ABSTRACT INTRODUCTION:
Non-invasive assessment of load bearing capacity is an important issue in the advanced clinical routine of callus distraction. Several methods have been proposed in the past to predict the load bearing capacity non-invasively, e.g., dual energy X-ray absorptiometry (DEXA), quantitative computerized tomography (QCT) or quantitative ultrasound. While recent studies used measures of bone density to estimate mechanical properties, they do not account for the microstructural organisation of the bone regenerate. Furthermore previous studies only analyzed a single type of callus stiffness. This approach neglects the multi-dimensional characteristics of callus loading in compression, bending and torsion.

In our study a tibial sheep distraction osteogenesis model was used and multiaxial stiffness measurement was performed. The regenerate microarchitecture was assessed using 3-D-microcomputed tomography and density measurements were performed using a high resolution DEXA-device. The specific research question was, whether parameters of trabecular microarchitecture outmatch the bone mineral density predicting the bending, compressive and torsional stiffness of callus tissue.

METHODS:
Mid-diaphyseal osteotomies were created at the right limb of twentyfour skeletally mature sheep (81 ± 13.6 kg) and stabilized with an external fixator. After a latency period of 4 days the tibiae were distracted at a rate of 1.25 mm daily in two increments over a period of 20 days, resulting in total lengthening of 25 mm. Sheep were sacrificed after 74 days. The animal experiment was conducted under an ethic commission approved protocol according to german federal animal welfare legislation. The tibiae were harvested, scanned by micro-CT at a resolution of 120 µm per voxel. The reconstructed data were analyzed for trabecular number (Tb.N), trabecular thickness (Tb.Th.), trabecular spacing (Tb.Sp.) and Connectivity using a modified algorithm of directed secants, the Hipp and Simmons method. The region of interest (ROI) was fit into the distraction zone as two spheres with half of the diameter of the distraction zone. Bone mineral density (BMD) measurements were performed using a high resolution Hologic® DEXA device. Following embedding in PMMA the tibiae were tested mechanically at day 74 using a material test system (MTS). The distraction zones were tested for torsional stiffness and bending stiffness in antero-posterior (AP) and medio-lateral (ML) direction, compression strength and the maximum axial torsion. Regression analysis were performed using power functions. Statistical significance was defined as p<0.05.

RESULTS SECTION:
The regression analysis revealed significant non linear relationships between Tb.N., Tb.Sp. and all mechanical properties. The Tb.Sp. shows the best correlation with each of the stiffness parameters. Maximal correlation coefficients were found for the Tb.Sp. vs. the bending stiffness AP and ML with R²=0.69 and R²=0.70 (p<0.0001; n=24). Poor correlations (R²<0.4) were found for Connectivity with all mechanical parameters. Because of negative Connectivity values a linear plot was performed using power functions. Statistical significance was defined as *p<0.05, **p<0.001; n=24.

DISCUSSION:
The results of this study highlight a strong relation between microstructure parameters (Tb.N and Tb.Sp) and the multiaxial stiffness in callus tissue. The trabecular separation (Tb.Sp.) was observed to best predict callus stiffness. In contrast to the results of multiple studies concerning the correlation between apparent bone density and bone stiffness in cancellous and cortical bone we found a poor, non significant relationship between the BMD and the stiffness measurements in distraction callus. This weak relation may be explained by the incompetence of the BMD to differ between biomechanical relevant bone mass connecting the two bone ends and the overall bone mass including isolating bone particles. Isolated bone particles don’t contribute to the mechanical stiffness of the bone regenerate but increase the BMD of the distraction zone. Furthermore the presence of isolated bone particles in the distraction zones can explain the poor correlation between the connectivity and the stiffness parameters, because they will produce positive Euler numbers and consequently negative values of Connectivity without forcing up the load bearing capacity of the callus. Therefore the connectivity is seen to be susceptible to falls in the analysis of distraction callus. The high correlations found for Tb.Sp and Tb.N. support the ability of micro-CT derived parameters to be a suitable tool to predict load bearing capacity of the callus. Further developments will direct towards the use of MRI derived techniques to provide a precise tool to forecast load bearing ability in patients undergoing bone distraction procedures.