Late Dynamization by Reduced Fixation Stiffness Improves the Fracture Healing in a Rat Femoral Osteotomy Model

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INTRODUCTION:
Dynamization involves a reduction in stiffness of the external fixator during the healing process, which allows increased axial loading of the fracture through physiological weightbearing and muscle contraction. Dynamization of fracture fixation is used clinically to improve the bone healing process. The best time for dynamization however is still unknown. This study evaluated the effect of late dynamization on callus stiffness and size in a rat diaphyseal femoral osteotomy. The following hypotheses were tested: dynamization later in the healing process will lead to improved healing compared to previously published data using either continuously rigid or flexible fixation.

METHODS:
A femoral osteotomy (1 mm gap size) was performed on male Wistar rats (weight 350–400 g), stabilized using a unilateral external fixator with four titanium threaded 1.2 mm diameter pins. For a rigid fixation, two fixator bars were utilized with one bar set at a 6 mm offset while the second bar was set at a 15 mm offset, leaving a 4.5 mm space between the two bars (fig. 1). For a more flexible fixation, a single fixator bar was set at a 15 mm offset. The offset distance was defined as the free length of the pins between the lateral surface of the rat’s femur and the inner side of the fixator bar. In vitro axial compression testing indicated that the more flexible one-bar configuration at a 15 mm offset resulted in an in vitro axial stiffness of 10N/mm and the more rigid two-bar configuration at a 6 mm offset resulted in an in vitro axial stiffness of 74 N/mm.

Figure 1: rigid external fixator

The external fixator was dynamized by removal of the inner fixator bar, at three weeks (D3-group: n=8) or four weeks (D4-group: n=9) post-operation. Previously published data of a five week rigid fixation group (R-group: n=8) and a five week flexible fixation group (F-group: n=8) was also included in the current study for comparison 1. Four days prior to operation and 2, 7, 14, 21, 28, and 34 days following operation, the number of movements of the rats were measured during their twelve hour dark cycle using a motion detection system. After 5 weeks the rats were sacrificed and healing was evaluated by biomechanical and densitometric methods. The flexural rigidity of the healed femurs was evaluated using a non-destructive three point bending test. Bending was applied separately from two different directions: anterior-posterior and medial-lateral. A quasi-static load was applied in a three-point bending mode with a materials testing machine using a 50 N load cell at a deflection rate of 1mm/minute and a maximum force of 10N. The bending load F was recorded continuously versus sample deflection, d. From the linear region of the load/deflection curve the flexural rigidity EI was calculated according to: ΔF/4I=EI. Micro computed tomography was performed at a resolution of 38 μm, using a μCT Fan beam μ-Scope system operating at a peak voltage of 40 kV and 140 μA. The bone volume (BV), total volume (TV), and bone volume fracture (BV/TV) for the whole callus and former osteotomy gap were measured using CT Analyser software. A VOI (volume of interest) was created, which encompassed the callus between the two inner pins, with contours of the VOI drawn on sequential slices. A second VOI encompassing the cortical bone and medullary canal except at the level of the osteotomy, was created and subtracted from the initial VOI to create a final VOI. Global thresholding was performed using 25% of the mineral attenuation of cortical bone for BV and bone mineral density (BMD) calculations. BMD/TV was calculated as the number of bone voxels divided by the total number of voxels. At the level of the osteotomy, a VOI with a height of one millimeter was created including the endosteal and periosteal callus. BMD of the BV and tissue mineral density of the TV were calculated from the final VOI after conversion of the greyscale values, using a correction algorithm. An ANOVA was performed followed by pairwise comparisons of means using an independent group t-test. If normality was not met then a Kruskal-Wallis test was performed followed by pairwise comparisons of means using a Wilcoxon–Mann-Whitney test. All analyses were performed using statistical software (SAS 9.1, Cary, NC). A significance level was set at p<0.05.

RESULTS:
By 34 days post-operation, rats from the four fixation groups had similar activity levels. There was no significant difference in flexural rigidity, callus volume or callus mineral density between the D3 and D4 groups. Both the D3-group and D4-group had significantly greater flexural rigidity (p<0.01) and significantly lower callus total volume (p<0.03) and callus bone volume (p<0.03) compared to the F-group (fig.2,3). There was no significant difference in flexural rigidity or callus mineral density between the dynamized groups compared to the R-group. However, the D3-group had less callus bone volume (p=0.06) compared to the R-group. The D4-group had significantly less callus bone volume (p=0.02) and less callus total volume (p=0.05) compared to the R-group (fig.2,3).

Figure 2: μCT-images

DISCUSSION:
There was enhanced healing in the late dynamized groups (3 weeks and 4 weeks postoperation) compared to either the continuously flexible or continuously rigid fixation. The late dynamized groups had less callus volume than the continuously rigid group, but the stiffness and calcification of and the callus were similar. The late dynamized groups showed better bony bridging of the fracture zone and a more advanced bone remodeling process, indicative of more advanced healing. An increased loading of the bone-healing zone in the healing phase just before bony bridging seems to enhance the healing process.

REFERENCES: