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ORIGINAL ARTICLE
EXERCISE PHYSIOLOGY AND BIOMECHANICS

The geometric curvature of the lumbar spine during restricted and unrestricted squats

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ABSTRACT

BACKGROUND: The main purpose of this study was to analyze the behavior of the geometric curvature of the lumbar spine during restricted and unrestricted squats, using a novel investigative method. The rationale for our hypothesis is that the lumbar curvature has different patterns at different spine levels depending on the squat technique used.

METHODS: Spine motion was collected via stereo-photogrammetric analysis in nineteen participants (11 males, 8 females). The reconstructed spine points at the upright neutral position and at the deepest position of the squat exercise were projected onto the sagittal plane of the trunk, a polynomial was fitted to the data, and were quantified the two-dimensional geometric curvature at lower, central and higher lumbar levels, besides the inclination of trunk and lumbosacral region, the overall geometric curvature and overall angle of the lumbar spine. The mean values for each variable were analysed with paired *t*-test ($P<0.05$).

RESULTS: The lumbar presents a flexion from upright neutral posture to deepest point of the movement, but for the lower lumbar the flexion is less intense if the knees travel anteriorly past the toes. The trunk and the lumbosacral region lean forward in both squat techniques and these effects are also reduced in unrestricted squats.

CONCLUSIONS: The data collected in the study are evidence that during barbell squats the lumbar curvature has different patterns at different spinal levels depending on the exercise technique. The lower lumbar spine appears to be less overloaded during unrestricted squats.

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Key words: Spine - Torso - Biomechanical phenomena - Resistance training.

The barbell half-squat is an important resistance training exercise, applied to muscle hypertrophy development and performance, which is a part of high level sports training, fitness training and rehabilitation programs.[1, 2]

One previous empirical report indicated that the back and knees appear to be most at risk during squats.[1] The risk of back injury is directly related to the pattern of the high forces involved that are associated with the lifting technique.[3-6] During lifting, the paravertebral musculature produces large extensor moments on joints of the lumbar spinal column to overcome the flexor moment caused by the weight of the upper body and load.[3, 4]

A very popular strategy to avoid the development of high forces on the back and knees is to restrict the movement of the knees during squats, preventing the knees from traveling anteriorly past the toes (restricted squat). It is supposed that this procedure protects the knees because patellofemoral forces [7] as well as knee torque [7-9] are lower. However, biomechanical consequences on the lumbar spine related to this procedure are not completely understood to date.

Due to the invasive nature of the methods available for the direct quantification of the applied loads on the spinal column,[10, 11] researchers have investigated this topic indirectly by using other variables associated with spine loads such as hip torque,[7-9] trunk inclination [7, 9, 12] and the range of motion (ROM) of the spine posture.[12]

Hirata and Duarte [7] estimated that, during the squat, the restricted movement of the knees is associated with the reduction of the hip torque, which may indicate a decreased load on the lower back. However, Abelbeck [8] and Fry *et al.*[9] observed otherwise. Some studies reported a forward lean of the trunk during the squat, and showing that this inclination is higher for the restricted squat,[7, 9, 12] which is another indicative of spine overload.[7, 9, 12, 13]

It was established that alterations in lumbar curvature while lifting result in significant changes in the spinal load pattern.[14-16] To ensure the safety and effectiveness of squat techniques, information about the lumbosacral inclination and posture are necessary.[17] These variables could change the patterns of the pressure distribution in the intervertebral discs and the magnitude of compressive and shear forces in the intervertebral joints.[6, 15, 18]

To our knowledge, there are no studies reporting the lumbosacral inclination patterns in restricted and unrestricted squats. Although it can be expected a similar pattern between the lumbosacral inclination and the trunk inclination during squats, this assumption must be confirmed with only empirical data.

Additionally, to our knowledge, only one study investigated lumbar postural patterns in restricted and unrestricted squats.[12] List *et al.*[12] showed that the lumbar lordosis and the thoracic kyphosis decreases during the first half of the squat cycle, from upright standing to the lowest position of the exercise. This work found that the ROM of the thoracic curvature was significantly increased during restricted squats. It is expected that there is a lumbar geometric adaptation to squat technique because the changes in the spine curvature and trunk inclination are strictly correlated during lifting.[19] However, List *et al.* did not found differences in the ROM of the lumbar curvature between restricted and unrestricted squat. Unfortunately, this work did not report the lumbar curvature at the lowest position of the squats, when the lumbar is less extended. It can be lumbar postural differences between squats techniques, even if the ROMs of the lumbar curvature are equal. In addition, List *et al.*[12] computed an overall geometric curvature of the lumbar spine, based on a circle fitting method. It is possible that this approach is occulting some important information, since the patterns of the lumbar spine posture can presents regional differences during movements, which has implications for interpretation of measures of spinal posture, motion and loading.[20] Thus, the analysis of the lumbar shape needs further data to improve the knowledge about the squat exercise.

In this context, some researchers have suggested that a promising approach to evaluate the vertebral column during body movements is to use methods that enable the detailed measurement of the shape of the spine.[20-24] Particularly, Campos *et al*.[24] described a new method that enables to compute the geometric curvature of the spine at different levels of the vertebral column during dynamic situations. The analysis of this behavior during restricted and unrestricted squats may be useful for health professionals related to rehabilitation and exercise science.

The main purpose of this study was to analyze the behavior of the geometric curvature of the lumbar spine during restricted and unrestricted squats, using a novel investigative method. Our hypothesis is that the lumbar curvature has different patterns at different spine levels depending on the squat technique used. It is well known that the geometric curvature is more suitable than angular variables for spine posture quantification.[23] However, the curvature is a rarely used approach in spinal kinematics studies, which makes it difficult to interpret the results. The lumbar angle, the trunk inclination and the lumbosacral inclination were quantified in order to facilitate the data interpretation and to complement the results.

Materials and methods

Nineteen participants (11 males, 8 females) were included in the present study (Table I), who had more than a year of resistance training experience with half-squat

TABLE I.—*Descriptive characteristics of the participants (11 males, 8 females).*

Characteristics	Mean	SD	Min	Max
Age (years)	25.5	8.3	18	43
Height (m)	1.70	0.11	1.51	1.88
BW (N.)	670	100	512	911
TrLoad (N.)	719	300	373	1668
ExpLoad (%)	55	29	29	163

BW: body weight; TrLoad: declared training load; ExpLoad: used in the experiment (relative to BW).

exercise included in their training routine. All of the participants reported that they did not have any important orthopaedic injuries within the last year. Each participant declared the training load that was used during the last squat set with 8-12 repetitions (concentric failure) for muscle hypertrophy (Table I). Additionally, all of the participants declared that they were taught to execute the restricted squat technique by their resistance training instructors.

The participants wore shorts, running shoes, and the woman wore a top that was strait at the back. All of the participants were informed of the intent and procedures of the study, and informed written consent was obtained from all of the participants before data collection. The study protocol was approved by the Human Research Ethics Committee and is in accordance with the Declaration of Helsinki.

Experimental design

Adhesive retro-reflective markers (plane, rectangular [12×8 mm]) were placed to mark and identify anatomical points on the back (Figure 1) as previously described by Campos *et al.*[24] Markers were placed at the point of intersection between the medial border of the scapula and the spine of the scapula as well as two markers at the posterior superior iliac spines (PSIS) and the spinous process of the second sacral vertebra (S2), fourth lumbar vertebra (L4), and twelfth and sixth thoracic vertebrae (T12 and T6). A pair of bilateral markers was placed for use as reference points in the analysis, lateral to and at the height of the L4, T12, and T6 spinous processes following the alignment of the PSIS. After marking the above points, the line defined by the spinous processes of the vertebrae was filled with regularly spaced markers approximately every 2.5 cm. Many other anatomical points were marked in the beginning of the experiment but were not considered for the purpose of the current study. The points above T6 were disregarded for analysis because for some participants these points were occluded by the muscle mass adjacent to the spine during squats.

After the marker positioning session, the spine posture of the participants was registered during the upright neutral position without barbell (neutral posture). Subsequently, participants completed a five-minute warm-up program on a treadmill (5 km/h, slope 1%; Movement LX 160, Brudden Equipamentos, São Paulo, Brazil). Then, they started a specific warm-up performing squats. During the specific warm-up session, the volunteers were instructed how to execute restricted and unrestricted half-squats by an examiner who was trained and experienced with resistance training. The volunteers were instructed to perform the descending phase of the squats from an extended knees position (upright position) to 90º of flexion of the knees, the deepest position of the half-squat.

The principal part of the experiment was the registration of the spine posture during the execution of one set of five consecutive repetitions of unrestricted half-squats and another set of five consecutive repetitions of

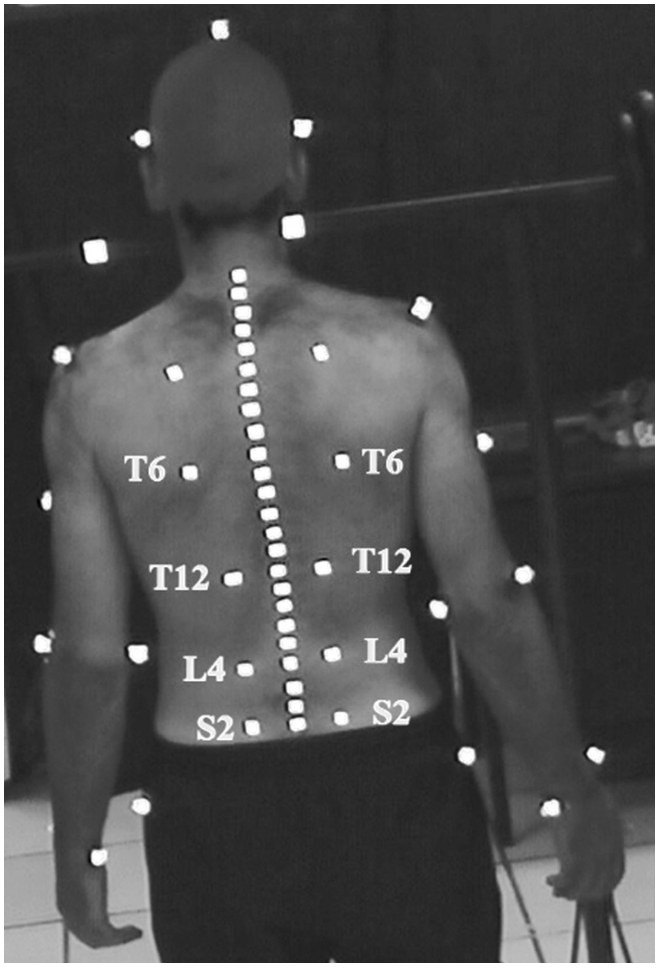

Figure 1.—Illustration of dorsal demarcation indicating the height of the S2, L4, T12, and T6 spinous processes.

restricted (knees not beyond toes) half-squats. The sequence of the conditions was randomized for each volunteer. The participants had a one minute rest interval between squat sets. During the experiment, all squats were executed using half of the declared training load shown in Table I as a percentage of the body weight.

The half of the training load was used to protect the subjects, minimizing the risks of injury, as, during the experimental session, the volunteers performed the squat with a technique that is not recommended. Besides that, the declared training load was chosen as the load parameter in order to maintain the "ecologic validity" of the present study. The term "ecologic validity" in this setting refers specifically to the interaction of participants with their natural environment and practices.[25]

Three-dimensional reconstruction and posture quantification

Illuminators with four 3-W high-power LEDs were placed near the lenses of three camcorders (NV-GS320 Mini-DV, Panasonic, Tokyo, Japan), used to record the movement of the back at 60 Hz. Before the experiment, the focus, shutter speed (1/500), and all other parameters of the cameras were regulated and set to manual.

Image processing and all data processing were performed using Matlab® software (The MathWorks, Natick, MA, USA). In each image from each camcorder the two-dimensional coordinates of the markers centroid was localized at the barycenter.[26] System calibration was performed by registering points with a known location, which enabled the three-dimensional reconstruction using the direct linear transformation method.[27] This measurement setup shows that the system has a systematic error of 0.51 mm, and a random error of 0.61 mm.[24] The global reference frame of the laboratory was defined as: vertical axis Z (upward), posterior-anterior horizontal axis X (forward) and lateral horizontal axis Y (to the left).

The posture of each participant was analyzed at the instant of the lowest vertical position of S2 during the 5th repetition of each squat condition, as seen in List *et al.*[12] who reported that flexion of the lumbar spine during a squat peak at the deepest position of the exercise. Additionally, the posture was analyzed at the neutral posture (upright) without barbell.

The 3D coordinates of all the spinal markers between S2 and T6 were described in a local frame of reference on the trunk,[24] originating at T12. The vector from L4 to T6 defined the orientation of the longitudinal axis z (upward). An auxiliary vector y' was defined with its origin at the midpoint of the reference points to the right of L4 and T6 and the end at the midpoint of the reference points to the left of L4 and T6. The cross product between y' and z defined the orientation of the sagittal axis x (forward), and the cross product between z and x defined the orientation of the transverse axis y (to the left).

For the local geometric curvature computation, the positions of the spinal markers were projected onto the sagittal plane of the trunk (normal to y). A polynomial function $P(z)$ was adjusted to the spine points using the least squares fitting technique. The degree of all polynomials was 5°, which was defined by using the reduced chi-square test.[28] To quantify the shape of the vertebral column, the concept of geometric two-dimensional curvature, $K(z)$, was used and calculated from the first and second derivatives, $P'(z)$ and $P''(z)$, respectively, using the following equation:

$$K(z) = P''(z) / [1 + P'(z)^2]^{3/2}$$

At each point of a curve in two-dimensional space, the geometric curvature can be interpreted as the reciprocal of the radius of the circle that fits locally at the curve. The unit of measurement of the geometric curvature is m^{-1}. The ends of the spine, were disregarded in the analysis because they could not provide a robust enough polynomial fit. The local sagittal geometric curvature of the lumbar spine was analyzed at the lower lumbar (L5), central lumbar (L3), and higher lumbar (L1). It was assumed that L1 level, for every volunteer, was in the marker below T12, L5 was the in marker below L4, and L3 level was between L5 and L1. The overall sagittal geometric curvature [12] of the lumbar spine was computed by fitting a circle [29] to the points from L1 to L5, projected onto the trunk sagittal plane. The overall sagittal angle of the lumbar spine was also quantified by the angle between the following two spinal segments, projected onto the trunk sagittal plane (Figure 2): thoracolumbar segment was the straight line from L4 to T12; and the lumbosacral segment from S2 to L4. For these postural variables, positive values indicated anterior concavities (kyphosis), negative values indicated posterior concavities (lordosis) and null values represented a rectified spine.

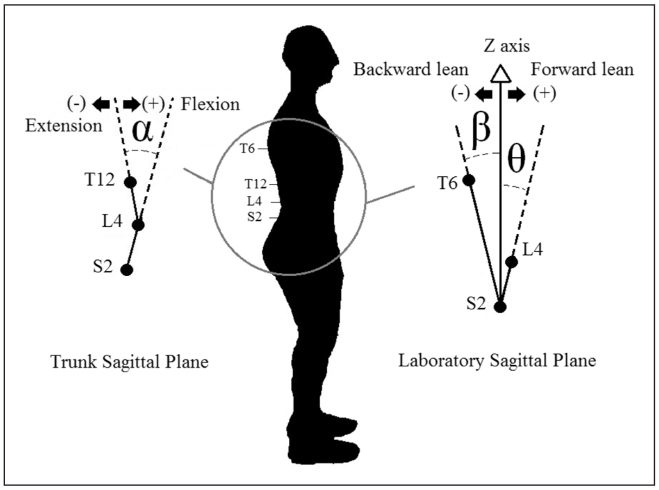

Figure 2.—Angular variables definition.

Since each individual has a very characteristic posture,[22] the standing posture (neutral posture) was used as a reference, and the lumbar posture during squats were referred to the normal standing. The posture of the standing position was subtracted from squat, so standing upright corresponded to 0° (angle) and 0 m^{-1} (curvature). Positive values presented during exercise mean that the lumbar curve during squat was more flexed than during neutral posture.

A trunk segment was defined as the straight line from S2 to T6. The lumbosacral segment and the trunk segment were projected onto the sagittal plane of the laboratory (normal to Y) and the angles between Z axis (vertical) and these segments (Figure 2) defined respectively the trunk (β) and the lumbosacral (θ) inclination. For both segments, 0° corresponded to a vertical position, positive values to forward lean and negative angles to backward lean.

Statistical analysis

Shapiro-Wilk normality test (P>0.05) revealed that the data were normally distributed and the *F* test showed equal variances. The data were presented with descriptive conventional statistics as minimum, maximum, mean and standard deviation values. For each postural variable, the average values of the nineteen subjects were grouped by the squat technique (restricted/unrestricted) and compared using the paired Student's *t*-test (P<0.05). Furthermore, Cohen's effect size (*d*) was calculated to determine the magnitude of the differences between conditions ($0.2 \leq d < 0.5$, small; $0.5 \leq d < 0.8$, medium; $0.8 < d$, large effects). Data analysis were performed in Matlab®, except Shapiro-Wilk test, executed online.[30]

Results

After 3D marker position reconstruction, the two-dimensional geometric curvature of the vertebral column was computed. In Figure 3, the curve fitting procedure (A) and the respective two-dimensional geometric curvature quantified along the longitudinal axis (B) are exemplified for the data of one participant at the upright neutral posture. Notably, the lumbar region (longitudinal axis <0) was concave posteriorly and presented a negative geometric curvature, whereas the thoracic spine had positive values, because it was concave anteriorly. The geometric curvature at the lower, central, and higher lumbar are indicated with circles in the graph (Figure 3B). These curvatures, the overall geometric curvature, the angle of the lumbar spine, besides the inclination of the trunk and the inclination of the lumbosacral region were computed for every volunteer during the neutral posture (Table II) and in the deepest position of the two squat techniques (Table III).

During the upright neutral posture, the trunk of the participants was slightly tilted backwards (-3.5±1.9°), the lumbosacral region was tilted forward (16.2±8.2°) and all the participants presented lordosis in lumbar

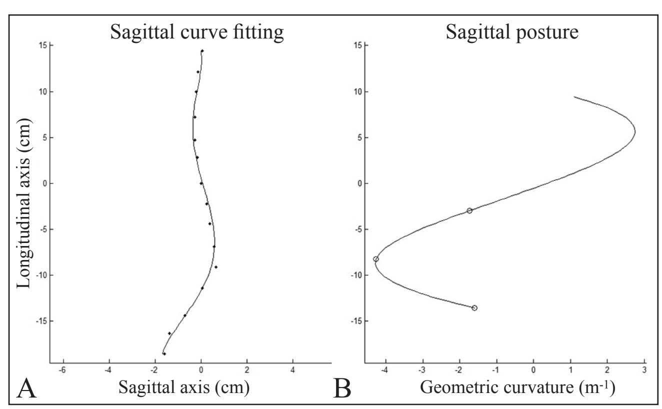

Figure 3.—Illustrative example of the polynomial curve adjusted to the data at the sagittal plane of the trunk (A) and the respective two-dimensional geometric curvature (B).

TABLE II.—*Postural variables during upright standing position.*

	KHL (m^{-1})	KCL (m^{-1})	KLL (m^{-1})	KOL (m^{-1})	α	θ	β
Mean	-3.2	-5.5	-5.6	-6.2	-22.0°	16.2°	-3.5°
SD	2.4	2.6	2.8	3.2	7.5°	8.2°	1.9°
Min	-7.3	-11.4	-10.7	-13.7	-40.5°	5.3°	-6.6°
Max	1.3	-0.5	-0.6	-0.7	-13.5°	32.9°	0.4°

K: geometric curvature; HL: higher lumbar; CL: central lumbar; LL: lower lumbar; OL: overall lumbar; α: lumbar angle; θ: sacral inclination; β: trunk inclination.

TABLE III.—*Postural variables at the deepest position of restricted and unrestricted squats.*

	Mean	SD	Min	Max	t	P value	d	Interpret
KHL (m^{-1})								
R	1.5	2.0	-1.4	5.0	0.3552	0.7266	–	–
U	1.4	2.3	-2.0	5.2				
KCL (m^{-1})								
R	4.3	2.0	1.5	8.0	14.053	0.1770	–	–
U	3.8	2.5	0.0	9.1				
KLL (m^{-1})								
R	5.3	2.5	1.8	9.3	30.297	0.0072	0.4109	Medium
U	4.3	2.1	0.8	8.4				
KOL (m^{-1})								
R	5.4	2.9	1.3	11.9	29.458	0.0086	0.3538	Medium
U	4.3	3.4	-0.2	11.4				
α								
R	18.6°	6.6°	8.2°	30.0°	23.118	0.0328	0.4194	Medium
U	15.6°	7.6°	3.1°	29.6°				
θ								
R	51.6°	10.6°	25.3°	67.3°	44.722	0.0003	0.4816	Medium
U	46.7°	9.9°	19.0°	62.1°				
β								
R	44.3°	8.3°	19.9°	59.0°	49.599	0.0001	0.8493	Large
U	36.7°	9.4°	11.6°	51.1°				

K: geometric curvature; HL: higher lumbar; CL: central lumbar; LL: lower lumbar; OL: overall lumbar; α: lumbar angle; θ: sacral inclination; β: trunk inclination; R: restricted squat; U: unrestricted squat; *t*, P: paired Student's *t*-test results, 18 degrees of freedom; *d*: effect size; Interpret: effect size interpretation.

spine, as the overall lumbar curvatures and angles were negative.

At the deepest position of squat, independently of the squat technique, the trunk and the lumbosacral region lean forward, and the lumbar spine flexed (positive average values), considering all lumbar variables. The average trunk forward inclination was 7.6° (large effect) higher and the lumbosacral forward inclination was 4.9° (medium effect) higher during restricted squat than unrestricted. The geometric curvature of the lower lumbar, the overall geometric curvature and the overall angle of lumbar showed that the lumbar spine was more flexed during restricted squats than unrestricted (medium effect). The central lumbar presented a tendency to this pattern, but not significant, and this pattern was not presented in the higher lumbar.

Discussion

The main purpose of this study was to analyze the behavior of the geometric curvature of the lumbar spine during restricted and unrestricted squats, using a novel investigative method. The current study was based on the hypothesis that the lumbar curvature has different patterns at different spine levels depending on the squat technique. The results corroborate the hypothesis. During lifting, the lumbar spine presented a flexion from standing to deep position, independent of the squat technique (Table III). The overall geometric curvature and the overall lumbar angle provided similar results what showed that the restricted squats lead to a more flexed lumbar spine. The local geometric curvature approach makes it possible to go further, presenting that this pattern was present in lower lumbar level and that the curvature of higher lumbar levels did not change between squats styles. The quantification of the curvature at different levels of the column enabled to identify additional and important information about lumbar spine pattern during squat exercises that may be useful for health professionals related to sports medicine and physical fitness sciences.

Interpretation of the results

The high number of muscles, bones and another passive structure of the trunk as well as the possible lift setup variations lead to controversial conclusions in the literature regarding the best lumbar posture of choice for lifting. The results of the present study must be interpreted carefully and some suppositions about intervertebral loads are presented hereinafter.

Adams and Hutton [18] and Arjmand and Shirazi-Adl [14] advocate kyphotic postures during lifting because their experiments found that lordotic postures are associated with increased internal loads at the lower lumbar. However, the tests conducted in the studies were not about restricted and unrestricted squats, which makes the application of these data to interpret these squat techniques difficult. For example, the experimental design of Adams and Hutton [18] and Arjmand and Shirazi-Adl [14] did not consider different trunk inclinations associated with squat technique. McKean *et al.*[17] suggested that kyphosis of the lumbar spine in deep squatting is a natural part of the squat movement when using loads equal to 50% body weight and advised that the coaches should not prevent experienced squatters from allowing this to happen. However, they did not present any quantitative data to support this advice. Additionally, it is interesting to note that traditionally the weightlifters are trained to maintain the lordotic posture during squats [31] and they presented low prevalence indices of lower back injury.[32]

Morphologically, the anterior part of the annulus fibrosus is higher and thicker than the posterior [33] what indicate that the pressure could be symmetrically distributed during lumbar lordotic postures. The center of the neutral zone described by Panjabi [34] appears to be a good parameter for defining the curvature ideal for lifting tasks. Probably, the stress is uniformly distributed in the discs in neutral zone. The lumbar flexion could lead to an asymmetric stress distribution in the lumbar intervertebral disc, with a higher stress at the anterior annulus,[6, 18] which increases the hydrostatic pressure in the nucleus pulposus of the discs, increasing the risk of a spinal disc herniation.[18] In the present study, it was assumed that the spinal posture presented during the upright neutral posture was in the neutral zone. The results of the present study showed that both squats technique lead to deviations from this region, but the restricted squats lead to higher deviation, especially in the lower lumbar region.

In the sagittal plane of the intervertebral joints, the resultant force can be analyzed by its two perpendicular components, the compressive force (axial direction, perpendicular to vertebral body end-plate) and the shear force (anterior-posterior direction). Apparently, the compressive force tends be maximal when the trunk is vertical. However, when the trunk tilts forward during lifting, the paravertebral musculature produces large extensor moments on joints of the lumbar spinal column to overcome the flexor moment caused by the weight of the upper body and barbell.[3, 4] Because of this, the more is the forward lean of the trunk, the higher is the back muscle activity, leading to higher compressive loads at lumbar spine.[4] The results of the present study corroborated previous studies that also reported a higher forward lean of the trunk during restricted squats than during unrestricted,[7, 9, 12] which is an indicative of spine overload.[7, 9, 12, 13]

For upright postures, a more extended lumbar posture correlate with a more vertical sacral endplate [35] that lead to shear forces increases at lower lumbar region. The data from the present study showed that the unrestricted squat presented a more extended lumbar spine. Besides that, the trunk inclination changed between squat techniques and the lumbosacral inclination was more vertical during unrestricted squats. It is reasonable to suppose that this situation is associated with a more horizontal sacral endplate that is advantageous for minimizing shear forces at lumbosacral region. Additionally, lumbar extension changes the line of action of extensor muscles, what favors then to support anterior shear forces on the spine, causing reduced shear forces on the intervertebral discs.[15, 16, 36]

Practical applications

The data presented at the current study showed that to diminish the lumbar flexion and to reduce the trunk and lumbosacral forward inclinations, one should choose a squat technique that does not restrict the forward movement of the knee. It is possible to suppose that the lower lumbar spine is less overloaded during unrestricted squats.

Nevertheless, the results of the present study showed that the lumbar spine presented a flexion in both technique and the postural variables did not show large differences (medium effects) between unrestricted and restricted techniques, except for trunk inclination (large effect). So, if somebody cannot flex the lumbar spine, like the ones that has disc herniation at lumbar spine, it is better to not perform squats. One should take into account the characteristics of each person when choosing the squat technique.[18] It is appropriate to remember that the patellofemoral forces [7] and the knee torque [7-9] were higher during unrestricted squats and the restricted squats must be chosen for people that must avoid knee loads.

Limitations of the study

It was performed a postural non-invasive analysis of the lumbar spine in the sagittal plane of the trunk using skin markers. This practice is common in biomechanical analysis, and there is evidence that it is a valid procedure.[37-40] Zemp *et al.*[39] showed that the spinal curvature values, obtained with skin markers, suffer from uncertainty and could be different from internal posture. However, the authors [39] found that skin marker measurements allow for the assessment of changes in the lumbar curvature between quasi-static whole body postural changes, like the postural changes found between restricted and unrestricted squats. It is also reasonable to assume that, although the lumbosacral segment adopted is not exactly perpendicular to sacral endplate, the forward lean of this segment was associated to forward tilts of the sacrum.

Furthermore, the spinal levels were defined as lower, central, and higher lumbar as it is not possible to know if the quantified heights of L5, L3, and L1 are exactly at the respective real spinous process levels. The likely anatomic deviations from these heights were considered negligible for the purpose of the current paper; therefore, caution must be given when using the methods presented in future studies.

Finally, this study investigated restricted and unrestricted half squats with average loads near 50% of the body weight (Table I), similar to previous biomechanical squat investigations.[12, 17] This load intensity was chosen for injuries prevention during the experiments. Thus, it is reasonable to presume that the results of current study are in the context of rehabilitation process and weight training for beginners. Therefore, it is not possible to know the curvature pattern and lumbosacral inclination during squats with heavier loads.

Conclusions

The data collected in the study are evidence that during barbell squats the lumbar curvature has different patterns at different spinal levels depending on the exercise technique. The lumbar presents a flexion from upright neutral posture to deepest point of the movement, but for the lower lumbar the flexion is less intense if the knees travel anteriorly past the toes. The trunk and the lumbosacral region lean forward in both squat techniques and these effects are also reduced in unrestricted squats. These data mean that the spine appears to be less overloaded during unrestricted squats. However, if somebody cannot flex the lumbar spine, like the ones that has disc herniation at lumbar spine, it is better to not perform squats.

Although the presented data are relevant from a practical perspective, additional studies with other populations and workloads are necessary to improve the knowledge about the squat exercise in different contexts like the high-level sports training.

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