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Research Article

Lumbar Spine Postures in Marines During Simulated Operational Positions†

Running title: Lumbar Spine Postures in Marines

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AUTHORS' CONTRIBUTIONS

DB, AR, JS, SG, BS, LP, and AJ collected data. DB, AR, JS, SG, BS, LP, and AJ designed the research question. DB, AS, JS, BS, and CC processed the data. DB processed statistics and drafted the paper. All authors have read and approved the final submitted manuscript.

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ABSTRACT: Low back pain has a 70% higher prevalence in members of the armed forces than in the general population, possibly due to the loads and positions soldiers experience during training and combat. Although the influence of heavy load carriage on standing lumbar spine posture in this population is known, postures in other operationally relevant positions are unknown. Therefore, the purpose of this study was to characterize the effect of simulated military operational positions under relevant loading conditions on global and local lumbar spine postures in active duty male US Marines. Secondary objectives were to evaluate if intervertebral disc degeneration and low back pain affect lumbar spine postures. Magnetic resonance images were acquired on an upright scanner in the following operational positions: natural standing with no external load, standing with body armor (11.3 kg), sitting with body armor, and prone on elbows with body armor. Custom software was used to measure global lumbar spine posture: lumbosacral flexion, sacral slope, lordosis, local measures of intervertebral angles, and intervertebral distances. Sitting resulted in decreased lumbar lordosis at all levels of the spine except L1−L2. When subjects were prone on elbows, a significant increase in local lordosis was observed only at L5−S1 compared with all other positions. Marines with disc degeneration (77%) or history of low back pain (72%) had decreased lumbar range of motion and less lumbar extension than healthy Marines. These results indicate that a male Marine’s pathology undergoes a stereotypic set of postural changes during functional tasks, which may impair performance.

Keywords: upright MRI, lumbar spine posture, intervertebral disc, low back pain

INTRODUCTION

Low back pain (LBP), one of the most common musculoskeletal complaints, affects between 70% and 85% of the population at any given time,[1] and is a particularly large problem in the military. In 2013, military medical encounters due to back pain were greater than any other major medical condition (975,000).[2] Additionally, the Veterans Health Administration has seen an increasing trend in the incidence of LBP in recent years.[3] These trends yield a large financial burden on the Departments of Defense and Veterans Affairs to provide health care to these individuals, costing over $2 billion annually.[4,5]

Members of the US Armed Forces are a unique population due to the physical demands required by their job. Increased rates of intervertebral disc (IVD) degeneration have been associated with increased military service, time, and age,[6] and individuals with IVD degeneration have been shown to have a higher incidence of LBP.[7] The increased rates of reported LBP in Marines may be attributed to pathophysiologic changes occurring in the lumbar spine, resulting from heavy loads and unusual positions experienced in training and combat.[8] Until recently, these ideas had not been measured directly. Rodriguez-Soto et al.[9] observed that heavy loading creates postural changes in standing that are not further exacerbated by the duration of loading or activity (e.g., marching with load). Although standing with heavy loads is not necessarily an injury- or pain-provoking activity in these subjects, the effect of other operationally relevant tasks and positions on posture have not been studied. For example, military members are often required to maintain static positions such as standing, sitting, and prone for extended periods of time (depending on military occupational specialty), which may contribute to LBP. In particular, members of the military have reported LBP induced by prolonged sitting in vehicles, suggesting sitting posture may also be related to back pain in this population.[10]

The influence of IVD degeneration and LBP on posture has also been studied in a male civilian population. Subjects with idiopathic LBP have been found to have less overall lordosis, but increased local lordosis in the upper lumbar spine compared with healthy controls.[11] In subjects with disc degeneration and LBP, decreased segmental range of motion between extension and flexion positions was found at levels with degenerated IVDs compared to levels with nondegenerated IVDs.[12,13] Understanding the relationship between the health and posture of the lumbar spine is crucial to understanding why subjects may be at risk of developing LBP. However, the results of the previous studies may not translate to the military due to the difference in age, loads worn in training, and physical activity level. The influence of IVD degeneration and LBP on posture in operationally relevant positions has not been studied in a military population, and may provide insight into whether task modification would be recommended for military personnel with these pathologies.

Therefore, the purpose of this study was to investigate changes in lumbar spine posture, in a variety of operationally relevant positions, with the minimum operationally relevant load, in active duty male Marines. Secondary analyses were performed to compare lumbar spine postures between Marines with and without IVD degeneration, and with and without LBP. We hypothesized that Marines with IVD degeneration or LBP would have less lower lumbar lordosis in operationally relevant positions than healthy Marines.

METHODS

Participants

Forty-three active duty male Marines from the Marine Corps Base Camp Pendleton volunteered to participate in this study. The University of California, San Diego and Naval Health Research Center Institutional Review Boards approved this study, and all Marines gave oral and written consent to participate.

Low Back Pain Evaluation

The Baecke questionnaire on habitual physical activity was administered to classify a Marine's daily work, leisure, and sport-related activity levels.[14] The Roland-Morris Disability Questionnaire data were collected to assess how a participant's LBP limits the ability to perform everyday activities.[15] We used another questionnaire to assess self-reported LBP on an 11-point numeric rating scale (0–10; 0 = no pain, 10 = worst imaginable pain) at the time of data collection, duration of the current episode of LBP (if applicable), duration of LBP since the first episode (if applicable), and number of LBP episodes within the last year. Additionally, volunteers were asked to report the activities that aggravated or eased their LBP symptoms.

Imaging

Marines were scanned using an upright 0.6T magnetic resonance imaging (MRI) scanner (Upright Multi-Position MRI, Fonar Corporation, Melville, NY) and a planar coil. An elastic band was used to hold the coil against the volunteer's lumbar spine between the L1–S1 levels while standing. The band was secured to hold the coil in place while retaining the volunteer's natural position. A three-plane localizer (TR = 1254 ms, TE = 100 ms, FOV = 34 cm, matrix = 256 × 256, in-plane resolution = 1.33mm x 1.33mm, THK = 9 mm, NEX = 1, time = 0:17) and sagittal T2-weighted images (TR = 1974 ms, TE = 160 ms, FOV = 35 cm, matrix = 224 × 224, in-plane resolution = 1.56mm x 1.56mm, THK = 3 mm, gap = 0 mm, NEX = 1, time = 2:12) were acquired.

Load Carriage and Position Tasks

Marines were scanned in the following positions: standing without load, standing with body armor (11.3 kg), sitting with body armor, and prone on elbows with body armor (Fig. 1). Positions with external load were randomized to control for the cumulative effects of loading over time. Body armor was selected for the load configuration in the current study, because it is the minimum protective equipment Marines are required to wear at all times during military operations/training. Marines were not instructed on how to assume each position, but were asked to hold each position steady for the duration of the MRI acquisition. At the end of each scan, volunteers were asked to rate their level of LBP in each position on an 11-point numeric rating scale. Volunteers were classified as having increased pain in a position if LBP on the numeric rating scale was greater than baseline levels when standing without load.

Disc Grading

Lumbar IVD degeneration was assessed by an experienced radiologist (C.C.) using the Pfirrmann grading scale.[16] The Pfirrmann classification system categorizes IVD degeneration from Grade I (normal) to Grade V (severely degenerated), based on nucleus pulposus signal strength and homogeneity, and intervertebral distance. Marines were separated into degenerated or nondegenerated groups based on the Pfirrmann grade of the L5−S1 IVD. A threshold of Pfirrmann Grade III was used to define spine degeneration because data support that IVD biomechanics begin to change at this grade.[17–19]

Kinematic Measurements

Postural measurements were generated from upright MRI images in each position, using a previously validated algorithm.[20] Briefly, digital seed points were manually placed on the corners of the vertebral body and on the posterior elements of each vertebra using OsiriX.[21] The locations of the seed points were imported into MATLAB (MathWorks Inc., Natick, MA) and used to define an endplate-based joint coordinate system applied to the superior and inferior endplate of each vertebra (L1−S1).

Global and local measurements of lumbar spine posture, intervertebral angles, and distances were calculated for all positions (Fig. 2). Global measurements included angle with respect to the horizontal, sacral slope, and sagittal Cobb angle. The angle with respect to the horizontal is defined as the angle between a line connecting the geometric centroids of L1 and S1, and a line perpendicular to gravity, pointing anteriorly. This measurement indicates the degree of lumbosacral flexion or extension of the entire lumbar spine in the sagittal plane. For the prone loaded position, images were rotated 90 degrees to allow for comparison of the measurements from the prone position to other positions (Fig. 1).The sacral slope is defined as the angle between the superior endplate of S1 and the horizontal, and describes the orientation of the sacrum to provide an estimate of pelvic rotation. The sagittal Cobb angle is used extensively to measure the curvature of the spine and is defined from the superior endplate of L1 to the superior endplate of S1.[22] Sagittal intervertebral angles were measured between the superior and inferior endplates of adjacent vertebrae to describe local changes in lordosis and distribution of lordosis throughout the lumbar spine. Intervertebral distances were measured as the anterior, central, and posterior Euclidean distance between planes fit to the endplates of each vertebra.

Statistical Analysis

Demographic comparisons of age, height, weight, and body mass index (BMI) between volunteers with and without IVD degeneration or LBP were evaluated using independent t-tests. Global kinematic measurements (angle with respect to the horizontal and Cobb angle) were compared using one-way repeated measures analysis of variance (ANOVA) tests with post hoc Sidak tests to identify differences between positions. Local measurements (intervertebral angles and heights) were analyzed using two-way repeated measures ANOVA tests with post hoc Sidak tests to identify differences between positions and intervertebral levels. Secondary analyses were conducted to determine kinematic differences in Marines with and without LBP or IVD degeneration. Volunteers were grouped based on presence of LBP on the day of data collection (yes, no), when the current episode of LBP began (chronic >6 months, acute <6 months, none), history of LBP (yes, no) and positional back pain (extension, neutral, sitting, none), and degeneration of the lumbar spine assessed by Pfirrmann grading (L5−S1 IVD > Grade II). Separate two-way ANOVAs (position × LBP or IVD variable) with post hoc Sidak tests were performed to identify differences for each variable describing LBP or disc degeneration. To investigate the relationship between disc degeneration, LBP, and segmental range of motion, we calculated the difference in postural measurements between the sitting and prone positions. Differences in segmental range of motion for each variable describing LBP or disc degeneration were compared using independent t-tests. The threshold for significance (α) was set to 0.05 for all analyses. η^2 and Cohen's d effect sizes are reported for ANOVA and post hoc tests respectively. Analyses were conducted using IBM SPSS Statistics 20.0 (IBM, Armonk, NY). All data are reported as mean ± standard deviation.

RESULTS

Marine Demographics

Complete image data sets were obtained from 43 male Marines (mean age = 26.8 ± 6.4 years, height = 1.78 ± 0.07 meters, weight = 82.04 ± 9.85 kg, BMI = 25.90 ± 2.86 kg/m^2; Table 1). IVD degeneration assessed using the Pfirrmann classification system (>2) was observed in 125 out of 215 (58%) of all graded lumbar IVDs (Fig. 3). Based on the Pfirrmann grades (>2) of the L5−S1 IVD, 33 of 43 (77%) Marines were in the degenerated group, and 10 were in the nondegenerated group.

The Baecke and Roland-Morris questionnaires were collected from 32 Marines. The average Baecke score was 9.96 ± 1.61 (range: 7.25–13.25). The Roland-Morris average score was 2.69 ± 3.25 (range: 0–13, 22/32 had score >0). Back pain history information was collected from 39 Marines. At the time of data collection, 16 of 39 (41%) Marines reported current back pain (7 chronic LBP, 9 acute LBP), and 28 of 39 (72%) Marines reported previously experiencing at least one episode of LBP. Marines self-reported that sitting, standing for extended periods of time, and hiking with a pack resulted in increased LBP. Additionally, lying supine and positions of lumbar spine extension were reported to decrease LBP in this population. Positional back pain information was collected from 32 Marines. Seven participants reported LBP when standing unloaded (22%), 9 when standing loaded (28%), 6 when sitting loaded (19%), and 11 when prone loaded (34%).

Effect of Position on Global Posture

Significant differences occurred in lumbosacral flexion ($p < 0.001$, $\eta^2 = 0.22$), sacral slope ($p < 0.001$, $\eta^2 = 0.51$), and lumbar lordosis ($p < 0.001$, $\eta^2 = 0.60$) between tasks (Fig. 4). Compared to standing without load, standing wearing body armor resulted in a small decrease in sacral slope (3°, $p = 0.006$, d = 0.19), indicating slight posterior tilt of the pelvis, while lumbosacral flexion and lumbar lordosis remained constant. Decreased sacral slope (>21°, $p < 0.001$, d = 0.33-1.03) and lumbar lordosis (>30°, $p < 0.001$, d = 0.92-1.18) were observed when sitting loaded compared with other positions. No change in lumbosacral flexion was observed during sitting relative to standing positions.

Compared with standing unloaded, when Marines were prone on elbows, lumbosacral flexion increased (5.5°, $p = 0.016$, d = 0.40), sacral slope decreased (14°, $p < 0.001$, d = 0.98), and lumbar lordosis increased (6°, $p = 0.001$, d = 0.33). Interestingly, both sitting and prone on elbows positions resulted in significantly decreased sacral slope compared to standing without load, indicating posterior pelvic tilt.

Effect of Position on Local Posture

Local intervertebral angles were measured to identify regional contributions to overall lumbar posture. A significant effect of level ($p < 0.001$, $\eta^2 = 0.49$), position ($p < 0.001$, $\eta^2 = 0.54$), and an interaction of level x position ($p < 0.001$, $\eta^2 = 0.30$) for intervertebral angles was found. When volunteers were sitting, a significant decrease in lordosis was evident at all levels of the lumbar spine except at L1−L2 (Fig. 5). Larger decreases in lordosis were found in the inferior lumbar spine than in the superior lumbar spine when seated. When Marines were prone on elbows, the only level where a significant increase in lordosis was found was L5−S1, indicating that overall lordosis changes in this position originate from L5−S1.

Intervertebral distance was measured to identify local IVD compression and excursion in different postures (Fig. 6). A significant effect of level ($p < 0.001$), position ($p < 0.001$), and an interaction of level x position ($p < 0.001$) for anterior ($\eta^2_{level} = 0.31$, $\eta^2_{position} = 0.37$, $\eta^2_{interaction} = 0.13$), central ($\eta^2_{level} = 0.06$, $\eta^2_{position} = 0.21$, $\eta^2_{interaction} = 0.01$), and posterior ($\eta^2_{level} = 0.07$, $\eta^2_{position} = 0.12$, $\eta^2_{interaction} = 0.05$) intervertebral distance was found. Intervertebral distance changes paralleled changes in intervertebral lordosis at all levels. The sitting position resulted in anterior compression from L2−L3 to L5−S1 ($p < 0.009$, d = 0.62 – 0.90), and posterior distraction from L3−L4 to L5−S1 ($p < 0.017$, d = 0.20 – 0.38), with magnitude of effect increasing inferiorly through the lumbar spine. Additionally, sitting resulted in a slight loss of central intervertebral distance from L2−L3 to L5−S1 ($p < 0.011$, d = 0.15 – 0.31) compared with standing unloaded, with magnitude of effect increasing inferior through the lumbar spine. Similarly, the prone on elbows position induced an anterior intervertebral distance distraction at L5−S1 ($p < 0.001$, d = 0.28 – 0.68).

Effect of Intervertebral Disc Degeneration on Lumbar Spine Posture

No lumbar spine postural differences were found between Marines with and without disc degeneration at L5−S1. However, Marines with IVD degeneration at L5−S1 were found to have less whole lumbar range of motion, measured as the Cobb angle between sitting loaded and prone on elbows loaded positions, than Marines with no IVD degeneration (9°, p = 0.002, d = 0.13). Interestingly, this difference between groups appears to be driven by decreased intervertebral segmental range of motion at L2−L3 (2.1°, p = 0.031, d = 0.29), L3−L4 (1.0°, p = 0.015, d = 0.14), and L4−L5 (1.9°, p = 0.039, d = 0.19).

Effect of Low Back Pain on Lumbar Spine Posture

There were no significant differences in lumbar spine posture, intervertebral angle, or intervertebral distance between Marines with and without back pain at the time of data collection, or with and without reported back pain in each position. However, there was a difference in angle with respect to the horizontal ($p < 0.001$, $\eta^2 = 0.27$) when the current episode of LBP was subclassified into chronic, acute, or no LBP. Marines with chronic LBP displayed more extension of the lumbosacral spine than those without LBP (~4°, p = 0.024, d = 0.61) and Marines with an acute episode of LBP (~3°, p = 0.048, d = 0.08) when standing without external load. Additionally, when sitting with body armor, Marines with chronic LBP displayed more extension of the lumbosacral spine than those with an acute episode of LBP (5°, p = 0.021, d = 0.24), but their posture was the same as Marines without LBP (p = 0.105, d = 0.21). When subjects were classified by history of LBP, a significant effect was found for angle with respect to the horizontal ($p < 0.001$, $\eta^2 = 0.12$). Participants who reported a history of LBP displayed less intervertebral extension at L5−S1 (6°, p = 0.024, d = 0.78) when prone on elbows, with corresponding less anterior distraction (4 mm, p = 0.028, d = 0.50) than those who did not have an episode of LBP.

DISCUSSION

In this study, we evaluated the lumbar spine posture in 43 active duty male Marines in simulated, relevant operational positions and loading conditions. Position-dependent changes in global lumbar spine postures were found in lumbosacral extension, sacral slope, and lumbar lordosis. Sitting with body armor resulted in a reduced lumbar lordosis of over 30°, but no changes in the forward inclination of the lumbar spine with respect to standing positions was observed. The addition of load did not change standing posture as was previously observed.[9] This is likely related to the small load magnitude used in this study (11.3 kg) compared with the previous study (50.8 kg). This load magnitude was used because tasks involving sitting and being prone on elbows typically do not involve the heavy packs used in previous studies. Additionally, the load from the body armor was evenly distributed anterior-posterior, while the load distribution in previous studies was distributed with a posterior bias, which may have an effect on the response of the lumbar spine to loading.

To determine the location of global position-dependent differences in posture, we measured sagittal intervertebral angles and intervertebral heights. The largest decrease in lordosis relative to standing was observed between L2 and S1 when volunteers were sitting, with magnitudes of change increasing caudally, similar to previous studies.[23] Interestingly, when volunteers were prone on elbows, the only intervertebral segment with a measured increase in lordosis was found in L5−S1. Additionally, this level had the largest segmental range of motion between sitting and prone positions, and the largest number of discs that were classified as degenerated (33/43). Decreases in anterior intervertebral distance, driven by intervertebral flexion, were observed between L2 and S1, with anterior intervertebral distance progressively decreasing caudally. This follows previous observations that changes in intervertebral distance appear to track changes in sagittal intervertebral angle, not task or load.[9]

During this study, we did not specifically recruit Marines with LBP. However, we observed a relationship between history of LBP and posture in Marines. In standing and sitting positions, Marines with chronic LBP (current episode lasting >6 months) had more lumbosacral extension than Marines with no back pain or Marines with an acute (<6 months) case of LBP. O'Sullivan identified that LBP subjects with lumbar segmental instability can be classified into four groups, based on the manifestation of the patients' symptoms and motor dysfunction: flexion, extension, lateral shift, and multidirectional patterns.[24,25] Of those subclassifications, the extension pattern has been reported to be due to repetitive low impact trauma associated with sporting activities, such as hiking with a heavy pack.[24] These data support the idea that postural changes in soldiers with chronic LBP may be due to heavy loads carried in training and combat.

In the present study, approximately half of the Marines reported LBP as a result of sitting for extended periods of time. It was previously reported that volunteers who sit for extended periods of time are at risk for developing LBP.[26] A 2007 review paper by Lis et al. determined that people with occupations requiring them to sit for over half of the workday, and who are exposed to factors such as whole body vibration and/or awkward postures, are at an increased risk of developing LBP.[26] The Marines in this study are often exposed to whole body vibration during transport in tactical vehicles and helicopters, and remain in awkward positions such as prone on elbows, for extended periods of time. Therefore, the high rate of LBP in this young population of Marines is likely attributable to their high occupational demands during both training and combat situations.

In this study, 58% of all IVDs were classified as degenerated, which is greater than among older patients imaged for LBP (45.5 years old, 44% degenerated).[13] Marines with IVD degeneration experienced less whole lumbar range of motion between sitting and prone positions. It has been established that disc degeneration decreases local segmental range of motion using upright MRI.[13] As a disc degenerates, functional spinal units become hypermobile (Pfirrmann Grades III and IV) and then hypomobile (Pfirrmann Grade V).[17-19] Although we did not identify local changes in segmental range of motion, possibly because they were below our threshold of detection, we hypothesize that small changes at each level all contributed to the overall observed change in lumbar range of motion. Several studies have found trends toward differences in the posture of the lumbar spine with disc degeneration; however, it is unclear if disc degeneration leads to increased or decreased lordosis.[12,13,27,28] Disc degeneration occurs in the normal progression of aging, but it can be accelerated by lifestyle factors such as excessive loading or smoking.[11] People with physically intensive jobs are at risk for accelerated IVD degeneration. Marines in our study had higher levels of habitual physical activity, measured by the Baecke questionnaire, than civilians of similar age[14,29] because they routinely engage in physical activity and training per their infantry program of instruction.

There are several limitations to this study. First, imaging resolutions were 1.56 mm in plane and 3.0 mm thick. We know from prior validation work[20] that this yields low angular error rates (~1 deg), but it does mean that our confidence in linear changes in disc height is relatively coarse. Second, our secondary analyses included a number of univariate comparisons aimed at identifying kinematic differences between Marines with and without LBP or with and without IVD degeneration. Because of the structure of these variables and our statistical approach, type I error rates could have been elevated. However, the subtle effects of LBP and IVD degeneration on whole spine kinematics are consistent with prior observations in civilian populations.

This study was performed on active, young Marines, and their postural responses to loading may not apply to a civilian population. Due to the intense training and demands of their jobs, the Marines in this study were extremely fit, and trained on how to adapt their posture in different positions while wearing body armor to minimize their risk of injury. One of the long-term goals of this line of research is to identify Marines who were at risk for developing LBP based on their posture profile. We observed that Marines with chronic LBP exhibit an extension pattern of LBP, which may be related to the loads they carry during training and combat. Marines carry required equipment to ensure they can successfully complete their job, a load that sometimes exceeds the standard 32 kg. Since we have previously investigated the effect of heavy load on lumbar spine posture, and have identified postural differences in Marines with pathology in this study, further studies on LBP and disc degeneration in

Marines should focus on managing the anterior-posterior distribution of load around the torso center of mass. We have previously noted that balanced loads minimize postural changes in standing[30], but their influence on non-standing postures (e.g. sitting) have not been investigated. A second long-term goal of this research is to understand position-related lumbar spine disease and to understand the influence of loading and position on existing lumbar spine pathology. For example, future work should test the influence of relevant positions and loads on stable and unstable disc protrusions/fragmentations in the civilian population. These studies may shed light onto more appropriate, or patient specific, exercise regimes for individuals with anatomically identifiable sources of low back pain.

CONCLUSION

This study investigated the effect of operationally relevant positions on lumbar spine posture in active duty male Marines. Sitting and prone on elbows positions resulted in large global postural differences in the lumbar spine, with the greatest local change found at L5−S1. This level also had the highest incidence of IVD degeneration in the lumbar spine. Overall, we found that Marines have a high incidence of lumbar disc degeneration and high rates of LBP, particularly in the sitting position. Marines with disc degeneration at L5−S1 had decreased lumbar range of motion and Marines with chronic LBP had more lumbar extension. Subtle postural changes were seen in subjects with disc degeneration or LBP, resulting in increased overall lumbar lordosis and decreased lumbar range of motion. These results provide the framework for postural interventions aimed at reducing LBP, and perhaps, risk factors for LBP in Marines during operational tasks.

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Table 1. Participant characteristics by intervertebral disc degeneration, and current and past low back pain. No significant differences were found between groups

	Aggregate	Degeneration		Low Back Pain			
				"Are you currently experiencing LBP?"		"Have you ever experienced LBP?"	
		Yes = 33	No = 10	Yes = 16	No = 23	Yes = 28	No = 11
Age (years)	26.8 ± 6.4	27.6 ± 6.8	24.0 ± 3.7	26.9 ± 5.7	27.1 ± 7.4	27.7 ± 6.6	25.4 ± 6.6
Height (m)	1.78 ± 0.07	1.78 ± 0.07	1.76 ± 0.07	1.78 ± 0.07	1.78 ± 0.08	1.79 ± 0.07	1.77 ± 0.09
Weight (kg)	81.9 ± 9.8	83.8 ± 9.5	75.6 ± 8.6	81.8 ± 10.6	82.3 ± 10.0	82.5 ± 9.9	81.0 ± 11.2
BMI (kg/m^2)	25.9 ± 2.9	26.4 ±2.8	24.3 ±2.4	25.7 ± 3.1	26.1 ± 2.9	25.9 ± 2.8	26.0 ± 3.5

BMI, body mass index.

Figure Legends

Figure 1. T2-weighted midsagittal magnetic resonance images (MRIs) of the lumbar spine (top) and photographs of Marines in the MRI scanner (bottom). Volunteers were scanned standing unloaded (A, E), standing with body armor (B, F), sitting with body armor (C, G), and prone on elbows with body armor (D, H).

Figure 2. Distribution of Pfirrmann-graded intervertebral discs by level.

Figure 3. Schematic depicting lumbar spine postural measurements on a 3D model of the lumbar spine. Measurements included A.) Angle with respect to the horizontal to assess lumbar flexion/extension. B.) Sagittal Cobb angle to measure lumbar lordosis. C.) Sacral slope to assess rotation of the pelvis. D.) Intervertebral angles to provide a measurement of local lumbar lordosis.

Figure 4. Global measures of lumbar spine posture. Angle with respect to horizontal (top), sacral slope (middle), Cobb angle (bottom). Statistically significant difference between measurements ($p > 0.05$) indicated by line. Data reported as mean (standard deviation).

Figure 5. Local measures of lumbar spine posture. Intervertebral angles from L1–L2 (top) to L5–S1 (bottom) are shown. Statistically significant difference between measurements ($p > 0.05$) indicated by line. Data reported as mean (standard deviation).

Figure 6. Anterior (left column), central (middle column), and posterior (right column) intervertebral distance measurements for each level of the lumbar spine. Intervertebral heights from L1–L2 (top) to L5–S1 (bottom) are shown. Statistically significant difference between measurements ($p > 0.05$) indicated by line. Data reported as mean (standard deviation).

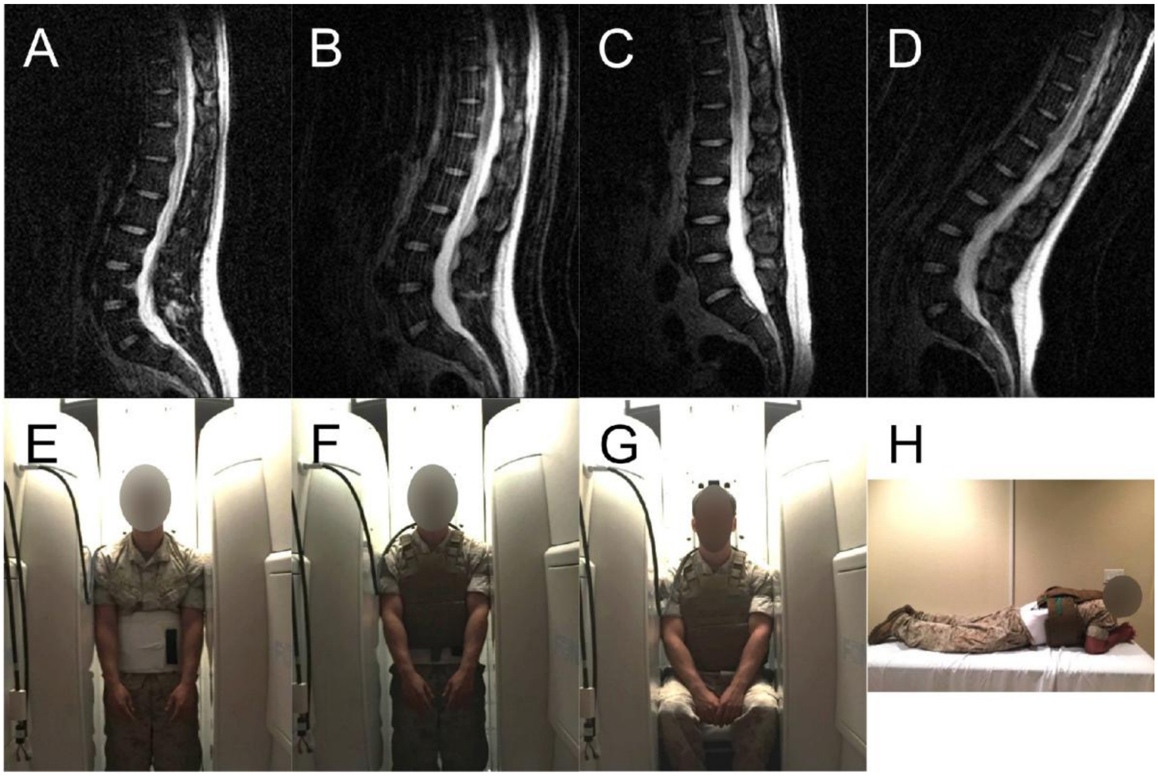


Figure 1

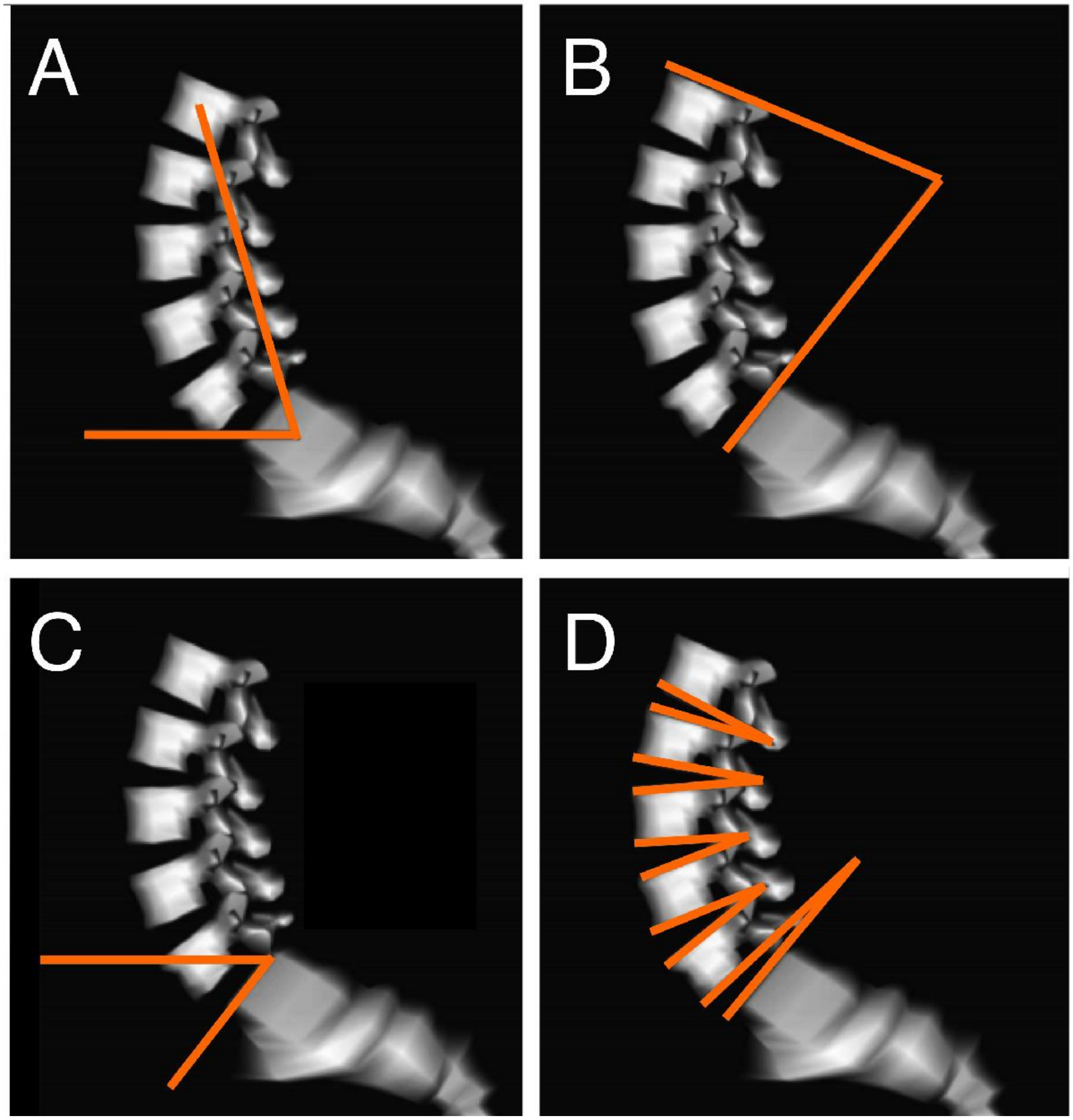


Figure 2

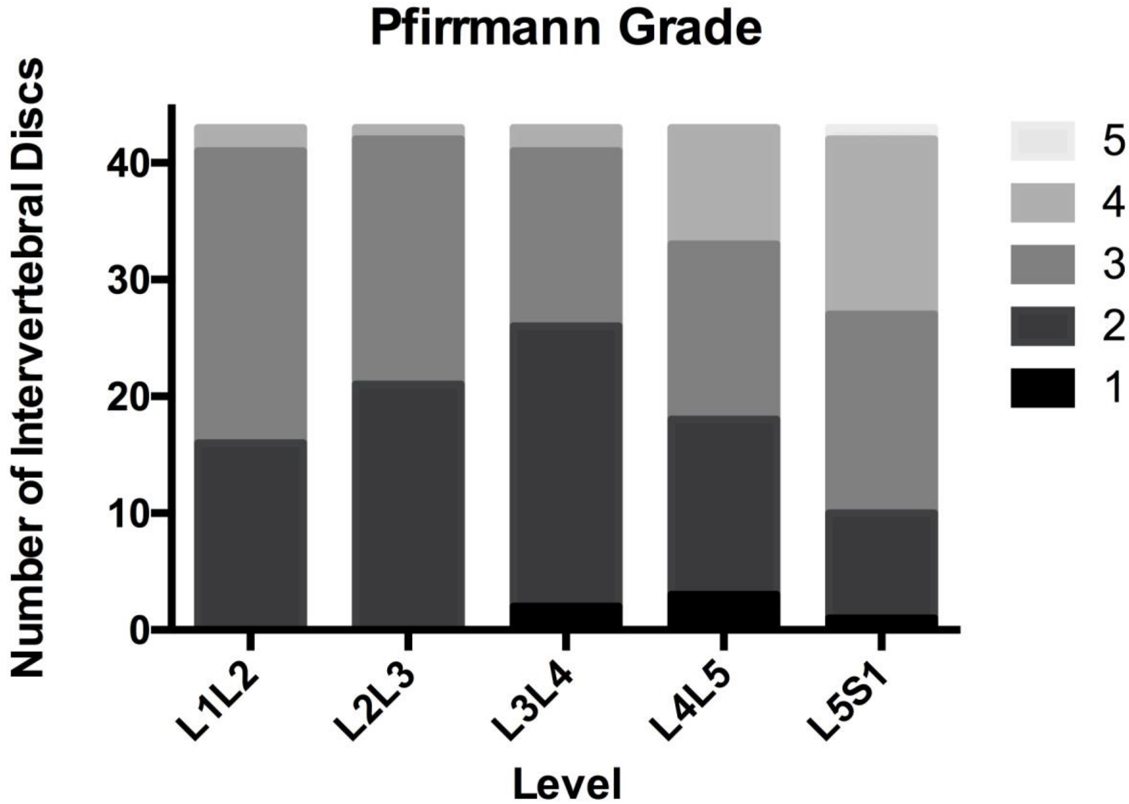
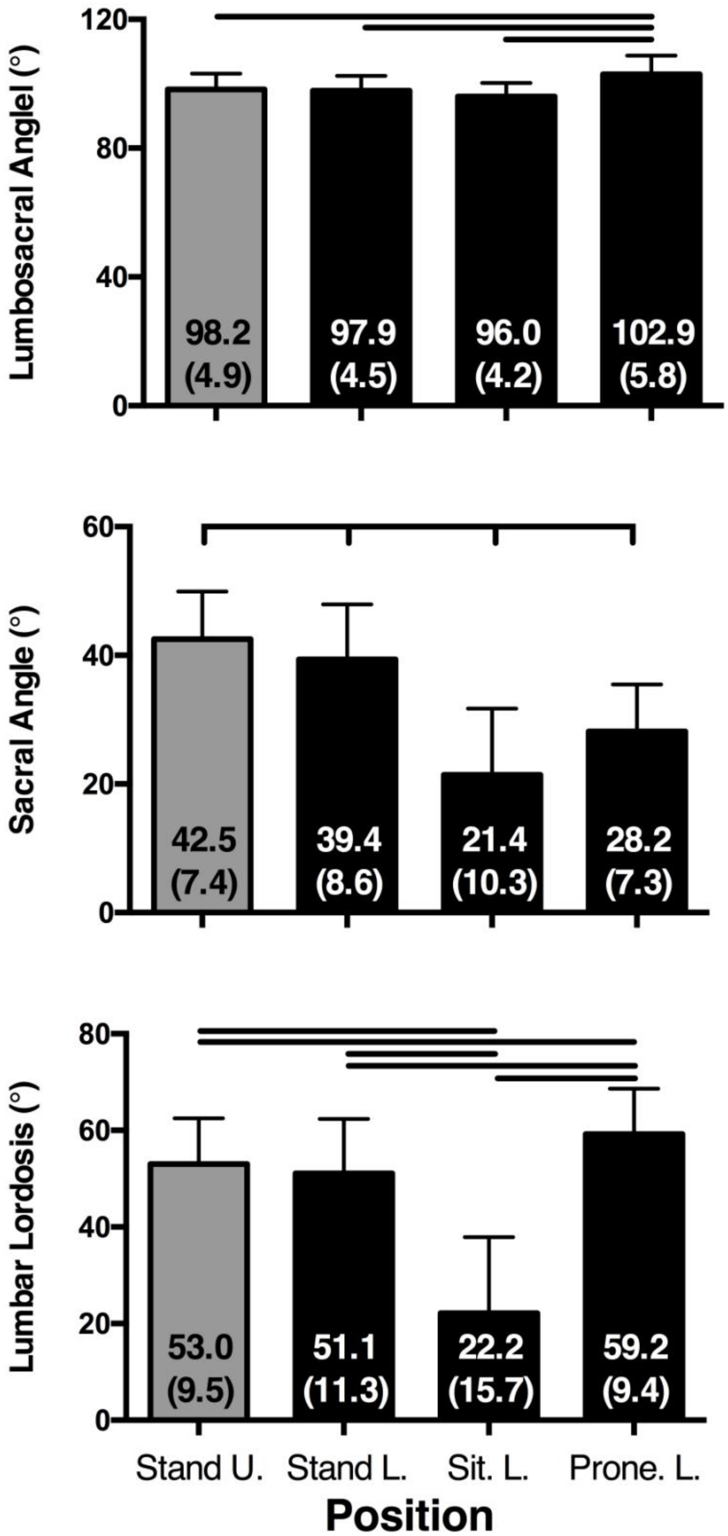

Pfirrmann Grade
Number of Intervertebral Discs
0
10
20
30
40
L1L2
L2L3
L3L4
L4L5
L5S1
Level
5
4
3
2
1

Figure 3



120
80
40
0
Lumbosacral Anglel (°)
98.2
(4.9)
97.9
(4.5)
96.0
(4.2)
102.9
(5.8)
60
40
20
0
Sacral Angle (°)
42.5
(7.4)
39.4
(8.6)
21.4
(10.3)
28.2
(7.3)
80
60
40
20
0
Lumbar Lordosis (°)
53.0
(9.5)
51.1
(11.3)
22.2
(15.7)
59.2
(9.4)
Stand U.
Stand L.
Sit. L.
Prone. L.
Position

Figure 4

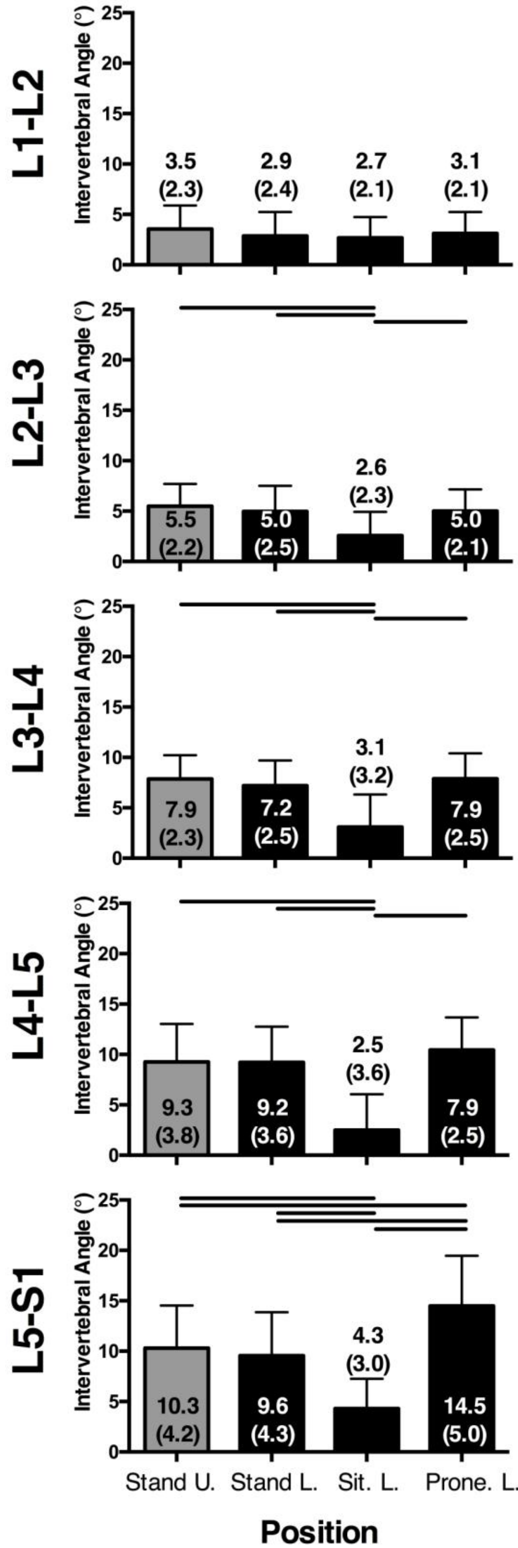

L1-L2
L2-L3
L3-L4
L4-L5
L5-S1
Intervertebral Angle (°)
0
5
10
15
20
25
3.5 (2.3)
2.9 (2.4)
2.7 (2.1)
3.1 (2.1)
5.5 (2.2)
5.0 (2.5)
2.6 (2.3)
5.0 (2.1)
7.9 (2.3)
7.2 (2.5)
3.1 (3.2)
7.9 (2.5)
9.3 (3.8)
9.2 (3.6)
2.5 (3.6)
7.9 (2.5)
10.3 (4.2)
9.6 (4.3)
4.3 (3.0)
14.5 (5.0)
Stand U.
Stand L.
Sit. L.
Prone. L.
Position

Figure 5

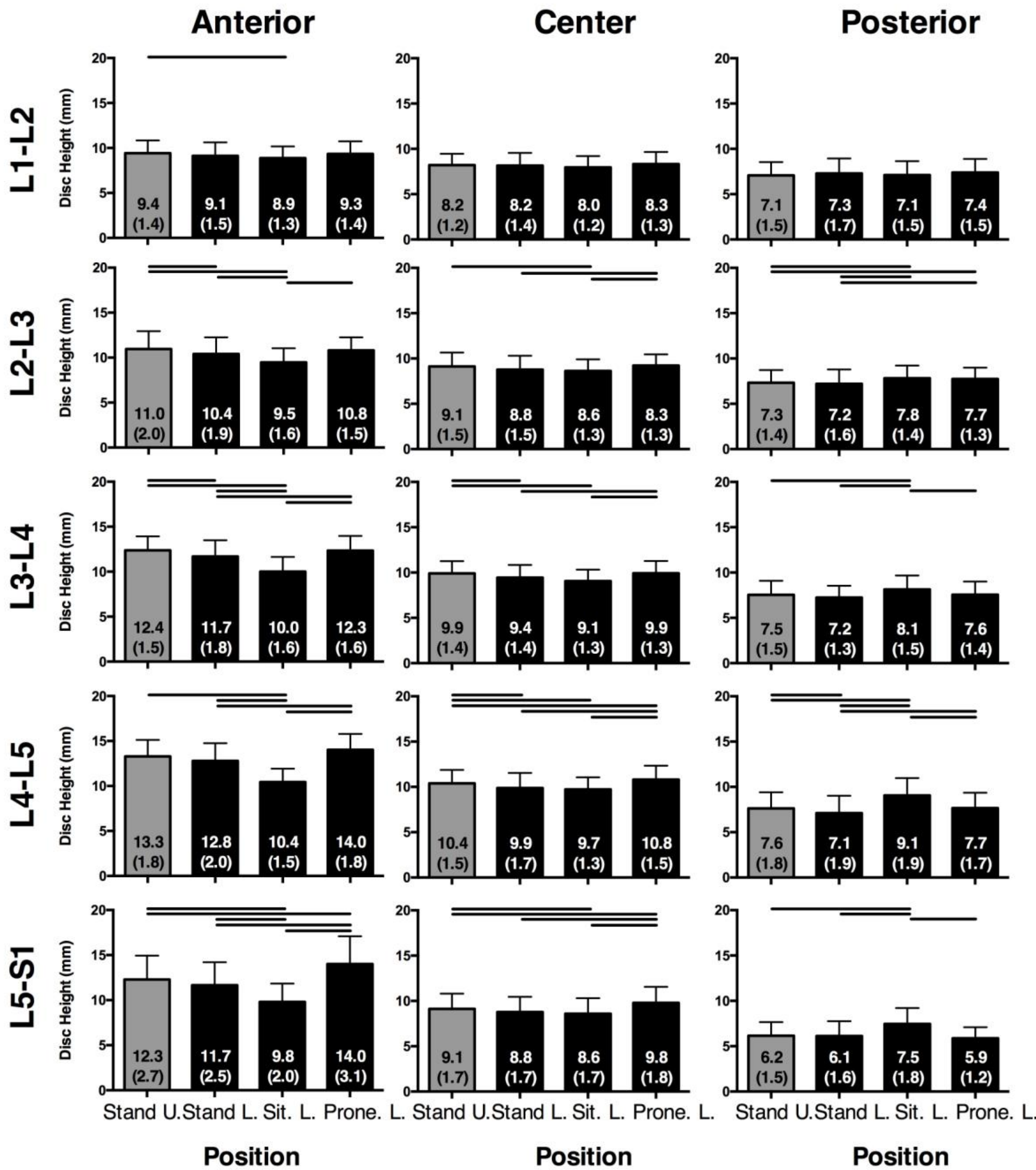

Anterior
Center
Posterior
L1-L2
L2-L3
L3-L4
L4-L5
L5-S1
Disc Height (mm)
9.4 (1.4)
9.1 (1.5)
8.9 (1.3)
9.3 (1.4)
8.2 (1.2)
8.2 (1.4)
8.0 (1.2)
8.3 (1.3)
7.1 (1.5)
7.3 (1.7)
7.1 (1.5)
7.4 (1.5)
11.0 (2.0)
10.4 (1.9)
9.5 (1.6)
10.8 (1.5)
9.1 (1.5)
8.8 (1.5)
8.6 (1.3)
8.3 (1.3)
7.3 (1.4)
7.2 (1.6)
7.8 (1.4)
7.7 (1.3)
12.4 (1.5)
11.7 (1.8)
10.0 (1.6)
12.3 (1.6)
9.9 (1.4)
9.4 (1.4)
9.1 (1.3)
9.9 (1.3)
7.5 (1.5)
7.2 (1.3)
8.1 (1.5)
7.6 (1.4)
13.3 (1.8)
12.8 (2.0)
10.4 (1.5)
14.0 (1.8)
10.4 (1.5)
9.9 (1.7)
9.7 (1.3)
10.8 (1.5)
7.6 (1.8)
7.1 (1.9)
9.1 (1.9)
7.7 (1.7)
12.3 (2.7)
11.7 (2.5)
9.8 (2.0)
14.0 (3.1)
9.1 (1.7)
8.8 (1.7)
8.6 (1.7)
9.8 (1.8)
6.2 (1.5)
6.1 (1.6)
7.5 (1.8)
5.9 (1.2)
Stand U. Stand L. Sit. L. Prone. L.
Position

Figure 6