Muscle and fat mapping of the trunk: a case study

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Received: 15 April 2015 / Accepted: 26 August 2015 / Published online: 14 September 2015
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Abstract The following case study examines the muscle and fat thickness of the trunk in a 25-year-old, former collegiate gymnast. Previous studies have quantified total and regional skeletal muscle mass using magnetic resonance imaging and muscle volume and distribution using ultrasound. However, to the best of our knowledge, the distribution and symmetry of skeletal muscle and subcutaneous adipose tissue (AT) of the anterior and posterior trunk have never been investigated. Ultrasound was used to identify skeletal muscle and AT thickness of 143 data points on the anterior portion of the trunk and 140 data points on the posterior portion of the trunk. Muscle thickness values in the anterior trunk ranged from 0.5 to 5.6 cm, and muscle thickness of the posterior trunk ranged from 0.6 to 6.6 cm. Total muscle volume of the trunk was 2935 and 4195 cm³ for the anterior and posterior portions, respectively. The total predicted muscle mass in the anterior and posterior trunk was 7.4 kg. This case study begins to provide a picture of the distribution and symmetry of skeletal muscle and AT of the trunk. Future studies are necessary to confirm these findings and examine relationships among different populations.

Keywords Ultrasound · Volume · Gymnastics · Hypertrophy

Astratto Il caso che presentiamo esamina lo spessore del muscolo e grasso del tronco di un venticinquenne ex ginnasta professionista. Precedenti studi hanno quantificato la massa muscolare scheletrica totale e regionale utilizzando la risonanza magnetica, il volume muscolare e la distribuzione con l'ecografia. Tuttavia, per quanto a nostra conoscenza, la distribuzione e la simmetria della muscolatura scheletrica e del tessuto adiposo sottocutaneo (AT) del tronco anteriore e posteriore, non sono mai stati indagati. Pertanto, lo scopo di questo studio è stato valutare la quantità assoluta e relativa di muscolo e del grasso in tutta la regione tronco, in un atleta altamente qualificato. Metodi: Il soggetto si trovava nella posizione fondamentale, l'ecografia è stata usata per identificare lo spessore della muscolo scheletrico e del AT in 143 punti prestabiliti sulla parte anteriore del tronco e in 140 punti prestabiliti sulla parte posteriore del tronco. Il volume muscolare è stato calcolato per ciascun segmento del tronco moltiplicando lo spessore muscolare (cm) per la lunghezza e la larghezza di ogni segmento (3 cm × 3 cm). Risultati: I valori di spessore del muscolo nella parte anteriore del tronco variavano da 0.5 cm a 5.6 centimetri e lo spessore del muscolo nella parte posteriore del tronco variavano da 0.6 centimetri a 6.6 centimetri. Il volume totale dei muscoli del tronco era 2935 cm³ e 4195 cm³, rispettivamente per la parte anteriore e posteriore. Il totale previsto della massa muscolare della parte anteriore e posteriore del tronco era di 7.4 kg. Conclusioni: Questo studio inizia a fornire un quadro della distribuzione e della simmetria della muscolatura scheletrica e dell'AT del tronco. Ulteriori studi sono necessari per confermare questi risultati e valutarli nelle diverse popolazioni.

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Introduction

Artistic gymnastics (AG) is a sport that requires a great deal of strength in the musculature of the trunk. Specifically, the muscles of the back and abdominal area must work together to provide stabilization in a way that is not seen in most other sports [1]. The handstand for example, a seemingly basic skill for a gymnast (Fig. 1a), may be impossible for the average person; whereas, basic skills for other sports (i.e., swinging a bat; shooting a basketball) can be attempted with moderate success by any normal, healthy individual. This difference, in part, may be due to a much greater development of the trunk musculature. The muscles of the trunk are commonly included in what is referred to as the musculoskeletal “core”, which is responsible for the stability of the spine and pelvic region [2]. In a functional sense, the core is described as the musculature that helps in the generation and transfer of energy from large to small body parts, especially in sports activity [2]. Skills, such as the “plank” (prone bridge), are used to strengthen the core and have been shown to produce activation of the abdominal muscles such as the rectus abdominis [2]. In the

sport of AG, athletes will perform this same exercise without using their feet (Fig. 1c). Presumably, performing this exercise without the support of the feet increases the work of all other muscles involved in the exercise and places a much greater stress on the musculature of the trunk. Unfortunately, there are no published studies on muscular contributions to different skills in the sport of gymnastics; however, it is plausible that a greater development of the trunk musculature contributes to many of a gymnast’s abilities.

Previous magnetic resonance imaging (MRI) studies investigated the characteristics of total and regional skeletal muscle mass in humans [3, 4] and found that approximately 40 % of total muscle mass is located in the trunk region [4], which includes hip and shoulder muscles. Compared to the limb muscles, a limited number of studies have been reported regarding the characteristics of muscle distribution in the anterior and posterior aspect of the trunk. Anatomical textbooks have clearly illustrated individual muscles in the trunk, but to date, no one has attempted to measure actual trunk muscle distributions in man and women. Ultrasound is a non-invasive, quick, and safe imaging technique that can be easily applied in clinical and field assessments. Rankin et al. [5] used ultrasound to investigate muscle thickness distributions in the anterior trunk and found that the rectus abdominis (RA) muscles are the largest, followed by the internal obliques (IO), external obliques (EO) and transverse abdominis (TA). They also reported that abdominal musculature was symmetrical between the right and left sides, although muscle thickness varied based on the placement of the ultrasound probe on the abdominal muscles. However, measurements were only taken at two sites per muscle in the previous study. Muscle thickness of the posterior trunk in individual muscles such as the trapezius [6] and the erector spinae [7] has also been examined. To the best of our knowledge, the relationship between the distribution of the anterior and posterior trunk musculature has never been investigated.

The current study examines the muscle and fat thickness of the trunk in a 25-year-old, former collegiate gymnast. The participant retired from sport 6 years prior to data collection, but has continued to train strength skills related to the sport of AG (e.g., handstand pushups, planche pushups, pull-ups, dips). Specifically, the participant performs approximately 100 handstand pushups (HSPUs) and 50 planche pushups daily, with the addition of resistance training exercises. The participant has (prior to data collection) submitted a world record for “most consecutive ninety degree pushups” (NDPU), which is currently under review. A NDPU (Fig. 2a, b) is a skill that combines a HSPU with a planche pushup. The participant’s past athletic history, as well as current training habits, makes him of particular interest in the current study. Since the

Fig. 1 Displays the beginning (a) and end (b) of the eccentric phase of a handstand pushup and the execution of a planche exercise (c)

Fig. 2 The beginning (a) and end (b) of the eccentric portion of a 90° pushup. This skill is performed from start to finish with only the hands touching the ground. On full repetition includes: lowering from handstand (a) to the parallel position (b) and back up to a handstand (a)

musculature of the trunk is presumably one of the primary limiting factors during exercise, it is of value to be able to quantify the amount of muscle in this region.

For athletes, such as the individual in this case study, the muscle mass of the trunk plays a large role in his athletic capabilities. In addition, the distribution and symmetry of the muscle may also contribute to performance. Therefore, the purpose of this case study was to quantify the absolute and relative muscle and fat across the trunk region in a highly trained athlete.

Methods

Mapping sites

Prior to taking ultrasound measurements, the subject stood in the fundamental position while measurement sites were marked. Using the xiphoid process as an anatomical reference, the anterior trunk was separated into 4 quadrants: upper right (UR); upper left (UL); lower left (LL) and lower right (LR). Within each quadrant, the total area was divided into 3 × 3 cm segments, the midpoint of which was used as the representative data point. Total area of measurement spanned 15 cm superior, 21 cm inferior and 15 cm lateral in either direction from the anatomical reference.

The posterior trunk was segmented in a similar fashion. Using the 7th cervical vertebrae as the anatomical reference, the posterior trunk was separated into the same four quadrants (UR, UL, LL, and LR). Within each quadrant, the total area was divided into 3 cm × 3 cm segments, the midpoint of which was used as the representative data point. Total area of measurement spanned 18 cm superior, 21 cm inferior to the anatomical reference. Width was 18 cm lateral in either direction at the greatest width of the back and 3 cm in width at the narrowest portion of the

back. In total, there were 143 data points on the anterior portion of the trunk and 140 data points on the posterior portion of the trunk (Fig. 3a, b).

Ultrasound measurement of muscle and fat thickness

Measurement of subcutaneous adipose tissue (AT) and skeletal muscle thickness was taken using a B-mode ultrasound. A real-time linear electronic scanner with a 5 MHz scanning head (SSD-500, Aloka Co., Tokyo) was coated with a water-soluble transmission gel, which allowed acoustic contact with the skin without causing depression. The scanning head was placed perpendicular to the skin on the surface of each data point and the center of the probe was aligned with the center of each data point. Distortion of tissues due to excess compression of the scanning head was eliminated by the observation of no movement of tissues in the real-time ultrasound image. Subcutaneous AT (including skin) and skeletal muscle thickness measurements were conducted from the machine using electronic calipers. AT thickness was measured as the distance from the skin to the AT-muscle interface and muscle thickness was measured as the distance from the AT-muscle interface to the muscle–bone interface or the deep muscle fascia interface. The validity of muscle thickness measurements has been confirmed previously using human cadavers [8] and test–retest reliability of this technique has been previously reported for muscle ($r = 0.97$ – 0.99) and AT ($r = 0.96$ – 0.99) [9].

Muscle volume estimations

Muscle volume was calculated for each trunk segment by multiplying the muscle thickness (cm) by the length and width of each segment (3 cm × 3 cm). Total muscle volume of each quadrant, as well as total volume of the

Fig. 3 Muscle thickness values across the anterior (a) and posterior (b) trunk. Dots represent center of site for ultrasound measurement and line indicates division of upper from lower quadrants

anterior and posterior trunk, was calculated as the sum of muscle volumes from each respective area of interest. Previous studies have calculated muscle volume using muscle thickness in combination with limb length [10]; however, this technique cannot be employed with the trunk musculature. Therefore, ultrasound scans were measured every 3 cm to map the changes in muscle across the entirety of the trunk, although hip and shoulder muscles were not included. The center of each 3 cm × 3 cm scan was chosen as the representative thickness for volume calculations.

Results and discussion

Mapping of muscle thickness

Muscle values are displayed in Table 1 and visually depicted in Fig. 4a, c. Muscle thickness values in the anterior trunk ranged from 0.5 to 5.6 cm, with the greatest values measured in the chest, followed by the internal and external obliques. Previous ultrasound muscle thickness values have been reported by Rankin et al. [5], with muscle thickness of a single scan averaging 1.25 cm (0.81–1.69) in the rectus abdominis muscles in moderately active men. In addition Rankin et al. [5] reported that muscle thickness values were greater in the upper abdomen, and less on the lower abdomen. However, the authors only measured muscle thickness at two sites in four different muscles of the anterior trunk. Muscle thickness values in the current study, as visually depicted in Fig. 4a, do not follow a pattern of descending thickness, but rather appear very uniform from the superior to inferior portions of the abdominals. In addition, rectus abdominis values in the current study ranged from 1.6 to 2.4 cm and average value of this muscle was 1.9 cm. The average value is approximately 50 % higher than previously reported values (1.2–1.3 cm) [5, 11]. Ranken et al. [5] also reported muscle thickness values of 0.54 cm (0.32–0.36) in the transverse abdominis, and 1.18 cm (0.64–1.72) and 0.97 cm (0.51–1.43) for the internal and external obliques, respectively. However, in the current study, we are not able to discriminate between internal or external obliques or transverse abdominis muscles separately, as our technique examined and quantified 3 × 3 cm segments and not entire muscles. Although entire muscles were likely measured, each measurement was a single snapshot of muscle thickness of one portion of musculature.

Muscle thickness of the posterior trunk in individual muscles such as the trapezius [6] and the erector spinae [7] has also been examined. O'Sullivan et al. [6] found trapezius values ranging from 0.3 cm (±0.11) to 0.9 cm (±0.17); however, values were greater in the middle

Table 1 Muscle thickness values (millimeters) for anterior and posterior trunk

Right					Left						
Anterior											
47	43	34	29	26	0	25	30	38	48	35	
48	40	41	34	28	0	30	34	38	51	46	
54	50	45	39	34	0	30	39	36	50	48	
56	44	40	37	32	0	27	35	40	45	37	
31	26	24	20	6	0	8	21	27	26	28	
8	14	16	12	19	0	19	13	22	10	13	
7	6	8	19	21	0	19	22	11	5	6	
8	6	16	23	17	0	17	24	18	5	6	
38	32	19	26	17	0	14	18	13	31	34	
39	37	15	23	21	0	20	26	21	29	31	
33	32	18	17	16	0	16	17	14	26	31	
0	25	14	18	20	15	20	18	17	20	0	
19	0	15	20	22	22	24	19	17	0	22	
Posterior											
40	6	32	49	42	45	10	42	46	46	29	8
44	28	18	45	45	45	10	47	46	44	20	28
45	28	15	44	41	40	11	42	44	42	17	31
39	25	13	46	39	37	9	41	43	39	15	30
32	29	10	37	35	38	10	37	40	39	14	24
56	22	8	32	32	39	14	35	30	38	12	23
60	21	27	28	32	43	8	39	27	30	29	23
	39	37	26	35	43	8	38	31	30	36	41
	40	39	29	34	41	8	40	32	28	36	38
		28	32	39	43	10	41	33	26	35	
			30	38	41	11	40	33	27		
				40	55	14	53	38			
					63	9	59				
					50	16	48				

Muscle thickness values for each segment of the anterior and posterior trunk expressed in millimeters. Anatomical reference is indicated with bold face. Each number represents a 3 × 3 cm segment positioned right or left and superior or inferior to the anatomical reference

trapezius when measured by MRI, reaching values as high as 1.6 cm (±0.34). In the current study, values ranged from 3.0 to 4.7 cm in the area of the trapezius. However, as previously mentioned, the current study did not discriminate between surface and underlying muscle tissue. Watanabe et al. [7] found muscle thickness values of the erector spinae ranging from 2.5 cm (±0.76) at the level of the first lumbar vertebra to 3.2 cm (±0.67) at the level of the fourth lumbar vertebra in healthy volunteers. In the present study, the muscle thickness of the erector spinae ranged from 4.0 to 6.3 cm. The total muscle thickness of the posterior trunk ranged from 0.6 to 6.6 cm (Fig. 4c). Greatest values were observed at the external latissimus dorsi and the inferior portion of the erector spinae, which were 80–100 % greater than the values of non-athletes [7].

Fig. 4 Anterior muscle thickness (a), anterior adipose tissue thickness (b), posterior muscle thickness (c) and posterior adipose tissue thickness (d) are displayed using a color gradient. Legend indicates color and corresponding thickness (mm)

Estimated muscle volume using mapping data

In the present study, estimated muscle volumes for the anterior trunk were 977, 949, 667 and 631 cm³ for the UR, UL, LL, and LR quadrants, respectively, and muscle volumes for the posterior trunk were 1099, 1144, 930 and 889 cm³ for the UR, UL, LL, and LR quadrants, respectively. Total muscle volume of the anterior trunk was 2935 cm³ and total volume of the posterior trunk was 4195 cm³. When muscle volume units were converted to mass units using the assumed constant density for skeletal muscle (1.041 kg/l), the predicted muscle mass in the anterior and posterior trunk was 7.4 kg. A study reported that MRI measured trunk muscle mass was approximately 9.7 kg (± 1.6) in healthy young men, although this value includes hip and shoulder muscles [4]. In addition, a recent study found that elite weightlifters had a total trunk muscle mass of 14.7 kg (± 2.0), compared to active controls that had an average trunk mass of 9.4 kg (± 1.8) [12]. However, trunk muscle volume measured by MRI included several muscles such as gluteus, deltoid, and iliopsoas. On the other hand, the current study did not include these muscles. It has been previously reported that the gluteus maximus was 3.35 kg (total gluteus; about 4 kg), the deltoid was 1.25 kg, and the iliopsoas was approximately 2 kg [12]. If

excluding those muscle mass (total gluteus, 4 kg; deltoid, 1.2 kg; iliopsoas, 2 kg) from 14.7 kg in elite weightlifters, the value of trunk muscle mass is about 7.5 kg. Considering the difference in standing height between weightlifters and our subject, the relative value of muscle mass (divided by height square) would be greater in AG than in the elite weightlifters. Furthermore, the current study measured only 1287 cm² (143 sites $\times$ 3 $\times$ 3 cm²) for anterior trunk and 1260 cm² (140 sites $\times$ 3 $\times$ 3 cm²) for posterior trunk. Thus, our measurements did not cover whole trunk surface, although the majority of major muscles were measured.

Muscle symmetry in the trunk

Muscle symmetry between the right and left sides of the trunk is displayed in Fig. 5a, b. The average difference in muscle thickness between the right and left sides was 2.8 % for the anterior aspect of the trunk and 1.2 % for the posterior aspect of the trunk. To our knowledge, Ranken et al. [5] is the only study to look at symmetry of the trunk musculature; however, they only measured muscle thickness values in 4 different muscles at 2 sites per muscle. The current study uses 143 sites in the anterior and 140 points in the posterior trunk, which provides a much greater

Fig. 5 **a** Anterior muscle thickness (mm), and **b** posterior muscle thickness (mm) are displayed. The x-axis represents 3 cm averages starting at the most superior point of the trunk (1) and ending at the most inferior point (13)

picture of muscle symmetry. There was very little difference in muscle volume between right and left sides for the anterior (2.8 %) and posterior (1.2 %) aspects of the trunk. However, symmetry was less apparent when comparing total anterior and posterior musculature, with 58.8 % of the total measured trunk musculature in the posterior portion of the trunk and 41.2 % located in the anterior portion.

Mapping of fat thickness

Fat tissue was more homogenous than muscle tissue across the trunk. Fat values of the anterior trunk ranged from 0.4 to 2.2 cm. The average fat thickness of the anterior trunk was 0.8 cm. Fat thickness values in posterior trunk ranged from 0.4 to 0.9 cm, with an average of 0.6 cm. Fat thickness values across the entirety of the trunk are visually depicted in Fig. 4b, d.

Previous studies have used B-mode ultrasound for body composition assessment [9]. Previously, Yuasa and Fukunaga [13] reported distribution of whole body subcutaneous fat thickness in two healthy men and found that fat thickness distribution varied in trunk compared with extremities. The current study shows that fat tissue in the trunk (relative to muscle) is quite homogeneous, with greatest values found in the lower abdominal region. Of the 284 sites, only 14 had a fat thickness values greater than 1.3 cm, all of which were located in the anterior portion of the trunk.

Muscle mapping and AG performance

The findings of the current study may have implications on sports performance and may speak to the specific demands of the sport of gymnastics. Although the total estimated

skeletal muscle mass is not directly comparable to those of previous studies [4, 12], it is plausible that the gymnast would have greater total estimated trunk musculature compared to the weightlifters previously reported [12]. The differences observed in symmetry may be due, in part, to the subject's athletic background. In the sport of gymnastics, there is great demand for both anterior and posterior trunk strength. For example, skills such as a back lever and muscle-up rely predominately on the posterior trunk, whereas skills such as a front lever and planche rely heavily on the anterior portions of the trunk. It is plausible that a gymnast with more pronounced musculature of the posterior trunk may have more success on events such as the high bar and rings, whereas athletes with a more pronounced anterior musculature may be more proficient on the vault and pommel horse. However, more research is necessary to examine this hypothesis. With further regard to symmetry, a gymnast almost always performs skills bilaterally. The still rings can only be performed bilaterally and strength skills that engage the trunk musculature are almost exclusively bilateral. The only event that would favor on side of the trunk is the pommel horse, which consists of the athlete continuously rotating in one direction; however, strength skills are rarely performed on this apparatus.

The current study is not without limitations. For example, the addition of a non-athlete comparison would have been of great interest. However, being that this is the first time this technique has been used, these findings still provide relevant and intriguing insight. In addition, our estimate of muscle size was muscle thickness and not the gold standard estimate from magnetic resonance imaging but previous studies indicate a strong relationship between ultrasound estimates and more sophisticated measures [10, 14].

Perspective

The results of the current study examined the total amount and distribution of skeletal muscle in the trunk of a former collegiate gymnast. Considering that approximately 40 % of total skeletal muscle is located in the trunk [4], it is important to be able to quantify both the amount and the degree of change and distribution of this musculature. The overall distribution of total trunk muscle mass has not been previously examined. These findings demonstrate the heterogeneous nature of the trunk musculature, as well as, the distributions and symmetry. Results indicated that there is a high level of symmetry between the right and left sides; however, symmetry was less apparent between the anterior and posterior portions of the trunk. In addition, fat thickness appears to be quite homogenous throughout the trunk. However, these data are limited to one former collegiate gymnast. Nonetheless, these data begin to provide a better understanding of the overall amount and distribution of muscle and fat tissue in the trunk. Additional research is needed to examine these patterns and distributions of muscle and fat tissue thickness in larger samples of both athletic and non-athletic populations.

Compliance with ethical standards

Conflict of interest The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this manuscript. This study was not supported by any funding.

Informed consent All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000. The participant provided written informed consent to enrollment in the study and to the inclusion in this article of information that could potentially lead to their identification.

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