

A FRONTAL PLANE LUMBAR SPINE ANALOGUE SUBJECTED TO A FOLLOWER LOAD BY PNEUMATIC MUSCLES

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INTRODUCTION

The follower load represents the path of the internal force resultant passing through the centers of rotation of successive spinal segments. An ideal follower load is perpendicular to the mid-plane of the intervertebral disc and minimizes shear and bending moments at all levels. Patwardhan and colleagues showed that a follower compressive preload increases the stability and load carrying capacity of the ligamentous spine [1]. Results from their ex-vivo experiments suggest a possible muscle activation pattern by which large compressive loads are supported in-vivo. Although several mathematical models have studied the role of the trunk muscles in generating a follower load [2, 3], no experimental technique using an idealized muscle architecture has been developed yet. Thus, the goal of this study was to develop a lumbar spine analogue with an idealized representation of multi-segmental muscles capable of generating a follower load

METHODS

A mechanical lumbar spine analogue (L1-S1) was built using polyurethane blocks of different durometers. Custom built pneumatic muscles were placed at each vertebral level from L1 to L5 assuming frontal-plane symmetry. Pressure control valves regulated the force generated by the muscles. The muscle lines of action were guided by a cable and pulley system so as to represent multi-segmental muscles whose fascicles originate in the lumbar vertebra and insert in the sacrum/pelvis region. Vertebral motions relative to the sacrum were measured using angle sensors. In addition, a six-degree-of-freedom load cell was placed under the model to allow real time feedback (Figure 1). The model was subjected to the following loading conditions:

- (1) 4Nm bending moment applied to L1 vertebra using an air muscle with a sinusoidal input,
- (2) 4Nm moment plus a 60N vertical load applied to L1 using dead weights,
- (3) 4Nm moment plus a 100N vertical load applied to L1.

For the second and third loading case, muscles were activated to approach the same shear and bending moment loads at the base as those collected during the bending moment only loading condition. Muscle loads were measured by single axis load cells placed in the line of action of the muscles. The control algorithm and real-time simulation was performed using Simulink and Real-time Windows Target (The Mathworks, Inc., Natick, MA). A static equilibrium analysis was performed for each loading case to predict the joint reaction loads and moment for three different spinal postures: 5°, 10° and 15° of rotation.

RESULTS AND DISCUSSION

For all loading conditions one muscle was active at each vertebral level. The muscle with the highest activation was

located at L1 on the convex side of the spinal curve. All other muscles were activated on the concave side of the spinal curve. Differences were found between the mathematically estimated joint reactions and those measured experimentally. This is because the experimental muscle loads do not pull only in the frontal plane, but cause slight bending in the sagittal plane as well. The magnitude of the shear reaction in all planes of motion best matched the values obtained mathematically. When muscles were activated, the ratio of shear force to follower force decreased by at least 86% and was smallest for the highest vertical load regardless of the spinal posture. Joint reaction moments decreased, except at L4 and L5 for 10° of bending and L3 and L5 for 15° of bending (Figure 2).

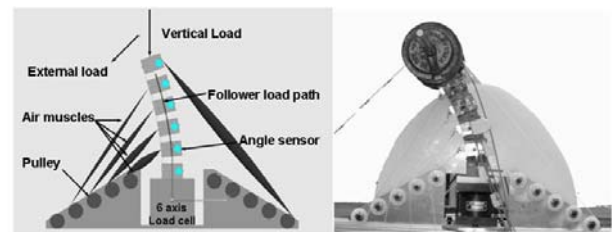


Figure 1: Experimental setup. (Left) Schematic; (Right) Photo.

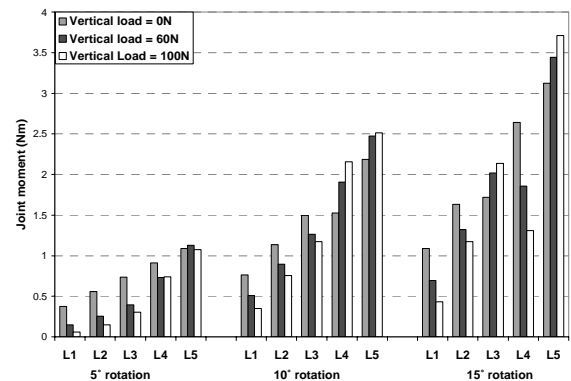


Figure 2. Resultant joint moment for different spinal postures.

CONCLUSIONS

An experimental validation was provided showing that the trunk muscles in the frontal plane can control the direction of the internal force resultant to be in the follower load path. These results suggest a possible mechanism by which the trunk muscles support large compressive loads in-vivo.

REFERENCES

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