Mechanical strength and rigidity of long bones during the healing period

Introduction: Refracture of long bones after the removal of screw-plate device for internal fixation has been observed [5, 6]. Those fractures appear to have occurred with less trauma than those which produced the initial fracture. A decrease in strength may be attributed not only to disuse osteoporosis but also to the alteration in the bone architecture following removal of screws. A void in the wall of a hollow tube will weaken the tube, for, besides decreasing the material available to withstand the applied loads, the defect also raises the local stress around the hole. Several investigators [1, 3, 6] have reported the effect of implant stiffness on the stress shielding. Mechanical testing, ultrasound, and Computerized Tomography (CT) have been used to measure the strength, rigidity, and local variation of material properties of bone [2, 4, 7]. The purpose of this investigation was to measure the amount of strength and rigidity reduction resulting from drill holes in diaphyseal bone and to investigate the recovery of its mechanical strength and rigidity during the healing period after plate removal. This study should answer the question of how long after the plate removal the bone regains its initial strength and rigidity. It should also clarify our hypotheses that callous bone formation may not provide sufficient rigidity. Results of this study may help in choosing a safe rehabilitation program post fracture fixation.

Materials and Methods: Eighty, 6 months old white German rabbits were used and 144 fresh rabbit femurs were mechanically tested. Under anesthesia, the mid tibia shafts were totally osteotomised and then fixed internally using mini plates and screws. In one group, at postoperative sequences of 2, 4 and 6 weeks, the rabbits were sacrificed and bones were mechanically tested following plate removal. In another group, plates were removed 6 weeks postoperatively but rabbits were not sacrificed until 45 days later, when the bones were mechanically tested. Intact specimens and unosteotomised bones with the screw holes were also tested as controls. Test modes included: 4-point bending, axial compression and combined torsion-compression. Our main method of statistical analysis was the student t-test and the significant was judged by p < 0.05. Computed tomography (CT) and ultrasound techniques were also employed to determine local variation of bone density and modulus of elasticity. The animal protocol was reviewed and approved by the animal care and use committee of the University concerning the laws and regulations of the country of origin.

Results: Compared to intact specimens, unosteotomised bones with screw holes were weaker 2% in bending, 33.5% in axial compression and 23% in torsion. Their rigidities were not significantly different from those of intact bones. As the fractured bones healed the bone strength progressively increased in all modes of testing. The mechanical strength at 6 weeks postoperation was higher than those of unosteotomised bone with screw holes due to callous bone formation. At this stage, the strength of bone was less than intact bone (85% in bending; 83% in compression and 96.6%, in torsion). Those bones tested 45 days post plate removal had an increased strength compared to the intact bones by 22% in bending, 12% in compression and 15% in torsion, see Figure 2. In this group the callous formation was partially resorbed and the screw holes were almost filled due to remodeling. The bones tested 6 weeks postoperation had low rigidity in all modes of loading, particularly in bending. Compared to those of intact bone, their rigidity was 85.5% in compression, 66% in torsion and only 35.5% in bending. Those specimens 45 days post plate removal, although had less callous bone formation were more rigid and their rigidity approached those of intact values, see Figure 1. Both CT scanning and ultrasound techniques confirmed the progressive nature of bone density and modulus of elasticity postoperatively.

Discussion: Geometric disturbances cause high-localized stress in bone and significantly increases the risk of fracture during normal activity. Screw holes created in orthopaedic surgery are among the most critical stress risers. Results of this study confirm our hypothesis that callous bone formation does not provide strong rigidity. After a complete healing period of 6 weeks, the bone did not gain its initial strength. At least 45 days post plate removal is required for complete bone remodeling and full strength recovery.

Acknowledgements: This research was supported by the Ministry of Higher Education and Sharif University of Technology, Iran.