Increased Joint Mobility Is Associated With Impaired Transversus Abdominis Contraction

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Abstract
Mitchell, UH, Owen, PJ, Rantalainen, T, and Belavý, DL. Increased joint mobility is associated with impaired transversus abdominis contraction. J Strength Cond Res 36(9): 2472–2478, 2022—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 whether 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 magnetic resonance imaging–derived measures of transverse abdominis and multifidus muscle contraction during a spinal loading maneuver. The level of significance was set for \( p \leq 0.05 \). The results showed greater joint mobility (a higher BOM score) correlated \( r = 0.468; p = 0.009 \) with reduced transversus abdominis (TrA) 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 TrA 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 TrA muscle. This should be considered when coaching athletes or treating patients with functional spinal instability. The quantitative approach developed to measure joint mobility 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 stabilizing 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. Because of 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 (LBP) and rehabilitation has been the subject of discussion, mostly regarding its ability to contract before 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 4-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). Generalized joint hypermobility 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 4 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 subjects and between subjects (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 the Belavy-Owen-Mitchell (BOM) score. The purpose of this study was to assess TrA and multifidus length changes with contraction in healthy middle-aged subjects and correlate this to their mobility. The subjects 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 subjects. 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 subjects were informed of the benefits and risks of the investigation before signing the institutionally approved informed consent document to participate in the study. The exclusion criteria included a 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 subjects (N = 18 men and 12 women) were analyzed. Subjects had a mean (SD) age of 43 (7) years, age range 36-56 years, height of 170.7 (9.0) cm, and body mass of 67.9 (10.9) kg.

Procedures
Magnetic Resonance Imaging, Image Processing, and Analysis. Magnetic resonance imaging was performed under 2 conditions in a supine position, with the subject: (a) at rest with knees slightly flexed over a rolled towel and (b) performing an isometric narrow chest press with arms maintained torso width apart, while simultaneous raising the sternum (Figure 1). Resistance bands were used to provide loading through the arms during the exercise condition, with a resistive load at an estimated 20% 1-repetition maximum based on the threshold between “fair” and “good” normative values for age, sex, and body mass (1) achieved when the hands were 28 cm anterior to the chest. Resistance was determined by a 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 with the abdominal drawing-in maneuver. Hence, the position (a) was used to scan the TrA at rest; the position (b) 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, subjects were instructed to hold their breath after breathing in and remain static during scans.

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, 2,643 ms; echo time, 60ms; and field of view, 347 × 347 mm, 768 × 768 pixels) was used with spinal coils to collect 14 axial images encompassing the volume of the TrA 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 TrA muscle (Figure 2), a custom written ImageJ plugin (“ROI Analyzer”; https://github.com/tjrantal/ROIAnalyzer and https://sites.google.com/site/danjellbelavy/home/roianalyzer) was used to fit a fourth order polynomial to the region of interest, and the curvature from the muscle was removed. The mean muscle length and thickness were calculated in both conditions (at rest and during contraction). Similarly, the multifidus was traced around (Figure 2); peak anteroposterior and mediolateral thicknesses were calculated. Data were averaged across all slices and between the left and right sides.

Belavy-Owen-Mitchell (BOM) Score. Our modified, quantitative, version of the Beighton score (4) was calculated as the sum of 9 variables that consisted of measurements on a continuous scale, as opposed to the sum of 9 categorical (positive test = 1 and 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 9 variables and their calculations are as follows:

Variables 1 and 2: Passive Extension of the Fifth Fingers (Digitus Minimus). These 2 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°). The angle of extension was obtained to the nearest degree (test outcome). As per criteria proposed by Beighton et al. (4), 90° 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° were recorded as 90°; hence resulting in a score of 1) (Figure 3).

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

Variables 5 and 6: Hyperextension of the Elbows. These 2 variables examined hyperextension of the elbows (left and right) with the subject sitting, the shoulder flexed to 90°, and the forearm supinated. The angle of hyperextension beyond 180° was obtained to the nearest degree (test outcome). As per criteria proposed by Beighton et al. (4), 10° 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° were recorded as 10°; hence resulting in a score of 1) (Figure 4).

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

Variables 7 and 8: Hyperextension of the Knees. These 2 variables examined hyperextension of the knees (left and right), whereas the patient was in the supine position. The angle of hyperextension beyond 0° was obtained to the nearest degree (test outcome). As per criteria proposed by Beighton et al. (4), 10° 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., test outcomes >18.4 cm were recorded as 18.4 cm; hence resulting in a score of 0).

\[
\text{Item 3 and 4 (score)} = \frac{18.4 - \text{test outcome} \ [\text{range, 18.4-0}]}{18.4}
\]
used for calculations (e.g., hyperextension >10° were recorded as 10°; hence resulting in a score of 1).

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

**Variable 9: Forward Flexion of the Trunk with Knees Straight.** This variable examined forward flexion of the trunk with knees straight, whereas 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 used. 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 performed 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) = \( \frac{14.1 - \text{test outcome} \ (\text{range, } 14.1 - 0)}{14.1} \)

Data for joint subdomains were calculated as follows: (a) left plus right little fingers [2 variables combined], (b) left plus right thumbs [2 variables combined], (c) left plus right elbows [2 variables combined], (d) left plus right knees [2 variables combined], and (e) trunk [a single variable].

To obtain test-retest reliability of the BOM score, it was measured 6 times each on 6 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 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)

**Statistical Analyses**

All analyses were conducted using STATA statistical software version 15 (College Station TX). Transversus abdominis and multifidus contraction were quantified as the difference between the “contraction condition” and “rest condition” for TrA peak length and mean thickness, and multifidus peak anteroposterior and mediolateral thickness. All data were distributed normally, as assessed by the Shapiro–Wilk test. Independent t-tests were used to compare outcomes (Beighton scores [0/>0] and BOM scores) stratified by sex (male/female). Pooled data from men and women 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 subjects had a Beighton score of zero, whereas 5 subjects (16.7%) had a score of 1, and 1 subject (3.3%) had a score of 2. No Beighton scores greater than 2 were observed (Figure 5).

**BOM Score (Modified Quantitative Beighton Score)**

The mean (SD) BOM score was 2.95 (0.87) for the total sample (N = 30). Subjects who had a Beighton score of zero had a lower (p = 0.006) mean (SD) BOM score, 2.74 (0.68), than the subjects with a Beighton score of greater than zero, 3.80 (1.09). Men (N = 18) had a mean (SD) BOM score of 2.73 (0.73), whereas women had 3.28 (1.00). There was no significant difference in the 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**

The percent mean (SD) change in TrA and multifidus length and thickness between the 2 conditions (i.e., the contraction state
compared with the rest state) are shown in Table 1. In subjects with a Beighton score greater than zero, the TrA 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 the Beighton score. Moreover, no muscle activity outcomes differed between sexes.

**Correlations**

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

**Discussion**

The current study was the first, to the best of 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 than 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 previous 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 subjects 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 a greater risk of injury. Other than the bony anatomy of a synovial articulation \((e.g.,\text{congruency between the 2 joint partners})\), passive structures, such as 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-articular 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 by connective tissues will remain a problem. Regarding spinal hypomobility, 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 the neutral position (i.e. not in extension or in flexion) and subjects the segment to potentially damaging forces (19).

The change in the TrA length was associated with the BOM score but not the change in TrA thickness. This is most likely because of the small change in thickness (< 1 mm) compared with the greater change in the length (>10 mm). 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 and 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 is not correlated. Notably, subjects were not recruited because of their hypomobilities 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 2. At the very least, it suggests that this particular subdomain is likely not mediating the overall BOM score.

There was a strong, albeit nonsignificant, correlation between the trunk subdomain score and the change in the TrA length. Future studies in subjects with LBP are therefore warranted to assess whether there is an association between these 2 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 subjects were all pain free, we cannot make any inferences on this matter.

The 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. First, we did not directly measure TrA muscle contraction force or intrafascial forces because this would require technically challenging and invasive procedures. Whether the intrafascial 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 is unknown whether our BOM score would also provide greater sensitivity in those with diseases known to influence joint mobility. In this study, we did not explicitly recruit people with joint hypermobility. Whether the impediments of muscle contraction are greater in people with diagnosed joint hypermobility is open. Furthermore, we did not collect information on the history of pregnancy, which could have an impact on core strength and TrA 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 measure general joint mobility (BOM score) could be used to quantify the qualitative Beighton score.

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