INTRODUCTION
Painful tendon tears are often endoscopically examined prior to repair or debridement. The decision to surgically repair a partial thickness tendon tear commonly depends upon a subjective intraoperative visual assessment of the tear severity and estimation of the likelihood for tear enlargement.

We target an intra-operative endoscopic tool to quantify in vivo tendon tissue strains under physiological loads, with the goal to objectively and functionally classify partial tear severity. 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 the image distortion induced by typically extreme wide angle endoscope lenses. We first performed a calibration [2] to correct for “barrel” distortion of the lens.

Strips of equine superficial digital flexor tendons were cut into 40 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 in a PBS filled chamber mounted to a universal material testing machine (Bose EF3200, Minnesota USA) and observed under tension (14 MPa) 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 axial tissue strains were calculated using a custom algorithm (Matlab v7.9).

Benchmark measurements using a conventional measurement lens (telecentric) were generated, together with a finite element analysis (Ansys v12.1), these data were used as a gold standard to compare the endoscopic measurements.

Sensitivity of endoscopic strain measurement related to movement artifacts along the imaging axis was also examined; Loaded tendon surface movements can create a ‘zoom’ effect in the resulting image that drastically affects strain measurement accuracy. Here, the diameter of a spherical dot was measured at incremental distances from the camera.

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.

Figure 1: A uniform grid imaged with endoscope (A) without distortion correction (B) with distortion correction C) FE model of the injured tendon sample D) An example of benchmark measurements.

The clinical grade endoscope was able to successfully characterize tissue strains in both intact and torn tendons. Consistent with both finite element (FE) analysis and benchmark telecentric lens measurements (Fig 1C, 1D), tissue strains were endoscopically observed to increase medial and lateral to the lesion and decrease distal and proximal to the injury site (Fig 2).

Characterization of tendon surface movement artifacts along the imaging axis showed that for each 0.04mm change in distance, approximately 0.6% of strain error resulted. Therefore, endoscopic strain measures were extremely sensitive to the camera-object distance, but artifacts could be successfully corrected by compensating for out of plane movements of the tendon surface (here measured using an orthogonally mounted camera).

DISCUSSION AND CONCLUSIONS
Partial tendon tears shunt load to surrounding intact tissues, and give rise to higher tendon tissue surface strains. We have
demonstrated that distortion-corrected images from a clinical grade endoscope can sensitively and accurately detect these altered strain patterns.

The measurements in this in vitro study were performed under tightly controlled conditions that mitigated motion artifacts. However, with adequate post-processing to correct for image distortion and quantified relative movements between the objective and the tendon, the method proved capable of accurate and clinically relevant measurements similar to those from a high quality metric lens.

While additional work is required on technical implementation, particularly tracking of tendon surface movements along the imaging axis, we view the method to hold potential for intraoperative functional imaging of tendon.

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REFERENCES
1 Arnoczsky et al., Int J Exp Path 2007;

Figure 2A. Measurements from telecentric lens. 2B. Measurements from endoscopic lens after movement compensation.