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Lateral abdominal muscles of adults with hypermobility may be partially impaired during contraction

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ABSTRACT

Background Muscle function may be impaired in people with generalised hypermobility, yet prior studies have primarily focused on muscles within the extremities. We aimed to examine changes in lateral abdominal muscle (transversus abdominis (TrA) and the external (EO) and internal abdominal obliques (IO)) thickness and length during contraction between participants with and without hypermobility.

Methods This cross-sectional study examined 12 participants with hypermobility and 12 age-matched, sex-matched, height-matched and weight-matched participants without hypermobility. The Beighton and Belavy-Owen-Mitchell score assessed systemic hypermobility. Muscle thickness and length were measured via panoramic ultrasound scans at rest and during contraction.

Results When compared with rest across all lumbar levels (L1–L5), contraction produced a lesser increase in TrA thickness (β=0.03, p=0.034) for participants with hypermobility compared with control. No group-by-condition interaction was observed for TrA length across all lumbar levels (L1–L5; p=0.269). Contraction produced a greater decrease in EO thickness (β=0.08, p=0.002) at L3 only for participants with hypermobility compared with control. No group-by-condition interactions were observed for IO thickness.

Conclusion Participants with hypermobility had partially impaired lateral abdominal muscle function given a lesser ability to increase TrA muscle thickness during contraction compared with controls.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Individuals with non-symptomatic generalised joint hypermobility have less total and specific isometric extremity muscle group strength when compared with a reference population without generalised joint hypermobility.

⇒ In runners, there is an association between greater overall joint mobility and impaired transversus abdominis muscle contraction.

WHAT THIS STUDY ADDS

⇒ Participants with hypermobility had partially impaired lateral abdominal muscle function given a lesser ability to increase transversus abdominis muscle thickness during contraction compared with controls.

⇒ No signs of impaired internal or external abdominal oblique function were detected during contraction.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Impaired lateral abdominal muscle function should be considered working with clients who have hypermobility.

⇒ Future studies examining individuals with specific diagnoses of conditions associated with hypermobility (eg, Marfan syndrome, Ehlers-Danlos syndrome) are warranted to validate our findings.

BACKGROUND

A joint is considered to be hypermobile when its range of motion exceeds the expected normalised standard.[1] When several joints are affected, the condition is commonly referred to as generalised joint hypermobility (GJH) or generalised joint laxity.[2] If accompanied by pain (eg, chronic joint pain or ligament pain), this condition is referred to as joint hypermobility syndrome, benign joint hypermobility syndrome or hypermobility syndrome.[2] However, it has been suggested that this syndrome also exists without joint pain.[3] The primary cause of this syndrome is connective tissue laxity, often due to a genetic connective tissue disorder (eg, Marfan syndrome, Ehlers-Danlos syndrome and osteogenesis imperfecta).[1] In the clinical setting, GJH is diagnosed via the Beighton score,[4] a 9-point scale that assesses the end ranges of motion of four joints on each extremity and of the spine. A score of 5 or greater is considered a sign of generalised hypermobility.[5] Beighton *et al*[4] intended the scale to be an easily administered epidemiological screening tool that uses dichotomous categorical yes/no questions. The Beighton score was not designed to quantify the degree of overall hypermobility, nor to assess for subtle mobility differences within or between participants.[6] Therefore, we previously developed a modified

quantitative version of the Beighton scoring system that viewed outcomes as continuous, the Belavy-Owen-Mitchell (BOM) score.[7]

GJH is often associated with musculoskeletal conditions, such as glenohumeral joint instability and temporomandibular joint dysfunction.[8 9] Additionally, people with non-symptomatic GJH also had impaired muscle function within the extremities when compared with a reference population without GJH.[10] However, whether lateral abdominal muscles that are important for segmental stability of the spine,[11] such as transversus abdominis (TrA), are also impaired in individuals with GJH is unknown.

In a recent study,[7] we showed an association between greater overall joint mobility and impaired contraction (ie, less TrA shortening with contraction) in runners. While intriguing, this study did not evaluate people with GJH. Therefore, in the current exploratory study, we aimed to evaluate changes in lateral abdominal muscles (ie, TrA, external abdominal oblique (EO) and internal abdominal oblique (IO)) thickness and length during contraction[12] between participants with and without hypermobility. Similar to our prior work,[7] a lesser ability to increase muscle thickness or reduce muscle length during contraction was considered as impaired muscle function. Secondary aims were to evaluate associations between measures of hypermobility (Beighton and BOM score) and abdominal muscle thickness and length during rest and contraction.

METHODS

Study design and setting

A cross-sectional study at a university laboratory was conducted. Data collection spanned 2019 to 2021 and included 12 hypermobile participants and 12 sex-matched, height-matched, weight-matched and age-matched non-hypermobile participants in line with established recommendations for sample sizes in exploratory studies.[13]

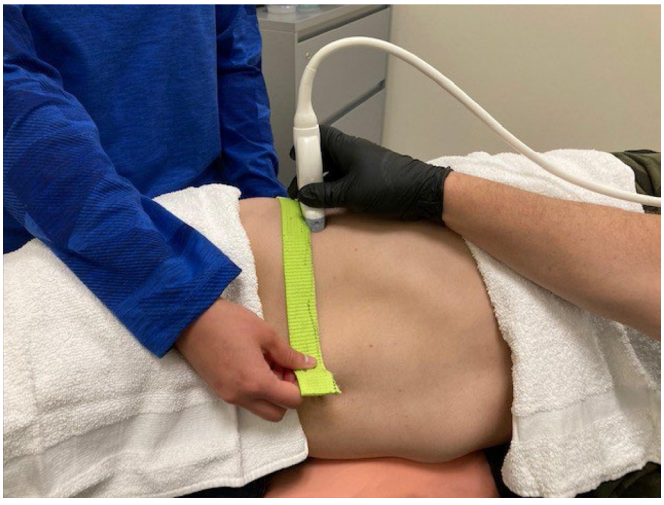

Figure 1 Participant positioning and probe guide during ultrasound imaging.

Participants

We initially sought participants who self-identified as hypermobile via word of mouth from the general community. No specific diagnosed condition associated with hypermobility was required to participate. Potential participants had their systemic hypermobility evaluated prior to enrolment.[4 7] A participant was considered hypermobile if five of the nine joints measured[5] met the criteria established by Beighton (ie, elbow extension greater than 9°, knee extension greater than 9°, little finger extension greater than 89°, able to touch the forearm with the thumb and able to touch the floor with palms with knees extended). The modified, quantitative version of the Beighton score, the BOM score (ICC=0.99),[7] was calculated as the sum of nine continuous measurements, as opposed to the sum of nine categorical (positive test=1; negative test=0) measurements. The nine items are the same as above. Each continuous measurement was calculated (in degrees or cm) based on the ratio between the test outcome and a result that would correspond with a positive test using the Beighton score criteria (upper limit). Once 12 participants with hypermobility were enrolled, we then sought to enrol 12 participants without hypermobility via similar recruitment strategies. Participants without hypermobility were matched based on sex, height (within 5 cm), weight (within 2 kg) and age (within 5 years).

Data collection

Ultrasound imaging

Scan acquisition methods were adapted from an established protocol[14] previously used within our laboratory.[15 16] Participants were asked to lie on their side on a treatment table with a pillow between their knees and one under their waist for ultrasonic data collection. The side was determined by random assignment. Ultrasound images were gathered with the GE Logiq S8 system and the ML6-15 MHz or 9L sound heads. Marks were made with a soft tipped marker at the apex of the first, third and fifth lumbar spinous processes. To create a panoramic view, the sound head was glided transversely across the participant's trunk from posterior to anterior starting from these marks. To ensure that the gliding of the sound head was relatively constant, researchers underwent training that focused on image acquisition, including appropriate speed and probe movement. If the sound head was moved too quickly, the image was distorted and the trial was repeated. We used a custom-made probe guide made from a flexible body-contouring material to ensure a straight line suitable for panoramic ultrasound picture (figure 1).

Participants were then trained in the contraction of the lateral abdominal muscles through an established abdominal hollowing manoeuvre (actively drawing in the navel to spine)[17–19] and practised contracting their abdominal muscles while observing the muscle movement on the ultrasound screen as real-time feedback. Participants maintained the lateral abdominal muscle

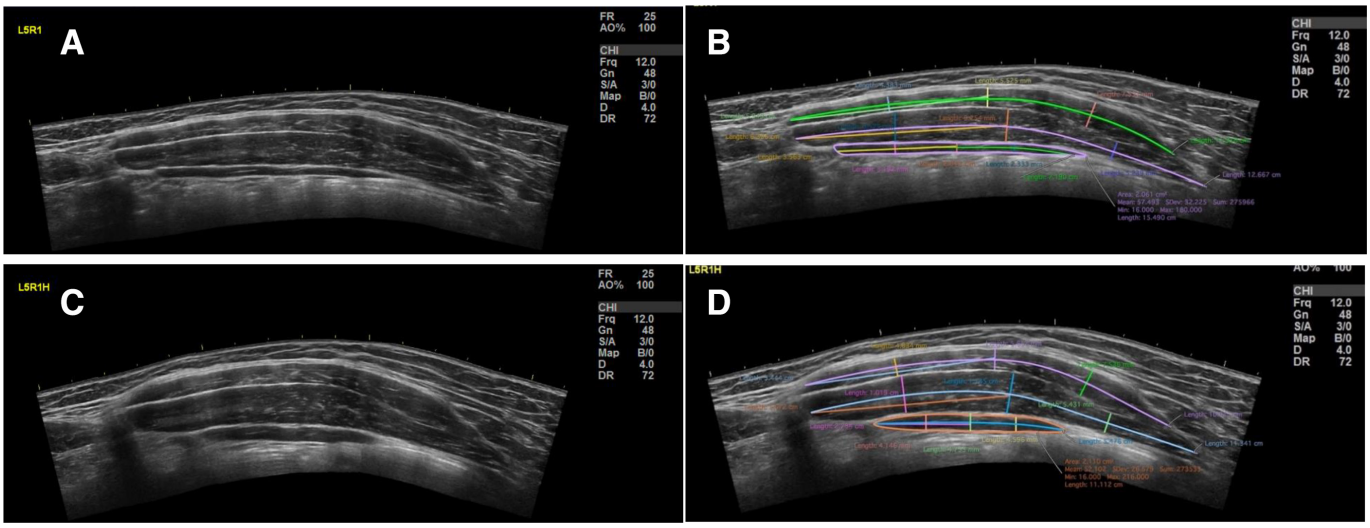

Figure 2 Ultrasound image analyses, images and measurements. (A) Resting state. (B) Resting state with measurements. (C) Contracted state. (D) Contracted state with measurements.

contraction and continued to breathe normally while one image was recorded.[18] This procedure was repeated twice at each of the marked levels and the measurements were averaged for statistical analysis.[16] Each image capture took about 3–5 s. The contralateral side was then imaged in the same manner. Our intertester and intratester reliability in measuring lateral abdominal muscle thickness and length changes using this method has been shown to be excellent (ICC at rest: 0.926 to 0.992; ICC during contraction: 0.961 to 0.993). The average SE of the measurement ranges from 0.02 cm for thickness measurements to 0.2 cm for length measurements.[16]

The ultrasound images were measured at a later time following the data collection by the assigned researchers, who were blinded to the participant's group allocation, as per methods previously used within our laboratory.[15 16] The postprocessing measurements were conducted using the Osirix DICOM Viewer (Pixmeo SARL, 266 Rue de Bernex, CH-1233 Bernex, Switzerland). First, we measured the cross-sectional area of the TrA by tracing the internal fascial borders of the muscles using the closed polygon function.[16] The length measurements were then performed using the open polygon function through the centre of the muscle, staying equidistant from the superficial and deep fascial borders. Next, the thickness measurements for the three muscles were obtained by measuring three separate locations using the straight-line function. The first thickness measurement was taken at the half-way point of the measured length. The other two measurements were taken approximately equidistant of the halfway point on either side[15 16] (figure 2). Changes in muscle thickness and length (TrA only) were calculated by subtracting values during contraction from values at rest.

Trunk strength measurement

Isometric trunk flexor and extensor strength (online supplemental figure 1) were measured using peak force with a MicroFET 2 dynamometer (Hoggan Scientific LLC, Salt Lake City)[20] that was attached to a pole. A cushioned bar that connected to the dynamometer was placed around the participants with them facing away from it for flexor strength and facing towards it for extensor strength measurements. The bar was placed on the sternum for the assessment of flexion strength, and on the level of mid-scapulae for the assessment of extension strength. A belt that was attached to the treatment table was used to fixate the pelvis during isometric trunk flexion testing. The testing order (flexion/extension) was randomised by a researcher external to the one who collected the data. Submaximal contractions were performed with

Table 1 Participant characteristics, joint mobility scores and trunk muscle strength/endurance

Variable	Hypermobile (n=12)	Control (n=12)
Age, year	22 (2)	23 (2)
Height, cm	172.5 (7.7)	170.7 (7.3)
Weight, kg	64.0 (8.8)	64.6 (9.0)
Transversus abdominis area, cm^2	2.63 (1.23)	2.56 (1.28)
Beighton score, 0–9 points	7.7 (1.2)	1.3 (1.1)‡
Belavy-Owen-Mitchell score, 0–9 points	8.4 (0.5)	4.9 (1.0)‡
Trunk flexion strength, kg	15.4 (5.9)	12.1 (4.8)
Trunk extension strength, kg	15.0 (4.8)	13.6 (6.1)
Trunk flexion endurance, s	475.8 (281.6)	270.1 (162.1)*
Trunk extension endurance, s	155.4 (37.5)	172.9 (55.9)

Data are mean (SD). *P<0.05, ‡ p<0.001 compared between groups.

60 s rests before data collection started. The participants performed a set of three isometric maximal contractions in each direction with 20 s rests in between trials. The average of these three trials was used for data analysis. Verbal encouragement for maximal contraction was given during all sets. For all testing, a research assistant observed the hip flexion angle and pelvic rotation to ensure that it stayed relatively constant. Test–retest reliability from our own laboratory for isometric strength testing was ICC=0.991 (95% CI 0.984 to 0.996) for trunk extension and ICC=0.992 (95% CI 0.986 to 0.996) for trunk flexion.

Trunk endurance measurement

Trunk flexion and extension endurance testing (online supplemental figure 2) were performed according to the methods described by Reiman *et al*.[21] This test was capped at 900 s (15 min). For the trunk extension endurance test, participants laid prone on a back extension bench with their anterior superior iliac spine resting on the edge and upper body hanging over the end of the bench. The pelvis, hips and knees were touching the bench and the feet were secured posteriorly. The timer was started when the participants lifted their upper body to be in line with their lower body with their hands resting on opposite shoulders and was ended when they were no longer able to hold the position. Verbal cues were given for both tests to assist in maintaining the correct position.

Statistical analyses

All analyses were conducted using Stata (17, StataCorp). Normality of the distribution was assessed visually via quantile–quantile plots of residuals. Between-group (hypermobile vs control) differences in participant characteristics (age, height, weight, TrA area, trunk flexion strength, trunk flexion endurance, trunk extension strength, trunk extension endurance) were examined by independent t-test, where Cohen's d was used as an effect estimate. Linear mixed models with random (participant) and fixed effects (muscle area) assessed within-group and between-group differences produced by contraction on muscle parameters (TrA length, TrA thickness, EO thickness, IO thickness), where β coefficients were used as an effect estimate. The strength and direction of association between joint mobility scores (Beighton score, BOM score) and muscle thickness and length (by condition), as well as trunk muscle strength/endurance, were assessed via Spearman rank correlation coefficient. An alpha level of 0.05 was adopted for all statistical tests.

Table 2 Lateral abdominal muscle length and thickness during each condition

	Hypermobile (n=12)			Control (n=12)		
Variable	**Rest**	**Contraction**	**Change**	**Rest**	**Contraction**	**Change**
Transversus abdominis length, cm						
AvLx	6.97 (1.76)	5.66 (1.66)‡	−19%	6.76 (1.81)	5.09 (1.81)‡	−25%
L1	7.63 (1.88)	6.56 (1.66)‡	−14%	7.28 (1.91)	5.81 (1.87)‡	−20%
L3	6.95 (1.52)	5.56 (1.33)‡	−20%	6.81 (1.89)	4.94 (1.72)‡	−29%
L5	6.31 (1.66)	4.85 (1.54)‡	−23%	6.21 (1.48)	4.53 (1.62)‡	−27%
Transversus abdominis thickness, cm						
AvLx	0.38 (0.10)	0.54 (0.17)‡	42%	0.40 (0.10)	0.57 (0.15)‡	43%
L1	0.40 (0.11)	0.56 (0.17)‡	40%	0.44 (0.10)	0.59 (0.16)‡	34%
L3	0.39 (0.10)	0.54 (0.15)‡	38%	0.39 (0.10)	0.56 (0.14)‡	44%
L5	0.35 (0.08)	0.51 (0.19)‡	46%	0.38 (0.10)	0.55 (0.15)‡	45%
External abdominal oblique thickness, cm						
AvLx	0.68 (0.20)	0.64 (0.20)‡	−5.9%	0.60 (0.13)	0.58 (0.14)*	−3.3%
L1	0.66 (0.24)	0.67 (0.22)	1.5%	0.59 (0.13)	0.59 (0.12)	0.0%
L3	0.72 (0.19)	0.66 (0.18)‡	−8.3%	0.61 (0.13)	0.61 (0.14)	0.0%
L5	0.66 (0.17)	0.59 (0.20)‡	−11%	0.60 (0.13)	0.53 (0.14)‡	−12%
Internal abdominal oblique thickness, cm						
AvLx	0.75 (0.18)	0.90 (0.26)‡	20%	0.71 (0.21)	0.83 (0.24)‡	17%
L1	0.71 (0.18)	0.79 (0.24)†	11%	0.62 (0.15)	0.66 (0.18)*	6.5%
L3	0.76 (0.16)	0.91 (0.24)‡	20%	0.70 (0.20)	0.84 (0.17)‡	20%
L5	0.79 (0.19)	0.99 (0.28)‡	25%	0.80 (0.23)	0.98 (0.26)‡	23%

Data are unadjusted mean (SD). AvLx: average of L1–L5. *p<0.05, †p<0.01, ‡p<0.001 compared with rest within-group (condition).

Table 3 Correlations between joint mobility scores (Beighton and Belavy-Owen-Mitchell (BOM)) and muscle length/thickness (by condition) and trunk muscle strength/endurance

	Correlation for variable:			
	Beighton score		BOM score	
Variable	Rest	Contraction	Rest	Contraction
Transversus abdominis length, cm				
AvLx	0.060	0.096	0.078	0.172†
L1	0.070	0.118	0.085	0.185
L3	0.089	0.162	0.147	0.272†
L5	0.051	0.056	0.037	0.138
Transversus abdominis thickness, cm				
AvLx	−0.048	−0.090	−0.095	−0.145*
L1	−0.080	−0.164	−0.149	−0.191
L3	0.026	−0.024	−0.017	−0.089
L5	−0.061	−0.079	−0.114	−0.156
External abdominal oblique thickness, cm				
AvLx	0.243‡	0.187†	0.208‡	0.154†
L1	0.171	0.123	0.125	0.114
L3	0.296†	0.202*	0.295†	0.172
L5	0.253*	0.240*	0.209*	0.193
Internal abdominal oblique thickness, cm				
AvLx	0.234‡	0.153†	0.242‡	0.121*
L1	0.345‡	0.251*	0.314†	0.233*
L3	0.251*	0.204*	0.279†	0.172
L5	0.149	0.076	0.193	0.055
Trunk muscle strength, kg				
Extension	0.131†		0.114†	
Flexion	0.347‡		0.356‡	
Trunk muscle endurance, sec				
Extension	0.045		−0.015	
Flexion	0.382‡		0.328‡	

Data are Spearman rho. AvLx: Average of L1–L5. *p<0.05, † p<0.01, ‡p<0.001.

RESULTS

Among the total sample, mean (SD) participant age was 22[2] years, height was 171.6 (7.4) cm, weight was 64.3 (8.7) kg and TrA area was 2.59 (1.25) cm^2 (table 1). None of these variables were different between hypermobile and control (all: p≥0.492). Similarly, there was no difference in trunk extension strength (p=0.547), flexion strength (p=0.149) and extension endurance (p=0.377); however, flexion endurance was 55% greater in hypermobile participants compared with control (p=0.039, d (95% CI): 0.90 (0.04 to 1.73)).

TrA length and thickness for both groups during each condition as well as per cent change are shown in table 2. When compared with rest and across all lumbar levels (L1-L5), contraction produced a smaller increase in TrA thickness (β=0.03, p=0.034) for hypermobile participants compared with control. This was similar for level L3 where contraction produced a smaller increase in TrA thickness (β=0.05, p=0.005) for hypermobile participants compared with control, yet not for levels L1 (p=0.193) or L5 (p=0.774). No group-by-condition interactions were observed for TrA length across all lumbar levels (p=0.269), L1 (p=0.745), L3 (p=0.173) or L5 (p=0.218).

EO and IO thickness for both groups during each condition as well as per cent change are shown in table 2. When compared with rest at L3, contraction produced a greater decrease in EO thickness (β=0.08, p=0.002) for hypermobile participants compared with control. No group-by-condition interactions were observed for EO thickness across all lumbar levels (p=0.095), L1 (p=0.802) or L5 (p=0.793). No group-by-condition interactions were observed for IO thickness across all lumbar levels (p=0.276), L1 (p=0.208), L3 (p=0.907) or L5 (p=0.591).

Correlations between joint mobility scores (Beighton score, BOM score) and muscle parameters, as well as trunk muscle strength/endurance, are shown in table 3 and online supplemental figures 3–7.

DISCUSSION

The current study was the first to assess the changes in lateral abdominal muscle (TrA, IO and EO) length and thickness during contraction between participants with and without hypermobility. We showed that participants with hypermobility produced a lesser increase in TrA thickness during contraction compared with controls. Changes in TrA length, EO thickness or IO thickness during contraction did not differ between groups. Correlations observed between joint mobility scores and muscle function tended to be non-existent or weak.

Individuals with hypermobility in the current study appeared to demonstrate impaired TrA function given the lesser increase in thickness during contraction when compared with matched participants without hypermobility. The largest between-group discrepancy was observed at level L3. This finding might be related to muscle morphology, as the TrA can be separated into three regions: upper, middle and lower.[22] Each of these regions varies in its fascicle orientation, thickness and length that may affect their function.[23] The middle fascicles of the TrA are the longest of all muscle regions in the TrA[22] and attach to the sheath of the rectus abdominus. Contraction of the TrA and lateral abdominal muscles results in lateral pull of the rectus abdominis and rectus sheath.[24] Therefore, findings from the current study suggest that individuals with hypermobility may have impaired TrA function, which may further vary by anatomical region.

Limited evidence that EO and IO muscles are impaired in adults with hypermobility was observed in the current study. It should be noted, however, that neither EO nor IO contract maximally during the hollowing manoeuvre we employed, as fibre orientation is oblique and the main function of these muscles is to rotate and flex the

trunk. Interestingly, participants with hypermobility in the current study demonstrated a greater decrease in EO thickness at L3 during contraction when compared with controls, which tends to indicate better muscle function. Conversely, given IO and TrA are considered to be 'local muscles'[25] and therefore work together for the segmental stabilisation of the lumbosacral spine, whereas EO is considered part of the 'global muscle group' that generates torque and general spinal stability,[25 26] our observations may indicate a differing muscle recruitment pattern during contraction in adults with hypermobility.

Correlation analyses between joint mobility scores and muscle function in the current study tended to yield non-existent or weak relationships. Consequently, evidence linking both the Beighton and BOM scoring systems of generalised hypermobility remains inconclusive.

Physical therapy is commonly recommended for people with hypermobility to improve muscle strength and proprioception,[27] which in turn may increase joint stability and control.[28] Despite observations in the current study that TrA appears impaired in adults with hypermobility, we are unaware of any studies that investigated the efficacy of physical therapy specifically targeting TrA to improve spinal segmental stability in this susceptible population group. This may in part be explained by prior observations that reductions in pain intensity in people with hypermobility are similar between joint targeted therapy that is meant to improve the stability of specific joints[29] and a generalised exercise programme that improves general muscle strength and cardiovascular condition.[30] Regardless, given the observations in our current study, we contend that the efficacy of joint targeted therapy on lateral abdominal muscle function warrants investigation in adults with hypermobility. Establishing such efficacy may not only inform rehabilitation, yet also potential preventative interventions given the known consequences of muscle impairment.

This study was strengthened by the use of both the Beighton scale and BOM score; the latter allowed quantification of the degree of hypermobility. Moreover, examining multiple lateral abdominal muscles overcame common limitations in prior ultrasound trials whereby only a single muscle is examined. However, this study had several limitations. First, the sample size was inherently small given the exploratory nature of this study. Regardless, statistically significant between-group and within-group and condition observations suggest that larger samples may detect further group-by-condition interactions. Second, the position in which the participant was imaged (side-lying) may not reflect muscle morphology changes that occur in more functional positions, such as sitting or standing. However, our design was robust from an investigative perspective (ie, variance in movement patterns associated with gross motor skills was avoided by using a simplistic and consistent hollowing movement to elicit lateral abdominal muscle contraction). Only one of the hypermobile participants included in the current study was diagnosed with a known underlying condition associated with hypermobility; thus, our ability to extrapolate our findings to that of conditions commonly associated with hypermobility, such as Marfan or Ehlers-Danlos syndrome, is limited. Replicating the current study in individuals with clinically diagnosed conditions associated with hypermobility is warranted. Finally, there are other factors that could have influenced muscle size measurements, such as probe orientation (toggle, tilt) and compression of the probe. However, we standardised our procedures and conducted extensive training for the ultrasonographers.

CONCLUSIONS

The current study suggested that participants with hypermobility had partially impaired lateral abdominal muscle function given a lesser ability to increase TrA muscle thickness during contraction compared with controls. Impaired lateral abdominal muscle function should be considered working with clients who have hypermobility and future studies examining individuals with specific diagnoses of conditions associated with hypermobility (eg, Marfan syndrome, Ehlers-Danlos syndrome) are warranted.

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Contributors UHM was involved in the conception and design of the study, data acquisition, interpretation of data, draft of the work and has approved the submitted version. UHM is also responsible for the overall content as is the guarantor. AWJ was involved in the design of the study, data acquisition, draft of the work and has approved the submitted version. LA, JK and NP were involved in data acquisition, draft of the work and has approved the submitted version. PJO was involved in conception and design of the study, interpretation of data, revising the draft of the work and has approved the submitted version. All authors have agreed both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval The study was conducted in line with the Declaration of Helsinki and was approved by the Brigham Young University Institutional Review Board (X2019-336). All participants provided written informed consent prior to study enrolment.

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Data availability statement Data are available upon reasonable request.

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