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Characterisation of the rat ulna compression model using microCT and Finite Element calculations

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The rat ulna compression model(1) is used by several research groups to study functional adaptation, microdamage and stress fractures resulting from repetitive mechanical loading of bones. In this model, the forearm of an anaesthetised rat is placed between the two cups of a mechanical loading machine, which cyclically and axially loads it in compression with a given displacement amplitude. Loading is performed until the stiffness of the bone drops below a threshold value, which indicates the occurrence of damage in the bone, either microdamage or a stress fracture. Some work has been done previously to characterise the influence of the axial loading on the local stress distribution of the bone, but so far only the deformation of the isolated ulna has been analysed, while the loading of the ulna-radius construct with a connecting interosseus ligament in the rat is more complex. The goal of this study was therefore to develop a full three-dimensional characterisation of the deformation behaviour of the rat forelimb in this loading situation.

The right forelimbs of 20 rats were fatigue loaded and the animals sacrificed after 4, 7, 14, 21 and 28 days of recovery time (n=4 for each time point). After sacrifice, both forelimbs were scanned at high resolution (18 mm spatial resolution) in a micro CT scanner (μCT 40, Scanco Medical, Switzerland). The right, fatigued forelimbs were scanned to identify the location of the stress fracture, and to analyse the callus formed in response to the stress fracture at different time points. The left, intact forelimbs were scanned using a special compression chamber that allowed the imaging of the bones under defined axial compression. Reconstructions of these scans from bones under axial compression were used to track the movement of points on the bone ends during loading, which were then used to define the boundary conditions for Finite Element (FE) models of the same limbs that were developed from scans of the unloaded bones. The resulting FE analyses showed that the FE models which included the interosseus

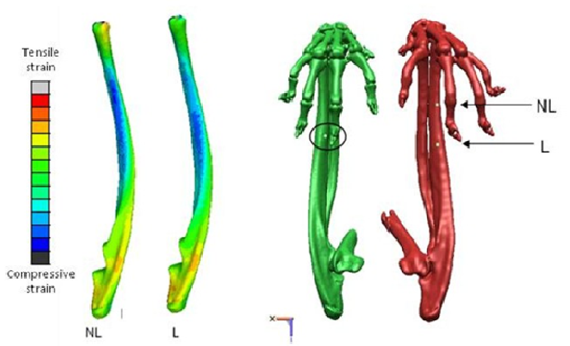

Figure. Left: Contour plots of the longitudinal strain distribution in models without (No Ligament, NL) and with (L) the interosseus ligament. Right: Comparison between the location of maximal compressive, longitudinal strain in FE models (red) without (NL) and with (L) the interosseus ligament, and the location where the stress fracture was detected in the scans of the contralateral, experimental limb (green, circle).

ligament predicted the location of the bone damage observed in the fatigued forelimbs much better (Figure). This confirmed the important role of the interosseus ligament for the deformation behaviour of the rat ulna. We are therefore able to determine the full three-dimensional stress-strain distribution in the loaded rat ulna, which will greatly aid in the interpretation of the results obtained using this experimental model.

References:

1. Torrance AG, Mosley JR, Suswillo RF, Lanyon LE. 1994. Noninvasive loading of the rat ulna in vivo induces a strain-related modeling response uncomplicated by trauma or periostal pressure. Calcif Tissue Int 54: 241-247.