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Original Article

Examination of a lumbar spine biomechanical model for assessing axial compression, shear, and bending moment using selected Olympic lifts

Moataz Eltoukhy [b], Francesco Travascio [a], Shihab Asfour [a], Shady Elmasry [a], Hector Heredia-Vargas [b], Joseph Signorile [b,c,*]

[a] Biomechanics Research Laboratory, Department of Industrial Engineering, University of Miami, Coral Gables, FL, USA
[b] Sports Medicine and Motion Analysis Laboratory, Department of Kinesiology and Sport Sciences, University of Miami, Coral Gables, FL, USA
[c] Center on Aging, Miller School of Medicine, University of Miami, Miami, FL, USA

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ABSTRACT

Background/Aims: Loading during concurrent bending and compression associated with deadlift, hang clean and hang snatch lifts carries the potential for injury to the intervertebral discs, muscles and ligaments. This study examined the capacity of a newly developed spinal model to compute shear and compressive forces, and bending moments in lumbar spine for each lift.

Methods: Five male subjects participated in the study. The spine was modeled as a chain of rigid bodies (vertebrae) connected via the intervertebral discs. Each vertebral reference frame was centered in the center of mass of the vertebral body, and its principal directions were axial, anterior-posterior, and medial-lateral.

Results: The results demonstrated the capacity of this spinal model to assess forces and bending moments at and about the lumbar vertebrae by showing the variations among these variables with different lifting techniques.

Conclusion: These results show the model's potential as a diagnostic tool.

1. Introduction

The hang snatch and hang clean are variations of two Olympic lifts, the snatch and the clean-and-jerk, commonly used as conditioning exercises by strength and conditioning coaches. Similarly, the deadlift, one of three lifts used in powerlifting competitions, is commonly incorporated into athletes' strength training programs. Loads used during the Olympic lifts are usually designed to maximize power development and varied due to training cycle, performance level and training goal.[1–4] Additionally, these lifts are used in varying forms as assessment tools following training interventions,[5] in descriptive studies[2,6–9] and as indicators of athletic performance.[10,11]

Variations in lifting technique, load, or environment can dramatically change kinematics and muscle utilization patterns during these lifts. For the deadlift exercise differences in form,[12,13] bar utilization,[14] type of contraction,[15] load,[16] base stability,[2] and lifting experience[17] have been shown to affect power output, as well as kinetic and kinematic variables. This information is more difficult to find for the hang clean and hang snatch, but is available for the power clean, the snatch and their variations. For example, while no differences in peak power, peak vertical force or rate of force development were seen due to variations in the power clean (power clean, hang power clean, midthigh power clean) in a study incorporating young female athletes[18]; differences in these variables were detected between these three variations in elite male rugby players.[19] Additionally, load changes have been shown to affect kinematics and kinetics in experienced lifters during the midthigh clean pull.[1,20] The impact of loading has also been established for power output during the power clean.[3,10,21] Further, kinetic differences have been reported between free weight and machine lifts[22] and differences in kinetics, including

* *Corresponding author.* Department of Kinesiology and Sport Sciences, University of Miami, 1507 Levante Ave, Max Orovitz, Rm 114, Coral Gables, FL 33146, USA. Tel.: +1 305 284 3105; fax: +1 305 284 4183.
E-mail address: jsignorile@miami.edu (J. Signorile).

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peak force, peak velocity and power, have been noted among the hang clean, jump shrug and high pull exercise, with these differences varying due to load changes (30%–80% 1RM).[23] Finally, ground reaction forces and segmental forces can be expected to vary among the hang clean, hang snatch and deadlift and within different phases of each lift. For example, in an analysis of ground reaction forces during different phases of the power clean, Souza et al,[24] found that greater peak force occurred during the second pull compared to the first pull and unweighted phases of the lift whether performed at 60 or 70%1RM.

For the snatch, kinematic analyses have been performed demonstrating differences in both spatial and temporal variables among competitive lifters in different weight classes[25] and of different genders[26,27] and in kinetics due to gender.[28] As was the case with the deadlift and power clean, variations in kinematics were also seen with different loading patterns during the snatch[29] and for younger, compared to older, competitors.[26] Of special interest to the present study was the use of a three-dimensional finite element model by Bao and Meng[30] to assess the stresses on the vertebral body, facet joint, pedicle of the vertebral arch and intervertebral disc at L_1–L_2 during performance of the snatch.

To date, information on spine biomechanics during weightlifting is limited.[17,30,31] Hence, the purpose of this study was to validate a biomechanical model designed to quantify the moments and forces on the lumbar spine during the performance of the deadlift, hang clean, and hang snatch. This was done using comparisons to the limited number of studies that employed spinal models during the performance of these lifts, demonstrating changes in forces and moments among the lifts, and comparing patterns of change to kinematic and kinetic variables reported during the deadlift, hang clean and hang snatch. The model was based solely on standard motion capturing data, and was capable of estimating spinal segments kinematics and loads. The process included two steps. First, the new biomechanical framework was validated by comparing its spine kinematics estimates with data from a continuous spine motion analysis previously reported.[32,33] Next, the model was directly applied for mapping mechanical loads on lumbar spine during the performances of the deadlift, hang clean, and hang snatch.

2. Methods

2.1. Spine biomechanical model

In this model, the lumbar spine was modeled as a chain of rigid bodies (vertebrae) connected to each other via the intervertebral discs. The movement of the spine was driven by the relative motion between the pelvis and thorax, which was computed via a motion capture system. The location and the orientation of the pelvis was computed by tracking four stereotactic markers applied on both anterior (left anterior superior iliac spine, and right anterior superior iliac spine) and posterior (left posterior superior iliac spine, and right posterior superior iliac spine) aspects of the ilium. The pelvic coordinate frame was centered in the midpoint between the two anterior superior iliac spine (ASIS) markers. The principal directions were axial, medial-lateral (line passing through the ASIS), and anterior-posterior (line orthogonal to the medial-lateral and lying on the plane individuated by the ASIS and PSIS; see Fig. 1a). The thorax was discriminated by four other markers located at the midpoint of the two clavicles (CLAV), on the sternum directly above the solar plexus (STRN), on the superior spinal process of the thoracic vertebra T10 (T10), and on the superior spinal process of the cervical vertebra C7 (C7). The origin of its reference frame was at the CLAV. The axes of the reference frame were: a line passing through C7 and CLAV (anterior-posterior direction), orthogonal to the plane defined by C7, CLAV, STRN, and T10 (in the medial-lateral direction), and a line passing through C7 and T10 (in the axial direction) (see Fig. 1b).

The spine tract was composed of three-dimensional linked segments representative of the five lumbar vertebrae and the thoracic vertebrae T12, T11, and T10. All vertebrae were treated as rigid bodies. In the neutral configuration (body fully erect with no axial rotation and no loads applied) the spinal vertebrae lay equally spaced on a cubic spline connecting the pelvis with the thorax. The local coordinate frame of each vertebra had its center in the center of mass of that vertebra; the axial direction laid on the sagittal plane, and was tangential to the spine curvature; the anterior-posterior direction also lay in the sagittal plane, but was

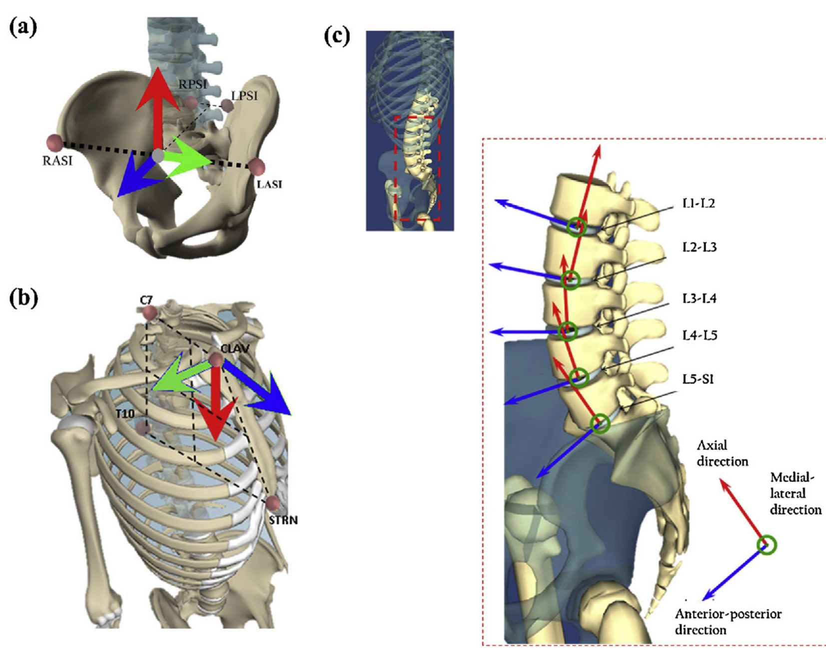

Fig. 1. The static trial and the definition of the lumbar spine.