

Female and male trunk geometry: size and prediction of the spine loading trunk muscles derived from MRI

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Abstract

Objective. Develop a gender specific database of trunk muscle cross-sectional areas across multiple levels of the thoracic and lumbar spine and develop prediction equations for the physiological cross-sectional area as a function of gender and anthropometry.

Design. This study quantified trunk muscle cross-sectional areas of male and female spine loading muscles.

Background. There is a lack of comprehensive data regarding the female spine loading muscle size. Although biomechanical models often assume females are the same as males, little is known regarding gender differences in terms of trunk muscle areas and no data exist regarding the prediction of trunk muscle physiological cross-sectional areas from commonly used external anthropometric measures.

Methods. Magnetic resonance imaging scans through the vertebral bodies from T_8 through S_1 were performed on 20 females and 10 males. Muscle fiber angle corrected cross-sectional areas were recorded at each vertebral level. Linear regression techniques taking into account anthropometric measures were utilized to develop prediction equations for the physiological cross-sectional area for each muscle of interest, as well as tests for differences in cross-sectional areas due to gender and side of the body.

Results. Significant gender differences were observed for the prediction of the erector spinae, internal and external obliques, psoas major and quadratus lumborum physiological cross-sectional areas. Anthropometric measures about the xyphoid process and combinations of height and weight resulted in better predictions of cross-sectional areas than when using traditional anthropometry.

Conclusions. This study demonstrates that the trunk muscle geometry of females and males are different, and that these differences should be considered in the development of biomechanical models of the torso.

Relevance

The prediction of physiological cross-sectional areas from external anthropometric measures provide gender specific equations to assist in estimation of forces of muscles which load the spine for biomechanical purposes. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Biomechanical model; Low back pain; Physiological cross-sectional area; Gender differences

1. Introduction

Biomechanical torso models that evaluate injury potential due to spinal loading are necessary as it is not possible to directly measure spinal loading in living humans. Assessing spinal loading is of interest to those wishing to evaluate industrial tasks such as manual material handling that are believed to place individuals at increased risk of low back disorders. Currently,

models used to assess spinal loading are based on male trunk geometry [1–3]. However, these models may not be representative of the female population as differences exist in muscle size and direction of the muscles (females have a wider pelvis), and females tend to exhibit more pronounced lordosis [4,5].

In order to assess spinal loading using an electromyography (EMG)-assisted biomechanical model, the force exerted by the spine loading muscles must be estimated [1,2]. Muscle force is related to the maximum force potential, among other factors (e.g., neural activation, muscle length–strength and force–velocity relationships, etc.). A muscle's maximum force generation

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potential is related in part to its physiological cross-sectional area (PCSA) defined in cadaver studies as the muscle volume divided by its length [6–8]. However, PCSAs derived from cadaver studies are typically representative of an elderly population, which may not be reflective of the population engaged in industrial tasks such as manual material handling. Therefore, it is necessary to estimate the muscle size via alternate methods, and also to develop prediction equations for the muscle sizes for inclusion in biomechanical models.

Few studies have estimated female trunk muscle cross-sectional area (CSA) at multiple levels of the spine [9,10], or quantified more than two trunk muscles [9]. Hence, there is a void in the body of knowledge that comprehensively describes female muscle geometry in the trunk.

The need for comprehensive accurate trunk geometry data for females is important for several reasons. First, differences from males with respect to muscle size may alter the magnitude of the loadings and the loading paths on the spine such that biomechanical models based on male anthropometry may not be valid if applied to females. Thus, female data are needed to develop valid biomechanical models of the female trunk. Second, females are increasingly present in material handling tasks that traditionally were exclusive to males, and are thus exposed to factors that increase the risk of low back disorders. Third, previous databases may not have described the largest CSAs due to limited scan levels investigated. Identification of the largest CSA is important as it is related to the maximum force generation potential [8,11–13]. Finally, EMG-assisted biomechanical models may eventually play a clinical role in the identification of deficits of performance due to injury and also enhance the return-to-work process. Thus, accurate female data are needed to build more comprehensive models.

1.1. Objectives

The objectives of this study are threefold: first, develop an accurate database of fiber angle corrected trunk muscle CSAs across multiple levels of the spine

for multiple trunk muscles, for both males and females. Second, determine if significant gender differences exist for trunk muscle geometry while controlling anthropometric differences. Third, develop prediction equations for the trunk muscle PCSAs for both males and females.

2. Methods

2.1. Subjects

Twenty female and ten male subjects were recruited from the local community. None of the subjects reported a history of activity limiting chronic back or leg injuries, nor were any experiencing any low back pain at the time of the MRI scan. Anthropometric measurements are shown in Table 1.

2.2. Data extraction

A Philips 1.5 T GyroScan MRI was set to a spin echo sequence of TR = 240 and TE = 12, generating slices of 10 mm in thickness. Subjects were placed in a neutral position (supine posture with knees extended and hands lying across their abdomen) on the MRI table. A single set of 11 torso scans was performed, which were perpendicular to the MRI table at transverse levels through the approximate centers of the vertebral bodies from T₈ through S₁.

The scans were transferred onto a Philips GyroView, which allowed an object of interest to be inscribed using a computer mouse. Descriptive statistical data including the area of the enclosed region and the three-dimensional location of the area centroid relative to the scan origin were derived. The quantified muscles included the right and left pairs of the erector spinae group, latissimus dorsi, internal obliques, external obliques, rectus abdominis, psoas major, and the quadratus lumborum (see Fig. 1). Each muscle, vertebral body and the torso were inscribed several times at each level, with the average of the observation used as the representative values. Three observations resulted in average coefficient of

Table 1
Mean (SD) anthropometric and demographic data for the male and female subjects

Gender	Age (yr)	Height (cm)*	Weight (kg)*	Trunk depth at iliac crest (cm)*	Trunk width at iliac crest (cm)*	Trunk depth at xyphoid process (cm)*	Trunk width at xyphoid process (cm)*	Body mass index (kg/m ²)*
Female (n = 20)	25.0 (7.2)	165.5 (5.9)	57.9 (6.4)	19.8 (2.1)	28.0 (2.4)	18.4 (1.8)	27.0 (1.9)	21.2 (2.5)
Male (n = 10)	26.4 (5.5)	175.9 (9.1)	79.8 (13.3)	22.3 (2.2)	30.3 (2.2)	22.9 (2.2)	32.4 (2.0)	25.7 (2.3)

* Indicates males significantly different than females ($P \leq 0.05$).



Fig. 1. Cross-sectional scan at the L_3 vertebral level of a female subject.

variation (CV) of 9% or less for each muscle based on the first 15 female subjects with most CVs less than 5%.

2.3. Muscle fiber corrections

Since the scan planes were perpendicular to the scan table, the raw CSAs derived directly from MRI scans will be overestimates of the true CSA as the direction of most muscles will not be perpendicular to the scan plane. Thus, similar to the approach used by McGill et al. [14], corrections to the raw muscle CSAs were performed by taking the dot product of the unit vectors using muscle fiber angles determined from different literature sources. Fiber angles for the latissimus dorsi, rectus abdominis, external oblique, internal oblique and quadratus lumborum were obtained from Dumas et al. [15]. Data from Macintosh and Bogduk [16] were used for the lumbar and thoracic portions of the erector spinae, and fiber orientations reported in McGill et al. [14] were used for the psoas major. The resulting corrected CSAs at each vertebral level corresponds to the anatomical cross-sectional area (ACSA) [13]. The PCSA, which is necessary to estimate the force producing capability of the muscle, is defined as the maximum CSA that “cuts” all fibers at right angles [13]. Thus, the largest ACSA for each muscle will be defined as the estimate of the PCSA.

2.4. Statistical analysis

Descriptive statistics (means and standard deviations at each vertebral level) were generated for the ACSAs for both females and males. Similarly, descriptive statistics were also determined for the PCSAs for both females and males.

Differences between the right and left side PCSA for each muscle were assessed by using dependent sample t -tests, performed independently for each gender. Differ-

ences between the right and left side ACSA at each specific vertebral level were assessed by performing a two-way repeated measures analysis of variance (ANOVA). The dependent variable was the ACSA, and the independent variables included the subject, vertebral level, side of the body (right or left), and a vertebral level by side of the body interaction. Post-hoc analyses consisted of Tukey pairwise comparisons on significant vertebral level by side of body interactions, using a significance level of $\alpha = 0.05$.

Linear regression techniques were used to predict the gender specific PCSA from anthropometric measures for each muscle (both right and left side PCSA, as well as the average of the right and left side PCSA). Regression equations were restricted to one independent variable, which included subject weight, body mass index (kg/m^2), the product of subject height and weight ($\text{kg} \cdot \text{m}$), the product of trunk width and trunk depth (cm^2) measured at the xyphoid process and the iliac crest, and the product of trunk width and trunk depth measured at the xyphoid process divided by subject height, and subject height divided by weight and subject weight divided by height [9,17–19].

Gender differences between the regression equations predicting PCSAs were investigated using a hierarchical multiple linear regression approach, testing the significance of a gender indicator variable. Finally, gender differences for the ACSAs at each vertebral level were determined by using t -tests with independent observations, with either equal or unequal variances where appropriate, using a significance level of 5%.

3. Results

The ACSAs of the muscles, vertebral bodies and torso, by vertebral level, are shown in Table 2. Males exhibited larger ACSAs for all muscles at most levels, and at all levels for the vertebral body and torso CSAs. The gender and muscle specific PCSAs are shown in Table 3.

Differences in PCSA were found as a function of side of the body. The PCSA for the right latissimus dorsi was more than 10% larger than the PCSA for the left latissimus dorsi for both males and females (Table 3), and the female left psoas major and quadratus lumborum PCSAs were larger than their respective right sides. On a vertebral level-by-level comparison, only the latissimus dorsi exhibited a significant right versus left ACSA difference with post-hoc tests indicating that the right side was larger than the left from T_8 to T_{10} for both males and females.

Table 4 lists the independent variables (description and units) used for the prediction of the various PCSAs from external anthropometry. The regression equations for the different muscles are shown in Table 5.

Table 2
Mean (SD) fiber angle corrected ACSAs (cm²) for each muscle and gender. All male ACSAs are significantly larger than female ACSAs *except* for bold-italicized cells ($P \leq 0.05$)

Muscle	Gender	T_8	T_9	T_{10}	T_{11}	T_{12}	L_1	L_2	L_3	L_4	L_5	S_1
R. lat. dorsi	F	13.15 (4.4)	11.51 (5.1)	9.77 (5.1)	8.45 (4.9)	7.34 (4.4)	5.39 (3.0)	3.44 (1.8)	1.45 (0.6)			
	M	21.68 (4.3)	19.53 (4.4)	16.61 (4.4)	14.10 (4.2)	12.03 (3.7)	8.96 (2.5)	6.22 (2.0)	2.71 (1.4)			
L. lat. dorsi	F	12.01 (4.7)	10.56 (4.9)	9.04 (4.9)	8.12 (4.8)	6.88 (4.3)	5.46 (3.0)	3.51 (2.4)	1.63 (0.7)			
	M	19.36 (5.2)	17.76 (4.4)	15.08 (4.9)	13.63 (4.6)	11.07 (4.0)	8.62 (2.8)	5.93 (2.3)	2.74 (1.5)			
R. er. spinae	F	7.63 (1.7)	8.38 (1.7)	9.56 (1.9)	10.92 (2.5)	11.69 (2.5)	13.67 (3.3)	15.68 (3.6)	15.43 (3.6)	12.37 (2.5)	2.81 (1.1)	
	M	12.96 (2.1)	13.91 (2.5)	15.38 (2.9)	17.28 (2.8)	19.65 (3.0)	22.49 (3.7)	25.60 (4.2)	25.03 (3.7)	20.08 (2.3)	4.95 (1.8)	
L. er. spinae	F	7.87 (1.6)	8.42 (1.9)	9.69 (2.3)	10.95 (2.5)	11.94 (2.7)	13.84 (3.0)	15.64 (3.5)	15.58 (3.2)	12.74 (2.4)	2.80 (1.1)	
	M	13.09 (2.2)	13.97 (2.4)	15.94 (3.1)	17.92 (3.5)	19.84 (3.5)	22.53 (3.7)	25.41 (4.2)	25.21 (4.1)	20.15 (2.7)	5.17 (1.7)	
R. rect. abd	F					4.25 (0.7)	4.85 (1.0)	4.23 (1.2)	4.44 (1.3)	4.88 (1.8)	5.33 (1.5)	6.01 (2.2)
	M					5.80 (1.9)	6.39 (1.7)	6.02 (1.2)	7.32 (2.9)	7.05 (2.2)	8.53 (2.2)	8.86 (2.3)
L. rect. abd	F					4.54 (0.9)	4.89 (1.1)	4.43 (1.3)	4.51 (1.3)	5.04 (2.3)	5.41 (1.3)	6.14 (2.4)
	M					6.13 (1.9)	6.67 (2.1)	6.22 (1.4)	7.77 (2.7)	6.92 (2.4)	8.69 (2.4)	8.88 (2.4)
R. ext. oblique	F					5.0 (1.1)	5.68 (1.2)	6.45 (1.3)	6.15 (0.9)	6.60 (1.0)		
	M					6.54 (1.5)	8.63 (1.9)	9.33 (1.9)	8.97 (1.8)	10.21 (2.0)		
L. ext. oblique	F					4.58 (0.7)	5.46 (1.1)	6.47 (1.3)	5.94 (1.1)	6.31 (1.0)		
	M					6.35 (1.6)	8.17 (1.8)	9.31 (2.1)	9.16 (2.1)	10.36 (2.0)		
R. int. oblique	F						3.51 (1.6)	3.73 (1.4)	3.73 (1.4)	6.17 (1.4)		
	M						3.79 (1.6)	6.38 (2.4)	9.96 (2.4)	9.96 (2.4)		
L. int. oblique	F						3.31 (1.8)	3.54 (1.4)	6.41 (1.1)	6.41 (1.1)		
	M						4.28 (1.8)	6.37 (2.3)	10.25 (2.5)	10.25 (2.5)		
R. psoas major	F						2.17 (1.2)	3.30 (0.9)	6.69 (1.8)	9.65 (1.7)	10.13 (1.7)	
	M						2.58 (-)	6.88 (2.3)	13.32 (3.1)	18.32 (3.6)	18.90 (3.8)	
L. psoas major	F						2.24 (0.4)	3.56 (0.9)	6.79 (1.7)	9.93 (1.8)	10.75 (1.8)	
	M						3.23 (1.4)	7.81 (2.5)	13.68 (2.7)	18.68 (3.1)	19.00 (2.9)	
R. quad. lumb.	F						1.71 (0.6)	1.88 (0.5)	2.11 (0.5)	1.97 (0.3)		
	M						2.50 (-)	3.04 (1.2)	5.20 (1.7)	3.56 (1.1)		
L. quad. lumb.	F						1.71 (0.4)	1.91 (0.5)	2.39 (0.7)	2.28 (0.4)		
	M						2.71 (1.3)	3.03 (1.1)	5.38 (1.9)	3.59 (1.0)		
Vertebral body	F	7.28 (1.1)	7.80 (0.9)	8.43 (0.8)	8.93 (1.0)	9.37 (1.2)	9.49 (1.0)	10.11 (1.2)	10.89 (1.1)	11.25 (1.2)	11.80 (2.2)	12.75 (2.5)
	M	9.83 (1.8)	10.41 (2.1)	10.87 (1.7)	12.25 (1.8)	12.87 (1.9)	12.49 (2.1)	13.11 (2.4)	14.13 (2.0)	14.78 (2.4)	14.66 (2.2)	17.42 (2.6)
Trunk	F	482.30 (65.7)	466.05 (63.3)	444.05 (61.2)	430.92 (59.9)	425.51 (60.0)	415.98 (61.6)	399.13 (61.4)	377.56 (57.9)	388.82 (71.7)	471.66 (77.7)	533.20 (79.6)
	M	733.38 (110.8)	688.31 (90.2)	645.59 (82.6)	616.48 (85.5)	594.41 (84.6)	574.78 (79.3)	544.35 (81.1)	525.43 (87.7)	514.32 (101.8)	524.81 (88.2)	565.47 (77.0)

Table 3

Mean (SD) PCSAs (cm²) for each muscle and gender. Bold-italicized cells within each gender indicates a significant difference between right and left PCSAs of a specific muscle ($P \leq 0.05$)

Muscle	Females	Males
R. latissimus dorsi	13.29 (5.0)	21.74 (4.2)
L. latissimus dorsi	12.01 (4.7)	19.44 (5.1)
R. erector spinae	16.16 (3.8)	25.95 (4.1)
L. erector spinae	16.12 (3.4)	26.00 (4.2)
R. rectus abdominis	6.28 (2.1)	9.05 (2.3)
L. rectus abdominis	6.46 (2.3)	9.04 (2.3)
R. external oblique	7.24 (1.1)	10.60 (2.0)
L. external oblique	6.92 (1.1)	10.59 (2.2)
R. internal oblique	6.18 (1.3)	10.26 (2.2)
L. internal oblique	6.43 (1.1)	10.54 (2.4)
R. psoas major	10.39 (1.7)	19.49 (3.6)
L. psoas major	10.96 (1.7)	19.76 (2.8)
R. quadratus lumborum	2.24 (0.4)	5.26 (1.6)
L. quadratus lumborum	2.64 (0.6)	5.42 (1.9)

Measurements about the xyphoid process resulted in significant prediction equations for the latissimus dorsi, for females, whereas weight and height combinations were significant predictors of male latissimus dorsi PCSA. There were no differences between the male and the female prediction equations for the latissimus dorsi PCSA. The best predictors of the erector spinae PCSAs consisted of combinations of height and weight for both genders. Weight divided by height explained between 61% and 72% of the PCSA variability for females; conversely, height divided by weight explained between 53% and 62% of the male PCSA variability. A significant gender effect was present when predicting erector spinae PCSA.

Measurements about the xyphoid process and BMI were significant predictors of rectus abdominis PCSA for the females, however, different combinations of height and weight were significant predictors for the males. Additionally, no gender effect was found for the prediction of the rectus abdominis PCSA from the anthropometric variables investigated. Measures about the xyphoid process were the best predictors of the external oblique PCSA for females, and for only the left external oblique for males. As indicated in Table 5, a significant

gender effect was present for the prediction of the external oblique PCSA.

Measures which included the xyphoid process and BMI were significant predictors of the female internal oblique PCSA, with gender differences present for almost all regression equations. Subject weight was the best predictor of the male internal oblique PCSA, with the PCSA variability between 51% and 62% explained.

There were no significant predictors of female psoas major PCSA, and only the xyphoid process significantly predicted male psoas major PCSA. Finally, many of the independent variables for predicting the quadratus lumborum PCSA were significant for females, with measures about the xyphoid process consistently better than other predictors. Only the left quadratus lumborum had significant predictors of PCSA for males.

4. Discussion

The results of this study are useful to those interested in biomechanical modeling of the torso for investigation of spinal loading during torso motion or material handling activities. The utility of these data lies in the ability to predict trunk muscle cross-sectional areas based on externally measured individual differences, for both males and females, to allow more realistic predictions of muscle force. Several other significant contributions to the body of knowledge for biomechanical modeling of the low back can be derived from this study, as discussed below.

First, a comprehensive dataset of ACSAs for spine loading muscles for both females and males now exists. The only comparable study used MRI to scan young males from T_5/T_6 through L_5/S_1 [14]. The ACSAs between these studies were similar for the latissimus dorsi, erector spinae, rectus abdominis, and psoas major, where average percent differences ranged between 1.7% and 12.0% for comparable muscles and vertebral levels. Female ACSAs for the latissimus dorsi, rectus abdominis and external obliques in our study were larger than those quantified by Chaffin et al. [9], whereas the ACSAs for the erector spinae, internal obliques, psoas major and quadratus lumborum of this study were

Table 4

Linear regression independent variables and descriptions for the prediction of the PCSAs

Independent variable	Description
TDTWXP (cm ²)	Trunk depth (cm) multiplied by trunk width (cm) measured at the level of the xyphoid process.
BMI (kg/m ²)	Body mass index: subject weight (kg) divided by square of subject height (m ²).
HTWT (m kg)	Height (m) multiplied by weight (kg).
Weight (kg)	Subject weight (kg).
TDTWXP/HT (cm ² /m)	Trunk depth (cm) multiplied by trunk width (cm) measured at the xyphoid process, divided by subject height (m).
HTDWT (cm/kg)	Subject height (cm) divided by subject weight (kg).
WTDHT (kg/cm)	Subject weight (kg) divided by subject height (cm).

smaller than those found in Chaffin et al. [9]. These differences may be due to a combination of several factors. The subjects in Chaffin et al. [9] were taking part in an osteoporosis study, whose average age was 49.6 yr, compared to healthy subjects in our study, with an average age of 25.0 yr. Thus, the older subjects may have experienced some age-related muscle atrophy. The scans were taken with the subjects lying supine, and the knees and hips flexed, whereas the subjects' hips and knees were extended in our study. Thus, differences in muscle length and orientation may have affected the resulting CSAs between the two studies. Additionally, the ACSAs in Chaffin et al. [9] were not corrected for muscle fiber angle, thus they were not normal to the muscle vectors.

Second, significant differences in the ACSAs of a muscle group as a function of side of the body were found. Both males and females exhibited larger right than left side ACSA of the latissimus dorsi between T_8 and T_{10} (10.2–12.0% larger for males, and 8.1–9.5% larger for females), consistent with the findings of McGill et al. [14]. The latissimus dorsi contributes both to twisting and lateral trunk motions, thus, differences in muscle size as a function of side of the body may need to be accounted for in biomechanical models.

Third, this is the first study to develop predictive equations for the estimated PCSAs based on external anthropometry, where the prediction equations in our study have resulted in better predictability than most other studies using uncorrected CSAs. For females, Chaffin et al. [9] found that height plus weight significantly predicted the erector spinae ACSA ($R^2 = 0.26$). However, knowledge of female height and weight in our study (weight divided by height) produced significant prediction equations accounting for a greater portion of the erector spinae PCSA variability than found by Chaffin et al. [9] (between 61% and 72%).

For males, no prior studies have found significant predictors of CSAs for the latissimus dorsi [18] or the quadratus lumborum [18,20]. However, our study found significant predictors of the latissimus dorsi (R^2 ranging from 0.43 to 0.52) and for the left quadratus lumborum ($R^2 = 0.61$). Male height divided by weight resulted in the best prediction equations for both the erector spinae (R^2 of 0.53 and 0.62 for right and left side, respectively) and rectus abdominis (R^2 of 0.60 and 0.63 for right and left side, respectively). Contrary to other studies which did not find significant anthropometric predictors of erector spinae CSA [17,18,20], Reid et al. [21] found significant predictors, however, their model was over-specified with six independent variables ($R^2 = 0.77$). Thus, our models performed almost as well for the prediction of the erector spinae PCSA with only one independent variable. Our regression models for the prediction of the rectus abdominis PCSA also performed better than those by Tracey et al. [18] (R^2 from 0.27 to 0.44) and Reid et al. [21] ($R^2 = 0.40$), whereas

McGill et al. [17] did not find a significant relationship between the rectus abdominis CSA at L_4/L_5 and height and weight measures. The current study found that measures about the xyphoid process (R^2 from 0.38 to 0.47) significantly predicted the external oblique PCSA, and different combinations of height and weight significantly predicted the internal oblique PCSA, previous studies found mixed results. Only McGill et al. [17] and Wood et al. [20] found significant relations between anthropometric measures and oblique muscle CSA. Finally, similar to other studies, external anthropometric measures were predictive of the psoas major PCSA [17,18,21]. Overall, the results of this study provide additional prediction equations not previously found for female as well as male trunk muscle PCSA. All prior studies that have attempted to predict trunk muscle CSAs from external anthropometry have been developed using either uncorrected CSAs or CSAs at vertebral levels which are not the largest CSA [3,9,17–21] which is necessary to estimate the PCSA for prediction of muscle force. Thus, the predicted CSAs from these studies will either overestimate the PCSA due to the obliquity of the muscle in relation to the direction of the muscle and the scan plane, or underestimate the PCSA if the CSA used was not at the largest point of the muscle.

Finally, gender differences were found regarding muscle geometry that may be important when considering inputs into biomechanical models. A significant gender effect was present for the prediction of the PCSA of the erector spinae, external and internal obliques, psoas major and quadratus lumborum, but not for the rectus abdominis or latissimus dorsi muscles. This indicates that gender differences need to be accounted for when using estimates of muscle PCSAs to predict trunk muscle forces in biomechanical models. The erector spinae and internal obliques are active during trunk extensions, and the external and internal obliques are active during twisting and lateral bending motions. Thus, when modeling materials handling activities, the estimates of muscle force of most motions will be affected by gender differences affecting the estimation of the PCSAs.

The results of this study should be interpreted in light of several methodological considerations. First, unlike most previous reported data, these results reflect a young healthy population. When compared to anthropometry from an industrial population [22], the female averages were at the 60th and 30th percentile for average height (ranged between 154.0 and 175.2 cm) and weight (ranged between 45.8 and 68.0 kg), respectively, and the male mean dimensions were at the 40th percentile for both height (ranged between 158.2 and 186.9 cm) and weight (ranged between 61.2 and 102.1 kg). Second, the estimates of the ACSAs and PCSAs were generated from subjects lying supine. McGill et al. [23] estimated, via ultrasound, that the difference between

Table 5
Regression equations, R^2 , P -values, and standard error for the prediction of the PCSA (cm^2) for females and males from various anthropometric measures

Muscle	Females					Males				
	Male vs Female	Regression equation (cm^2)	R^2	S.E. of prediction	P -value	Male vs Female	Regression equation (cm^2)	R^2	S.E. of prediction	P -value
Average of right and left latissimus dorsi	0.4402 0.6084	-7.647 + 0.041TDTWXP -5.42 + 5.98 TDTWXXPH	0.38 0.35	3.87 3.95	0.0039 0.0059	0.2734 0.3265 0.3033	5.565 + 0.106HTWT 1.588 + 0.238 Weight -4.12 + 54.68WTDHT	0.49 0.48 0.45	3.45 3.47 3.58	0.0245 0.0254 0.0334
R. latissimus dorsi	0.2509 0.3464	-8.24 + 0.043TDTWXP -5.82 + 6.32TDTWXXPH	0.40 0.37	3.95 4.05	0.0029 0.0048	0.1731 0.2372 0.2604	7.43 + 0.101HTWT 3.44 + 0.229 Weight -2.59 + 53.84WTDHT	0.51 0.52 0.50	3.16 3.13 3.18	0.0206 0.0194 0.0219
L. latissimus dorsi	0.5708 0.8092	-7.05 + 0.038TDTWXP -5.02 + 5.64TDTWXXPH	0.35 0.32	3.89 3.96	0.0062 0.0088	0.5708 0.3391	-4.65 + 0.032TDTWXP 3.7 + 0.11HTWT	0.48 0.43	3.91 4.11	0.0265 0.0410
Average of right and left erector spinae	0.0041 0.0075 0.0162	-9.92 + 0.45 Weight 40.97 - 8.59HTDWT -10.95 + 77.4WTDHT	0.66 0.61 0.68	2.12 2.30 2.07	0.0008 0.0001 0.001	0.4199 0.0041 0.0075	-0.265 + 0.247Weight 8.07 + 0.225 Weight 52.18 - 11.69HTDWT	0.41 0.54 0.59	4.15 2.95 2.78	0.0450 0.0162 0.0097
R. erector spinae	0.0025 0.0221 0.0139	-12.34 + 0.492 Weight 43.72 - 9.54HTDWT -13.78 + 85.55WTDHT	0.69 0.65 0.72	2.19 2.32 2.07	0.0001 0.0001 0.0001	0.0162 0.0025 0.0221	1.47 + 54.22WTDHT 9.27 + 0.209 Weight 50.7 - 11.04HTDWT	0.55 0.47 0.53	2.90 3.12 2.94	0.0139 0.0283 0.0166
L. erector spinae	0.0077 0.0027 0.0171	-7.51 + 0.408 Weight 38.21 - 7.65HTDWT -8.12 + 69.25WTDHT	0.61 0.54 0.61	2.15 2.34 2.15	0.0001 0.0002 0.0001	0.0139 0.0077 0.0027	2.83 + 51.16WTDHT 6.86 + 0.24 Weight 53.65 - 12.34HTDWT	0.50 0.58 0.62	3.04 2.87 2.72	0.0225 0.0103 0.0065
Average of right and left rectus abdominis	0.2729 0.3525 0.4734	-2.676 + 0.018TDTWXP -2.716 + 0.429BMI -2.5 + 2.935TDTWXXPH	0.38 0.25 0.42	1.73 1.90 1.67	0.0040 0.0245 0.0019	0.6904 0.1334 0.6113	0.106 + 57.28WTDHT -1.662 + 0.134 Weight 24.14 - 6.73HTDWT	0.61 0.62 0.61	1.52 1.49 1.52	0.0078 0.0068 0.0079
R. rectus abdominis	0.3244 0.2729 0.5809	-2.5 + 0.018TDTWXP -2.56 + 0.412BMI -2.23 + 2.81TDTWXXPH	0.38 0.24 0.42	1.66 1.84 1.61	0.0036 0.0295 0.0020	0.6864 0.1165 0.6059	-1.392 + 0.131 Weight 23.84 + 6.6HTDWT -5.04 + 31.18WTDHT	0.58 0.60 0.58	1.58 1.55 1.58	0.0108 0.0090 0.0106
L. rectus abdominis	0.2404 0.4377 0.3841	-2.85 + 0.019TDTWXP -3.22 + 0.457BMI -2.78 + 3.06TDTWXXPH	0.36 0.26 0.41	1.86 2.00 1.78	0.0053 0.0231 0.0023	0.6829 0.1514 0.5739	-1.93 + 0.137 Weight 24.44 - 6.87HTDWT -5.7 + 32.62WTDHT	0.63 0.63 0.62	1.49 1.48 1.50	0.0063 0.0058 0.0066
Average of right and left external oblique	0.1393 0.0272	3.158 + 0.008TDTWXP 3.51 + 1.18TDTWXXPH	0.28 0.27	0.93 0.94	0.0162 0.0183	0.1393	1.2 + 0.013TDTWXP	0.44	1.67	0.0380
R. external oblique	0.2251 0.0505	3.1 + 0.008TDTWXP 3.554 + 1.217TDTWXXPH	0.29 0.27	0.97 0.99	0.0151 0.0202					
L. external oblique	0.0414 0.1069 0.0247	2.03 + 14.87WTDHT 3.22 + 0.007TDTWXP 3.462 + 1.144TDTWXXPH	0.25 0.22 0.23	1.00 1.03 1.03	0.0241 0.0365 0.0345	0.1069	0.315 + 0.014TDTWXP	0.47	1.72	0.0297

Average of right and left internal oblique	0.0396 0.0069	2.586 + 0.007TDTWXP 2.65 + 1.21TDTWXP	0.23 0.26	1.01 0.99	0.0316 0.0213	0.0032 0.0048 0.0017	2.574 + 0.055HTWT 0.387 + 0.125 Weight -3.03 + 29.72WTDHT	0.61 0.62 0.61	1.41 1.39 1.41	0.0078 0.0071 0.0075
R. internal oblique	0.1169 0.0013 0.0290	1.662 + 0.009TDTWXP 0.337 + 0.276BMI 1.6 + 1.514TDTWXP	0.24 0.27 0.29	1.19 1.17 1.15	0.0278 0.0197 0.0144	0.0127 0.0245 0.0172	2.986 + 0.052HTWT 1.01 + 0.116 Weight -2.02 + 27.16WTDHT	0.50 0.51 0.49	1.62 1.62 1.65	0.0215 0.0212 0.0244
L. internal oblique						0.0039 0.0037 0.0009	2.162 + 0.059HTWT -0.233 + 0.135 Weight -4.05 + 32.29WTDHT	0.56 0.58 0.58	1.65 1.63 1.62	0.0122 0.0103 0.0100
Average of right and left psoas major						0.0001	5.36 + 0.019TDTWXP	0.49	2.47	0.0344
R. psoas major						0.0001	3.07 + 0.022TDTWXP	0.46	2.78	0.0313
L. psoas major						0.0001	7.65 + 0.016TDTWXP	0.41	2.27	0.0468
Average of right and left quadratus lumborum	0.0164 0.0023 0.0019	0.328 + 0.004TDTWXP 0.555 + 0.623TDTWXP -0.11 + 7.28WTDHT	0.43 0.40 0.35	0.36 0.37 0.39	0.0017 0.0028 0.0061					
R. quadratus lumborum	0.0001 0.0001 0.0009	-0.168 + 0.114BMI 4.62 - 0.82HTDWT -0.38 + 7.483WTDHT	0.43 0.38 0.43	0.34 0.35 0.34	0.0017 0.0041 0.0017					
L. quadratus lumborum	0.0657 0.0130 0.0077	0.095 + 0.005TDTWXP 0.418TDTWXP 0.162 + 7.07WTDHT	0.39 0.34 0.20	0.48 0.49 0.54	0.0034 0.0066 0.0457	0.0657 0.0240 0.0237	-2.68 + 0.011TDTWXP -0.387 + 0.04HTWT -1.8 + 0.09 Weight	0.41 0.44 0.42	1.51 1.47 1.50	0.0457 0.0369 0.0425

lying supine versus standing was to increase the erector spinae moment-arm by 3% and 12% for males and females, respectively, which may have an affect on the vector directions. Third, the ACSAs and PCSAs found in this study, as well as most other studies using MRI and CT do not reflect changes in muscle geometry during awkward postures such as twisting, lateral bending, or sagittal trunk flexion. Finally, the same muscle fiber angle correction factor was used for both male and females, however, it is unknown if both genders exhibit the same muscle fiber angle for a given muscle at a given vertebral level.

5. Conclusions

Utilizing MRI technology, muscle ACSAs from the T_8 through S_1 vertebral levels were tabulated for the right and left sides of the latissimus dorsi, erector spinae, rectus abdominis, external and internal obliques, psoas major and quadratus lumborum for both males and females. Gender differences for prediction of the PCSAs were found. These gender differences can affect the prediction of muscle forces and internal moments in biomechanical models, and may need to be accounted to improve the predictability of spinal loading.

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