ACOUSTIC EMISSION MONITORING OF COMPRRESSIVE BONE FRACTURES AND TENSILE LIGAMENT INJURIES IN THE SPINE

Carolyn Van Toen1,2, John Street2, Thomas R. Oxland1,2, Peter A. Cripton1,2
1Orthopaedic & Injury Biomechanics Group, Department of Mechanical Engineering, and ICORD, University of British Columbia, Vancouver BC, carolyn@mech.ubc.ca
2Department of Orthopaedics, University of British Columbia, Vancouver BC

INTRODUCTION
Acoustic emission (AE) sensors record dynamic stress waves generated from release of energy in a material, such as a fracture [1]. These have been used to detect the time of fracture of skull and lower extremity bones [2-3]; however they have not been used to detect and differentiate between dynamic bone fractures and ligament injuries in the spine. The objective of this study was to evaluate the effectiveness of using AE signals to detect and differentiate between the time of injury of vertebral body (VB) and ligamentum flavum (LF) specimens tested in compression and tension, respectively.

METHODS
Isolated human cadaver VB (n=7) and LF (n=7) specimens from the cervical and upper thoracic spine were potted in polymethylmethacrylate (PMMA). Two AE sensors (Nano30, MISTRAS Group) were attached to the PMMA (superior and inferior). Specimens were attached to a load cell inferiorly (model MC3A-6-1000, Advanced Mechanical Technology) and to a materials test system actuator superiorly (model 8874, Intron Corporation). VB and LF specimens were tested in compression and tension, respectively, to nominal strains of 25 and 40%, respectively at a rate of 0.4 m/s. AE signals were pre-amplified and collected at 5 MHz. High speed video was collected at 33,057 fps (Phantom v9, Vision Research).

Times of injury (time of peak AE amplitude) were compared to those using traditional methods (LF: visual evidence in high speed video, VB: time of peak force). ‘Characteristic frequencies’ were defined as those with peak coefficients of the continuous wavelet transform of the AE signal at the time corresponding to applied stress values between 80% and 100% maximum stress. Peak AE signal amplitudes and characteristic frequencies for the LF and VB specimens were compared with analysis of variance and Friedman’s test, respectively.

RESULTS

Figure 1: Sample results of force and AE signals (inferior sensor) vs. time for a VB specimen (A) and a LF specimen (B). High speed video images of the LF specimen for the time points indicated (A, B, C) are shown in Figure 2.

Six specimens failed in each group (VB, fracture; LF, periosteal stripping or attenuation) and one did not. AE signals were recorded during loading and after the peak forces were reached (Figure 1). AE signals were recorded in the initial stages of loading for the VB specimens which were identified as artifacts of the impact (Figure 1A).

Time of injury using AE signals for LF and VB specimens produced average absolute differences to traditional methods of 2.4 (SD 1.5) ms and 0.7 (SD 0.2) ms, respectively (Figure 2). AE signals from VB fractures had higher amplitudes and frequencies than those from LF injuries (average peak amplitude 87.7 (SD 6.9) dB vs. 71.8 (SD 9.8) dB for the inferior sensor, p<0.05; median characteristic frequency from the inferior sensor 97 (interquartile range, IQR, 41) kHz vs. 31 (IQR 2) kHz, p<0.05).

Figure 2: High speed video images of a LF specimen before loading (A), when rapid motion of a ligament fibre was first observed (B), after the time of peak force when a portion of a torn fibre was observed (C). These times are also indicated in Figure 1B.

DISCUSSION & CONCLUSIONS
This study confirms the potential of using AE signals to detect time of injury and to differentiate between failures of different spinal components in dynamic loading. AE signals from compressive VB fractures were associated with higher amplitudes and frequencies than those from tensile LF failures. Although the loading and boundary conditions in these experiments may not fully replicate those of the in vivo spine, this allowed us to be certain that AE signals were not originating from other anatomical structures. Also, despite the fact that we tested specimens from various spinal levels, as was necessitated by the low number of specimens available, statistically significant differences were observed.

REFERENCES