The Rib Cage Has A Strong Stabilizing Effect On The Human Thoracic Spine: An In Vitro Study Using Stepwise Reduction Of The Single Rib Cage Structures

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Disclosures: -

INTRODUCTION: The human rib cage is considered to stabilize the thoracic spine. Despite this, the influence of various surgical treatments and traumata regarding the rib cage is still not known. Therefore, the purpose of the study was to determine the contribution of the rib cage and its single structures to human thoracic spine stability. Additionally, data of the mechanical properties were generated to validate finite element models of the human thoracic spine including the rib cage.

METHODS: Six fresh frozen human thoracic spine specimens (C7-L1, 56 years in average, range 50-65) including the intact rib cage with intercostal muscles were tested quasi-statically in a spinal loading simulator and monitored with an optical motion tracking system (Fig. 1). While applying 2 Nm and 5 Nm pure moments in flexion/extension (FE), lateral bending (LB), and axial rotation (AR), the relative motions of the functional spinal units of the thoracic spine (T1-T12) were studied (1) in intact condition, (2) after removing the intercostal muscles, (3) after median sternotomy, (4) after removing the anterior part of the rib cage up to rib stumps, after removing the rib head joint of (5) the seventh right rib, (6) the sixth right rib, and (7) the eighth right rib to simulate a scoliosis correction, and finally (8) in the isolated spine after removing all rib head joints. Statistical analysis was performed by Shapiro-Wilk-test for normality (p < 0.1), t-test of significance (p < 0.05), and Holm-Bonferroni method to control the familywise error rate. Experiments were approved by the ethical review committee of the University of Ulm. The specimens were harvested from human voluntary donors.

RESULTS: The range of motion (ROM) of the n=6 specimens increased largely in all three loading planes at 2 Nm (FE: + 55%, LB: + 58%, AR: + 131%) and at 5 Nm (FE: + 31%, LB: + 36%, AR: + 92%) in the isolated spine relative to the intact condition (FE: 12 ± 5°, LB: 18 ± 5°, AR: 25 ± 10°). Removing the anterior part of the rib cage already induced a statistically significant (p < 0.05) increase of the ROM in the three loading planes at 2 Nm (+ 48%, + 42%, + 96%) and in axial rotation at 5 Nm (+ 67%) relative to the intact condition. The intercostal muscles had a statistically significant (p < 0.05) influence on thoracic spine stability at 2 Nm in lateral bending (+ 22%) and in axial rotation (+ 22%). The splitted sternum caused a significant (p < 0.05) increase of the ROM in flexion/extension at 2 Nm (+ 12%) and in axial rotation (+ 22%, + 18%) related to intact condition (Fig. 2). Removing the rib head joints resulted in a slight, symmetric increase of the ROM. The monosegmental ROMs showed in some cases contrarily directed motions in flexion/extension and in lateral bending in the caudal region, e.g. a slight extension of T11-T12 during flexion. Coupled motions were detected mainly in lateral bending with secondary axial rotation in the opposite direction and slightly in axial rotation with secondary lateral bending in the same direction.

DISCUSSION: The rib cage has a significant influence on overall human thoracic spine stability, e.g. in axial rotation by a factor of approximately 2. Therefore, the thoracic spine should be tested with regard to all rib cage structures in vitro. Because of coupled motions, the ranges of motion of the functional spinal units could not be measured reproducibly in this study. These should be analyzed separately in a monosegmental test set-up with entire ribs and its sternal portion. Splitting the sternum, as it is performed in cardiac surgeries, as well as removing the rib head joints for treating scoliosis showed a significant influence on thoracic spine stability and should be clinically considered.

SIGNIFICANCE: The influence of surgical interventions concerning the rib cage, e.g. in scoliosis treatment, or traumata like rib and sternal fractures on thoracic spine stability is still little known. Therefore, data concerning the influence of the rib cage on the thoracic spine is essential for the basic understanding of the biomechanics of the thoracic spine as well as for the calibration and validation of finite element models of the whole human spine.

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IMAGES AND TABLES:

Fig. 1: Optical marker set-up for the single functional spinal units of the thoracic spine (orange) and the ribs (gray) during relative motion analysis.

Fig. 2: Offset of the sternal cut faces in the condition after median sternotomy in axial rotation at 2 Nm pure moment.