fat distribution around the lower abdomen and pelvis and over the lower spinous processes than around the upper trunk. Results of Dataset A also align with this assumption as significant correlations were observed at L5 but not at L1 and L3. In contrast to the lumbar spine, Dataset B suggests a positive correlation between thoracic spinal stiffness and body weight or BMI. This correlation may be explained in that fat is less likely to accumulate in the thoracic region (21). These opposite correlations observed in the lumbar and the thoracic regions highlight the need to evaluate spinal regions individually and to limit generalisation of results between spinal regions.

Previous studies have not reported correlations between height and spinal stiffness.(9, 14, 16, 17) In the current study, height was significantly correlated with spinal stiffness in the three datasets. However, these correlations were all positive in the thoracic spine (Dataset B), while positive and negative correlations were obtained in lumbar spine (Datasets A and C). Vertebrae morphology, such as vertebral body height and spinous process length, as well as the magnitude of spine curvatures are known to be related to the individual body height.(22-24) Body height can therefore affect measurement angulation which could explained the correlation with spinal stiffness measurement.

However, it remains unknown as to why the correlation between these variables appears to be more consistent in the thoracic spine compared to the lumbar spine.

Across the three datasets, lower spinal stiffness was observed in females compared to males, a finding that is consistent with previous studies (9-11). Differences in fat distribution or in weight between females and males may partially explain these results. Females are known to have higher subthoracic and abdominal skinfold thickness, which may increase the compliance of tissue during spinal stiffness measurements and results in lower spinal stiffness values (21). Further supporting this hypothesis are the results of Snodgrass and colleagues, who found a significant correlation between cervical spine stiffness and sex at C7 but not C2. Interestingly, in all datasets, no significant difference was observed when only participants without back pain were evaluated. Although the reason of this lack of difference remains unknown, it might explain why some studies (14, 16, 17) did not showed significant lower spinal stiffness in females since only asymptomatic or healthy participants were included.

Theoretically, age could influence spinal stiffness through changes in body composition over the years. Until the age of 50, a decrease in fat-free mass and an increase in fat mass and abdominal fat can be observed. However, the magnitude of these changes depends on the individuals' BMI.(25) Further, age-related spinal degenerative changes may affect spinal stiffness. This complex interaction between BMI, changes in fat composition, spinal degeneration, and age may explain the lack of significant correlations between spinal stiffness and age in the current study as well as in others; (9, 11, 12, 14, 17)

The current study also highlights the influence of testing protocol and testing device on spinal stiffness measurements. Spinal stiffness values are known to be affected by parameters such as the applied load, rate of force application (or measurement velocity), measurement angulation, indenter size and respiration cycle.(5) Participants were instructed to hold their breath at the end of normal exhalation during measurement in the three included studies, however, the load, velocity, indenter size

and padding varied across studies. While Dataset A device, called Vertetrack (20) assessed spinal stiffness based on a brief postero-anterior force component applied to the spinous process region, both the Dataset B and C devices applied a gradual postero-anterior load over the targeted spinous process over a few seconds. Comparison and relationships between spinal stiffness values obtained using both types of devices should be conducted in the future.

Considering the relatively new use of instrumented stiffness measures and the potential value of their measures, great amount of investigative work remains in this area. Although the utilisation of the same or similar device between different institutions is a challenge, future studies should adopt this approach. A common device and protocol across studies and institutions would lead to the development of normative values and ultimately assist clinicians in their evaluation and management of patients with spinal pain. Future studies may also consider normalising spinal stiffness values (e.g. by weight, BMI or trunk fat caliper measures) to remove, or mitigate, the effects of some of these factors.

5. Limitations

There are two main limitations to this study. Given that this was a secondary analysis of three datasets, data collection protocols were unique to each dataset thereby introducing some heterogeneity. It was, however, our purpose to study the results of varying methodology and this allowed us to identify the correlations between spinal stiffness and individual characteristics that are consistent even with different patient populations, assessment devices and protocols. We do acknowledge that the development and use of standardized spinal stiffness assessment methodology would allow for the identification of additional individual characteristics that might also be correlated to spinal stiffness. Second, the results of this study are only applicable to the thoracic and lumbar spine. Considering the limited literature regarding correlations between cervical spine stiffness and clinical status, age and sex (9, 17, 26), studies are needed to evaluate correlations with other individual characteristics such as height and weight for comparison with the thoracic and lumbar spine. Finally, we would be remiss not to acknowledge that the small sample sizes of the included

datasets may have limited the statistical power of our analysis. Although our study is the largest of its type, we acknowledge the possibility of small samples leading to type 1 error. Notwithstanding, our approach was a narrative synthesis of three datasets, and by its nature attempts to account for single inconsistencies, such as false positives Given this field of research is currently vulnerable to issues surround small samples, we suggest that future in-vivo spinal stiffness experiments ensure a priori samples size requirements have been satisfied.

6. Clinical implications

Based on the results of the current study, clinicians should be aware that several variables may influence their perception during manual spinal stiffness assessment. Weight, BMI, sex, waist circumference and waist-to-height ratio all showed significant correlations with spinal stiffness in all or some of the included datasets. Furthermore, some variables such as height seem to affect thoracic and lumbar spinal stiffness differently. Consequently, clinicians should limit comparison between patients and between spinal levels of distinct spinal regions. Our data supports the recommendation that the choice of the vertebra to receive a treatment should not only be based clinical perception during manual spinal stiffness assessment, but should also include patient pain during assessment, patient complaint localization, posture, and regional movement.(4)

7. Conclusion

Three datasets, derived from a total of five studies conducted in three institutions, were analysed to describe the main individual characteristics associated with spinal stiffness. The three datasets included different testing protocols and testing devices that yielded different spinal stiffness values. Despite these differences, height and BMI presented significant correlations with spinal stiffness and lower spinal stiffness was observed in females in at least two Datasets making these variables of future interest. As such, these variables in should be reported in future studies evaluating spinal stiffness. Moreover, a standardised testing device and protocol, including normalization, should be prioritised in future studies conducted in different research sites.

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Table 1. Method details for three datasets included for secondary analysis in the present paper.

Information	Dataset A	Dataset B	Dataset C
Publication Status	Published (20)	Under Review	Published (7, 8, 15)
Study Location	Macquarie University of Sydney, Sydney, NSW, Australia	Université du Québec à Trois-Rivières, Trois-Rivières, Québec, Canada	University of Alberta, Edmonton, Alberta, Canada
Ethics boards name	Human Research Ethics Committee (HREC [Medical Sciences]) of Macquarie University, Australia	Université du Québec à Trois-Rivières Human Research Ethics Committee	• Human Research Ethics Board - Health Panel and Biomedical Panel, University of Alberta. • Human Subjects Ethics Subcommittee at The Hong Kong Polytechnic University (PolyU)
Ethics certification number and approval date	5201600008 approved on April 24th, 2016.	CER-16-220-07.04 approved on February 10th, 2016.	• Pro00026307 approved on November 29th, 2011 • Pro00027069 approved on August 6th, 2013 • HSEARS20170817005 approved on August 17th, 2017 (for secondary analysis by PolyU)
Study start and completion months	May to June 2016	April to December 2016	December 2012 to September 2014
Number of participants	84 (20 without LBP / 64 with LBP)	75 (25 healthy / 50 with chronic thoracic pain)	129 (85 without LBP / 44 with current LBP)
Inclusion Criteria	Adults (≥ 18 years old) with or without spinal pain.	Adults (18 to 60 years old) either healthy (no report of thoracic pain for at least 3 months) or with chronic thoracic pain (reporting thoracic pain for at least 3 months, however, pain at study start was not required).	Adults (18 to 60 years old) either healthy (asymptomatic) or with nonspecific LBP.
Exclusion Criteria	Unable to lie prone for ≥ 20 minutes, late pregnancy, head/neck/thoraco-abdominal or spine surgery within the past 4 weeks, severe respiratory condition that precludes lying prone, inability to hold breath for 10 seconds.	Diagnosed visceral condition that could refer pain to the chest wall.	Asymptomatic individuals had to report no current LBP or to report an ongoing LBP intensity of fewer than 1 on a 0-10 NPRS and did not have to report any LBP related sick leave in the past 12 months.

Questionnaires Completed	Web-based characteristic questionnaire (author created) to determine participant sex, age, recent LBP history.	1. Characteristic questionnaire (author created) to determine participant sex, age, weight and height. 2. Chronic Thoracic Pain Participants rated their pain intensity (max, min, and mean) in the past three months as well as current pain (0-100 numerical pain rating scale - NPRS)	1. Characteristic questionnaire (author created) to determine the participant's age, sex, height, weight and LBP history at baseline. 2. All participants rated their current LBP intensity on an 11-point NPRS
Baseline Physical Assessment	Free-standing height (cm), sitting height (cm), weight (kg), waist circumference (cm), waist posteroanterior diameter (cm)	No	No
Description of the testing protocol.	VerteTrack (VibeDx Diagnostic Corp. Edmonton, AB, Canada) applied a pre-selected vertical load (increments of 10 N with a maximum of 60 N) using weight plates. The load was applied in a continuous manner over the spine by a rolling system. The indenter apparatus consisted of a rod suspended within a linear bearing to permit near-frictionless vertical translation and an indentation roller comprising two circular plastic disks (Diameter 70 mm, width 15 mm). The indentation roller was moved in the X (longitudinal, superior-inferior), Y (transverse, left-right) and Z (vertical, P-A) axes by a stepping motor system (Resolution = 0.007 mm) (Stepperonline.com, China). The vertical position of the indenter relative to the frame was measured by a string potentiometer that provides real-time feedback to the control system (Resolution = 0.020 mm) (TE Connectivity, USA). A more	An apparatus using a servo-controlled linear actuator motor (Linear Motor Series P01-48x360, LinMot Inc., Zurich, Switzerland). The device indenter (θ = 18 mm) was manually positioned over the targeted spinous process. The indenter gradually (18 N/s) applies a 45 N load over the targeted spinous process following a 5 N preload application. The indenter displacement and load was recorded using LinMot-Talk 5.1 (LinMot Inc., Elkhorn, Wisconsin, United States) at a frequency of 135 Hz. Four experimental trials were performed for each spinal level (T5, T6, T7 and T8) and the average of the last three trials were used for data analysis. Participants were instructed to hold their breath at the end of normal exhalation during each spinal stiffness assessment. A complete description of the apparatus and its security features can be found elsewhere.(27)	A computer-controlled mechanical indentation device that applied an anteroposterior force to the participant's spinous process. The device was comprised a motor (Dual Motion Motor, Waterbury, CT) to move an indenter probe, a rotary encoder (Dual Motion Motor, Waterbury, CT) to quantify probe displacement, and a compression-tension load cell (Entran, Fairfield, NJ) to measure applied loading force. The device has demonstrated high accuracy (28) and excellent within- and between-day test-retest reliability measuring stiffness in people with and without LBP (15). Custom written LabVIEW software (National Instruments, Austin, USA) was used to control the loading speed (2.0 mm/s) of the probe and to collect force and displacement signals. All indentation was performed with force applied vertically at the contact site. Three experimental indentations were then performed with a preload of 5 N and with

	comprehensive overview of this device has been published elsewhere. (20)		a target load of 60 N. The participant was instructed to hold the breath at the end of normal exhalation throughout the indentation process.
Method to identify spinal levels	Through a combination of bony landmarks and motion palpation (29)	Through a combination of bony landmarks (30, 31)	Ultrasound
Loading Profile	Incrementally increasing by 10 N from 0-60 N	Continuously increased from 5 N to 45 N at 18 N/s	The indenter was lowered at 2 mm/s with a 1-second pause at a preload of 5N, and then continued to advance until the applied force reached 60 N. The indenter paused at 60N for 1 second before its withdrawal.
Spinal levels evaluated	L1, L2, L3	T5, T6, T7 and T8	L3
Calculation of the global spinal stiffness coefficient	The slope of the best straight line fitting the force displacement curve between 10 and 60 N.	The slope of the best straight line fitting the force displacement curve between 10 and 45 N.	The slope of the best straight line fitting the force displacement curve between 5 and 60 N.
Calculation of the terminal spinal stiffness coefficient	The ratio of the maximal applied force (60 N) to the maximal resultant displacement (mm).	The ratio of the variation of the load and the variation of the displacement between 10 and 45 N.	The ratio of the variation of load and the variation of the displacement between 5 and 60 N.

Table 2. Participants' characteristics per dataset

characteristic	Dataset A			Dataset B			Dataset C		
	All (n = 84)	0 day of LBP in the past week (n = 20)	≥ 1 day of LBP in the past week (n = 64)	All (n = 75)	Not reporting chronic thoracic pain (n = 25)	Reporting chronic thoracic pain (n = 50)	All (n = 129)	0 day of LBP in the past week (n = 85)	≥ 1 day of LBP in the past week (n = 44)
Males: females	54: 30	16: 4	38: 26	37: 38	13: 12	24: 26	51: 78	38: 47	13: 31
Age (years)	Median: 23 IQR: 3	Median: 23 IQR: 6	Median: 23 IQR: 3	Median: 27 IQR: 9	Median: 25 IQR: 7	Median: 27 IQR: 12	Mean: 29.3 SD: 10.1	Mean: 28.4 SD: 10.0	Mean: 31.0 SD: 10.3
Weight (kg)	Mean: 72.0 SD: 15.8	Mean: 72.8 SD: 9.2	Mean: 71.8 SD: 17.5	Median: 69.17 IQR: 16.77	Mean: 69.63 SD: 11.24	Median: 68.95 IQR: 15.88	Mean: 69.0 SD: 14.5	Mean: 67.9 SD: 15.0	Mean: 71.1 SD: 13.2
Standing height (m)	Mean: 1.72 SD: 0.95	Mean: 1.73 SD: 0.82	Mean: 1.71 SD: 0.99	Mean: 1.71 SD: 0.10	Mean: 1.72 SD: 0.11	Mean: 1.71 SD: 0.09	Mean: 1.7 SD: 0.1	Mean: 1.7 SD: 0.1	Mean: 1.7 SD: 0.1
BMI (kg/m^2)	Mean: 24.3 SD: 3.9	Mean: 24.39 SD: 2.28	Mean: 24.28 SD: 4.35	Mean: 23.94 SD: 3.60	Mean: 23.50 SD: 2.48	Mean: 24.17 SD: 4.07	Mean: 23.4 SD: 4.4	Mean: 22.7 SD: 4.4	Mean: 24.6 SD: 4.0
Seating height (cm)	Mean: 90.8 SD: 5.4	Mean: 91.3 SD: 4.9	Mean: 90.7 SD: 5.5						
Waist circumference (cm)	Mean: 84.2 SD: 10.4	Mean: 83.4 SD: 7.4	Mean: 84.5 SD: 11.2						
Waist P-A diameter (cm)	Mean: 18.7 SD: 3.4	Mean: 18.1 SD: 3.1	Mean: 18.9 SD: 3.5						
Waist-to-height ratio	Mean: 0.49 SD: 0.06	Mean: 0.48 SD: 0.05	Mean: 0.49 SD: 0.06						

Table 3. Global and terminal spinal stiffness per dataset (mean ± SD)

Stiffness coefficient	Spinal level	Dataset A			Spinal level	Dataset B			Spinal level	Dataset C		
		All (n = 84)	Males (n = 54) vs females (n = 30)	0 day of LBP in the past week (n = 20) vs ≥ 1 day of LBP in the past week (n = 64)		All (n = 75)	Males (n = 37) vs females (n = 38)	Not reporting chronic thoracic pain (n = 25) vs Reporting chronic thoracic pain (n = 50)		All (n = 129	Males (n = 51) vs females (n = 78)	0 day of LBP in the past week (n = 85) vs ≥ 1 day of LBP in the past week (n = 44)
Global	L1	1.14 ± 0.22	1.16 ± 0.22 vs 1.09 ± 0.22	1.11 ± 0.20 vs 1.15 ± 0.23	T5	7.87 ± 1.59	8.43 ± 1.30 vs 7.33 ± 1.68	8.23 ± 1.22 vs 7.69 ± 1.73	L3	5.70 ± 1.26	6.11 ±1.36 vs 5.44 ± 1.11	5.71 ± 1.24 vs 5.71 ± 1.24
	L3	1.14 ± 0.21	1.17 ± 0.22 vs 1.08 ± 0.20	1.13 ± 0.22 vs 1.14 ± 0.22	T6	8.13 ± 1.70	8.71 ± 1.73 vs 7.56 ± 1.45	8.55 ± 1.68 vs 7.91 ± 1.68				
	L5	1.16 ± 0.20	1.18 ± 0.19 vs 1.11 ± 0.22	1.15 ± 0.19 vs 1.16 ± 0.21	T7	8.32 ± 1.70	8.88 ± 1.65 vs 7.78 ± 1.58	8.79 ± 1.53 vs 8.08 ± 1.74				
					T8	8.22 ± 1.53	8.68 ± 1.66 vs 7.76 ± 1.26	8.78 ± 1.32 vs 7.93 ± 1.56				
Terminal	L1	1.04 ± 0.17	1.07 ± 0.17 vs 0.99 ± 0.17	1.02 ± 0.13 vs 1.05 ± 0.18	T5	8.11 ± 1.61	8.69 ± 1.28 vs 7.56 ± 1.71	8.54 ± 1.25 vs 7.90 ± 1.73	L3	5.68 ± 1.29	5.58 ±1.18 vs 5.01 ± 0.98	5.22 ± 1.07 vs 5.26 ± 1.15
	L3	1.02 ± 0.16	1.04 ± 0.15 vs 0.99 ± 0.17	1.00 ± 0.14 vs 1.03 ± 0.16	T6	8.36 ± 1.72	8.69 ± 1.78 vs 7.79 ± 1.46	8.86 ± 1.70 vs 8.11 ± 1.69				
	L5	1.00 ± 0.15	0.99 ± 0.15 vs 0.99 ± 0.16	0.98 ± 0.13 vs 1.01 ± 0.16	T7	8.50 ± 1.76	9.07 ± 1.77 vs 7.96 ± 1.59	9.02 ± 1.56 vs 8.25 ± 1.81				
					T8	8.39 ± 1.57	8.83 ± 1.70 vs 7.95 ± 1.31	8.99 ± 1.37 vs 8.08 ± 1.58				

Table 4. Correlations between terminal spinal stiffness and individual characteristics

Characteristic	Spinal level	Dataset A			Spinal level	Dataset B			Spinal level	Dataset C		
		All (n = 84)	0 day of LBP in the past week (n = 20)	≥ 1 day of LBP in the past week (n = 64)		All (n = 75)	Not reporting chronic thoracic pain (n = 25)	Reporting chronic thoracic pain (n = 50)		All (n = 129)	0 day of LBP in the past week (n = 85	≥ 1 day of LBP in the past week (n = 44)
Age	L1	r_e = 0.07 (-0.12, 0.24) p = 0.38	r_e = 0.09 (-0.39, 0.50) p = 0.60	r_e = 0.06 (-0.13, 0.26) p = 0.51	T5	r_e = 0.01 (-0.23, 0.28) p = 0.93	r_e = -0.11 (-0.54, 0.37) p = 0.62	r_e = 0.05 (-0.30, 0.35) p = 0.76	L3	r = 0.04 (-0.14, 0.21) p = 0.54	r = 0.09 (-0.12, 0.30) p = 0.22	r = -0.09 (-0.38, 0.21) p = 0.39
	L3	r_e = 0.05 (-0.13, 0.22) p = 0.51	r_e = 0.108 (-0.28, 0.49) p = 0.51	r_e = 0.03 (-0.18, 0.24) p = 0.71	T6	r_e = 0.00 (-0.24, 0.24) p = 1.00	r_e = -0.11 (-0.60, 0.41) p = 0.62	r_e = 0.07 (-0.24, 0.33) p = 0.67				
	L5	r_e = -0.02 (-0.20, 0.15) p = 0.76	r_e = 0.03 (-0.34, 0.38) p = 0.85	r_e = -0.05 (-0.23, 0.15) p = 0.61	T7	r_e = 0.02 (-0.24, 0.28) p = 0.87	r_e = 0.19 (-0.33, 0.61) p = 0.41	r_e = -0.02 (-0.38, 0.31) p = 0.89				
					T8	r_e = -0.10 (-0.33, 0.15) p = 0.44	r_e = -0.08 (-0.46, 0.34) p = 0.72	r_e = -0.08 (-0.41, 0.26) p = 0.62				
Sex[a]	L1	t(78) = 1.89 p = 0.06	t(17) = 0.58 p = 0.57	t(59) = 2.00 p = 0.05	T5	t(73) = 3.23 p = 0.002	t(23) = 0.93 p = 0.36	t(48) = 3.17 p = 0.003	L3	t(127) = 2.98 p = 0.04	t(83) = 1.68 p = 0.10	t(42) = 3.00 p = 0.01
	L3	t(78) = 1.33 p = 0.19	t(17) = 0.88 p = 0.39	t(59) = 1.25 p = 0.22	T6	t(73) = 3.06 p = 0.003	t(23) = 1.78 p = 0.09	t(48) = 2.44 p = 0.02				
	L5	t(78) = 0.67 p = 0.50	t(17) = 0.91 p = 0.38	t(59) = 0.58 p = 0.56	T7	t(73) = 2.86 p = 0.005	t(23) = 1.73 p = 0.10	t(48) = 2.25 p = 0.03				
					T8	t(73) = 2.52 p = 0.01	t(23) = 1.38 p = 0.18	t(48) = 2.09 p = 0.04				
Standing height	L1	r = 0.21 (0.01, 0.40) p = 0.06 n = 82	r = 0.35 (-0.05, 0.70) p = 0.14	r = 0.19 (-0.06, 0.41) p = 0.15	T5	r_e = 0.48 (0.16, 0.73) p = 0.01	r = 0.45 (0.05, 0.75) p = 0.02	r = 0.33 (0.03, 0.61) p = 0.02	L3	r = 0.18 (0.01, 0.34) p = 0.04	r = 0.11 (0.10, 0.32) p = 0.31	r = 0.33 (0.04, 0.57) p = 0.03
	L3	r = 0.15 (-0.06, 0.36), p = 0.17 n = 82	r = 0.39 (0.02, 0.73) p = 0.09	r = 0.11 (-0.19, 0.38) p = 0.42	T6	r_e = 0.49 (0.18, 0.71) p = 0.01	r = 0.30 (-0.20, 0.68) p = 0.14	r = 0.18 (-0.08, 0.45) p = 0.22				
	L5	r = 0.13 (-0.12, 0.36) p = 0.26 n = 82	r = 0.49 (0.15, 0.78) p = 0.03	r = 0.06, (-0.23, 0.35) p = 0.64	T7	r_e = 0.51 (0.21, 0.75) p = 0.003	r = 0.58 (0.35, 0.77) p = 0.003	r = 0.29 (-0.01, 0.56) p = 0.045				
					T8	r_e = 0.45 (0.11, 0.70) p = 0.01	r = 0.46 (0.15, 0.68) p = 0.02	r = 0.24 (-0.08, 0.51) p = 0.10				

Sitting height	L1	r = 0.16 (-0.04, 0.36) p = 0.16 n = 80	r = 0.06 (-0.48, 0.51) p = 0.80	r = 0.19 (-0.04, 0.40) p = 0.15	T5				L3			
	L3	r = 0.06 (-0.17, 0.28), p = 0.63 n = 80	r = 0.06 (-0.48, 0.50) p = 0.81	r = 0.06 (-0.18, 0.31) p = 0.66	T6							
	L5	r = -0.01 (-0.25, 0.22), p = 0.90 n = 80	r = 0.11 (-0.54, 0.59) p = 0.65	r = -0.036 (-0.28, 0.22) p = 0.78	T7							
					T8							
Weight	L1	r = 0.1 (-0.11, 0.32) p = 0.35 n = 82	r = 0.35 (-0.29, 0.71) p = 0.13	r = 0.07 (-0.17, 0.31) p = 0.57	T5	r_e = 0.32 (0.08, 0.52) p = 0.01	r = 0.42 (0.07, 0.70) p = 0.04	r_e = 0.40 (0.14, 0.66) p = 0.01	L3	r = -0.10 (-0.27, 0.07) p = 0.08	r = -0.13 (-0.33, 0.09) p = 0.08	r = - 0.08 (-0.36, 0.23) p = 0.63
	L3	r = -0.03 (-0.26, 0.21) p = 0.78 n = 82	r = 0.42 (-0.26, 0.78) p = 0.06	r = -0.09 (-0.33, 0.17) p = 0.47	T6	r_e = 0.41 (0.19, 0.61) p = 0.001	r = 0.10 (-0.29, 0.45) p = 0.62	r_e = 0.37 (0.08, 0.62) p = 0.02				
	L5	r = -0.21 (-0.39, 0.05) p = 0.06 n = 82	r = 0.21 (-0.37, 0.67) p = 0.39	r = -0.26 (-0.46, 0.01) p = 0.04	T7	r_e = 0.28 (0.07, 0.48) p = 0.02	r = 0.56 (0.19, 0.80) p = 0.003	r_e = 0.22 (-0.05, 0.46) p = 0.16				
					T8	r_e = 0.26 (0.01, 0.49) p = 0.04	r = 0.46 (0.11, 0.69) p = 0.02	r_e = 0.23 (-0.07, 0.52) p = 0.15				
BMI	L1	r = 0.01 (-0.23, 0.23) p = 0.96 n = 82	r = 0.12 (-0.65, 0.61) p = 0.63	r = -0.01 (-0.22, 0.25) p = 0.95	T5	r_e = 0.16 (-0.08, 0.41) p = 0.19	r = -0.22 (-0.64, 0.28) p = 0.30	r = 0.18 (-0.08, 0.42) p = 0.21	L3	r = -0.25 (-0.40, -0.08) p < 0.001	r = -0.25 (-0.44, -0.04) p = 0.001	r = -0.39 (-0.68, -0.11) p = 0.01
	L3	r = -0.14 (-0.35, 0.08) p = 0.20 n = 82	r = 0.17 (-0.64, 0.71) p = 0.48	r = -0.19 (-0.39, 0.04) p = 0.14	T6	r_e = 0.23 (-0.02, 0.47) p = 0.06	r = 0.16 (-0.33, 0.66) p = 0.43	r = 0.34 (0.01, 0.58) p = 0.02				
	L5	r = -0.35 (-0.54, -0.14) p = 0.001 n = 82	r = -0.21 (-0.84, 0.47) p = 0.37	r = -0.37 (-0.56, -0.13) p = 0.003	T7	r_e = 0.05 (-0.18, 0.28) p = 0.70	r = 0.15 (-0.30, 0.57) p = 0.48	r = 0.01 (-0.28, 0.27) p = 0.97				

					T8	r_e = 0.12 (-0.13, 0.35) p = 0.35	r = 0.04 (-0.29, 0.39) p = 0.87	r = 0.08 (-0.22, 0.40) p = 0.59				
Waist circumference	L1	r = 0.04 (-0.21, 0.28) p = 0.72 n = 82	r = 0.28 (-0.53, 0.68) p = 0.24	r = -0.01 (-0.23, 0.22) p = 0.97	T5				L3			
	L3	r = -0.05 (-0.32, 0.21) p = 0.63 n = 82	r = 0.34 (-0.50, 0.76) p = 0.14	r = -0.13 (-0.35, 0.10) p = 0.32	T6							
	L5	r = -0.22 (-0.44, 0.04) p = 0.049 n = 82	r = 0.11 (-0.58, 0.66) p = 0.64	r = -0.28 (-0.48, -0.05) p = 0.03	T7							
					T8							
Waist postero-anterior diameter	L1	r = 0.02 (-0.23, 0.25) p = 0.88 n = 82	r = 0.34 (-0.29, 0.71) p = 0.14	r = -0.07 (-0.32, 0.19) p = 0.60	T5				L3			
	L3	r = -0.05 (-0.29, 0.2) p = 0.65 n = 82	r = 0.39 (-0.36, 0.76) p = 0.09	r = -0.16 (-0.39, 0.11) p = 0.20	T6							
	L5	r = -0.2 (-0.42, 0.06) p = 0.08 n = 82	r = 0.30 (-0.33, 0.80) p = 0.20	r = -0.32 (-0.54, -0.03) p = 0.01	T7							
					T8							
Waist-to-height ratio	L1	r = -0.06 (-0.31, 0.18) p = 0.59 n = 82	r = 0.07 (-0.57, 0.52) p = 0.76	r = -0.10 (-0.38, 0.19) p = 0.46	T5				L3			
	L3	r = -0.13 (-0.38, 0.11) p = 0.24 n = 82	r = 0.11 (-0.57, 0.60) p = 0.65	r = -0.19 (-0.45, 0.09) p = 0.13	T6							
	L5	r = -0.29 (-0.51, -0.06) p = 0.01 n = 82	r = -0.14 (-0.70, 0.43) p = 0.54	r = -0.33 (-0.55, -0.07) p = 0.01	T7							
					T8							

[a] A significant difference implies lower spinal stiffness in females compared to males

Table 5. Correlations between global spinal stiffness and individual characteristics

Characteristic	Spinal level	Dataset A			Spinal level	Dataset B			Spinal level	Dataset C		
		All (n = 84)	0 day of LBP in the past week (n = 20)	≥ 1 day of LBP in the past week (n = 64)		All (n = 75)	Not reporting chronic thoracic pain (n = 25)	Reporting chronic thoracic pain (n = 50)		All (n = 129)	0 day of LBP in the past week (n = 85)	≥ 1 day of LBP in the past week (n = 44)
Age	L1	r_e = 0.08 (-0.08, 0.24) p = 0.33	r_e = -0.06 (-0.52, 0.39) p = 0.72	r_e = 0.13 (-0.10, 0.34) p = 0.15	T5	r_e = 0.02 (-0.23, 0.29) p = 0.89	r_e = -0.11 (-0.52, 0.36) p = 0.62	r_e = 0.06 (-0.29, 0.36) p = 0.68	L3	r = 0.06 (-0.11, 0.23) p = 0.31	r = 0.07 (-0.14, 0.28) p = 0.52	r = -0.04 (-0.33, 0.26) p = 0.74
	L3	r_e = 0.08 (-0.08, 0.24) p = 0.31	r_e = -0.09 (-0.46, 0.32) p = 0.60	r_e = 0.13 (-0.11, 0.33) p = 0.16	T6	r_e = 0.01 (-0.23, 0.26) p = 0.95	r_e = -0.12 (-0.59, 0.39) p = 0.59	r_e = 0.08 (-0.22, 0.37) p = 0.59				
	L5	r_e = 0.03 (-0.13, 0.21) p = 0.70	r_e = -0.10 (-0.52, 0.30) p = 0.57	r_e = 0.06 (-0.16, 0.29) p = 0.48	T7	r_e = 0.02 (-0.25, 0.27) p = 0.89	r_e = 0.10 (-0.43, 0.56 p = 0.66	r_e = -0.01 (-0.37, 0.32 p = 0.98				
					T8	r_e = - 0.09 (-0.34, 0.16) p = 0.49	r_e = -0.04 (-0.44, 0.41) p = 0.87	r_e = -0.05 (-0.38, 0.27) p = 0.73				
Sex [a]	L1	t(78) = 1.69 p = 0.10	t(17) = 0.50 p = 0.62	t(59) = 1.91 p = 0.06	T5	t(73) = 3.15 p = 0.002	t(23) = 0.85 p = 0.41	t(48) = 3.11 p = 0.003	L3	t(127) = 3.05 p = 0.03	t(83) = 1.75 p = 0.08	t(42) = 2.94 p = 0.01
	L3	t(78) = 2.29 p = 0.02	t(17) = 0.76 p = 0.46	t(59) = 2.38 p = 0.02	T6	t(73) = 3.09 p = 0.003	t(23) = 1.82 p = 0.08	t(48) = 2.43 p = 0.02				
	L5	t(78) = 2.01 p = 0.048	t(17) = 0.63 p = 0.54	t(59) = 2.08 p = 0.04	T7	t(73) = 2.95 p = 0.004	t(23) = 2.03 p = 0.05	t(48) = 2.17 p = 0.04				
					T8	t(73) = 2.71 p = 0.01	t(23) = 1.53 p = 0.14	t(48) = 2.22 p = 0.03				
Standing height	L1	r = 0.14 (-0.12, 0.38) p = 0.21 n = 81	r = 0.23 (-0.28, 0.73) p = 0.34	r = 0.13 (-0.21, 0.44) p = 0.31	T5	r = 0.31 (0.10, 0.52) p = 0.01	r = 0.29 (-0.22, 0.66) p = 0.16	r = 0.33 (0.02, 0.61) p = 0.02	L3	r = 0.21 (0.04, 0.37) p = 0.02	r = 0.13 (-0.08, 0.34) p = 0.23	r = 0.37 (0.08, 0.60) p = 0.01
	L3	r = 0.22 (-0.01, 0.40) p = 0.05 n = 81	r = 0.29 (-0.22, 0.75) p = 0.24	r = 0.20 (-0.06, 0.45) p = 0.11	T6	r = 0.32 (0.10, 0.49) p = 0.01	r = 0.55 (0.32, 0.74) p = 0.01	r = 0.18 (-0.08, 0.44) p = 0.22				
	L5	r = 0.20 (-0.01, 0.40) p = 0.07 n = 81	r = 0.39 (-0.17, 0.78) p = 0.10	r = 0.16 (-0.10 0.45) p = 0.20	T7	r = 0.33 (0.12, 0.53) p = 0.004	r = 0.47 (0.17, 0.68) p = 0.02	r = 0.27 (-0.03, 0.55) p = 0.06				
					T8	r = 0.31 (0.08, 0.50) p = 0.01	r = 0.45 (0.05, 0.75) p = 0.02	r = 0.24 (-.07, 0.52) p = 0.09				
Sitting height	L1	r = 0.07	r = 0.09	r = 0.07	T5				L3			

		(-0.23, 0.35) $p = 0.54$ n = 80	(-0.48, 0.52) $p = 0.73$	(-0.21, 0.37) $p = 0.58$								
	L3	$r = 0.13$ (-0.15, 0.39) $p = 0.25$ n = 80	$r = 0.14$ (-0.39, 0.56) $p = 0.59$	$r = 0.13$ (-0.13, 0.39) $p = 0.31$	T6							
	L5	$r = 0.07$ (-0.21, 0.33), $p = 0.55$ n = 80	$r = 0.17$ (-0.46, 0.58) $p = 0.50$	$r = 0.05$ (-0.25, 0.35) $p = 0.72$	T7							
					T8							
Weight	L1	$r = 0.08$ (-0.12, 0.27) $p = 0.47$ n = 81	$r = 0.25$ (-0.37, 0.66) $p = 0.29$	$r = 0.06$ (-0.18, 0.28) $p = 0.62$	T5	$r_e = 0.31$ (0.07, 0.52) $p = 0.01$	$r = 0.11$ (-0.29, 0.44) $p = 0.62$	$r_e = 0.41$ (0.15, 0.66) $p = 0.01$	L3	$r = -0.08$ (-0.25, 0.09) $p = 0.18$	$r = -0.11$ (-0.32, 0.10) $p = 0.13$	$r = 0.03$ (-0.27, 0.32) $p = 0.80$
	L3	$r = 0.05$ (-0.13, 0.22) $p = 0.64$ n = 81	$r = 0.27$ (-0.23, 0.66) $p = 0.26$	$r = 0.02$ (-0.18, 0.23) $p = 0.86$	T6	$r_e = 0.41$ (0.18, 0.61) $p = 0.001$	$r = 0.53$ (0.17, 0.79) $p = 0.01$	$r_e = 0.37$ (0.09, 0.63) $p = 0.01$				
	L5	$r = -0.08$ (-0.27, 0.12) $p = 0.47$ -n = 81	$r = 0.20$ (-0.25, 0.69) $p = 0.41$	$r = -0.12$ (-0.32, 0.13) $p = 0.35$	T7	$r_e = 0.30$ (0.08, 0.50) $p = 0.02$	$r = 0.50$ (0.14, 0.72) $p = 0.01$	$r_e = 0.25$ (-0.01, 0.49) $p = 0.11$				
					T8	$r_e = 0.30$ (0.05, 0.51) $p = 0.02$	$r = 0.41$ (0.07, 0.70) $p = 0.04$	$r_e = 0.27$ (-0.02, 0.54) $p = 0.08$				
BMI	L1	$r = 0.00$ (-0.17, 0.18) $p = 1.00$ n = 81	$r = 0.11$ (-0.66, 0.73) $p = 0.67$	$r = -0.01$ (-0.21, 0.19) $p = 0.92$	T5	$r_e = 0.17$ (-0.07, 0.41) $p = 0.16$	$r = -0.20$ (-0.63, 0.31) $p = 0.34$	$r = 0.18$ (-0.06, 0.42) $p = 0.21$	L3	$r = -0.24$ (- 0.39, 0.07) $p < 0.001$	$r = -0.22$ (-0.41, -0.01) $p = 0.003$	$r = -0.22$ (-0.49, - 0.08) $p = 0.03$
	L3	$r = -0.08$ (-0.26, 0.09) $p = 0.48$ n = 81	$r = 0.08$ (-0.62, 0.71) $p = 0.74$	$r = -0.11$ (-0.29, 0.08) $p = 0.41$	T6	$r_e = 0.25$ (0.00, 0.48) $p = 0.04$	$r = 0.16$ (-0.34, 0.63) $p = 0.46$	r = 0.34 (0.05, 0.58) $p = 0.02$				
	L5	$r = -0.25$ (-0.41, -0.07) $p = 0.03$ n = 81	$r = -0.11$ (-0.70, 0.77) $p = 0.64$	$r = -0.27$ (-0.45, -0.08) $p = 0.03$	T7	$r_e = 0.08$ (-0.14, 0.30) $p = 0.51$	$r = 0.19$ (-0.28, 0.60) $p = 0.36$	$r = 0.03$ (-0.25, 0.28) $p = 0.83$				
					T8	$r_e = 0.16$ (-0.10, 0.39) $p = 0.19$	$r = 0.47$ (0.17, 0.68) $p = 0.02$	$r = 0.10$ (-0.19, 0.42) $p = 0.49$				

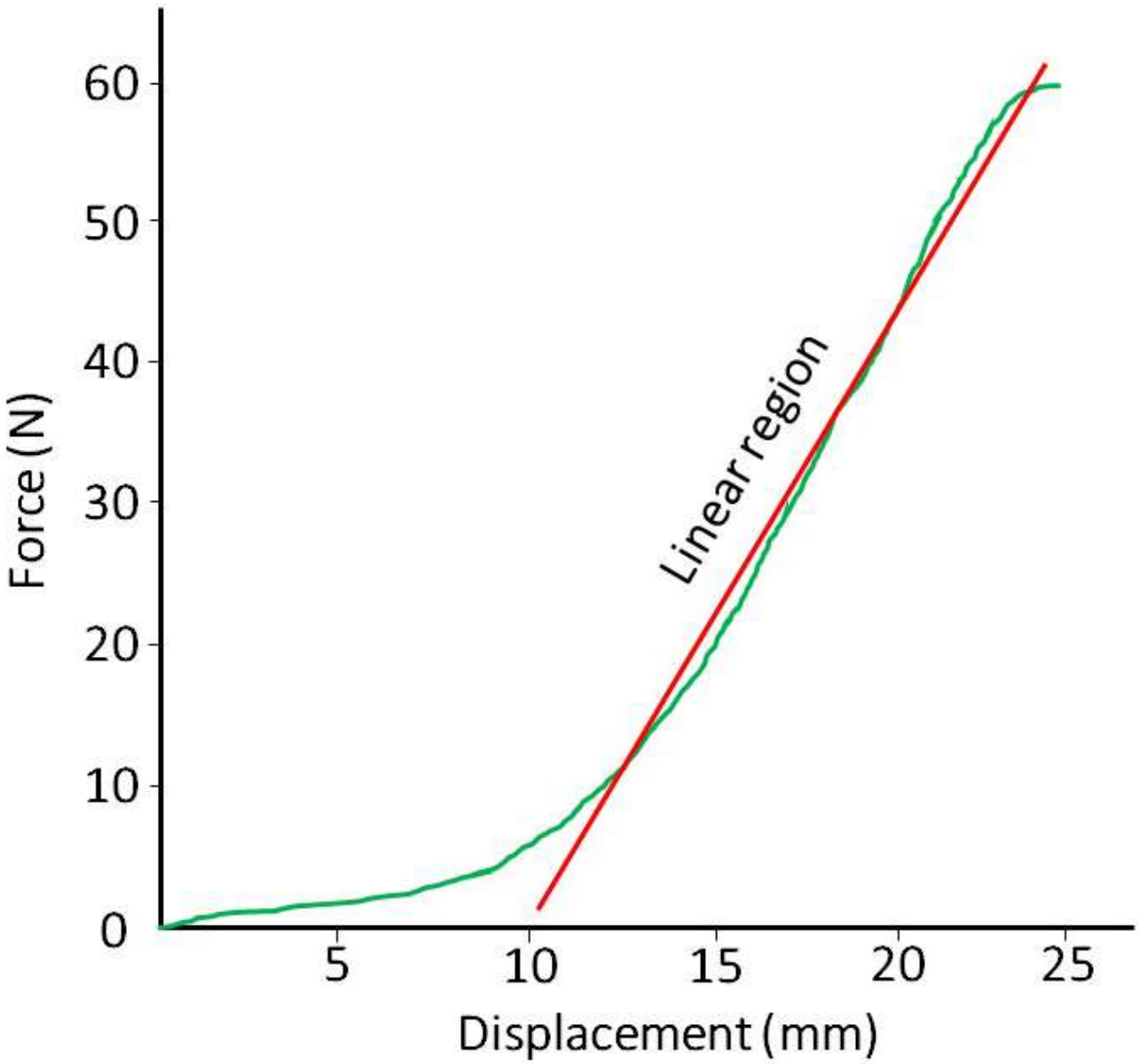
Waist circumference	L1	r = 0.01 (-0.18, 0.21) p = 0.93 n = 81	r = 0.21 (-0.49, 0.67) p = 0.39	r = -0.03 (-0.23, 0.19) p = 0.82	T5				L3			
	L3	r = -0.02 (-0.18, 0.16) p = 0.86 n = 81	r = 0.20 (-0.36, 0.66) p = 0.42	r = -0.07 (-0.26, 0.13) p = 0.61	T6							
	L5	r = -0.15 (-0.32, 0.05) p = 0.19 n = 81	r = 0.13 (-0.41, 0.72) p = 0.61	r = -0.2 (-0.38, 0.01) p = 0.12	T7							
					T8							
Waist postero-anterior diameter	L1	r = 0.05 (-0.19, 0.27) p = 0.66 n = 81	r = 0.27 (-0.24, 0.68) p = 0.27	r = -0.01 (-0.30, 0.24) p = 0.92	T5				L3			
	L3	r = -0.03 (-0.27, 0.19) p = 0.81 n = 81	r = 0.15 (-0.34, 0.60) p = 0.54	r = -0.08 (-0.34, 0.19) p = 0.55	T6							
	L5	r = -0.12 (-0.34, 0.13) p = 0.30 n = 81	r = 0.18 (-0.35, 0.72) p = 0.47	r = -0.19 (-0.43, 0.09) p = 0.13	T7							
					T8							
Waist-to-height ratio	L1	r = -0.07 (-0.25, 0.11) p = 0.56 n = 81	r = 0.08 (-0.50, 0.66) p = 0.75	r = -0.11 (-0.31, 0.09) p = 0.41	T5				L3			
	L3	r = -0.13 (-0.29, 0.04) p = 0.24 n = 81	r = 0.04 (-0.50, 0.62) p = 0.87	r = -0.18 (-0.36, 0.01) p = 0.16	T6							
	L5	r = -0.26 (-0.41, -0.06) p = 0.02 n = 81	r = -0.08 (-0.61, 0.68) p = 0.76	r = -.31 (-0.48, -0.09) p = 0.02	T7							
					T8							

[a] A significant difference implies lower spinal stiffness in females compared to males

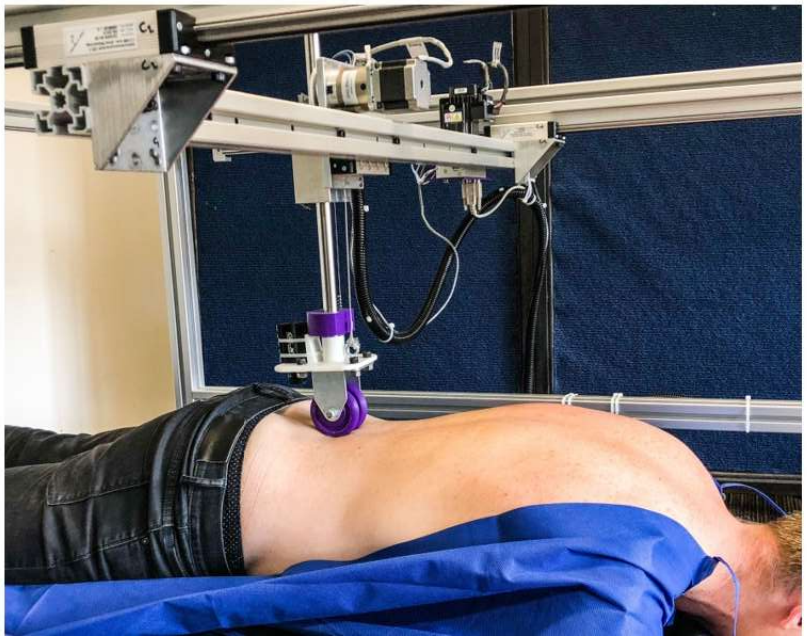
Figure captions

Figure 1. A typical force-displacement curve obtained from a thoracic or lumbar vertebra during an instrumented spinal stiffness assessment. Although there is no consensus in the literature, two common methods have been used to estimate the global and terminal spinal stiffness coefficients.(6) Global spinal stiffness is estimated from the slope of the linear region on a Force-Displacement (F-D) curve. This coefficient represents the stiffness of underlying tissues throughout the indentation (6) or the tissue dynamics in response to indentation force (8). Terminal spinal stiffness is estimated from the final loading force and the overall displacement of the indenter and indicates the overall bulk response.(8)

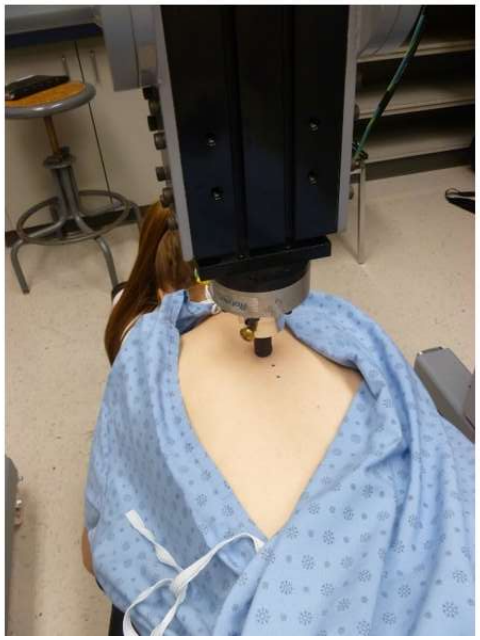
Figure 2. Devices respectively used in the studies providing dataset A, B and C. Spinal stiffness was determined based on the load displacement curve obtained by each device, however, the protocol used differed between studies.


60
50
40
30
20
10
0
Force (N)
5
10
15
20
25
Displacement (mm)
Linear region

A. Dataset A device



B. Dataset B device



C. Dataset C device