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Fixation of trochanteric hip fractures

A cadaver study of static and dynamic loading

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Human cadaveric femora were subjected to static and uniaxial dynamic load applied on the femoral head by a simulator. By two transducer-mounted aluminium rings attached to the bone, the static and the dynamic load causing an elastic deformation of 1 mm in the trochanteric region was assessed. A trochanteric fracture was then produced and stabilized by one of three fixation devices, after which the test was repeated.

The unfractured femora had the most rigid appearance (static load, 25.9 KN/mm; dynamic load, 33.1 KN/mm). Of the fractured and stabilized specimens, the Jewett nail-plate gave the most rigid fixation (static load, 5.4 KN/mm; dynamic load, 11.5 KN/mm). The least rigid femora were those stabilized by the dynamic Nolok™ (static, 4.7 KN/mm; dynamic, 9.2 KN/mm) and Hansson (static, 3.2 KN/mm; dynamic 6.1 KN/mm) telescoping devices.

Because of the viscoelastic properties of bone, the load applied in a hip simulator should be dynamic; otherwise, the ability of the device to withstand in vivo loading might be underestimated.

When testing the stability in experimental hip fractures, the load applied can be either static (Hackstock & Hackenbroch 1969, Sonstegard et al. 1974, Schöttle et al. 1977, Engesaeter et al. 1984) or dynamic (Martinek et al. 1976, Elloy 1977, Sauer et al. 1977, Mackechnie-Jarvis 1983). Because bone is not a simple elastic material, but has viscoelastic properties, its response to force is time-dependent (Sammarco et al. 1971). It therefore follows that because fixation devices partly depend on the bone for fracture stabilization, the bone-implant preparation might act differently under static and dynamic loadings.

We have compared the effects of static and dynamic loads when applied to cadaver femora, unfractured or with a trochanteric fracture stabilized by one of three possible fixation devices.

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Materials and methods

The hip simulator The simulator used consists of three major elements. First, a pressure generator that applies either static, uniaxial, or physiologic loading to an artificial acetabulum along three orthogonal axes (Figure 1). The longitudinal femoral neck axis is one load axis (X), with the lateral direction being positive. The second and third axes are perpendicular to the femoral neck axis in the frontal (Y) and the saggital (Z) plane, respectively, with the positive direction for the Y-axis being directed caudally, whereas for the Z axis, a posteroanterior direction is positive. The linear displacements plotted against the respective load components produced the stiffness values Fx, Fy, and Fz, which provided a measure of the strength of the unfractured femora, as well as the bone-implant preparation. The stiffness values for the Y (Fy) and the Z (Fz) axes provide a means for assessing the shearing resistance of the osteosynthesis. Because the Y and Z axes are

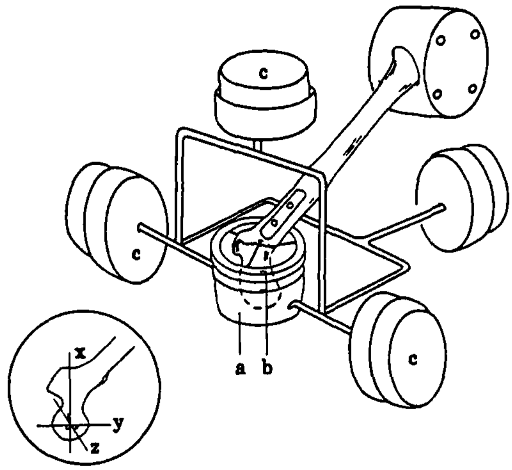

Figure 1. The basic simulator system. Femur clamped in position with the femoral head in the artificial acetabulum (a), with transducer rings (b) mounted. Load applied by four actuators (c). Inserted proximal femora with chosen load axes.

orthogonal, these two values can be summed up to give a combined stiffness and resistance to bending Fc = Fy + Fz.

The second part of the simulator is the measurement instrumentation. Two aluminium rings are mounted in the trochanteric region with one ring on each side of the fracture line. Each ring accommodates three displacement transducers, measuring the relative movement of the rings to each other. Sufficient data are provided to refer the relative movement of the transducer rings to the movement that occurs at the fracture surface, with an accuracy of 0.05 mm for linear displacement and 0.05° for angular displacement.

The third part of the hip simulator is the data collection system. It consists of a computer that simultaneously receives input from each transducer and load actuator, in all 10 channels.

Dynamic and static testing Twelve pairs of femora from donors aged 69–84 years, 9 females and 3 males, were obtained form the morgue within 2 days of death. The bones were kept deep-frozen until testing. There was no clinical evidence of previous fracture or bone abnormality.

By using a specific jig, an intertrochanteric line was made to mark the intended fracture. The femora, still intact, were then subjected to static and dynamic testing. In 12 femora the static test was done first, whereas in the remaining specimens a reversed testing order was used. The static test began with an initial load of 100 N, which was increased stepwise by 200 N, whereas at each load the elastic deformation at the proposed fracture was measured. Each of the three axes was individually tested, although when testing the Y and Z axes a constant load of 200 N was kept on the X axis for impaction

For the dynamic testing, a cyclic load was applied having a peak value according to the static loading. Each axis was tested separately, although, as during the static tests, a constant load of 200 N was kept on the X axis for impaction when testing the Y and Z axes. The duration of each cycle was kept constant at 1 second.

A trochanteric fracture was then produced by drilling multiple holes (2.5 mm low-speed drill) through the cortical bone along the marked line, after which the bone was fractured by pressing the posterior part of the trochanteric region against a steel wedge. The fracture was reduced to anatomic position and stabilized using one of three osteosynthetic methods. All the devices were inserted by using standard surgical techniques, and the bone was not in any way prepared for the fixation device until the fracture had been reduced to the desired position. Eight specimens were allocated for each type of device. The methods used were Jewett 135° nail-plate (Thackray, Great Britain) NoLok^{TM} 135° sliding screw-plate without key (DePuy, USA), and Hansson 140° pin-plate (Thackray, Great Britain/Söderström, Sweden). The femora were then retested in the same way as before, including both static and dynamic testings.

The statistical significance probability was calculated by analysis of variance for three samples and the Student's *t* test for two samples.

Results

The stiffness along the X axis (Fx) was so high that displacement values during static loads, as well as dynamic loads, were small compared with measurement errors.

For the unfractured femora the mean combined stiffness under static load (Fcs) when related to the proposed fracture plane was 25.9 ± 4.1 (19.7–31.9) KN/mm. The corresponding figure for the dynamic loading (Fcd) was 33.1 ± 3.2 (27.6–38.5) KN/mm, giving a ratio Fcd/Fcs of

1.27. The difference between Fcs and Fcd was highly significant.

Also for each bone-implant preparation the stiffness under dynamic loading was greater than under static loading (Table 1). Out of the different methods, the Jewett nail-plate produced a more rigid fixation than the Nolok™ ($P < 0.01$) and the Hansson ($P < 0.001$) system when subjected to dynamic loadings, whereas under static loading these differences were less pronounced. Still, the Jewett nail-plate as being the most rigid of the three devices showed only 21 and 35 per cent of the rigidity seen in the unfractured femora when subjected to static and dynamic loading, respectively.

Discussion

The purpose of the present study was to compare the result of static and dynamic loads when applied to a bone-implant preparation. In order to neutralize the effect of difference in biomechanical properties, care was taken not to apply loads capable of causing a permanent fracture displacement, thereby each specimen could be subjected to static testing, as well as dynamic testing.

The present study showed that the strength of the unfractured femora, as well as experimentally fractured and stabilized femora, was significantly greater when subjected to dynamic than to static loads. An effect due to the viscoelastic properties of the bone and its ability to absorb energy, which is particularly true of cancellous bone as illustrated by the stiffness ratio dynamic/static being consequently higher in bone-implant preparations, irrespective of the type of implant used, then in unfractured femora. In intact femora the load is mainly absorbed by the cortical bone with its less pronounced viscoelastic properties, whereas a substantial part of the load applied to a stabilized trochanteric fracture is absorbed by the cancellous bone because the implant is embedded in the femoral head and neck. According to Frankel et al. (1971), as much as 75 per cent of the load applied to an experimental hip fracture might be absorbed by the bone itself. It is for this reason important that the load applied is dynamic; otherwise, the important viscoelastic properties of the bone are not considered and the ability of the bone-implant preparation to withstand a load might be underestimated. In comparison, testing of isolated implants (Jensen 1981) will give results that are independent of the mode of load, for the metal of implants is a simple elastic material.

The fixation devices tested represent two different solutions in stabilizing a trochanteric fracture. While the Jewett device is a fixed nail-plate, the NoLok™ and Hansson systems admit telescoping. As expected the Jewett nail-plate gave the most rigid fixation, a fact that must not be regarded as a prediction of the ability to withstand the repetitive loadings seen in vivo. It is not the rigidity per se that makes an osteosynthesis efficient, but merely an adequate interplay between bone and the fixation device. A dynamic device might give a better resistance to fatigue because a part of the load is being converted into telescoping, thus reducing the stress on the bone-implant interface. Fatigue caused by the repetitive loadings seen in vivo is probably more common as a cause of implant/fracture failure than solitary extreme static loadings (Gallinaro et al. 1977)

Table 1. Mean stiffness in the trochanteric region when subjected to static and dynamic loading along y and z axes (Figure). Values are KN/mm (SD)

	Static			Dynamic			Ratio
	y	z	y+z	y	z	y+z	y+z Dynamic/static
Unfractured femora n 24	18.4	7.5	25.9 (4.1)	20.9	12.2	33.1 (3.2)	1.27
Jewett nail-plate n 8	2.9	2.5	5.4 (0.8)	6.4	5.1	11.5 (1.5)	2.12
NoLok™ screw/plate n 8	2.4	2.3	4.7 (1.0)	4.1	5.1	9.2 (1.6)	1.96
Hansson pin/plate n 8	2.1	1.1	3.2 (0.8)	3.9	2.2	6.1 (1.0)	1.93

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