Muscle Contraction is Impaired in Hypermobile People: A Study of The Lateral Abdominal Muscles

Ulrike H. Mitchell (rike_mitchell@byu.edu)
Brigham Young University
A. Wayne Johnson
Brigham Young University
Lauren Adams
Brigham Young University
Jade Kho
Brigham Young University
Daniel L. Belavy
Deakin University, Institute for Physical Activity and Nutrition (IPAN)
Patrick J. Owen
Deakin University, Institute for Physical Activity and Nutrition (IPAN)

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Abstract

Background: Emerging evidence suggests that muscle function can be impaired in people with generalized hypermobility. The Beighton scale was developed to assess for the presence of hypermobility. This cross-sectional study assessed the activation of the lateral abdominal muscles in hypermobile (N=10; Beighton score ≥5) and matched non-hypermobile control (N=10) participants.

Methods: Panoramic ultrasound scans of the transversus abdominis (TrA) and the external and internal abdominal obliques (EO and IO, respectively) were obtained at three lumbar levels (L1, L3, L5) at rest and during the hollowing maneuver.

Results: Between-group differences in the TrA length, as well as TrA, EO and IO thickness changes between conditions (rest vs hollowing) and trunk strength and endurance were examined. Hypermobile participants exhibited less TrA shortening than controls (L1-L5: 5.1% difference, L3: 8.9% difference) and greater thickness changes at level L1 (12.7% difference). EO and IO thickness differed between groups for both conditions, where both of the muscles were 0.07cm - 0.18cm thicker at rest and 0.07cm - 0.19cm thicker with hollowing in the hypermobile participants compared to control (all: $P<0.001$). The ability to contract the EO was less in hypermobile participants compared to controls ($P=0.002$; -5.3% vs no change in thickness), while the ability to contract the IO was greater in hypermobile participants compared to in controls ($P=0.038$; +21.3% vs +17.6% thickness change). Hypermobile participants demonstrated over 30% greater average trunk flexion strength. Moreover, greater joint mobility was associated with less TrA muscle shortening, reduced EO thickness changes, greater isometric trunk muscle strength for both extension and flexion (all: $P<0.001$) and with reduced trunk muscle endurance for extension and flexion ($P=0.006$ and $P=0.002$, respectively).

Conclusion: The results of this study indicate joint hypermobility is associated with reduced ability to contract TrA and EO, however, this did not appear to be associated with impaired function (e.g. muscle strength and endurance).

Background

A joint is considered to be hypermobile when its range of motion exceeds the expected normalized standard.(1) When several joints are affected, the condition is commonly referred to as generalized joint hypermobility or generalized joint laxity.(2) If accompanied by pain (e.g. chronic joint pain or ligament pain), this condition is referred to as joint hypermobility syndrome (JHS), benign joint hypermobility syndrome or hypermobility syndrome.(2) The primary cause of this syndrome is ligamentous laxity due to a genetic connective tissue disorder (e.g. Marfan syndrome, Ehlers-Danlos syndrome, and osteogenesis imperfecta).(1) JHS is commonly associated with musculoskeletal conditions, such as glenohumeral joint instability and temporomandibular joint dysfunction.(3, 4) Additionally, JHS is often linked with decreased muscle strength in shoulder (e.g. abductors), finger (e.g. flexors) and leg muscles (e.g. knee extensors).(5, 6) Muscle mass has been shown to be similar between people with Ehlers-Danlos syndrome who demonstrate reduced muscle strength and muscle endurance and sex-and age-matched healthy controls(7); thus it appears more likely that these differences in muscle strength stem from impaired muscle function (i.e. the ability of the muscle to contract).

In the clinical setting, JHS is measured with the Beighton scoring system(8), a 9-point scale that assesses the end ranges of motion of four joints on each extremity and of the spine. A score of five or greater is considered a sign of generalized hypermobility(9) Beighton et al.(8) intended the scale to be an easily administered epidemiological screening tool that uses dichotomous categorical yes/no questions. The Beighton score was not, however, designed to quantify the degree of overall hypermobility, nor to assess for subtle mobility differences within- or between-participant.(10) Therefore, we previously developed a modified quantitative version of the Beighton scoring system that viewed outcomes as continuous, the Belavy-Owen-Mitchell (BOM) score.(11) In a recent study Mitchell et al.(11) showed an association between greater overall joint mobility and impaired contraction of the transversus abdominis muscle (TrA) in runners. Whilst intriguing, this study did not evaluate people with JHS. Given that those observations suggested that overall joint mobility may be associated with impaired systemic muscle function, we conducted the current study to evaluate the activation of the lateral abdominal muscles, i.e. TrA, external abdominal oblique (EO) and internal abdominal oblique (IO) during the abdominal hollowing maneuver(12) using ultrasound imaging. More specifically, we measured TrA length and thickness changes, as well as EO and IO thickness changes, from rest to contraction via hollowing maneuver in healthy hypermobile and 'typical' mobile participants (determined via Beighton score). Additionally, we assessed isometric trunk flexion and extension length and the association with overall joint mobility. A secondary purpose was to assess the utility of the modified quantitative version of the Beighton score (i.e. BOM score).

Methods

The aim of this cross-sectional study was to assess the activation of the lateral abdominal muscles in hypermobile and matched non-hypermobile control (N=10) participants. The University Institutional Review Board 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. In 2019 and 2020 we recruited ten hypermobile participants first and then matched them by sex and height (within 2cm). This was a sample size of convenience. None of our participants had a diagnosed conditions associated with hypermobility (e.g. Marfan syndrome, Ehlers-Danlos syndrome or osteogenesis imperfecta). After completing an intake questionnaire, participant range of motion was measured as previously described elsewhere.(8, 11) Briefly, using a goniometer and tape measure, the following joint ranges of motion and distances were obtained: passive extension of the fifth metacarpalphalangeal joint, passive apposition of the thumb to the flexor aspect of the forearm, passive hyperextension of the elbow, passive extension of the knee and active forward flexion of the trunk from a standing position with the knees fully extended, attempting to have the palms of the hands rest flat on the floor. A participant was considered hypermobile if five of the nine joints measured(9) met the criteria established by Beighton (i.e. elbow extension greater than 9 degrees, knee extension greater than 9 degrees, little finger extension greater than 89 degrees, 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(11) 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). The range of score per item was 0-1, whereas the maximum overall score ranged 0-9, where higher scores indicated greater laxity. The test-retest reliability of the BOM score is ICC = 0.99 (SEM = 0.4).(11)

Participants were asked to lie on their side on a treatment table with a pillow between their knees for ultrasonic data collection. Ultrasound images were gathered with the GE Logiq s8 system and the ML6-15 MHz or 9L sound heads. Images recorded panoramic views of the TrA, EO and IO muscles, at rest and during the abdominal hollowing maneuver (actively drawing in the navel to spine to engage of contract the abdominal muscles). Prior to imaging the participants practiced this maneuver. Images were recorded for the right side and left side of the body in an order randomized external to the researcher collecting data.

Marks were made with a soft tipped marker at the apex of the 1st, 3rd, and 5th lumbar spinous processes. To create a panoramic view, the sound head was glided over the skin from posterior to anterior starting from these marks transversely across the participant's trunk. We used a custom-made probe guide made out of a flexible body-contouring material to ensure a straight line suitable for panoramic ultrasound picture (**FIGURE 1**). Participants were asked to lay still while two consecutive images at each of the three marked locations were imaged and recorded. Each panoramic scan took about five seconds. Participants were then asked to perform the abdominal drawing in (hollowing) maneuver while two more images were recorded at each of the marked levels. Participants were allowed to relax and rest 10 seconds between these active muscle contractions. The participants practiced contracting their abdominal muscles while observing the muscle movement on the ultrasound screen as real time feedback. The contralateral side was then imaged in the same manner.

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. The postprocessing measurements were conducted using the Osirix DICOM Viewer (Pixmeo SARL, 266 Rue de Bernex, CH-1233 Bernex, Switzerland). As part of the participant's characteristics we measured the cross-sectional area of the TrA. It was always measured first, using the closed polygon function to trace the internal fascial borders of the muscles. The length measurements were performed using the open polygon function through the center of the muscle, staying equidistant from the superficial and deep fascial borders. The thickness measurements for the three muscles were obtained by measuring three separate locations using the straight-line function. The first 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. An average of these three measurements was then taken and reported as the overall thickness (**FIGURE 2**).

Isometric trunk flexor and extensor strength were measured using peak force with a MicroFET 2 dynamometer (Hoggan Scientific LLC, Salt Lake City) 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 was used to fixate the pelvis during isometric trunk flexion testing. The testing order (flexion/extension) was randomized by a researcher external to that of who collected the data. The participants performed a set of three isometric contractions in each direction with 20 second pauses in between trials. For all testing a research assistant observed the hip flexion angle and pelvic rotation to ensure that it stayed relatively constant. Test-retest reliability of isometric strength testing was ICC=0.991 (95%CI: 0.984, 0.996) for extension and ICC=0.992 (95%CI: 0.986, 0.996) for flexion.

Trunk flexion and extension endurance testing were performed according to the methods described by Reiman et al.(13) During trunk flexion testing, the participant assumed a sit-up position with the back initially resting against a device that was wedged between the back rest of the treatment table, set at 60 degrees, and the back of the participant. The hip and knee flexion angles were placed at 90 degrees, the arms were folded across the chest with the hands placed on the opposite shoulder, and the feet were secured. The timer was started once the device was pulled out from behind the back of the participant and ended when the participant was not able to hold this position any longer (i.e. their back touched the back rest of the treatment table). This test was capped at 900 seconds (15 minutes). For the trunk extension endurance test participants laid prone on a back extension bench with their 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.

All analyses were conducted using Stata statistical software version 16 (StataCorp, College Station, TX, USA). Between-group differences in change between conditions (rest vs hollow) for each muscle parameter were examined by independent t-test. Within-group differences between conditions were examined by dependent t-tests. The strength and direction of association between muscle parameter change between conditions, joint mobility scores, trunk muscle strength and trunk muscle endurance were assessed with Pearson's correlation coefficient. An alpha level of 0.05 was adopted for all statistical tests.

Results

The characteristics of the 20 participants (males: n=6) are shown in TABLE 1. Among the total sample, mean (standard deviation; SD) age was 25 (11) years, height was171.4 (8.6) cm, weight was 63.0 (8.0) kg and TrA area was 2.48 (0.81) cm^2. None of these variables was different between hypermobile and control (all: p>0.310). However, hypermobile participants demonstrated over 30% greater average absolute trunk flexion strength compared to controls and approximately half the trunk flexion endurance (both p<0.050).

Mean (SD) Beighton scores were greater (p<0.001) in hypermobile participants (7.3 [1.4] points) compared to controls (1.4 [1.2] points). Mean (SD) BOM score was also greater (p<0.001) in hypermobile participants (8.2 [0.6] points) than controls (4.8 [1.4] points).

TrA length and thickness for both groups during each condition are shown in TABLE 2. Change in TrA length differed between groups when considering the average across all lumbar levels (L1-L5), where hypermobile participants had less shortening than controls (p=0.049; -21.2% vs -26.3%). Less muscle shortening was also observed at L3 specifically in hypermobile participants compared to controls (p=0.032; -20.6% vs -29.5%). TrA thickness changes only differed between groups at level L1, where hypermobile participants had greater increase than controls (p=0.035; +42.9% vs +30.2%).

EO and IO thickness during each condition is shown in TABLE 2. Changes in EO thickness differed between groups when averaged across all lumbar levels (L1-L5), where hypermobile participants decreased compared to controls (p=0.002; -5.3% vs no change). Hypermobile participants also decreased in EO thickness at L3 specifically, whereas controls increased (p<0.001; -9.0% vs +3.3%). Changes in IO thickness differed between groups when considering the average across all lumbar levels (L1-L5), with hypermobile participants observed to increase greater than controls (p=0.038; +21.3% vs +17.6%). Similarly, greater increases in IO thickness were shown for hypermobile participants compared to controls at L1 (p=0.045; +13.3% vs 6.7%).

Correlations between changes in muscle parameters, trunk muscle strength/endurance and joint mobility scores are shown in TABLE 3. Greater Beighton and BOM score correlated with reduced change in TrA muscle length across all lumbar levels (p=0.026 and p<0.001 respectively) and L3 specifically (p=0.027 and p=0.001 respectively). Higher Beighton and BOM score was associated with reduced EO thickness across the average of all lumbar levels (p=0.006 and p=0.019, respectively) and L3 specifically (p=0.001 and p=0.004, respectively). Greater Beighton and BOM score was also associated with greater isometric trunk muscle strength during both extension and flexion (all p<0.001). Conversely, greater Beighton and BOM scores were both associated with reduced trunk muscle endurance during extension and flexion (p=0.006 and p=0.002, respectively). No associations between changes in TrA or IO thickness and joint mobility scores were observed.

Discussion

This is the first study that assessed the association between generalized joint hypermobility and lateral abdominal (TrA, IO and EO) muscle activation in participants that were specifically recruited for their joint mobility. We showed that hypermobile subjects had less TrA shortening, decreased EO and increased IO activation compared to sex- and height-matched controls during hollowing. Moreover, greater joint mobility was associated with less TrA muscle shortening and decreased EO thickness changes across all lumbar levels and at L3 specifically. Therefore, these findings lend support to the notion that TrA and possibly EO muscle function is impaired in hypermobile adults, yet whether this implies compromised systemic muscle function is unclear. Interestingly, greater joint mobility was also correlated to greater isometric trunk muscle strength into flexion and extension.

Impaired muscle function in hypermobile people has been suggested prior.(7) Rombaut et al.(7) proposed that people with diagnosed Ehlers-Danlos syndrome had muscle weakness as a result of abnormalities in muscle extracellular matrix composition, which led to an altered force transmission. In addition, a more compliant connective tissue has been shown in people with syndromes associated with hypermobility(14), however, associated gene mutations have not been found in people with benign joint hypermobility(15).

The TrA at lumbar level L3 was particularly limited in shortening capacity when compared to non-hypermobile individuals, but not more limited compared to other levels in hypermobile participants. This might be related to muscle morphology, as the TrA can be separated into three regions: upper, middle, and lower.(16) Each of these regions vary in their fascicle orientation, thickness, and length that may affect their function.(17) The middle fascicles of the TrA are the longest of all muscle regions in the TrA(16) and attach to the sheath of the rectus abdominus. Contraction of the TrA and lateral abdominal muscles result in lateral pull of the rectus abdominis and rectus sheath.(18) In addition, different regions of the TrA have been shown to demonstrate distinct recruitment patterns during rotation, where the thorax was fixed and the pelvis was rotated on the thorax.(17) More specifically, the activity of the upper region of TrA was different from the lower and middle regions, while the lower and middle regions were similar in their activation in both rotation directions. It is possible that this kind of regional activation differences also exists during the hollowing maneuver in the side lying position.

There is a relationship between length and thickness changes during a concentric muscle contraction, where proportional thickening should occur during muscle shortening.(19, 20) In our study the change in TrA thickness with hollowing was similar in hypermobile and control subjects, yet the lengthening changes differed. We believe that we were able to obtain a more complete representation of the morphological changes that occur with TrA contraction than if we had only measured one of the variables. Several authors measured only TrA thickness changes prior(21-26) and thus were not able to comment on coinciding muscle shortening.

EO and IO thickness were different between hypermobile and control participants in both conditions. It should be noted that neither of the two muscles contract maximally during the hollowing maneuver, as the fiber orientation is diagonal and the main function is to rotate and flex the trunk. However, remains of note that the overall EO muscle thickness decreased with hollowing in hypermobile participants, while it stayed the same in the controls. Simultaneously, the overall IO muscle thickness underwent greater increases with hollowing compared to controls. These differences might be related to the specific function of the muscles during the hollowing maneuver. The IO and TrA are hypothesized to be 'local muscles'(27), and as such work together for the segmental stabilization of the lumbosacral spine. The EO is considered part of the 'global muscle group' that generates torque and general spinal stability.(27, 28)

Correlation analyses showed that the more hypermobile people were, the less their TrA shortened. It was interesting to learn that only the BOM score, not the Beighton score exhibited this negative correlation. This association may indicate that the TrA muscle was too weak to control the physiological range of motion and to stabilize the spine. It is our contention that the decreased TrA muscle shortening with contraction could lead to compromised lumbar joint stability. Alternatively, our observations may indicate that hypermobility affects motor control and activation of the muscle. Seemingly contradictory, there was also a moderately strong positive correlation between trunk flexion strength and trunk flexion endurance and amount of hypermobility, indicating that greater joint mobility was associated with greater strength and endurance. It is possible that the EO and IO, which exhibited significantly greater thickness at rest and with hollowing in hypermobile participants compared to controls, are stronger given their synergistic role with the TrA in stabilizing the spine.(27)

Conclusions

This study showed that generalized joint hypermobility was negatively correlated with TrA and EO muscle function (i.e. reduced TrA shortening and reduced EO thickening with contraction). Whether these findings indicate systemic impairment in muscle function is unknown, yet the current study suggests these investigations are warranted. We showed that the quantitative modified version of the Beighton score, the BOM score, has utility in the quantitative assessment of hypermobility.

Abbreviations

TrA: transversus abdominis (muscle)

EO: external abdominal oblique (muscle)

IO: internal abdominal oblique (muscle)

Declarations

- Ethics approval and consent to participate
- Informed consent was obtained from every participant before data collection. Brigham Young University Institutional Review Board approved this study, approval number X2019-336. All methods were carried out in accordance with relevant guidelines and regulations.
- Consent for publication
    - n/a
- Availability of data and materials
    - The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

- Competing interests
    - The authors have no competing interests

- Funding
    - Internal departmental funding was received

- Authors' contributions
    - 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.
    - AWJ was involved in the design of the study, data acquisition, draft of the work and has approved the submitted version.
    - LA was involved in data acquisition, draft of the work and has approved the submitted version.
    - JK was involved in data acquisition, draft of the work and has approved the submitted version.
    - DLB was involved in the interpretation of data, revisions of the work and has approved the submitted version.
    - PJO was involved in the interpretation of data, revisions 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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Tables

TABLE 1, Participant characteristics.

Variable	Hypermobile	Control
n	10	10
Female, n	7 (70.0%)	7 (70.0%)
Age, yr	22 (2)	27 (15)
Height, cm	171.2 (8.9)	171.5 (8.8)
Weight, kg	62.1 (8.3)	63.9 (8.0)
Transversus abdominis area, cm^2	2.54 (0.91)	2.42 (0.69)
Trunk flexion strength, kg	14.5 (4.2)	**10.4 (2.8)***
Trunk extension strength, kg	14.9 (4.2)	13.2 (6.0)
Trunk flexion endurance, sec	523.5 (277.2)	**266.5 (149.0)***
Trunk extension endurance, sec	173.1 (62.8)	179.5 (70.2)

Data are mean (standard deviation) or count (percentage) within-group. *p<0.05 compared between groups.

TABLE 2, Lateral abdominal muscle (TrA, EO, IO) morphology during each condition.

Variable	Hypermobile		Control	
	Rest	Hollow	Rest	Hollow
TrA length, cm				
AvLx	6.94 (1.70)	**5.47 (5.14)‡**	6.72 (1.53)	**4.95 (4.70)‡**
L1	7.64 (1.82)	**6.29 (5.70)†**	7.04 (1.26)	**5.62 (5.18)‡**
L3	6.80 (1.59)	**5.40 (4.91)‡**	6.85 (1.65)	**4.83 (4.43)‡**
L5	6.37 (1.44)	**4.71 (4.18)‡**	6.26 (1.57)	**4.41 (4.00)‡**
TrA thickness, cm				
AvLx	0.40 (0.10)	**0.58 (0.55)‡**	0.40 (0.10)	**0.56 (0.54)‡**
L1	0.42 (0.11)	**0.60 (0.54)‡**	0.43 (0.10)	**0.56 (0.51)‡**
L3	0.41 (0.11)	**0.58 (0.52)‡**	0.39 (0.10)	**0.56 (0.52)‡**
L5	0.36 (0.08)	**0.57 (0.50)‡**	0.39 (0.11)	**0.57 (0.53)‡**
EO thickness, cm				
AvLx	0.75 (0.18)	0.71 (0.18)	0.59 (0.13)	0.59 (0.13)
L1	0.74 (0.21)	0.75 (0.18)	0.57 (0.14)	0.58 (0.12)
L3	0.78 (0.17)	0.71 (0.18)	0.60 (0.14)	0.62 (0.13)
L5	0.73 (0.14)	0.66 (0.17)	0.60 (0.13)	0.57 (0.13)
IO thickness, cm				
AvLx	0.80 (0.18)	**0.97 (0.26)‡**	0.68 (0.22)	**0.80 (0.26)‡**
L1	0.75 (0.17)	**0.85 (0.21)***	0.60 (0.17)	0.64 (0.17)
L3	0.81 (0.14)	**0.98 (0.23) ‡**	0.68 (0.21)	**0.81 (0.20)†**
L5	0.85 (0.19)	**1.07 (0.29) ‡**	0.77 (0.25)	**0.95 (0.30)†**

Data are mean (standard deviation) within-group. AvLx: Average of L1-L5. *p<0.05, †p<0.01, ‡ p<0.001 compared to rest within-group.

TABLE 3, Correlations between changes in muscle parameters, trunk muscle strength/endurance and joint mobility scores.

Variable	Correlation for variable:	
	Beighton score	BOM score
Transversus abdominis length		
AvLx	**-0.144***	**-0.245‡**
L1	-0.127	-0.161
L3	**-0.248***	**-0.387‡**
L5	-0.061	-0.199
Transversus abdominis thickness		
AvLx	-0.046	0.027
L1	-0.126	-0.108
L3	0.060	0.177
L5	-0.055	0.038
EO thickness		
AvLx	**-0.177***	**-0.151***
L1	-0.097	-0.089
L3	**-0.371‡**	**-0.318***
L5	-0.068	-0.053
IO thickness		
AvLx	0.100	0.011
L1	0.157	0.070
L3	0.100	-0.012
L5	0.081	-0.002
Trunk muscle strength, kg		
Extension	**0.342‡**	**0.275‡**
Flexion	**0.603‡**	**0.421‡**
Trunk muscle endurance, sec		
Extension	**-0.126†**	**-0.141†**
Flexion	**0.470‡**	**0.504‡**

Data are Pearson's correlation coefficient. AvLx: Average of L1-L5. * $p<0.05$, † $p<0.01$, ‡ $p<0.001$.

Figures

Figure 1

Participant positioning and probe guide during ultrasound imaging

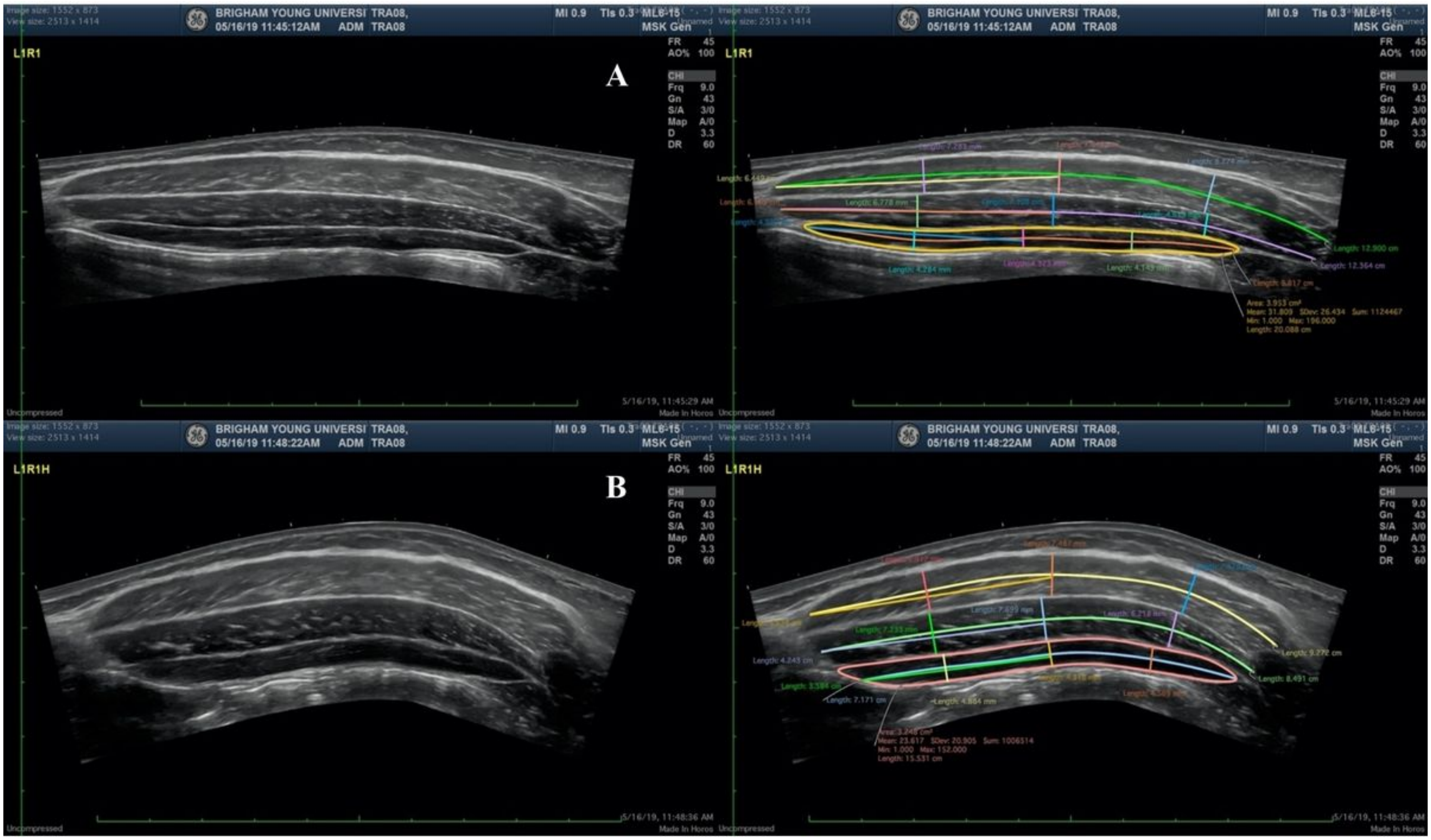

Figure 2

Ultrasound image analyses, images and measurements