INTRODUCTION: While full thickness tears of the rotator cuff are likely to be repaired surgically, treatment of partial thickness tears often depends upon a subjective surgical assessment of tear severity and estimation of the likelihood for enlargement. We target an intra-operative endoscopic tool to quantify in vivo tendon tissue strains under physiological loads, with the goal to classify partial tear severity and predict the likelihood of tear propagation. As a technical benchmark, we sought to verify the ability to accurately quantify tendon tissue strains above 3-5%, magnitudes known to be associated with micro-damage [1]. This study evaluates implementation of this method with an ex vivo tendon injury model.

METHODS: A key technical limitation of clinical endoscopy for measurement purposes is associated with image distortion induced by the typically extreme wide angle lens. Before applying an endoscope for measurement of tendon deformation (strain field), a post-processing calibration [2] was performed to correct the distortions of the endoscopic lens before making strain measurements. As a human test surrogate, equine superficial digital flexor tendons were cut into 15 mm x 3 mm x 1 mm samples for the study. A lesion was created at the center of each specimen using a 2 mm diameter biopsy punch. The injured tendon was then loaded on to a universal material testing machine (Bose EF3200, Minnesota USA) for tensile testing and observed using a clinical grade endoscope (Karl Storz Endoscope, Germany) mounted to a digital video camera (Basler A600, Germany).

The tendon surface was marked with graphite powder and marker displacements were recorded. The relative displacements of the tendon surface markers were tracked, and the corresponding tissue axial strains were calculated using a custom algorithm (Matlab v7.9).

RESULTS: The endoscope was successfully calibrated for barrel distortion in water with a back projection error of 1.67 pixels (approximately 0.1% of image size). Using a corrective transformation, these distortions could be successfully removed. Figure 1A and 1B show a uniform grid imaged with the endoscope and the image after distortion correction.

Both finite element (FE) analysis and benchmark measurements showed increase in strain at the sides of the injury and decrease in strain on top and bottom of the injury site (Fig 1C and 1D). Similar results were obtained using the clinical grade endoscope. Specifically, above and below the injury site, there was a decrease of strain in injured tendon samples compared to the healthy ones, and at left and right of the injury sites, strain was significantly increased (Figure 2A, Table 1). Strain maps over the entire sample surface showed higher concentration at the sites, strain was significantly increased (Figure 2A, Table 1). Strain measurements were calculated using a custom algorithm (Matlab v7.9).

DISCUSSION: We have demonstrated that intra-operative assessment of torn tendon tissue strains can be sensitively and accurately measured using distortion-corrected images from a clinical grade endoscope. However, this result was achieved using a stationary experimental setup that mitigated out of plane movements of the loaded tendon surface. Characterization of these movement artifacts indicated a drastic effect on measurement accuracy, and confirmed the necessity for compensation.