Human versus sheep intervertebral disc mechanical and vertebral cortical bone strain properties

INTRODUCTION

Obtaining human material for studies of the spine is difficult because of ethical and governmental regulatory restrictions. Animal models are increasingly being used for research studies of the spine [1], and the sheep lumbar intervertebral disc has been shown to have morphological [2] and biochemical [3] similarities to human lumbar discs. Sheep have been used as a large animal model to study the in-vitro mechanical properties and in-vivo effects of induced degeneration/injury and repair of discs. The advantages of using an animal model include the ability to use a more homogeneous sample (e.g. age, gender, weight, nutrition, disease condition, bone quality and exercise) to reduce specimen variability, obtain disease-free tissue and lessen the reliance on procuring human cadaver spines. However, the differences in disc compressive mechanical (stiffness and phase angle) and vertebral cortical bone strain properties have not been quantified. The null hypotheses for this study were that there were no differences, in ex-vivo tests, between the stiffness, phase angle and cortical principal strains of human and sheep vertebra-disc-vertebra segments (functional spinal units – FSUs).

METHODS

Twenty, lumbar FSUs from 14 human spines [mean (SD) age: 66 (16) yrs, range: 28-87 yrs, levels T12-L1 x 9, L2-L3 x 3, L4-L5 x 8] and six sheep (Merino wethers) were obtained. Zygopophyseal joints were removed for testing of the isolated disc segments. Triaxial rosette strain gages were bonded to the cortical bone surface of the inferior vertebral body, below the disc-endplate boundary at three locations: right/left lateral and anterior. Each FSU was initially subjected to a 0.2 MPa compressive preload for 14 hours in a 0.15M phosphate buffered saline bath with protease inhibitors to reach equilibrium hydration. The FSU was then subjected to 10 sinusoidal load-controlled cycles at 0.5 Hz in compression (1 MPa). Load, displacement and cortical strains were recorded and stiffness, phase angle (a measure of energy absorption) and principal strains for each rosette were calculated. Unpaired t-tests were conducted to identify significant interspecies differences.

RESULTS

Significant differences in compressive stiffness were found between human (mean±95% CI: 2,497±250 N/mm) and sheep (1,473±315 N/mm) discs (Figure 1). No differences were found for phase angle between human (4.9±0.2°) and sheep (5.1±0.2°) discs (P=0.5).

DISCUSSION

Human discs are thicker, larger and stiffer than sheep discs, though have similar biochemical composition and structural arrangement of collagen and proteoglycans, which supports the finding of no difference in energy absorption. The low phase angles suggest that the discs of both species, at the frequency tested, behaved more like an elastic material, and exhibited minimal biphasic viscoelastic behavior.

Assuming that the disc behaves as an isotropic linearly elastic material, the nominal modulus (E) can be related to the measured stiffness (k) by E=kLA, where A = nominal disc area and L = nominal disc height. The ratio L/A for an average human disc having a height of 10 mm and area of 1500 mm$^2$ is 0.0067, and for an average sheep disc having a height of 3 mm and area of 450 mm$^2$ is also 0.0067. Therefore, despite adjusting for simple disc geometric effects, the nominal modulus of human discs (16.6 MPa) is considerably larger than sheep discs (9.8 MPa) and directly proportional to the measured stiffness.

Cortical bone strains, particularly minimum principal strain were substantially larger in human bone, suggesting stiffer cortices in the sheep. Vertebral cortical bone density (BV/TV) has been measured as approximately 41% in sheep [4] and approximately 11% in humans [3], with this difference probably contributing to the stiffer minimum principal cortical strains measured in sheep. No data could be found on the cortical thickness in sheep, however, the higher sheep BV/BV suggests that it is likely to be greater than that of human cortical thickness (mean±SD: 0.52±0.35mm [6]), and consistent with the observations in goats demonstrating a higher trabecular density compared to human vertebrae [7].

These important differences should be taken into account when using a sheep model to assess disc and bone mechanical properties.

ACKNOWLEDGEMENTS

National Health and Medical Research Council (NH&MRC) for providing funding for this study.