INTRODUCTION:

Our knowledge of fracture healing is mainly based on experimental studies of diaphyseal fracture models, although clinically many fractures occur in metaphyseal areas and show different healing characteristics. Whereas diaphyseal fractures mainly heal via the formation of callus tissue, in metaphyseal spongy bone, fracture healing occurs with no or limited callus formation [1]. Clinically, metaphyseal fractures appear to heal faster than diaphyseal fractures and are obviously less sensitive to unstable fracture fixation. Whereas several studies investigated the effect of stability (interfragmentary movement, IFM or interfragmentary strain, IFS) on diaphyseal fracture healing, nothing is known about biomechanical effects on metaphyseal bone healing. The few existing experimental studies performed in different metaphyseal fracture models did not consider how the mechanical conditions affected fracture healing [1, 2]. We have recently developed a new model to study metaphyseal bone healing under defined biomechanical conditions [3]. The aim of the present study was to define tissue differentiation in metaphyseal fracture healing in this well-defined model and to correlate these results to the interfragmentary strain.

MATERIALS AND METHODS:

This experiment was conducted following national regulations for the care and use of laboratory animals and was approved by the National Ethical Committee. Twelve mature sheep underwent a partial osteotomy at the distal femur. The osteotomy was initiated 15 mm away from the junction of the distal trochlea and the femoral condyle, and had an open end at the proximal end of the trochlea (Fig. 1). The width of the osteotomy gap was 3 mm. Under physiological loads the patella presses against the trochlea, causing a deflection of the osteotomy gap. (Fig. 1)

This interfragmentary movement was limited by a steel implant fixed in the proximal region of the osteotomy (Fig. 1). Six sheep each were operated with stable fixation using an implant of 3 mm thickness (stable osteotomy, S) and flexible fixation with an implant of 2 mm thickness (flexible osteotomy, F) respectively. Eight weeks after the operation the animals were sacrificed and the distal femora and implants removed. The bone healing in the osteotomy region was investigated by pQCT, biomechanical indentation test and quantitative undecalcified bone histology. The indentation test was performed using a 1.5 mm diameter, flat-surfaced indenter made from hardened steel and a materials testing machine. The test was performed at three locations at the distal and proximal osteotomy gaps respectively. The slope of the load-deflection curve reflected the indentation stiffness calculated by the applied force (N), the contact area of the indentor (mm^2) and the indentation (mm) leading to values of MPa/mm. The bone healing was separately investigated in the distal and proximal gap regions, each 10.5 mm long (Fig. 1). For the correlation between the IFS and the bone healing, the IFS along the osteotomy was calculated using a finite element model (FEM, 10-node-tetrahedral elements) based on a 3D μCT image data set of the distal femur. The Young’s modulus of the bone was calculated from the μCT gray values based on the correlation described by Rüegsegger and Kalender [4]. The IFS was than calculated using the force F and the size of the implants [3]. Statistical analysis: Wilcoxon signed rank test, level of significance: p<0.05

RESULTS:

The calculated IFS range of the distal half of the osteotomy was smaller than for the proximal half in both groups, both regions being less for the stable group (S) compared to the flexible group (F), (Table 1). The histological images demonstrated intramembranous bone healing in the distal half of the osteotomy gap for both groups, the flexible (F) group having significantly (p=0.02) more bone compared to the stable (S) group. In the proximal half of the osteotomy woven bone and small amounts of enchondral ossification could be observed. For the stable group there was significantly (p=0.03) more bone formation in the proximal gap than in the distal gap. In no cases could peripheral callus formation be observed. There was a significantly lower bone density (p=0.0005) and in tendency lower indentation stiffness in the distal part of the stable fixed osteotomy compared to the flexible osteotomy group. In the proximal osteotomy there was no difference between both groups.

Conclusion:

To our knowledge this is this first study quantitatively determining the tissue differentiation in metaphyseal bone healing and correlating bone healing to the interfragmentary strain. We observed intramembranous bone healing under stable conditions confirming previous data of Jarry et al. [2]. In osteotomy gaps with higher IFS a combination of intramembranous and enchondral ossification occurred. In regions with IFS below 5% the mechanical stimulus for new bone formation was small. Very little new intramembranous bone formation and mainly mesenchymal tissue were observed. Intramembranous bone healing also dominated in the osteotomy in regions with IFS up to 10%. Small islands of chondroetic cells (approximately 6% of the gap area) with enchondral ossification were observed for IFS above 6%. Interfragmentary fibrocartilage layers occurred in some specimens for IFS between 20-40%. These results demonstrated that metaphyseal bone healing is mechano-sensitive, like diaphyseal bone healing. Even though the type of healing in metaphyseal bone is different, the IFS, which causes intramembranous or enchondral bone healing is similar to diaphyseal healing [5,6].

REFERENCES: