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Stability of osteosynthesis in trochanteric fractures

Comparison of three fixation devices in cadavers

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Stable trochanteric fractures were produced in 12 pairs of human cadaver femora, which were fixed by either a 135° Jewett nail plate, a 135° NoLok™ sliding screw/plate, or a 140° Hansson pin/plate. The bone-implant preparations were then subjected to 20,000 load cycles simulating full weight bearing, measuring the elastic and permanent fracture displacement. In each case, elastic displacement occurred during loading. For the Jewett-stabilized fractures, a steady increased elastic displacement, as well as permanent displacement, was seen throughout the test, causing 2/8 failures when the implant penetrated the femoral head. In the NoLok™- and Hansson-stabilized fractures, there were no failures, both giving better overall stability than the Jewett device with sufficient fracture stability throughout the test.

The strength and the mode of failure have been studied for a number of implants used in internal fixation of trochanteric fractures (Foster 1958, Holt 1963, Jensen 1981). In these tests the important interplay between bone and implant was not considered. In order to compare the performance of osteosynthesis when stabilizing a fracture, studies of fixed stable, as well as unstable, trochanteric fractures in cadaver femora have been made (Kaufer et al. 1974, Martinek et al. 1976, Sauer et al. 1977). In most cases the load applied on the bone-implant preparation was either static or uniaxial dynamic. This is a gross simplification of the physiologic loadings in vivo.

We have compared the stability and the resistance to fatigue of experimentally produced stable trochanteric fractures fixed by one of three different devices.

Material and methods

Twelve pairs of cadaver femora from elderly subjects (range 69–84 years, 9 females and 3 males) were used. The femora were obtained within 2 days of death and stored deep frozen until testing. There was no macroscopic evidence of previous fracture or bone diseases. An intertrochanteric line perpendicular to the longitudinal femoral neck axis was made by using a special jig. Multiple holes (2.5 mm low-speed drill) were drilled 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 (Larsson et al. 1987). After reduction to anatomic position, the two-fragment trochanteric fracture was stabilized by either a Jewett 135° nail-plate (Thackray, Great Britain), a NoLok™ 135° sliding screw/plate without key (DePuy, U.S.A.), or a Hansson 140° pin/plate (Thackray, Great Britain/Söderström, Sweden; Figure 1). The 135°Jewett and NoLok™ plates were selected to represent those in most common use. The Hansson device was only available with a 140° angle.

Each device was inserted by standardized surgical technique with the tip of the nail/screw ending about 8 mm from the surface of the femoral head. No measures for insertion of the

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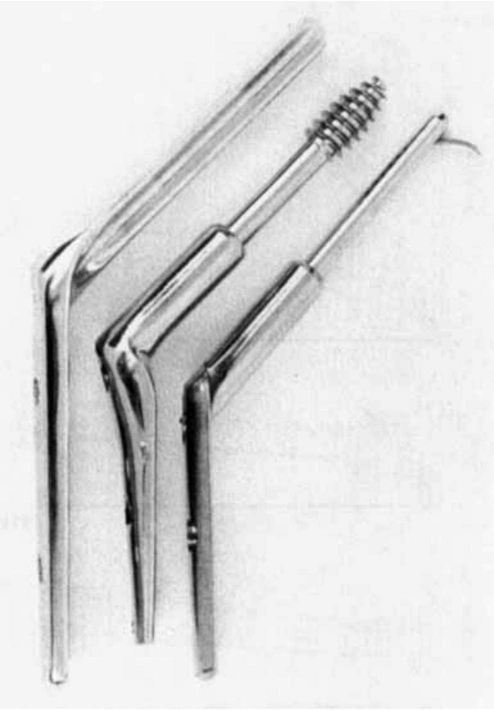

Figure 1. Jewett nail-plate (left), NoLok™ sliding screw/plate (middle), and Hansson pin/plate (right). All are manufactured from stainless steel.

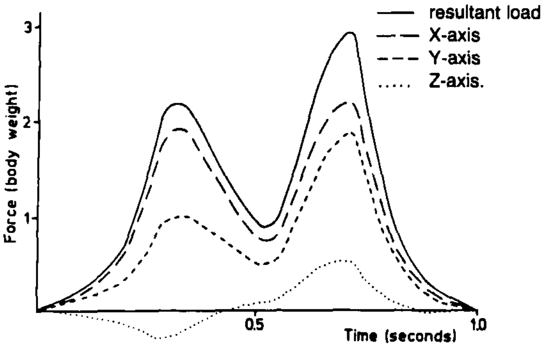

Figure 2. Load produced by the system when simulating a walking cycle

implants were taken until the bone had been fractured and reduced. For each pair of femora, the left and right bones were stabilized by different methods in a randomized way, giving a total of eight specimens for each type of device.

By means of a hip-force simulator (Elloy 1977, Larsson et al. 1987), each specimen was subjected to 20,000 cycles of a simulated physiologic loading, with a peak load of three times the body weight (Rydell 1966, Paul 1967), and using a force pattern derived from Paul (1967; Figure 2).

The simulator system consists of a three-channel pressure generator, supplying loading actuators that apply forces along three orthogonal axes to the proximal femur. To obtain consistent results, load axes were chosen that could be readily identified on the specimen (Larsson et al. 1987). The longitudinal femoral neck being one axis (X), whereas the second and third axes were defined as being perpendicular to the femoral neck axis in the frontal (Y) and the sagittal planes (Z), respectively. Fracture displacement was measured by two transducer-equipped aluminum rings attached to the bone with one ring on each side of the fracture. By using a special jig, the transducer mounting rings were attached to the bone so that the transducers were in a fixed relationship to the fracture plane. By a purpose-created computer program, the linear and angular fracture displacements were determined relative to the three orthogonal loading axes, positive values being lateral (X), downward (Y), and posteroanterior (Z). The progressive permanent fracture deformation during the test, i.e., the residual displacement after each load cycle, was determined, as well as the possible elastic fracture displacement during each cycle. The accuracy of the displacement measurement was 0.05 mm linear and 0.05° angular. From the fracture displacement measurements, calculations were made of the clinically recognized impaction, shear, rotation, and tilt at the fracture site. A premature termination of the test occurred if either the osteosynthesis/fracture collapsed or the elastic fracture displacement during an individual cycle exceeded the range of the displacement instrumentation (± 2.5 mm or ± 2°).

The significance probability was calculated by analysis of variance for three samples and by the Student's *t*-test for two samples. Linear displacement and angulation were given in mean ± SD.

Results

Elastic fracture displacements occurred during each loading cycle. In response to the repetitive loadings, each type of device showed a characteristic pattern of permanent, as well as elastic, displacement at the fracture in relation to an increased number of loading cycles (Figure 3).

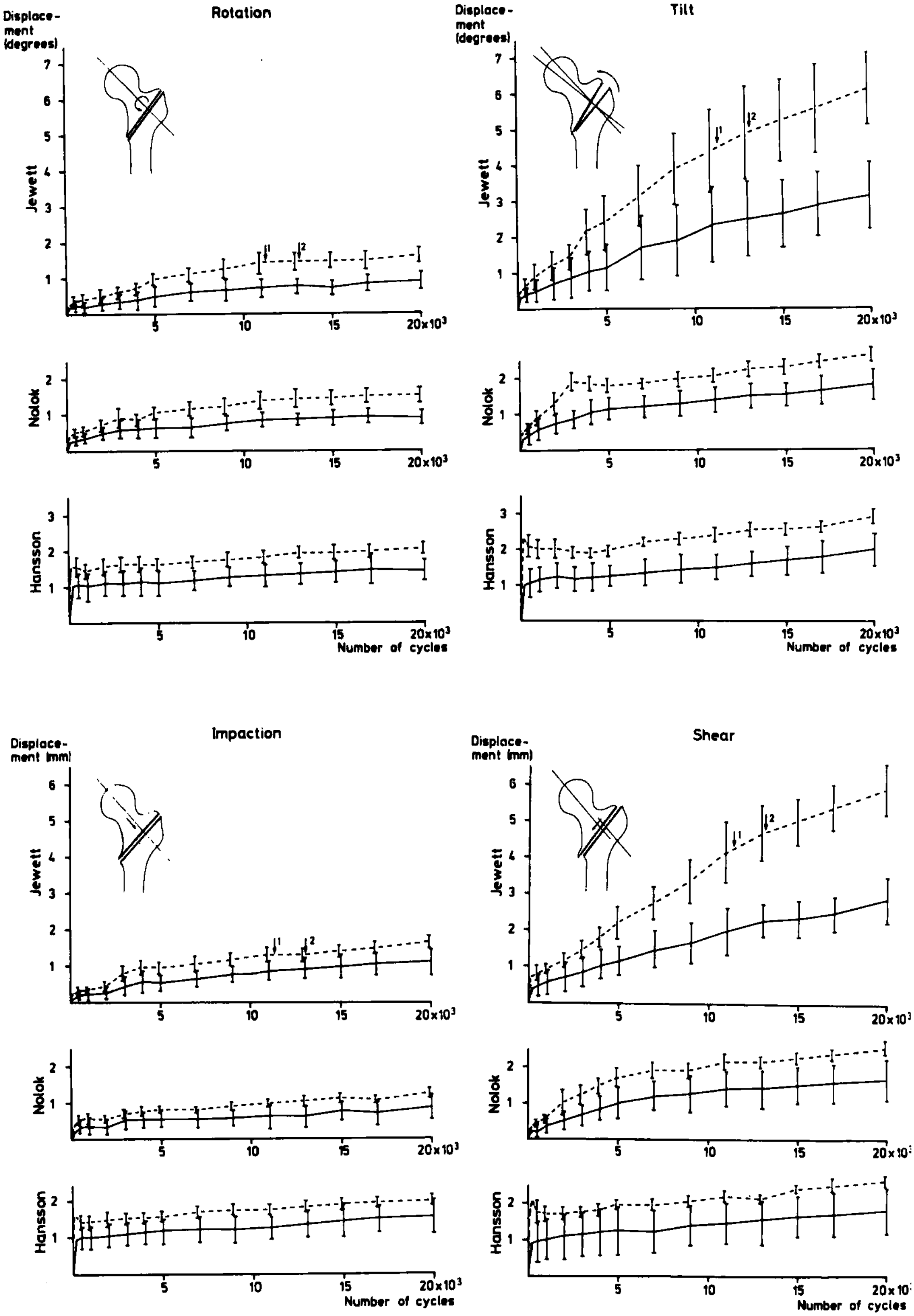

Figure 3. Permanent —— and elastic (– – –) fracture displacement (mean ± SD) in relation to an increased number of loading cycles. Failures during testing are indicated by arrows.

A – rotation in degrees, B – tilt in degrees, C – impaction in mm, D – shear in mm.

Specific findings

Jewett. Because of penetration of the nail through the superior part of the femoral head, 2/8 specimens failed. The failures occurred after 11,484 and 13,010 cycles, respectively, and were in both cases preceded by a rapid increase in the elastic displacement for both angular and linear movement. In the remaining six specimens, it was also a constant finding that the elastic displacement, while being initially small, gradually increased with the number of cycles. In shear, as well as tilt, the elastic displacement was greater for Jewett than for the NoLok^{TM} and Hansson devices at 5,000 ($P < 0.05$), 7,000 ($P < 0.01$), and 9,000–20,000 ($P < 0.001$) cycles.

The permanent displacement increased continuously. In tilt it was greater at 9–13,000 ($P < 0.05$), 15–17,000 ($P < 0.01$), and above 17,000 ($P < 0.001$) cycles, whereas in shear it was greater at 13–17,000 ($P < 0.05$) and above 17,000 ($P < 0.01$) cycles, when compared with both dynamic devices. The maximal permanent displacement seen after 20,000 cycles was 3.15 ± 0.95° angular (tilt) and 2.89 ± 0.61 mm linear (shear).

NoLok^{TM}. No failures occurred. For the elastic displacement, a consistent finding was a marked and rather sudden increase after 2–4000 cycles, most obvious in tilt and shear. The increase in elastic displacement occurred as the compression screw lost its effect in causing mechanical fracture compression. Following this increase the magnitude of the elastic displacement remained almost constant throughout the test.

The permanent displacement also showed a slight increase, but still after 20,000 cycles the maximal tilt was 1.81 ± 0.41° and the maximal shear 1.65 ± 0.56 mm.

Hansson. No failures occurred. For all four fracture movements the elastic displacement was greater, between 500 ($P < 0.001$) and 1,000 ($P < 0.01$) cycles when compared with both the Jewett and NoLok^{TM} systems. Above 5,000 cycles the elastic displacement in shear and tilt was lower in Hansson- and NoLok^{TM}- than in Jewett-stabilized femora.

The permanent displacement during the first 500 cycles was higher for all four movements when compared with both the Jewett ($P < 0.001$) and the NoLok^{TM} ($P < 0.001$) devices. Still, after 20,000 cycles with simulated full weight bearing, the maximal permanent displacement was 2.01 ± 0.45° tilt and 1.80 ± 0.87 mm shear.

Discussion

Using the rigid one-piece Jewett nail-plate, on the one hand, and the dynamic NoLok^{TM} and Hansson devices, on the other, two major principles in stabilizing a trochanteric fracture were tested. Both NoLok^{TM} and Hansson sliding systems allow telescoping without control of rotation. They differ in that the NoLok^{TM} system includes a compression screw for possible peroperative mechanical fracture compression.

With the Hansson system, peroperative compression is avoided. It is preferred that functional compression is produced by the muscle force of the patient and by weight bearing. The dynamic displacement seen in the Hansson-stabilized fractures during the first 1,000 cycles thus corresponds to the fracture settling in owing to functional/physiologic compression in vivo.

In the NoLok^{TM}-stabilized fractures an increase in elastic displacement occurred after approximately 2,000 cycles due to a decrease in mechanical compression. The inability of the compression screw in maintaining a compressive force is probably caused by both fracture impaction and fatigue of the cancellous bone surrounding the threaded part of the lag screw. The risk of pulling out a lag screw by a compression screw has previously been described by Frandsen and Madsen (1983). In the sliding systems, a dynamic steady state occurred after the loss of mechanical compression in the NoLok^{TM}device and after the fracture had settled in when using the Hansson implant. The almost constant elastic displacement is an effect of a controlled functional compression occurring as a result of telescoping. In contrast, such a steady state never occurred in the Jewett system, where the repetitive load caused a steady increase in the permanent and elastic displacements, either until failure or until the elastic movement exceeded ± 2.5 mm displacement or ± 2.0° angulation. The telescoping movement and the resulting support by the fracture surfaces probably explain why a telescoping device will have better resistance to fatigue than a rigid device.

The permanent displacement in the sliding systems was small, and still after 20,000 cycles no mechanical failure occurred. As for the Jewett-stabilized fractures, the permanent displacement in shear and tilt increased continuously. The two failures for the Jewett device were both preceded by a rapid increase in elastic displacement. The cause of failure was fatigue in the nail-cancellous bone interface, giving as a result a small hole in the cancellous bone surrounding the nail tip; thus, the initially rigid fixation was lost.

Our in-vitro findings agree with previously presented clinical series reporting failure rates of 0–6 percent following internal fixation of stable trochanteric fractures by sliding screw and plate (Jacobs et al. 1976, Jensen 1981, Høgh 1982, Heyse-Moore et al. 1983) and 4–30 percent of failures following fixed nail-plate fixation (Dimon and Hughston 1967, Jacobs et al. 1976, Jensen 1981, Heyse-Moore et al. 1983). As for the Hansson device, no clinical reports are available yet.

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