SHEAR MOVEMENT AT THE FRACTURE SITE DELAYS THE HEALING OF LONG BONE FRACTURES

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Introduction: One of the remaining controversies in fracture healing is whether interfragmentary shear (sliding) movement impairs the fracture healing process. Clinical experience as well as experimental studies yield contradictory conclusions. Delayed unions and non-unions have been explained by the existence of interfragmentary shear motion, which impedes vascularization and promotes fibrous tissue differentiation. Some experimental studies found shear movement to induce delayed unions and pseudarthrosis (1, 6), while other studies found no impairment of healing (4). In contrast to shear movement axial interfragmentary movement is widely accepted to enhance diaphyseal fracture repair. The purpose of this study was to compare the healing outcome of fractures with either axial or shear interfragmentary movement in a mechanically well controlled animal experiment. We hypothesized that axial movement of transverse diaphyseal osteotomies results in improved fracture healing compared to shear movement.

Methods: Ten skeletally mature merino sheep were randomly assigned to either interfragmentary AXIAL or SHEAR movement. The diaphyses of the right tibiae were osteotomized, adjusted to 3mm gap size, and stabilized with a custom designed external fixator. The design of the fixator allowed either 1.5mm axial movement or 1.5mm sliding movement. The movement was generated during locomotion and was monitored with a telemetric unit. After 6 weeks of healing the animals were killed and the success of the healing process was quantified. The apparent density of the newly formed bone was assessed by quantitative computed tomography. Radiographs were employed to quantify the amount of calcified periosteal callus tissue. The mechanical rigidity of the healed fractures was measured with a nondestructive three point bending test in 4 different directions. Using light microscopy the healing area was histomorphometrically analyzed for tissue composition (bone, cartilage, fibrous tissue). SHEAR and AXIAL group were compared with the nonparametric Wilcoxon test. All experimental procedures were in compliance with national regulations and were approved by the competent review board.

Results: The maximum movement amplitude continuously decreased for the SHEAR and the AXIAL animals and reached 64% (SHEAR) and 16% (AXIAL) of the initial value at the end of the 8 week investigation period. The movement amplitude considerably decreased between the third and fifth postoperative week with a much stronger decrease in the AXIAL than in the SHEAR group.

The amount of periosteal callus was 90% higher in the AXIAL group (809±140 mm³) compared to the SHEAR group (519±206 mm³; p=0.02). Bridging of the fragments in the AXIAL group occurred on average at 6±2 locations (Fig. 1). In the SHEAR group two osteotomies were not bridged at all and the average number of bridging locations was only 1±1 (p=0.05). BMD at the gap site was 640±213 mg/cm³ in the AXIAL group compared to 336±38 mg/cm³ in the SHEAR group (p=0.009). The bending rigidity (Fig.2) of the osteotomies with pure axial movement (88±25 Nm²) was more than three times higher than of the osteotomies under shear motion (24±9 Nm²; p=0.04). In the AXIAL group the healing zone was predominantly filled with woven bone (47±7% bone volume) Bone volume in the SHEAR group was 30% lower (32±4% bone volume, p). The amount of cartilage did not differ between SHEAR and AXIAL groups, however fibrous tissue occurred more frequently in the SHEAR group especially in the periosteal callus area and in the healing zone.

Discussion: The differentiation of mesenchymal tissue during fracture healing is, among other factors, strongly influenced by the local mechanical conditions. Intramembranous bone formation occurs in areas of moderate stress, hydrostatic compressive stress stimulates chondrogenesis, and high tensile strains lead to the formation of fibrocartilage or fibrous tissue. Excessive shear at the fracture site results in high tensile strains and might therefore limit direct bone formation. In previous as well as in our study, shear resulted in an increased amount of cartilagenious and fibrous tissue in the periosteal callus at the level of the fracture gap. (4, 6) Most of the bone formed periosteally at the level of the gap appeared to result from endochondral rather than intramembranous bone formation. Another possible aspect of shear movement is its disadvantageous effect on the vascularisation of the healing zone. The presence of sufficient blood supply is not only essential for intramembranous bone formation but also for the initiation of cartilage resorption and the subsequent bone formation. The early vascular response has been shown to be highly sensitive to the prevailing mechanical conditions. (5) Previous studies found that excessive interfragmentary movement reduces blood vessel formation in the periosteal callus. (3) Although we were not able to assess the vascularisation in this study it seems likely that shear or sliding movement of the fracture gap hampers the longitudinal growth of blood vessels across the gap. A deficient blood supply could explain the excess of fibrous tissue formation and the deficit of intramembranous bone formation in the healing zone. A limitation of our study is that the movement of the fracture gap was not enforced by external manipulation but rather initiated by the locomotion of the animals itself. The required interfragmentary movement did therefore not occur with a distinct frequency but according to the activity level of the animals, which however did not differ between AXIAL and SHEAR animals.

In conclusion, the results of our study suggest that excessive shear motion at the fracture site deteriorates, while axial motion of the same magnitude supports the healing of long bone fractures. Fracture fixation should therefore be performed with a minimization of shear motion. New designs for internal implants or external fixation systems should consider that shear forces of considerable amount might occur and the fixation system should be designed to generate only moderate shear.


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Fig 1: Fracture callus in the AXIAL group was larger than in the SHEAR group and showed bridging of the fragments.

Fig 2: As a measure of mechanical integrity the flexural rigidity of the healed tibia was assessed in a 3 point bending test. The rigidity in the AXIAL group was larger than in the SHEAR group in all but one fracture (p = 0.047).

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