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Morphometry of lumbar muscles in the seated posture with weight-bearing MR scans

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Running head: Lumbar muscle morphometry in seated posture with upright MRI

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Abstract

Conventional imaging studies of human spine are done in a supine posture in which the axial loading of the spine is not considered. Upright images better reveal the interrelationships between the various internal structures of the spine. The objective of the current study is to determine the cross-sectional areas, radii, and angulations of the psoas, erector spinae, and multifidus muscles of the lumbar spine in the sitting posture. Ten young (mean age 31±4.8 years) asymptomatic female subjects were enrolled. They were seated in an erect posture and weight-bearing T1 and T2 MRIs were obtained. Cross-sectional areas, radii, and angulations of the muscles were measured from L1-L5. Two observers repeated all the measurements for all parameters, and reliability was determined using the inter- and intra-class coefficients. The Pearson product moment correlation was used for association between levels, while level differences were used using a linear regression model. The cross-sectional areas of the psoas and multifidus muscles increased from L1 to L5 (1.9±1.1 to 12.1±2.5 cm² and 1.8±0.3 to 5.7±1.4 cm²). The cross-sectional area of the erector spinae was greatest at the midlevel (13.9±2.2 cm²) and it decreased in both directions. For the angle, the range for psoas muscles was 75-105 degrees, erector spinae were 39-46 degrees and multifidus was 11-19 degrees. Correlations magnitudes were inconsistent between levels and muscle types. These quantitated data improve our understanding of the geometrical properties in the sitting posture. The weight-bearing MRI-quantified morphometrics of human lumbar spine muscles from this study can be used in biomechanical models for predicting loads on spinal joints under physiological and traumatic situations.

Key Words: Lumbar spine muscles, upright MRI, human volunteers, morphometry
INTRODUCTION

Muscles stabilize the osteoligamentous lumbar spine column, protect the cord and cauda equina, and maintain the functionality under normal day-day activities and occupational exposures in the civilian, military, aviation, and other environments. Flexors and extensors contract under flexion and extension to allow respective motions of the intervertebral joints and spine segments. A quantification of the geometry and structural/mechanical properties of the spinal muscles is needed to accurately predict segmental forces, moments, and stresses and strains acting on the osteoligamentous column. Any changes in their properties affect the load carrying capacity of the column and alter the internal load (re)distributions within the individual segment(s). The load sharing between the anterior and posterior columns change due to alterations in the local loads carried by the disc and facet joints, with potential long-term implications such as sagittal balance and low back pain \(^1\). As the properties of spinal muscles change with age and disease, it is important to quantify them to estimate spinal loads via computational models. The first step is to establish the baseline values from a normative dataset.

Previous studies used computed tomography (CT) images to determine the anatomical and geometrical properties of muscles with the subject in the supine posture \(^2,3\). Ultrasound techniques were used \(^4\). Human cadaver dissections have served as an alternate model \(^5,6\). The magnetic resonance imaging (MRI) is another tool \(^2,7-11\). While the list in not inclusive, the posture of the human subject was recumbent. Because the supine modality does not replicate the spinal axial load acting, it does not accurately the mimic the properties of the sitting human \(^12\). It is known that posture affects internal osteoligamentous column load sharing,
injuries, and injury mechanisms. It is therefore important to determine the properties of the muscles with posture specificity. The objectives of the present study was to determine the morphometrics (geometrical properties) of the human lumbar spine muscles in the sitting posture from healthy young subjects.

Methods

Subject Selection

Approvals were obtained from the Institutional Review Boards of the authors and the US Department of Defense, and subject consent. The inclusion-exclusion criteria were such that the volunteers are females, healthy, asymptomatic for any back pain, with no history of lumbar injury or abnormalities, without prior surgical treatment, and under 40 years-of-age. The demographics and anthropomorphic measures included the age, stature, total body mass, erect sitting height, defined (vertical distance between the seat and the crown of the head); eye sitting height (distance from the seat to the eye); and shoulder sitting height (distance from the seat to the top of the shoulder with the Frankfurt plane horizontal). The details of the ten subjects were: age 31.0 ± 4.8 years, stature 1.6 ± 0.07 m, and body mass index 25.6+4.2 kg/m².

Imaging

Using an upright MRI scanner, (Fonar Corporation, Melville, NY, USA), T1 and T2 weighted MRIs were obtained. The subjects were in a seated posture. The scans followed the clinical imaging protocols under the supervision of the clinical team. The data from the scanner were stored in the Digital Imaging and Communications in Medicine (DICOM) format to obtain the morphologies of the muscles, described below. The cross-sectional areas were the psoas, erector spinae, and multifidus muscles were measured at the cranial surface.
from L1 to L5 levels \(^{14}\). The centroid and radius of the muscles were obtained at the same level. The position of the centroid, described by the radius and angulation of the muscle, was defined using the polar coordinate system. The reference was the centroid of the vertebral bodies. The radius was defined as the distance between the centroid of the muscle and vertebral body. The angulation was defined as the angle formed between the lines joining the centroid of the muscle and the centroid of the body, and the tip of the spinous process and the centroid of the body (Figure 1).

**Data analysis**

Commercial software (OSIRIX, Bernex, Switzerland) was used for data acquisition. A practicing and Board-certified clinician and a trained biomedical engineer obtained the cross-sectional areas, radii, and angulations of all the muscles (Image J version 1.53e). They were the two examiners for the data acquisition. The primary observer repeated measurements for all subjects and obtained the intra-observer dataset. The other observer performed the secondary measurements for all subjects and contributed to the inter-observer dataset. The intra-class correlation coefficient (ICC[3,1]) was used to assess the inter- and intra-observer repeatability for all the three parameters. Intraclass correlation coefficients of < 0.40 was categorized as poor, 0.40 to 0.60 as fair, 0.60 to 0.75 as good, and >0.75 as excellent \(^{15}\). The correlations of the three geometrical parameters for the five spinal levels for the three muscles were determined and rated as follows: < 0.20 negligible, 0.20 to 0.40 weak, 0.40 to 0.60 moderate, 0.60 to 0.80 strong, and > 0.80 high \(^{16}\). Results were expressed as means and standard deviations at each level, for each muscle, and for each of the three geometrical parameters. The Pearson product moment correlation was used to study the association between spinal levels; while the differences in levels were studied using a linear regression.
model, and the significance was set at 0.05 level \textsuperscript{17}. Box charts and mean and standard deviation bar charts are given at each spinal level, for each muscle, and for each of the three geometrical parameters.

**RESULTS**

For the psoas muscle, areas ranged from 1.9-12.1 cm\textsuperscript{2}, and the increase was from the cranial to the caudal level. For the erector spinae muscle, the areas ranged from 8.8-13.9 cm\textsuperscript{2}, and it was the smallest at the L1 level and greatest at the L3 level. For the multifidus muscle, the areas ranged from 1.8-5.7 cm\textsuperscript{2}, and the increase was from the cranial to caudal levels. Figure 2 shows the data for each muscle on a level-by-level basis. For the psoas muscle, angulations ranged from 75-105 deg, and it was the smallest at the L2 level and greatest at the L5 level. For the erector spinae muscle, the angulations ranged from 39-46 deg, and the increase was from the cranial to the caudal level. For the multifidus muscle, the angulations ranged from 11-19 deg, and the increase was from the cranial to caudal levels. Figure 3 shows the data for each muscle on a level-by-level basis. For the psoas muscle, radius results ranged from 2.4-4.5 cm, and the increase was from the cranial to the caudal level. For the erector spinae muscle, they ranged from 5.8-6.5 cm, and for the multifidus muscle, they ranged from 4.4-5.3 cm, and the increase was from the cranial to caudal levels for both muscle groups. Figure 4 shows the data for each muscle on a level-by-level basis.

The inter- and intra-class correlations for the area, angle, and radius for the three muscles were in the excellent category except for the multifidus muscle (inter-class: area at L2 and L3, radius at L1, angles at L2 and L4 were in the good, and angle at the L1 level was in the
fair category; intraclass: area at L1 and L5 and angle at L1 were in the good and area at L3 was in the fair category).

The areas of the muscles correlated in the strong to high category for the psoas muscles between L1 and L4, L2 and L3, and L4 and L5. For the erector spinae muscle, they were between L2 and L3, L3 and L4, L4 and L5, L1 and L2, and L1 and L3. For the multifidus muscle, they were L2 and L3, L2 and L4, L4 and L5, and L2 and L5. The angle was strongly correlated for the psoas at between L3 and L4 and L4 and L5 levels, for the erector spinae between L2 and L5 levels for 6 combinations, and for the multifidus at the L1 and L4, L3 and L4, and L4 and L5 levels. The radius was strongly correlated for the psoas at all levels in all combinations, for the erector spinae at all except L1 and L4 and L1 and L5, and for the multifidus between all the combinations except L1 and L3, and L1 and L5.

The area of the psoas muscles was significantly different at all levels except at the L1-L2 and L4-L5 levels. For the erector spinae muscle, there was significant difference at the L1-L2, L3-L1 and L4-L1 levels, and for the multifidus muscle, the area was significantly different at all levels except at the L1-L2 and L3-L2 levels.

The angle of the psoas muscle was significantly different at all levels except at the L2-L1, L3-L1, L3-L2 and L3-L4 levels. For the erector spinae muscle, the angle was significant only at the L5-L1 level, and for the multifidus, it was significant at all levels, except at the L1-L2, L1-L3 and L3-L2 levels. For psoas muscles the radius was significantly different at all levels except at L1-L2, L3-L2 levels. For erector spinae muscles, the radius was significantly different at L1-L3, L1-L4 and L1-L5 and for multifidus it was significant at all the levels except at L1-L2, L3-L4, L3-L5 and L4-L5.
DISCUSSION

As stated in the introduction, the objectives of the study were to determine the muscle geometries of the from healthy young female volunteers in a seated posture. Ultrasound, CT, quantitated CT, human cadaver, and MRI techniques have been used, and a majority continue to focus on the recumbent posture. Conventional (CT, MRI) techniques involve the scanning in the recumbent posture to identify the potential anatomic abnormalities and confirm clinical assessments. The inherent axial load on the human lumbar spine is not included in this posture, while supine scanning is a common clinical practice. The upright scanner used allowed the human volunteer to be seated so that the muscle geometries can be determined from the weight-bearing images. From this perspective, the present results are applicable to a seated occupant without extrapolations or corrections from the geometries obtained from the recumbent scans.

Scanning in a clinical environment is mainly done for patients with suspected pathologies. This has helped clinicians and others in improved treatment options for diseases such as spondylosis, herniated discs, spinal stenosis, and deformity. Supine scanning is more common, although upright scanners are also used to better visualize the abnormality as weight-bearing MRI provides a more realistic assessment of the patient’s spine under loading. While such images were available to the authors because of the academic hospital affiliation, they were not used in the present study. This is because patients (particularly in low back pain) may have altered muscles, and normative data cannot be obtained even if the pathology is confined to one motion segment. To eliminate these issues, the current study used healthy young subjects with no history of spinal disease, surgery, or pain. Because this investigation used women, the results are applicable to this group, and as sex differences
exist between males and females, additional studies are needed to delineate sex-specific data
\(^{19,20}\). This is a future study.

This study focused on the psoas major, erector spinae, and multifidus muscles as a first step. The erector spinae and multifidus muscles are extensors while the psoas is of the stabilizer type and lies close to the column. These muscles were selected due to their functional roles in both seated and standing positions, and their ease of consistent identification CT and MRI. They are used in comparative studies that involve low back pain patients \(^ {18} \). All geometries were extracted at each level so that they can be used as a normative female-specific data. The three muscles selected are known to have practical clinical implications in patients and or in situations that involve prolonged seated postures \(^{6,18}\). It is possible to extend this method to the other muscles in a future study.

Studies have reported the properties of lumbar muscles in the clinical and bioengineering literatures. Asymptomatic and symptomatic subjects have been studied with the latter category forming a majority of the clinical investigations. Properties extracted from imaging data from symptomatic patients may be confounded. Cadaver studies are also problematic because of the subject may be bedridden for a long period of time. Because men and women are known to have differences in muscles, women-specific and asymptomatic subject data are compared with literature here. An upright MRI study determined the cross-sectional areas from six female subjects (24.2±2.6 years) \(^ {21} \). The authors reported area, radius, and angles for the psoas muscle, and areas for the combined erector spinae and multifidus muscles. The mean values of the present data was lower (ranged from 1-17%, with an exception at the L3 and L5 level for the psoas area), while inclusion of the one standard deviation to the mean results demonstrated an overlap. Considering the subject population between the two studies,
the present results are in general agreement. It should be noted that the cited study provided data for L3-L5 levels while the present study determined the properties of three individual muscles at all the five levels of the lumbar spine, a data set hitherto not reported in literature. The present results can be used to define the muscle properties of the lumbar spinal column from L1 to L5 levels. To the best knowledge of the authors, current human body finite element models lack the posture-specific information for muscle geometries from a group of healthy subjects. The cross-sectional area, radius, and angulation data for these muscles at each spinal level from the present study can be incorporated into finite element models to better quantify local segmental spine responses. One of the limitations of the current study is a smaller sample size of 10 female volunteers. Studies in literature have used even smaller sample sizes to understand the spinal muscle morphology, presumably due to constraints such as subject enrollment and resources. Another limitation of the study is that imaging was performed only in upright sitting position. This was done as the objective of the study was to determine the lumbar muscle morphology in this posture. A study comparing morphological data between supine and standing scans would delineate the effect of posture, and this is a future study.

CONCLUSIONS

The weight-bearing MRI used to define the anatomical and geometrical properties of the lumbar spine muscles in a seated posture resulted in the following conclusions. The area, radius, and angle of the lumbar spine muscles are specific to the spinal level and muscle type. Although correlations were present, the degree of correlation was inconsistent between levels and muscle types. Normative data from this study can be used in the military and civilian
populations. The specific properties of the muscles from this investigation can be accommodated in finite element models to predict internal loads in the spinal column under physiological and traumatic situations.

REFERENCES


Biomechanics, Bioengineering and Biotransport Conference; June 17-20 2020; Virtual meeting.
FIGURE LEGENDS

Figure 1: Left shows the sagittal view and right shows the axial view of the muscle geometrical definitions from a subject.

Figure 2: Cross sectional areas of the muscles at each level. Top row shows the box chart and bottom row shows the mean and standard deviation for a quick read of the trend. Note that the bottom charts are positioned such that the spinal levels are from the inferior to superior paralleling the spinal anatomy.

Figure 3: Angulations of the muscles at each level. Top row shows the box chart and bottom row shows the mean and standard deviation for a quick read of the trend. Note that the bottom charts are positioned such that the spinal levels are from the inferior to superior paralleling the spinal anatomy.

Figure 4: Radii of the muscles at each level. Top row shows the box chart and bottom row shows the mean and standard deviation for a quick read of the trend. Note that the bottom charts are positioned such that the spinal levels are from the inferior to superior paralleling the spinal anatomy.
Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: