Introduction: Inappropriate tissue stiffness associated with inadequate healing of the rotator cuff tendons can result in increased susceptibility to re-injury [1]. The rat supraspinatus (SSP) tendon has emerged as a model in the study of rotator cuff injury [2,3], and the "standard" for assessing rotator cuff biomechanics is ex vivo testing. In contrast to ex vivo testing, non-destructive, in vivo biomechanical testing would open possibilities to gain essential information prior to and following surgery, as well as over the time course of healing. The present study aims to extend a novel functional endoscopic imaging method [4] to assess mechanical properties of the rat SSP tendon in vivo. This method has been shown to be highly sensitive to local differences in tissue stiffness. This study describes the implementation of this method to the rat shoulder and a preliminary validation of its use in assessing SSP tendon biomechanics in a partial tendon defect.

Materials and Methods: Animal experiments were approved by the appropriate Swiss authorities. Four 16-week-old Sprague-Dawley rats were anesthetized and the bilateral SSP tendons were surgically exposed. The rats were divided into two groups: uninjured and injured SSP, which underwent a partial defect using a 1 mm biopsy punch. The rat was placed supine on a custom made Supraspinatus Clamp in order to prevent scapulo-thoracal motion. Both the device and the scapula were orientated such that rotation about the device axis passively stretched the SSP tendon. A quantified external moment was then applied, over the full range of flexion and extension, while torque and angle were recorded.

To quantify the mechanical integrity of the component tendon tissues, a focused analysis of tendon surface strains was performed. The tendon surface was marked with Indian ink and marker displacement was recorded with an endoscopic video camera while load was applied to the SSP. This functional imaging was performed at incrementally increasing shoulder moments. The relative displacement of the markers, and the corresponding tissue strains were calculated using a custom algorithm (Matlab v7.1).

After in vivo measurements, all animals were sacrificed and the shoulders were dissected. Ex vivo biomechanical testing was performed for all specimens. SSP tendons were isolated with the muscle-tendon-bone complex, and fixed in a uniaxial testing machine. Samples were preconditioned for ten cycles to 3% nominal strain, and then ramp loaded to failure.

Results: The shoulder could be reproducibly loaded in flexion and extension for both the intact and partial tendon defect groups (Tab. 1, Fig. 1). Tendons with a partial defect showed no apparent change in shoulder range of motion, but showed less resistance to applied extension (Intact: 80.5 ± 2.8 N/mm, vs. Defect: 24.3 ± 2.4 N/mm, p=0.02). Analysis of endoscopic images of passively loaded SSP tendons (Fig. 2ab) indicated (non-significantly) higher tissue strains along the tendon functional axis in the injured group (2.8±1.7%) than seen in the uninjured group (1.2±1.0%). This reflects the ex vivo results on the same tendons, which showed compromised tendon stiffness in the partial defect tendons (Intact: 19.8±2.4 N/mm, vs. Defect: 13.9±2.8 N/mm, p=0.02).

Discussion: This pilot study explored a non-destructive method to assess in vivo biomechanical properties in passively loaded rat SSP tendons. To this end, we developed and implemented a device for quantifying and recording the moment-angle characteristics of the shoulder joint in flexion-extension. After configuring the device and positioning the animal to passively stretch the SSP tendon along its functional axis, we were able to characterize some macroscopic aspects of shoulder joint biomechanics. While general trends are indicated, it must be noted that this pilot study lacked sufficient statistical power to draw definitive conclusions.

The shoulder range of motion did not markedly change with implementation of a partial defect, but resistance to passive motion (quantified as joint torque) was reduced in the defect group. This indicates that the gross mechanical competency of the SSP tendon might be quantified using a non-invasive range of motion device such as the STAD. Specifically, the resistance of the shoulder joint to an applied angular excursion may provide a proxy indication of SSP integrity. Further studies are being performed to confirm this hypothesis.

With regard to the endoscopic assessment of local tendon mechanics, we hypothesized that a partial defect would shunt load to the surrounding intact tissues, and would give rise to higher tendon surface tissues strains. While higher tissue strains were in fact observed in the partial defect group, the differences were small, and additional methodological development is required to improve the sensitivity and accuracy of these measurements. Nonetheless, we have demonstrated the feasibility of the method, which may eventually serve in quantifying local changes in tendon mechanics that accompany injury and subsequent healing.

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Table 1: Angle and torque during shoulder motion

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<th>Intact</th>
<th>Defect</th>
<th>p-value</th>
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<tbody>
<tr>
<td>angle [°]</td>
<td>89.2±0.7</td>
<td>90.2±0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>torque [Nmm]</td>
<td>27.7±0.8</td>
<td>26.6±2.5</td>
<td>0.38</td>
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Fig. 1. The device in use (left) and a typical torque angle plot for a normal tendon (right).

Fig. 2. Endoscopic images of unstretched (left) and stretched (middle) tendon. Tissue strains in both normal and defect tendons (right).