INTRODUCTION

Cadaveric testing indicates that the rib cage adds significantly to thoracic stiffness. However, only a few studies have examined the in vitro mechanics of the full thoracic spine with the rib cage attached [e.g. 1, 2], or of the thoracic spine under a follower load [e.g. 3]. No study has previously done both simultaneously. Furthermore, it is not clear whether or how the rib cage might alter spinal loading. While the loading of a particular vertebral level cannot be measured directly, pressure within intervertebral discs is known to correlate strongly with compressive loading [4]. Thus, the purpose of this study was to determine whether the rib cage alters intervertebral disc pressure in static, upright loading conditions. We hypothesized that disc pressure would increase with increasing follower load, would decrease by artificially stiffening the rib cage, and would increase by the removal of the rib cage from the spine. We also assessed differences in disc pressure between two vertebral levels (T4/T5 vs T8/T9).

METHODS

Five full human cadaveric thoracic spines (T1-T12) with the rib cage intact were obtained (3 female and 2 male, mean age 65 years, range 61-71). Follower loads were applied by means of cables running lateral to the spine, connected to the spine by a rod inserted through each vertebral body with an eye nut at each end (Fig. 1). The specimen was positioned upright, and weights hung from the cables to apply follower loads. Five follower load levels were tested: 0 N, 200 N, 400 N, 600 N, and 800 N. Disc pressures were measured using pressure transducers side mounted on 1.3 mm diameter needles (Gaeltec, Isle of Skye, Scotland) inserted in the T4-T5 and the T8-T9 discs (Fig. 1).

Measurements were performed under three testing conditions: normal intact rib cage, “stiffened” rib cage, and removed rib cage (Fig. 2). Rib cage “stiffening” was achieved by attaching plates that bridged the costal cartilage and sternocostal joints for ribs 2-5.
The effects of follower load and testing condition on disc pressure were examined with a mixed effects model for each level measured (T4-T5 and T8-T9), adjusting for specimen as a random variable. The difference in pressure between levels (T4-T5 vs. T8-T9) was similarly examined for effects of load and testing condition. Significance was set at $\alpha = 0.05$, and analyses were performed in JMP (SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

Disc pressure at both T4-T5 and T8-T9 increased significantly with increasing follower load magnitude ($p < 0.001$, Fig. 3), from a mean of about 180 kPa with no follower load to 1,040 kPa with 800 N follower load. The testing conditions did not influence disc pressure at T8-T9, but T4-T5 pressures without ribs were about 100 kPa lower than in the intact condition ($p = 0.010$). There was no difference in pressure between vertebral levels with no follower load, but the difference between T4-T5 and T8-T9 increased with increasing follower load ($p = 0.032$).

The pressures measured here and trends with follower load compare well to previous reports. For example, an average pressure of 1,270 kPa was reported for T8-T9 motion segments under a direct compressive load of 1,000 N [5]. Extrapolating the trend found here predicts a T8-T9 pressure of 1,155 kPa at a follower load of 1,000 N. Thus, the follower load approach used here successfully produces similar disc pressures to comparable directly applied compressive loads.

The effect of test condition was limited, but the significant pressure reduction at T4-T5 with rib cage removal was counter to our hypothesis. It is possible that removal of the ribcage produced kinematic differences that tend to reduce pressure, and this could be examined in future analyses. Furthermore, this analysis was limited to pressures in a static, upright position, and it is likely that the results are not representative of disc pressures in dynamic or kinematically different conditions.

CONCLUSIONS

A static follower load applied to a full cadaveric thoracic spine with the rib cage produces intervertebral disc pressures proportional to the follower load. Stiffening or removal of the rib cage minimally affects disc pressures.

REFERENCES


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