SAGITTAL PLANE MOMENT ARMS OF THE MALE LUMBAR REGION RECTUS ABDOMINIS: UPRIGHT VS. SUPINE POSTURE

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Prior studies of torso muscle moment arms for inputs into torso biomechanical models have been derived from subjects lying supine. Recent research suggests that moment arms of the rectus abdominis increase when standing versus lying supine. The objective of this study was to quantify and compare the sagittal plane rectus abdominis moment arm from upright and supine postures. Cross-sectional MRI images from ten males in both upright and supine postures were obtained. Digitizing software was utilized to quantify the sagittal plane moment arms of the rectus abdominis muscle. The mean sagittal plane moment arms were significantly larger at each lumbar intervertebral level in the erect posture compared to the supine posture, ranging from 15.9% larger at L1/L2 to 49.3% larger at L4/L5. These findings indicate that the torso internal moment generating capability would be represented differently in biomechanical models that use data from studies where subjects were upright versus supine.

INTRODUCTION

Biomechanical models of the torso have increased in complexity since they were first introduced almost four decades ago. Many biomechanical models of the torso are three-dimensional, incorporate multiple muscles, and utilize electromyography as a method to estimate torso muscle forces and internal moment generation[3,7]. In order to have valid estimates of internal muscle forces and moments, it is necessary to have valid estimates of torso muscle geometry.

The anatomical geometry inputs into the multiple muscle biomechanical models of the torso have typically been derived from medical imaging studies[1,5,8]. All of these imaging studies have been performed with subjects in the supine position, thus, the anatomical geometry also reflect subjects in a supine position. However, McGill et al.[6] suggested that the rectus abdominis (RA) muscle geometry in a supine posture is not the same as when individuals are standing upright, and that biomechanical models should account for a 30% increase in the sagittal plane moment arm at the L3 level for subjects in an upright posture. This implies that using biomechanical models of the torso to model upright tasks will result in errors in internal muscle moment prediction, as well as erroneous estimates of muscle force and spinal loading. However, the estimate from McGill et al.[6] was based upon ultrasound technology and only at one lumbar level.

The objective of this research was to quantify the magnitude of the sagittal plane moment arms of the RA muscle along the lumbar region from subjects in an upright neutral torso posture, and compare to the moment arms of the same subjects from a supine posture.

METHODS

Ten males (age 32.9 +/- 4.1 yrs; height 172.0 +/- 6.6 cm; body mass 80.1 +/- 11.3 kg) volunteered as subjects for this study. Anthropometric dimensions were taken (i.e., height, weight, torso depth and torso width at the iliac crest and xyphoid process levels). T1 weighted MR images were collected on the subjects in both an upright posture and a supine posture using a 0.6 T FONAR Positional Open MRI. For both upright and supine postures, sagittal plane scans were performed with subjects in a neutral torso posture, followed by axial scans that were oriented parallel

with and passed through the approximate center of the lumbar intervertebral discs (L1/L2 to L5/S1).

MRI images were converted to a 512 ×512 pixel format and analyzed using ImageJ software (National Institutes of Health). The border of the intervertebral disc and the right and left RA muscles at each of the lumbar intervertebral levels were outlined by a mouse, and the *x*- and *y*-coordinates of the centroid for each structure were recorded.

The raw sagittal plane moment-arms were derived by calculating the absolute difference between the intervertebral disc centroid and the RA centroid. The resulting moment arm represents the distance between the centroid of the intervertebral disc and the RA centroid along the scan planes. To allow more direct comparisons between the moment arms in the upright and supine postures, the moment arms from the scan plane were adjusted such that the moment arm was oriented parallel with the transverse plane (Figure 1).

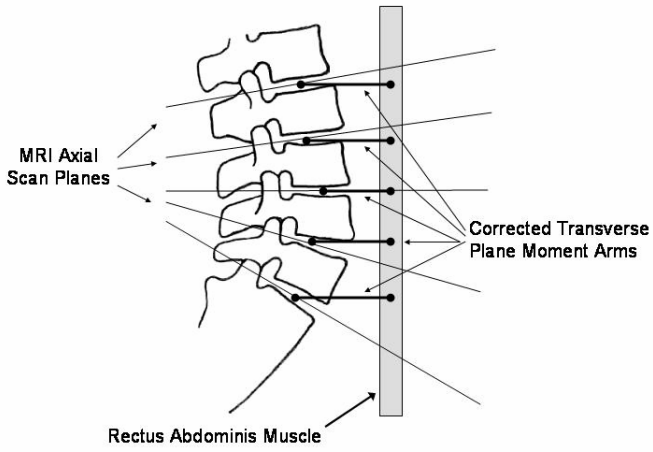

Figure 1. Graphical representation of the adjustment of the sagittal plane moment arms from the MRI scan planes to moment arms parallel with the transverse plane.

A two-factor ANOVA was performed to determine if there were differences in the moment arms as a function of posture (erect vs. supine), side (right vs. left), and intervertebral level. Significant main effects were investigated via Tukey pair-wise comparisons ($\alpha = 0.05$), and significant interactions were investigated via the least significant difference (LSD) post hoc test, utilizing a Bonferroni adjustment ($\alpha = 0.05$). To determine if the moment arms in the erect posture could be estimated from supine posture moment arms, stepwise linear regression was used. At each intervertebral level, the supine moment arm was forced into the model and all other anthropometric variables were allowed to be brought into the model.

RESULTS

The ANOVA indicated there was not a significant posture by side interaction ($p=0.6602$) nor was there a significant difference in moment arms as a function of side (right vs. left; $p=0.1882$). Thus, the right and left side moment arms were combined for the remaining analyses. A significant posture by intervertebral level interaction was present ($p<0.0001$), where the LSD post-hoc test indicated that the moment arm in the erect posture was significantly larger than the moment arm in the supine posture at every intervertebral level. The sagittal plane moment arms (parallel to the transverse plane) were larger in the erect posture compared to the supine posture by 15.9%, 27.2%, 40.0%, 49.3% and 45.8% at the L1/L2, L2/L3, L3/L4, L4/L5, and L5/S1 intervertebral levels, respectively (Table 1).

Table 1. Mean (SD) sagittal plane male lumbar rectus abdominis moment arms (cm) as a function of posture. Within each posture, intervertebral levels with the same letter are not statistically different.

Posture	Intervertebral Level				
	L_1/L_2	L_2/L_3	L_3/L_4	L_4/L_5	L_5/S_1
Supine	10.7 (1.7)	9.2 (1.5)	8.0^{A} (1.3)	7.5^{A} (1.3)	8.3 (1.2)
Erect	12.4^{A} (2.0)	11.7^{B} (1.9)	11.2^{C} (1.8)	11.2^{C} (1.7)	12.1^{AB} (1.6)
Difference (%)*	15.9	27.2	40.0	49.3	45.8

* Percent difference between the moment arm in the erect posture compared to the moment arm in the supine posture.

The moment arms in the erect posture could be significantly predicted from the supine posture moment arms at all intervertebral levels (Table 2). However, from L2/L3 to L4/L5, the subject height and trunk depth at the xyphoid process entered the

model along with the supine moment arm, whereas at L5/S1, the trunk width at the xyphoid process entered the final model. Thus, at the lower lumbar levels, the moment arm in the erect posture is not dependent only upon the supine moment arm, but also upon certain anthropometric measures.

DISCUSSION

The major finding from this study was that the distance between the spine and the RA muscle in the lumbar region of the torso increased when subjects went from a supine to upright posture, ranging from a 15.9% increase at L1/L2 to as large as a 49.3% increase at the L4/L5 level.

Biomechanical models of the torso are utilized to estimate the internal loading characteristics on soft tissues while subjects perform activities such as lifting, pushing and pulling. In part, the moment arms utilized in multiple-muscle biomechanical models contribute to the prediction of the internal moment, as well as the predicted muscle forces. Thus, accurate anatomical geometry is necessary for valid predictions of muscle forces and spinal loading from multiple-muscle biomechanical models. However, the anatomical geometric representation of the internal muscular structures such as the moment arms were derived from imaging studies with subjects in the supine position. Thus, the findings of this study suggest that at least for the RA muscle, consideration should be given for adjustments to the moment arms at various lumbar levels in biomechanical models to improve the accuracy of the loading predictions.

The differences in the moment arms between supine and upright postures may occur for several reasons. The mean L1/S1 lumbar curvature increased significantly ($t = 5.37$, $p<0.0001$) from 48.9° in the supine posture to 53.0° in the erect posture. Thus, the lower lumbar levels may be more posterior in the erect posture than in the supine posture. The difference at the lower lumbar levels may also be a result of the gravity acting upon the internal visceral structures when standing versus lying supine, which may displace the RA muscle in the anterior direction. It is also possible that the combination of increased lumbar curvature and the effects of gravity may account for the substantial increase in the sagittal plane moment arms of the RA muscle. Figure 2 shows sagittal plane MRI scans from the same subject in both the supine and erect posture. It can be seen visually an increase in lumbar curvature, as well as an increase in the distance between the lumbar spine and the anterior surface of the abdomen, suggesting the affect of gravity on internal components of the abdomen and changes in lumbar curvature may be partially responsible for the difference in sagittal plane moment arms of the lumbar region RA muscle.

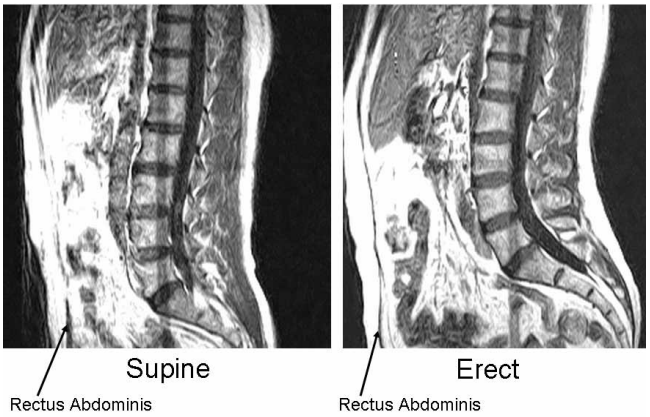

Figure 2. Sagittal plane MRI scan from one subject in the supine and upright posture.

Although the RA moment arm difference between the supine and erect posture appears to be quite large, there are consistencies with the findings from previous research. First, the maximum difference between the supine posture RA moment arms in this study and the mean moment arms at similar levels across other imaging studies on males in the supine posture is 0.6 cm[1,4,5,8,9]. Thus, the image analysis techniques from this study provide consistent results in the supine posture with prior studies, suggesting that the erect posture results may be valid. Second, the differences between supine and erect posture sagittal plane moment arms from L1/L2 (7.3%) to L5/S1 (43.7%) in a similar study on females[2] were similar in pattern to that observed in this study (smallest difference at the upper lumbar level, largest difference at the lower lumbar levels). Third, the percent increase in the estimated moment arm in the middle lumbar region is similar to that found by McGill et al.[6], who utilized ultrasound technology and an

anthropometer to estimate the percent change between the distance of the RA and the spine at the L3 level. Taking the average change in the moment arm at the L2/L3 and L3/L4 level in this study (to represent the change at the L3 level), resulted in a 33.6% increase between the supine and erect posture, this corresponds will with McGill's finding of a 30% increase at the L3 level.

Finally, McGill et al.[6] suggested that the increase in the RA moment arm from supine to standing was independent of subject height and body mass, and that the moment arms of current biomechanical models be adjusted by a factor of 1.3. However, with the exception of the L1/L2 level, our findings suggest that the change in the moment arm is dependent upon anthropometric characteristics, height and trunk depth between L2/L3 and L4/L5, and upon trunk width at the L5/S1 level.

CONCLUSIONS

The sagittal plane moment arms of the male rectus abdominis muscle were larger when subjects were in an erect neutral torso posture as compared to lying in a supine posture, by as much as 49.3% at the L4/L5 level. These findings suggest that biomechanical models of the torso utilizing moment arms from imaging studies on supine subjects may under represent the rectus abdominis moment arms, which would result in prediction error of the true moment generating capability of the rectus abdominis muscle.

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Table 2. Prediction equations for the sagittal plane rectus abdominis, parallel to the transverse plane. SMarm = supine moment arm; TDXP = trunk depth at xyphoid process; TWXP = trunk width at xyphoid process.

Level	Equation	Adjusted R^2	P-value
L1/L2	$0.697 + 1.094SMarm$	0.79	<0.0001
L2/L3	$1.361 + 1.127SMarm$ $-16.79 + 0.667SMarm + 0.095Height + 0.247TDXP$	0.73 0.85	<0.0001 <0.0001
L3/L4	$2.455 + 1.093SMarm$ $-14.27 + 0.632SMarm + 0.073Height + 0.326TDXP$	0.61 0.83	<0.0001 <0.0001
L4/L5	$2.968 + 1.089SMarm$ $-10.26 + 0.718SMarm + 0.05Height + 0.309TDXP$	0.64 0.88	<0.0001 <0.0001
L5/S1	$3.03 + 1.099SMarm$ $-2.99 + 1.139SMarm + 0.179TWXP$	0.69 0.87	<0.0001 <0.0001