The Balanced Spine: A Passive Mechanism for Maintaining Erect Posture

*Halverson, P; +*Bowden, A; *Stratton, E; **Pearsall, D; *Howell, L
+*Brigham Young University, Provo, UT. USA. **McGill University Montreal, Quebec, Canada.
Senior author abowden@byu.edu

INTRODUCTION

When removed from the surrounding tissues, the lumbar spine buckles at relatively small compressive loads (~90N). These loads are substantially lower than those measured in-vivo and, in the majority of adults, are lower than the weight of the torso. Patwardhan et al. showed that the load carrying capacity of the lumbar [1] and cervical [2] spine significantly increased when a "follower load" was applied. The follower load was placed in the posterior section of the vertebra, passing through the instantaneous axis of rotation (IAR) and acting tangential to the curvature of the spine, in order to minimize the internal bending and shear forces on the spine [2]. The physiological rational behind the follower load was presented that the load path followed roughly that prescribed by the muscle architecture [1,2]. We hypothesize that the location of the aggregate abdominal center of mass also plays a critical role in the load bearing capacity of the lumbar spine.

METHODS

Computed tomography (CT) images of four adults (two male and two female) were obtained. The height/mass percentiles were 40/45 and 90/45 and 95/70 and 35/50 for the males (subjects A and B) and females (subjects C and D) respectively. Pixel intensity values were associated with tissue density and used to calculate the mass and center of mass (CM) of the abdominal cross section of the thoracic and lumbar regions (T1-L5) [3]. The aggregate mass at each level was computed as the mass of that level in addition to the superior levels (e.g., the aggregate mass of L3 is the mass of T1-L3). The aggregate center at each level was defined as the mass center of the aggregate mass. Starting with T1 the mass of the level (T1) was applied at the center of mass to the lever model shown in Figure 1. The location of the IAR, represented by the lever's fulcrum, was calculated so as to put the level in static equilibrium with the aggregate mass and aggregate center of mass. This process was then repeated for levels T2-L5.

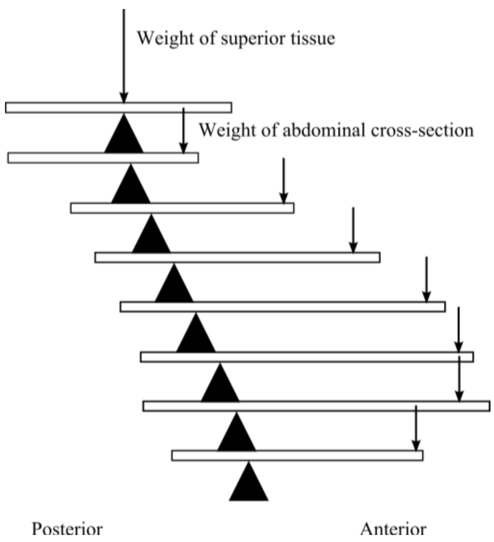

Figure 1: The lever model

RESULTS

As shown in Figure 2, the location of the aggregate center of mass (T2-L5) was posterior to the vertebral center for all of the patients. The anterior-posterior position correlates with the reported anterior-posterior location of the instantaneous axis of rotation for the thoracic [4] and lumbar [5] vertebrae.

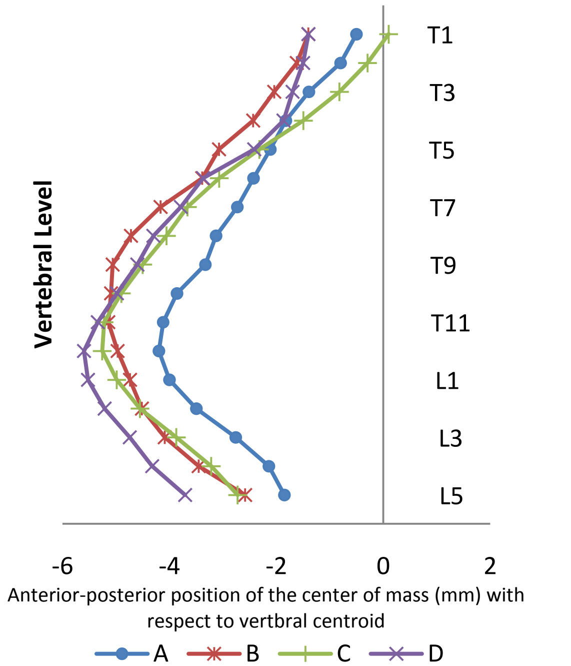

Figure 2: Center of mass with respect to the vertebral center

DISCUSSION

As the center of mass passes through or near the IAR, the internal bending moment required to maintain the spine in an upright position is small. Thus the spine is "balanced" around the IAR and can withstand a high compressive force without buckling and is energetically favorable to the neutral posture. Small perturbations of the center of mass can efficiently be controlled by the surrounding soft tissue. Similar balancing mechanisms have been found in the knee. The present work suggests that this same mechanism occurs in the lumbar and thoracic spine.

The implication of this study in the design and implantation of spinal prosthetics is evident. When the IAR of the prosthetic is placed anterior or posterior of the center of mass, an increased moment is required to balance the spine. This moment must be generated from the surrounding tissue. An implanted prosthetic with an IAR that deviates from the aggregate center of mass will have a greater risk of fatiguing the surrounding tissue.

The study has a few limiting factors that merit further research. First, while this method may be used to discover the anterior-posterior position of the IAR, it does not take into account the superior-inferior position. Second, the CT scans were taken of the patients in the supine position which may affect the location of the CM by changing the curvature of the spine. Finally, the study used a relatively small number of subjects. A much larger study is needed to properly determine the statistical location of the CM.

REFERENCES

[1] A.G. Patwardhan et al., *Spine*, vol. 24, May. 1999, pp. 1003-9.
[2] A.G. Patwardhan et al., *Spine*, vol. 25, Jun. 2000, pp. 1548-54.
[3] D.J. Pearsall, J.G. Reid, and L.A. Livingston, *Annals of Biomedical Engineering*, vol. 24, pp. 198-210.
[4] M.M. Panjabi et al., *Journal of orthopaedic research : official publication of the Orthopaedic Research Society*, vol. 1, 1984, pp. 387-94.
[5] M.J. Pearcy and N. Bogduk, *Spine*, vol. 13, Sep. 1988, pp. 1033-41.