Author(s): Mitchell, Ulrike H.; Owen, Patrick J.; Rantalainen, Timo; Belavý, Daniel L.

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Increased joint mobility is associated with impaired transversus abdominis contraction

ABSTRACT

Increased joint mobility is a risk factor for joint injury, but muscle function may be able to compensate for it. Current evidence suggests reduced force production capacity in people with hypermobility. However, little is known about the lumbar spine. The purpose of this cross-sectional study was to assess if there was a link between joint mobility and transverse abdominis and multifidus muscles contraction, muscles ascribed a core-stability role.

Using a modified quantitative version of the Beighton scale (BOM score), we measured joint mobility of 30 middle-aged individuals without low back pain. These scores were correlated with MRI-derived measures of transverse abdominis and multifidus muscle contraction during a spinal loading manoeuvre. The level of significance was set for $p \leq 0.05$.

The results showed greater joint mobility (higher BOM score) correlated ($r = 0.468$; $p = 0.009$) with reduced transversus abdominis shortening during contraction (i.e. less muscle shortening in people with greater joint mobility). The trunk subdomain score exhibited a correlation of 0.354 with transversus abdominis length change, but this did not reach statistical significance ($p = 0.055$). The subdomains of the BOM score did not correlate significantly with each other ($p \geq 0.097$). No association was seen between multifidus contraction and joint mobility.

The results suggest that greater general joint mobility is associated with impaired contraction of the transversus abdominis muscle. This should be considered when coaching athletes or treating patients with (functional) spinal instability. The quantitative approach to measuring joint mobility we developed could be used in the future studies of global flexibility.

Key words: Muscle; Rehabilitation; Physiotherapy; Physical Therapy; Fascia; Laxity

INTRODUCTION

The transversus abdominis muscle (TrA) is ascribed a role in stabilising the lumbar spine (26). The TrA arises from the inner surface of the 7th to 12th costal cartilages, the thoracolumbar fascia, the iliac crest, and the inguinal ligament and attaches to the linea alba. Due to the muscle’s insertions and largely transverse fiber orientation it tightens the thoracolumbar fascia when it contracts, thus increasing intra-abdominal pressure (12) and spinal stiffness (6, 13). Reduced or delayed TrA contraction has been linked to a greater lumbar spine “neutral zone” motion in flexion, which was explained by reduced tension in the thoracolumbar fascia (2). The importance of the muscle and its role in low back pain and rehabilitation has been the subject of discussion, mostly in regard to its ability to contract prior to extremity movements (feedforward function) (10, 14). The lumbar multifidus muscle acts as a force couple partner to the TrA in stabilizing the spine. It is a four-layer muscle with origins on the spinous process, mammillary process and superior articular process and insertions on facet capsule and mammillary process. In addition, it features interlaminar fibers (15). There is a positive relationship between the ability to contract the multifidus and the TrA muscles (11).

Hypermobility of joints is postulated to be a risk factor for joint injuries (17, 18). Hypothetically, greater joint laxity results in a higher likelihood of excessive joint translations, subluxations and dislocations and hence damage to articular and periarticular structures. A joint is considered to be hypermobile when its range of motion exceeds the expected normalized standard (8). When several joints are affected and when accompanied by musculoskeletal pains the condition is commonly referred to as generalized joint hypermobility (GJH) (7). The primary cause of this benign disorder is ligamentous laxity due to a connective tissue disorder and is genetically anchored (8). GJH has been found to be associated with decreased isokinetic (20) and isometric (21) muscle strength in shoulder abductors, finger flexors (grip strength), knee extensors and ankle dorsiflexors (20, 21). The impact of local or widespread joint (hyper)mobility on transverse abdominis and multifidus muscle function has not been studied.

Criteria for assessing GJH were first described by Carter and Wilkinson in 1964 (5) and should therefore be considered the original assessment tool. The scale was then modified by Beighton and Horan in 1969 (3), and amended in 1973 by Beighton et al. (4). Currently, GJH is commonly measured with the latter (4), a 9-point scale that assesses the end ranges of motion of four joints on each extremity and of the spine. Beighton et al. (4) intended the scale to be an easily used and uncomplicated epidemiological screening tool that uses dichotomous categorical yes/no questions. The Beighton-score was not, however, designed to quantify hypermobility or to assess for subtle mobility differences within- and between participants (22). To assess the relationship between TrA contraction and joint laxity, we implemented a modified, quantitative, version of the Beighton scoring system, referred to as [redacted for review purposes] (BOM) score.

The purpose of this study was to assess TrA and multifidus length changes with contraction in healthy middle-aged participants and correlate this to their mobility. The participants were not chosen for their mobility. We hypothesized that the TrA would, to account for the increased laxity and compliance of the connective tissue, demonstrate greater contraction (shortening) in more mobile participants. We also hypothesized that multifidus contraction would not correlate with increased mobility given that the muscle does not attach to soft tissue. A secondary purpose was to perform an exploratory analysis, i.e. to assess if this new version of the Beighton scale has, in principle, the potential of being used in the clinical field. We defined ‘success’ as the ability for our new scale to demonstrate a significant correlation with parameters of TrA and MF contraction.

METHODS

Experimental Approach to the Problem

This exploratory analysis uses a cross-section design.

Subjects

The University Faculty of Health Human Ethics Advisory Group approved this study. All participants were informed of the benefits and risks of the investigation prior to signing the institutionally approved informed consent document to participate in the study. Exclusion criteria included: history of or current shoulder, thoracic, neck or lumbar spine pain for which treatment was sought ("treatment" was defined as having seen a physiotherapist, chiropractor, osteopath or medical doctor for the condition), known scoliosis or osteoporosis, and inability to communicate in English. Thirty participants (N = 18 males and 12 females) were analysed. Participants had a mean(standard deviation; SD) age of 43(7) years, height of 170.7(9.0) cm and weight of 67.9(10.9) kg.

Procedures

Magnetic resonance imaging (MRI), image processing and analysis

MRI was performed under two conditions in a supine position, with the participant: 1) at rest with knees slightly flexed over a rolled towel and 2) performing an isometric narrow chest press with arms maintained torso width apart, while simultaneous raising the sternum (Fig 1). Resistance bands were used to provide loading through the arms during the exercise condition, with a resistive load at an estimated 20% one-repetition maximum based on the threshold between 'fair' and 'good' normative values for age, sex and weight (1) achieved when the hands were 28 cm anterior to the chest. Resistance was determined by digital force gauge (Digital Scale 40 kg, Rogue, China, Australia). This exercise was to increase intra-abdominal pressure and stimulate TrA contraction (14) in a more functional way compared to the abdominal drawing-in maneouver. Hence, position 1) was used to scan the TrA at rest, position 2) was used to scan the TrA during contraction. Each scan lasted about 30 seconds. Rolled towels were placed under the cervical and lumbar spine to ensure that a neutral spine position was maintained throughout the scan. A rolled towel was positioned under the knees to prevent knee straightening. During both conditions participants were instructed to hold their breath after breathing in and remain static during scans.

< Figure 1 about here >

To quantify muscle morphology on a 3T Phillips Ingenia scanner (Amsterdam, Netherlands) a T2-weighted sequence (thickness, 3 mm; interslice distance, 7 mm; repetition time, 2643 ms; echo time, 60ms; field of view, 347 x 347 mm, 768 x 768 pixels) was used with spinal coils to collect 14 axial images encompassing the volume of the transversus abdominis from the perineum up to the rib cage. Data were exported for offline processing. To ensure blinding of the examiner, each subject was assigned a random numeric code (obtained from www.random.org). ImageJ 1.48v (http://rsb.info.nih.gov/ij/) was used to perform all quantitative MRI measures.

After tracing around the transversus abdominis muscle (Fig 2), a custom written ImageJ plugin (“ROI Analyzer”; https://github.com/tjrantal/RoiAnalyzer and https://sites.google.com/site/daniellbelavy/home/roianalyser) was used to fit a fourth order polynomial to the region of interest and the curvature from the muscle was removed. Mean muscle length and thickness were calculated in both conditions (at rest and during contraction). Similarly, the multifidus was traced around (Fig 2), peak anteroposterior and mediolateral thicknesses were calculated. Data were averaged across all slices, as well as between the left and right sides.

< Figure 2 about here >

[redacted for review purposes] (BOM) score

Our modified, quantitative, version of the Beighton score (4) was calculated as the sum of nine variables that consisted of measurements on a continuous scale, as opposed to the sum of nine categorical (positive test = 1; negative test = 0) variables. Hence, a score closer to ‘0’ indicated no or little hypermobility, whereas a score closer to ‘1’ indicated greater hypermobility. The nine variables and their calculations are as follows:

Variables 1 and 2: Passive extension of the fifth fingers (digitus minimus)

These two variables examined passive extension of the little fingers (left and right) with the subject sitting, their forearm in a pronated position and hand placed firmly on a solid surface (lower limit = 0 degrees). The angle of extension was obtained to the nearest degree (test outcome). As per criteria proposed by Beighton et al. (4), 90 degrees corresponded with a positive test and was considered the upper limit. To obtain the score for these variables, the test outcome was divided by the upper limit. Values beyond the accepted upper limit were not used for calculations (e.g. angles of extension >90 degrees were recorded as 90 degrees; hence resulting in a score of 1).

$$Item\ 1\ and\ 2\ (score) = \frac{test\ outcome\ [range, 0 - 90]}{90}$$

< Figure 3 about here >

Items 3 and 4: Passive apposition of the thumb (right and left pollux) to the ventral aspect of the forearm in the sagittal plane

These two variables examined passive apposition of the thumbs (left and right). The subject apposed their thumb passively to the ventral aspect of the forearm. The distance from the most distal aspect of the thumb to the ventral aspect of the forearm was measured to the nearest 0.1 cm (test outcome). A positive test according to Beighton et al. (4) would correspond with 0 cm (upper limit). For calculations of the lower limit, the wrist was held in flexion, which provided a 90-degree angle between the metacarpal (and first and second phalanx) of the thumb and ventral surface of the forearm. The average distance from the carpometacarpal joint to the most distal aspect of the second phalanx of the thumb in humans is 11.7 cm (9). Using these data, we calculated the arc length (lower limit) between the most distal aspect of the second phalanx of the thumb to the ventral aspect of the forearm [Arc length = $2\pi r\left(\frac{C}{360}\right) = 2\pi(11.7)\left(\frac{90}{360}\right) = 18.4$]. Given these data, the score for these variables was calculated by subtracting the test outcome from the lower limit, which was then divided by the lower limit. Values beyond the accepted lower limit were not used for calculations (e.g. test outcomes >18.4 cm were recorded as 18.4 cm; hence resulting in a score of 0).

$$Item\ 3\ and\ 4\ (score) = \frac{18.4 - test\ outcome\ [range, 18.4 - 0]}{18.4}$$

< Figure 4 about here >

Variables 5 and 6: Hyperextension of the elbows

These two variables examined hyperextension of the elbows (left and right) with the subject sitting, the shoulder flexed to 90 degrees, the forearm supinated. The angle of hyperextension beyond 180 degrees was obtained to the nearest degree (test outcome). As per criteria proposed by Beighton et al. (4), 10 degrees corresponded with a positive test and was considered the upper limit. To obtain the score for these variables, the test outcome was divided by the upper limit. Values beyond the accepted upper limit were not used for calculations (e.g. hyperextension >10 degrees were recorded as 10 degrees; hence resulting in a score of 1).

$$Item\ 5\ and\ 6\ (score) = \frac{test\ outcome\ [range, 0 - 10]}{10}$$

Variables 7 and 8: Hyperextension of the knees

These two variables examined hyperextension of the knees (left and right) whilst the patient was in supine position. The angle of hyperextension beyond 0 degrees was obtained to the nearest degree (test outcome). As per criteria proposed by Beighton et al. (4), 10 degrees corresponded with a positive test and was considered the upper limit. To obtain the score for these variables, the test outcome was divided by the upper limit. Values beyond the accepted the upper limit were not used for calculations (e.g. hyperextension >10 degrees were recorded as 10 degrees; hence resulting in a score of 1).

$$Item\ 7\ and\ 8\ (score) = \frac{test\ outcome\ (range, 0 - 10)}{10}$$

Variable 9: Forward flexion of the trunk with knees straight

This variable examined forward flexion of the trunk with knees straight whilst the patient was standing on a flat solid surface. The distance from the distal carpal row to the ground was obtained to the nearest

0.1 cm (test outcome). A positive test according to Beighton et al. (4) would correspond with 0 cm (upper limit). For calculations of the lower limit, several referent values were utilised. Normative values for the sit-and-reach test, a test that similarly assesses flexibility during trunk forward flexion, were determined. The average ("good") reach value for adults aged 40-49 years is 4.5 cm beyond the level of the toes (1). This measurement is taken from the most distal point of the distal phalanx of the third digit, not from the carpals, as it is done in Beighton's forward flexion test. Therefore, the average distance from the most distal point of the distal phalanx of the third digit to the carpals (18.6 cm in humans (9)) was subtracted from this result, which determined that 14.1 cm was the average lower limit. Given these data, the score for these variables was calculated by subtracting the test outcome from the lower limit, which was then divided by the lower limit. Values beyond the accepted lower limit were not used for calculations (e.g. test outcomes > 14.1 cm were recorded as 14.1 cm; hence resulting in a score of 0).

$$Item\ 9\ (score) = \frac{14.1 - test\ outcome\ [range, 14.1 - 0]}{14.1}$$

Data for joint subdomains were calculated as follows: 1) left plus right little fingers [two variables combined], 2) left plus right thumbs [two variables combined], 3) left plus right elbows [two variables combined], 4) left plus right knees [two variables combined], and 5) trunk [single variable].

To obtain test-retest reliability of the BOM score, it was measured six times each on six different volunteers which is sufficient to attain a precise measure of repeatability (9). All measurements were performed on the same day. The intraclass correlation coefficients (ICC)2,1 and standard error of the measurement (SEM) were as follows:

BOM score: ICC=0.99 (SEM=0.4)

Right little finger: ICC=0.98 (SEM=2.9)

Left little finger: ICC=0.98 (SEM=2.6)

Right thumb: ICC=0.96 (SEM=0.3)

Left thumb: ICC=0.96 (SEM=0.3)
Right elbow: ICC=0.99 (SEM=1.4)
Left elbow: ICC=0.99 (SEM=1.1)
Right knee: ICC=0.84 (SEM=1.4)
Left knee: ICC=0.98 (SEM=1.2)
Trunk flexion: ICC=0.99 (SEM=1.8)

Statistical analyses

All analyses were conducted using STATA statistical software version 15 (College Station TX, USA). Transversus abdominis and multifidus contraction were quantified as the difference between the "contraction condition" and "rest condition" for transversus abdominis peak length and mean thickness, and multifidus peak anteroposterior and mediolateral thickness. All data were distributed normally, as assessed by Shapiro-Wilk test. Independent t-tests were employed to compare outcomes (Beighton scores [0/ >0] and BOM scores) stratified by sex (male/female). Pooled data from male and female were used for the correlation analysis. The strength and direction of associations between all variables were assessed by Pearson correlation coefficient. An alpha-level of 0.05 was adopted for all statistical tests.

RESULTS

Beighton score

The majority (N = 24; 80%) of participants had a Beighton score of zero, whereas five participants (16.7%) had a score of one and one participant (3.3%) had a score of two. No Beighton scores greater than two were observed (Fig 5).

< Figure 5 about here >

BOM score (modified quantitative Beighton score)

Mean(SD) BOM score was 2.95(0.87) for the total sample (N = 30). Participants who had a Beighton score of zero had a lower (p = 0.006) mean(SD) BOM score, 2.74(0.68), than the participants with a

Beighton score of greater than zero, 3.80(1.09). Males (N = 18) had a mean(SD) BOM score of 2.73(0.73), whereas females had 3.28(1.00). There was no significant difference in BOM score between sexes (p = 0.100). Mean(SD) BOM subdomain scores were 1.45(0.26) for little fingers, 0.67(0.25) for thumbs, 0.48(0.43) for elbows, 0.11(0.19) for knees and 0.24(0.41) for the trunk.

Muscle length and thickness changes

Percent mean(SD) change in transversus abdominis and multifidus length and thickness between the two conditions (i.e. contraction state compared to rest state) are shown in Table 1. In participants with a Beighton score greater than zero, transversus abdominis demonstrated less shortening of length than in those with a Beighton score of zero (p = 0.026). No other muscle activity outcomes differed based on Beighton score. Moreover, no muscle activity outcomes differed between sexes.

< Table 1 about here >

Correlations

Correlations between differences in transversus abdominis and multifidus muscle length and thickness changes between conditions are presented in Table 2. Total BOM score (r = 0.468; p = 0.009) and the subdomain for elbows (r = 0.456; p = 0.011) correlated with transversus abdominis length (i.e. less muscle shortening). The trunk subdomain score exhibited a correlation of 0.354 with transversus abdominis length change, but this did not reach statistical significance (p = 0.055). No other measures of muscle activity were significantly correlated with total BOM score. The subdomains of the BOM score did not correlate with each other ($p \geq 0.097$).

< Table 2 about here >

DISCUSSION

The current study was the first, to our knowledge, to consider the relationship between joint mobility and lumbo-pelvic muscle contraction. We developed a scale that is based on the original Beighton-scoring system (4) for measuring joint mobility, but with a more quantitative approach. The advantage of our BOM score is that it has a greater sensitivity for changes within or between individuals and could be used in the future studies of general joint laxity.

The results suggest that greater joint mobility (as measured by a Beighton score greater than zero) demonstrated less TrA shortening. This finding was supported when we applied the BOM score, which also correlated negatively with TrA shortening. Our first hypothesis was therefore rejected, but the secondary hypothesis was met in part.

Hypermobility is often a result of a more compliant connective tissue, rendering fasciae and ligaments less stiff and more yielding. A muscle that is at least partially inserted to said connective tissue, such as the TrA, would have to shorten more during a concentric contraction for its contraction to be translated into the desired action. In addition, some of the shortening force may not reach the intended target because it is attenuated by the lengthening of the fascia. Other authors have found a connection between strength and hypermobility. For example, Sahin et al. (20) found that knee extensor muscle strength was significantly lower in patients with GJH, compared to the controls. The authors hypothesized that the muscle weakness was connected to the lengthening of the quadriceps muscle. Scheper et al. (21) found decreased muscle strength in subjects with GJH in shoulder abductors, finger flexors (grip strength), knee extensors and ankle dorsiflexors. In line with this prior work, the current study shows that less shortening during contraction of the TrA muscle is also associated with increased joint mobility. As indicated earlier, the participants of this study were not selected because they exhibited increased joint range of motion, but rather represented a sample of convenience.

The findings of the current study deepen our understanding of why increased joint mobility may be associated with greater risk of injury. Other than the bony anatomy of a synovial articulation (e.g. congruency between the two joint partners), passive structures, like the articular capsule and ligaments, play an important role in determining the potential and available range of motion. They maintain the integrity of a joint and, together with the surrounding muscles, stabilize it during activity. A more mobile joint, by definition, has laxer stabilizing structures. Thus, the guiding restraints of the passive structures are reduced and the joint is exposed to altered biomechanics. Intra- and extra-articular structures therefore undergo increased strain and damage will likely ensue. Increased joint mobility has been named a risk factor for injury (e.g. for the knee (24)) and for recurrence of injury (e.g. for the shoulder (25)). Muscle contraction may, to a certain extent, be able to compensate for this, but attenuation of force transmission via connective tissues will remain a problem. With regard to spinal hypermobility, Panjabi introduced the concept of an increased "neutral zone" (18). A weakened stabilizing system, for example by weakened TrA and multifidus muscles, increases the available passive range of motion with the spine in neutral position (i.g. not in extension nor in flexion) and subjects the segment to potentially damaging forces (19).

The change in TrA length was associated with the BOM score, but not the change in TrA thickness. This is most likely due to the small change in thickness (< 1mm) compared to the greater change in length (> 10mm). As hypothesized, we did not find any association between the BOM and change in MF thickness. Again, these changes were small (anteroposterior thickness change < 2 mm; mediolateral thickness change < 1 mm) and therefore potentially not sensitive enough to be detected with current methods.

There were no associations between the different subdomains of the BOM score. This is of interest, because it implies that laxity in different parts of the body are not correlated. Notably, participants were not recruited because of their hypermobilities, but because they were healthy and free from impairments. Similarly, the little finger BOM subdomain score did not correlate to the overall BOM score. This suggests that the little finger ROM test might not be needed in the overall BOM score and could possibly be removed as a test variable. This would decrease the number of test variables by two. At the very least it suggests that this particular subdomain is likely not mediating the overall BOM score.

There was a strong, albeit non-significant, correlation between the trunk subdomain score and the change in TrA length. Future studies in participants with low back pain (LBP) are therefore warranted to assess if there is an association between these two variables. Those findings could possibly add to the highly debated subject of whether or whether not motor control of the TrA (16) or its “feed forward feature” (6) are directly associated with LBP. Given our participants were all pain free, we cannot make any inferences on this matter.

A strength of our study was the use of MRI, which in this specific study was further strengthened by the large sample size and blinded assessment of images. However, it is appropriate to consider some of the limitations of the current study. Firstly, we did not directly measure TrA muscle contraction force or intra-fascial forces, as this would require technically challenging and invasive procedures. Whether intra-fascial force was equivalent with greater shortening of the TrA muscle in people with greater joint mobility remains open. Moreover, we only considered healthy individuals and therefore it unknown whether our BOM score would also provide greater sensitivity in those with diseases known to influence joint mobility. In this study we did no explicitly recruit people with joint hypermobility. Whether the impediments of muscle contraction are greater in people with diagnosed joint hypermobility is open. Further, we did not collect information on history of pregnancy, which could have an impact on core strength and transversus abdominis activation (23). Further methodological developments, such as the assessment of validity of the assessment of joint mobility and more detailed study of reliability than what we assess here, would be appropriate.

PRACTICAL APPLICATIONS

People with increased joint mobility activate their anterior-lateral core stabilizing muscles less than those with less mobility. This should be considered when coaching athletes or treating patients with (functional) spinal instability. However, the cause and effect relationship is not clear.

Our new approach to measuring general joint mobility (BOM score) could be used to quantify the qualitative Beighton score.

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FIGURE LEGENDS

Figure 1. Exercise performed in the MR scanner to activate the transversus abdominis muscle A MR-compatible custom-made vest was used with elastic bands and grips which, based on practice tests prior to entering the MR-scanner, provided the required load at 28 cm of extension.

Figure 2. MR image with manual tracings of the transverse abdominis (TrA) and multifidus muscles

Figure 3. Measuring passive extension of fifth finger

Figure 4. Measuring passive apposition of the thumb

Figure 5. Beighton score vs. BOM score for each participant

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