

EFFECT OF ORIENTATION ON FAILURE CRITERIA FOR LUMBAR SPINE SEGMENTS

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INTRODUCTION

Many studies have been performed to determine the compressive failure limits of spinal segments. The majority have used force as the criterion and the results show significant scatter from 1.5 kN to 10 kN (Chaffin, 1999). A number of factors are known to influence the failure strength including bone density, age, size, and orientation. The failure results are typically reported in non-normalized terms such as force or deformation, and the tests were virtually all performed without considering the orientation of the specimens. Although some recent studies have correctly orientated the segments (Lindsey, 2005), they did not compare the values to non-oriented test results. Stress distribution is affected by orientation (Campbell-Kyureghyan, 2005), but current biomechanical model failure limits are based on non-oriented test results. This study examines the failure behavior of lumbar spine segments under compression loading considering the effect of (1) spinal segment orientation; (2) normalization; and (3) a proposed new criterion of energy density.

METHODS

Motion segments, consisting of one intervertebral disc and the adjacent pair of vertebral bodies, were removed from four fresh intact lumbar spines (L₁-L₅) from human cadavers (3 males, 1 female, age range 58-71 years) with no spinal pathologies. Lumbar segments were DXA scanned from both the lateral and

anteroposterior projections. Geometric properties of the vertebral bodies and the discs were measured and the segments were tested in accordance with a protocol approved by the institutional Human Tissue Committee.

During testing, the motion segments were orientated at either the neutral Harrison angle (normal standing human body posture – Table 1) (Harrison, 2001) or in-line axially (non-oriented).

Table 1: Harrison angles for lumbar region.

Level	Mean	SD	Level	Mean	SD
L1/L2	-1	6.3	L2/L3	-6.8	4.4
L3/L4	-10.9	4.5	L4/L5	-15.9	5.1

After a 15 minute static preload of 350 N, an axial compressive load was applied at a rate of 4 mm/hr. Force and axial deformation were collected at 100 Hz. Failure was determined by a drop in sustained force. The force and deformation were normalized to stress and strain values using the measured geometric properties.

RESULTS AND DISCUSSION

Results for force, stress, strain, energy, and energy density for both oriented and non-oriented specimens are reported in Table 2. Orientating the lumbar specimens in the neutral position decreased their failure force by 25%. Failure stress was also computed and the stress for lumbar segments oriented in the neutral position was 7% lower than in non-oriented segments, a statistically significant (80% CI) difference. Failure

strain was found to be 35% higher in the oriented segments.

Energy dissipation and energy density (normalized to disc volume) in the intervertebral disc were calculated. An average failure energy (SD) of 4769 (2318) KJ was found for the oriented specimens and 4054 (2516) KJ for the non-oriented specimens. The oriented segments had approximately 30% higher energy density at failure compared to the non-oriented segments.

Bone mineral density (BMD) ranged from 0.827 to 1.249. In agreement with previous research (Hansson, 1980) a linear correlation with failure force ($R^2=.89$) and stress ($R^2=.88$) were found. Interestingly, strain and energy density were not correlated with BMD. This is due to the influence of the disc response on these criteria.

SUMMARY/CONCLUSIONS

Orienting the motion segment varies the distribution of forces and mode of deformation, and therefore failure. The oriented lumbar spine segments failed at lower force and stress than non-oriented specimens, while undergoing larger strains. One possible explanation of these results is that the non-oriented specimens had more contact in the posterior regions with the resulting bone-to-bone interaction leading to the higher forces and lower deformations.

The variability in *in-vivo* segment alignment may explain a portion of the subject specificity regarding injury tolerances and ignoring orientation when determining failure limits can lead to over prediction of lumbar spinal strength.

This study provides a clear indication of the effect of segment orientation on the failure properties. Application of reported failure values must consider the testing orientation. Normalization of the results removes the effects of specimen size and reduces the scatter in the data. In addition, normalized values are more easily compared between studies. Finally, energy density shows promise as a failure criterion and incorporates both force and deformation.

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Table 2: Mean (SD) of failure criteria for oriented and non-oriented lumbar spine segments.

	Force (kN)	Stress (MPa)	Strain (%)	Energy (kJ)	Energy Density (kJ/mm³)
Oriented	2.6 (0.7)	1.7 (0.5)	23 (11)	4769 (2318)	0.25 (0.14)
Non-Oriented	3.3 (1.4)	1.8 (0.5)	15 (1.1)	4054 (2516)	0.17 (0.05)