INTRODUCTION:
Non-invasive fracture healing evaluation and staging in clinical orthopedics have not changed significantly over the last four decades despite a dramatic development of modern tissue imaging and publication of experiments that demonstrate strong associations between computed tomography data and biomechanical properties of fractured bone [1,2]. However, more and more patients present comorbidity that impairs bone quality and repair such as age-related osteoporosis and diabetes. There is an increasing demand for accurate staging of the fracture healing process and early and safe removal of restrictions and surgical implants.

On the basis of these considerations, we wanted to use a well-established experimental fracture model to investigate statistical correlations between voxel-based segmented quantitative micro computed tomography (µCT) data and mechanical properties (bending strength) in diaphyseal tibial fractures.

METHODS:
The experiment conformed to the Norwegian Council of Animal Research Code for the Care and Use of Animals for Experimental Purposes.

40 male rats were subject to a standardized tibial shaft osteotomy and initially stabilized either with intramedullary nailing (IMN, N=20) or unilateral external fixation (EF, N=20). Evaluation of half of the two groups at 30 days, and the other half at 60 days, included x-ray, µCT, and a 3-point fracture site specific cantilever mechanical bending test.

µCT scan settings were 300 steps with 200 degrees rotation and the x-ray camera detector size was 2048x2048 with a bin factor of 2. Exposure time was 500 ms and voxel size was 50.7μm cubic. The images were reconstructed from a region of interest (ROI) of both 1.25 mm (25 slices) and 3.75 mm (75 slices), encompassing the fracture site, and analysed with a commercially available reconstruction and visualization software package (Amira v4.1, Mercury Computer Systems Inc, Méringac Cedex, France). Interpretation of the voxel µCT-value was based on simultaneous scan of a Lucite phantom doped with hydroxyapatite with mineral densities equal to 50, 250 and 750 mg/cc, and Hounsfield units was linearly converted to HA densities. There is no clear defined consensus on what density thresholds one must apply to segment soft and hard callus and cortical bone as qualitative computed tomography research mostly have focused on intact bone and prediction of relative fracture risk. The voxels were segmented into exterior/fat (<171 mg/cc), soft callus (171<540 mg/cc), hard callus (540<1200 mg/cc), and cortical bone (>1200 mg/cc) based on thresholds in previous experiments and careful examination of µCT-images with standard bone window and comparison to segmented µCT-images.

In conclusion our results confirms the ability of segmented µCT data and biomechanical ‘splitting’ effect – which can be related to the measured soft and hard callus – is not a major contributor to the bending strength of the callus.

DISCUSSION:
Neither soft nor hard callus tissue had a clear, positive correlation to strength in our experiment. On the contrary, there is a tendency of negative relationship between soft callus at the fracture site and strength, but not significant in our groups. In a clinical setting, the visible periosteal callus on an x-ray in a flexibly fixated fracture usually denotes a normal course of healing and indicates that remodelling has commenced or soon will, with subsequent strengthening. Our results indicate that, even though callus provides stability for the remodelling process, its biomechanical ‘splitting’ effect – which can be related to the measured soft and hard callus – is not a major contributor to the bending strength of the callus.

The significant positive correlation between cortical bone and bending strength in the IMN group with the small ROI in the early phase of healing supports that cortical bone remodelling with formation of new, strong lamellar structures across the fracture gap is the major factor in the restoration of mechanical strength of the bone. Previous tests have shown initial bone implant rigidity for EF to be nearly 90 % of intact tissue, compared to just above 15% for IMN. Our results indicate that cortical bone and vBMD is equally correlated to strength the early phase of healing in less rigidly fixated fractures, and that in this situation around half the variability of the callus strength may be put down to variation in measured cortical bone.

In conclusion our results confirms the ability of segmented quantitative µCT to measure tissue volume, differentiate between calcified tissues, and quantify bone density. Furthermore, our results indicate that cortical bone and vBMD correlates with strength in a positive and significant manner in flexibly fixated fractures in an early phase of healing, and low density bone tissue have no or negative correlation with strength. Our results further indicate that the concept of voxel-based threshold segmentation may assist in identification and quantification of biomechanically important high mineral density bone tissue, and this technique may improve µCT as a tool for non-invasive fracture evaluation.

REFERENCES: