With prior creep loading cartilage is more vulnerable to micro-level impact-induced failure.
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INTRODUCTION
With respect to everyday joint use, creep loading, although common, receives little attention in the biomechanics literature. This study investigates the vulnerability of the cartilage to impact loading following a duration of creep.

METHODS
Cartilage-on-bone blocks, from young-adult bovine patellae, were prepared with en face dimensions approximately 15 mm by 15 mm, and 5 mm of subchondral bone. A total of seventeen such blocks were obtained from the distal-lateral quarter of each patella. Samples were embedded in a stainless steel holder with dental cement and equilibrated in 0.15 M saline for 2 hours prior to testing.

Impact testing. A previously validated pendulum-type device [1] was used to deliver a 1.6kg mass impact load at 1.1 m/s through a cylinder-ended indenter 10.2 mm wide with a radius of 2 mm. Using the pendulum drop height, the energy of impact delivered was ~0.65 J. All samples were aligned such that the articular cartilage surface was parallel to the indenter face. Each impact test was digitally filmed at 6000 frames per second to calculate velocities before and after impact. All 17 samples were impact loaded, however seven samples were creep loaded first. Creep loading was performed using a plane-ended rectangular indenter of dimensions 13 mm by 7 mm that was fitted over the impacting indenter and pressed against the articular cartilage surface. A pulley and weight system that was attached to the pendulum arm allowed for this compression to be maintained. Creep loading was for a period of 3 hours using a total weight of 16 kg (equating to an approximate stress of 2 MPa). Impact loading was performed immediately following creep loading by removing the pulley and weight system and priming the pendulum arm.

Sectioning for microscopy. Following impact testing samples were rehydrated in 0.15 M saline for 2 hours. The surfaces of the samples were then stained with India ink to reveal gross superficial damage. The samples were chemically fixed in 10% formalin overnight then mildly decalcified in 10% formic acid for 3 days for easy sectioning across cartilage and bone. A perpendicular cut was made through the samples using a surgical blade, to reveal a complete cartilage-on-bone cross-section of the impacted region and the adjacent, unloaded regions. The cross-sections were then cryo-sectioned to obtain 20 µm sections for microscopic study. Multizoom and Differential Interference Contrast (DIC) optical microscopy were used.

RESULTS
Group I (Samples that did not undergo prior creep loading). The coefficient of restitution calculated was 0.198 (SD 0.024), and not significantly different to Group I. The damage observed was however significantly different in that extended fractures lines progressed down into the deep matrix and osteochondral junction (Figure 2).

Group II (Samples that were creep loaded for 3 hours prior to impact). The coefficient of restitution calculated was 0.198 (SD 0.024), and not significantly different to Group I. The damage observed was however significantly different in that extended fractures lines progressed down into the deep matrix and osteochondral junction (Figure 2).

DISCUSSION
The obliquely-directed fracture pattern in the upper layers of the cartilage has been described recently [2], and is a result of the transition from tangential to radial fiber-direction within the fibrillar matrix. However, of interest is the manner in which creep-compressed samples, when subjected to impact, results in an extensive propagation of the fracture line into the deeper cartilage matrix and underlying bone. The lateral propagation of the fracture along the ZCC (Fig. 2B box XX) is a result of the soft-hard tissue interface and the subsequent gradual sloping penetration into the underlying bone is an indication of the mechanical gradient between the ZCC and harder bone tissue. Creep loading results in matrix consolidation and fluid being forced out from the tissue beneath the directly compressed region. The reduction in the tissue’s dissipative properties following creep loading highlights the increased vulnerability of joints that have undergone such sustained loading.

Acknowledgement
This study was supported by the Equine Trust NZ.

REFERENCES