Fixation of unstable trochanteric hip fractures

A cadaver study comparing three different devices

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A four-fragment trochanteric fracture was produced in 24 human cadaver femora. After reduction to anatomic position, the fractures were stabilized by either a Jewett 135°nail-plate, a 135°Nolok™ sliding screw-plate without a key, or a 140°Hansson pin-plate with an additional trochanteric plate. Using a hip-force simulator, the preparations were subjected to 10,000 loading cycles simulating partial weight bearing, followed by another 10,000 cycles with full weight bearing, while measuring the elastic and permanent fracture displacements.

Failure occurred in 3/8 of the Jewett stabilized fractures and in 1/8 each of the Nolok™ and Hansson stabilized specimens. Each failure was preceded by an increase in elastic tilt and rotation followed by a permanent rotation after which failure occurred as varus angulation of the fracture. Further, two Jewett nails, one Nolok™ screw, and three Hansson pins showed bending. Due to the controlled telescopic action in the Nolok™ and Hansson dynamic devices, the resistance to fatigue when subjected to repetitive loadings was increased and thereby a better overall result was achieved when compared with the rigid Jewett nail-plate. To maintain the dynamic function, the strength of the dynamic screw-pin must be sufficient to withstand physiologic loadings without bending; otherwise, the telescopic action will be obstructed.

In experimentally produced four-fragment trochanteric fractures in cadavers, we have compared the stability achieved by three different fixation systems when subjected to repetitive physiologic loading.

Materials and methods

Twelve pairs of femora from 7 females and 5 males, with an average age of 73 (62–83) years, were obtained from the morgue within 2 days of death. The femora were stored deep-frozen until testing. The donors had no history of bone abnormality, nor was there any clinical evidence of previous fracture.

By the technique described in a previous study (Larsson et al. 1987), a standard four-fragment trochanteric fracture, as described by Kaufer et al. (1974) and Sonstegard et al. (1974), was made (Figure 1).

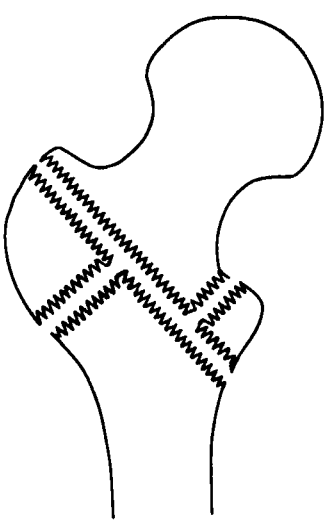

Figure 1. Experimental four-fragment fracture.

The fracture was reduced to anatomic position and stabilized by either a Jewett 135° nail-plate (Thackray, Great Britain), a Nolok™ 135° sliding screw-plate without a key (DePuy, USA), or a Hansson 140° pin-plate with an additional trochanteric plate with short cancellous screws (Thackray, Great Britain/Söderström, Sweden; Figure 2). Standard surgical technique was used, and the tip of the nail/screw was placed about 8 mm from the surface of the femoral head. In a randomized way, left and right femora from each pair were stabilized by different methods.

By a hip force simulator (Elloy 1977, Larsson et al. 1987), each specimen was subjected to 20,000 cycles

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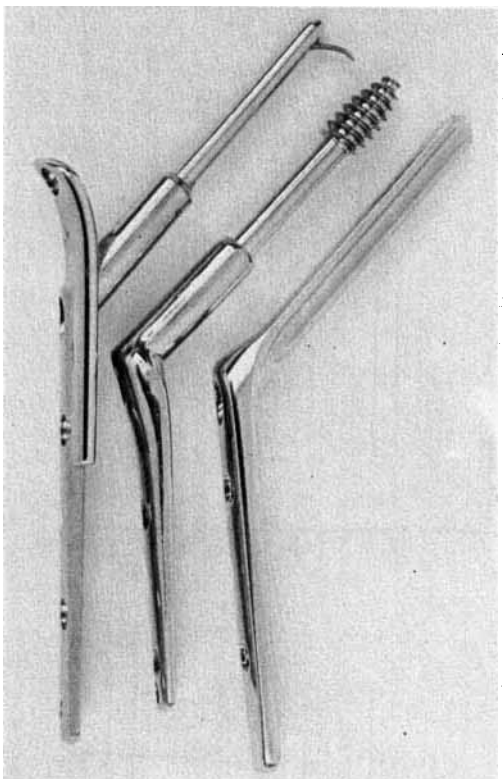

Figure 2. The Hansson pin-plate (left), the Nolok™ sliding screw-plate (middle), and the Jewett nail-plate (right). All are manufactured from stainless steel.

of a simulated physiologic loading (Paul 1967). The first 5,000 cycles was with 25 percent of full weight bearing, which was followed by another 5,000 cycles with a load of 50 percent full weight bearing. During the last 10,000 cycles the specimens were subjected to a simulated full weight bearing with a peak load of three times the body weight (Rydell 1966, Paul 1967).

The permanent displacement (i.e., the residual displacement) after each loading cycle, as well as the elastic fracture displacement during each cycle, was measured by two transducer-equipped aluminum rings mounted with one ring on each side of the major fracture line. The fracture displacement along (linear) and around (angular) three orthogonal axes were calculated by a purpose-created computer program with an accuracy of 0.05 mm linear and 0.05° angular. The axes chosen were one longitudinally along the femoral neck (X) and two perpendicular to the femoral neck in the frontal (Y) and the sagittal (Z) plane, respectively. Positive values were lateral (X), downward (Y), and posteroanterior (Z). Out of six components of relative fracture displacement measured, the four fracture movements — impaction, shear, rotation, and tilt — have been calculated.

A premature termination of the test occurred if either the implanted device or the fracture failed, or if the elastic displacement exceeded the range of the instrumentation, being ±2.5 mm or ±2.0°.

The statistical probability was calculated by analysis of variance for three samples and by the Student *t*-test for two samples. Displacement and angulation are given as the mean ± SD.

Results

The increase in load at 5,000 and 10,000 cycles caused an increase in permanent displacement, as well as elastic displacement, for all four types of movement, with no difference between the devices. Totally, four fifths of the failures occurred between 11,000 and 15,000 cycles, while there were no failures after 15,000 cycles. Each failure was preceded by a sudden increase in elastic tilt and rotation followed by a permanent rotation, after which failure occurred by varus angulation of the fracture.

In two other specimens the elastic displacement exceeded the range of the measurement instrumentation, causing a premature termination of the test (Figure 3).

Jewett

Three failures occurred after 4,370, 12,970, and 14,700 cycles, respectively, while in another specimen the elastic displacement in tilt exceeded the range of the instrumentation after 6,200 cycles. In each failure, the fracture displaced into varus followed by penetration of the femoral head by the nail. Two nails demonstrated 5 and 9° of varus bending at the fracture site, while the remaining six implants showed no macroscopic damage at extraction.

For each of the eight specimens tested, a constant finding was an initial small elastic movement that gradually increased throughout the test. Elastic rotation was less at 0–4,000 cycles when compared with the Nolok™ ($P < 0.05$) and the Hansson ($P < 0.01$) systems.

Permanent displacement in impaction and rotation showed only a slight increase, whereas permanent displacement in tilt and shear was more pronounced. For the four specimens still intact after 20,000 cycles, the maximum permanent displacement was 3.45 ± 1.38 mm linear (shear) and 6.06 ± 2.07° angular (tilt).

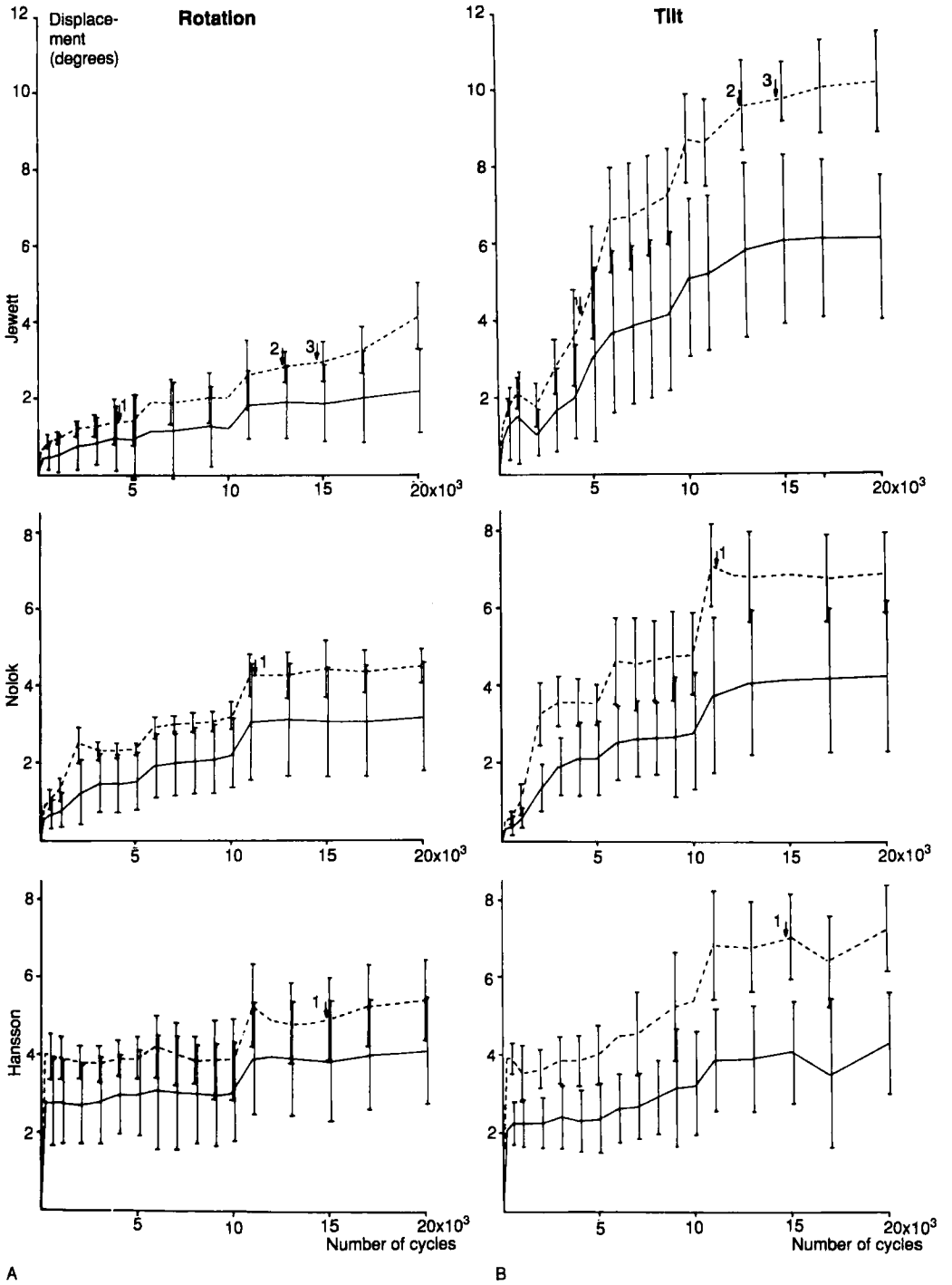

Figure 3. Permanent and elastic fracture displacement in relation to an increased number of loading cycles. Failures indicated by arrows.
A. Rotation degrees.
B. Tilt degrees.
C. Impaction mm.
D. Shear mm. Mean, SD.

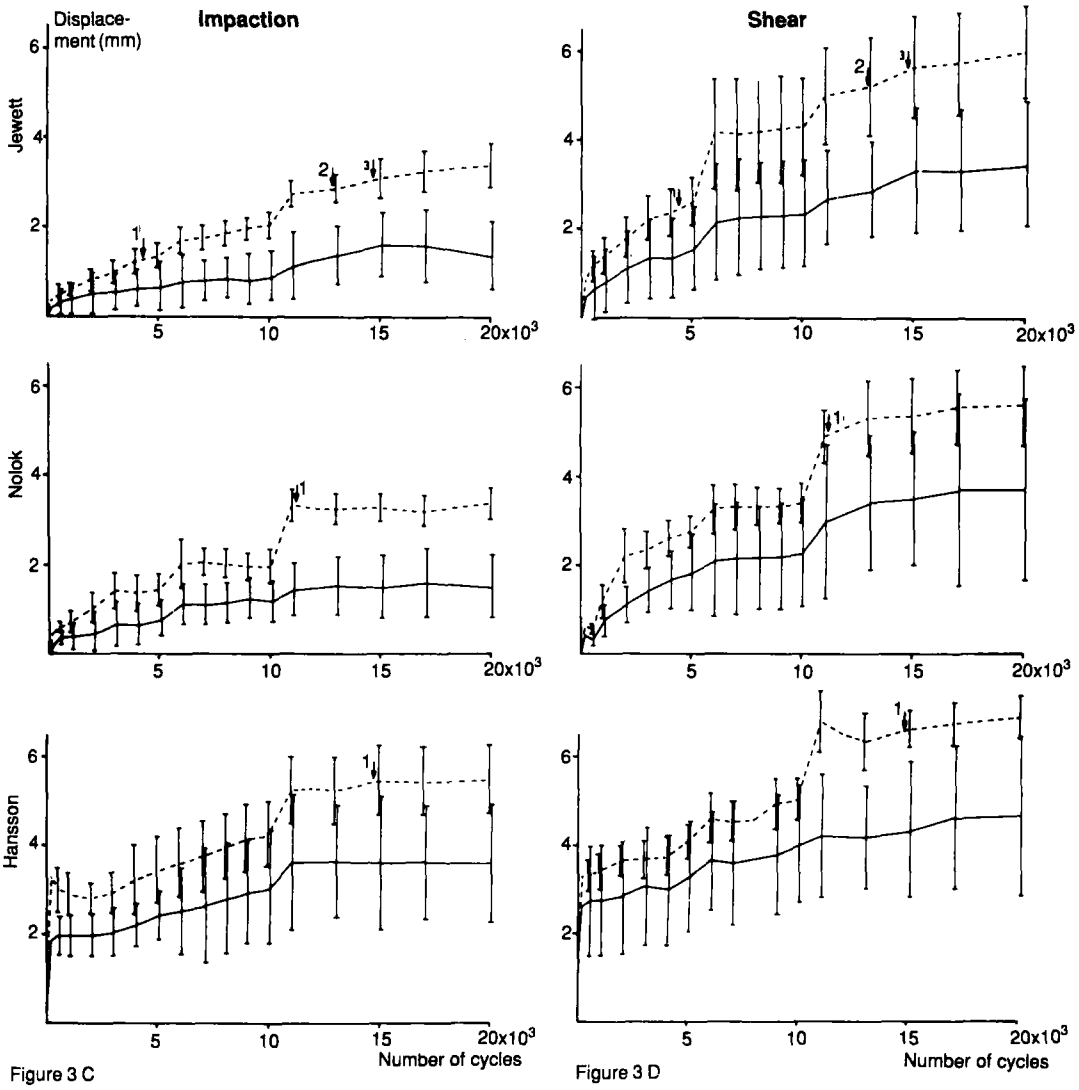

Figure 3 C

Figure 3 D

Nolok™

For the elastic displacement, angular, as well as linear, a marked increase occurred after 1–2,000 cycles as the screw gradually lost its compressing effect. One failure occurred after 11,200 cycles, with the fracture going into varus followed by penetration of the screw through the superior part of the femoral head. The lag screw of the failed specimen showed a bending of 4° at the end of the barrel, while the remaining seven devices showed no macroscopic damage at removal.

The maximal permanent displacement of the seven specimens completing 20,000 cycles was 3.72 ±2.08 mm linear (shear) and 4.20 ±2.00° angular (tilt).

Hansson

One failure occurred after 14,800 cycles due to the pin penetrating the superior part of the femoral head. In another specimen the elastic displacement in tilt exceeded the range of the instrumentation after 9,700 cycles. At extraction, these two pins were bent at the end of the barrel into 16 and 19° of varus and 9 and 4° posteriorly. A third pin showed bending downwards of 9° after completing 20,000 cycles, while the remaining five pins were unaffected. Elastic impaction, shear, and tilt were greater ($P < 0.001$) during the first 500 cycles when compared with the Jewett and Nolok™ devices. Elastic impaction was greater ($P < 0.01$) also

at 1–3,000 cycles when compared with the Jewett system.

Permanent impaction, rotation, and tilt were greater ($P < 0.001$) during the first 1,000 cycles, as well as permanent shear ($P < 0.01$), when compared with both the Jewett and Nolok™ devices. The difference in permanent impaction continued throughout the test for less than 5,000 ($P < 0.001$) as well as above 5,000 cycles ($P < 0.05$).

The maximum permanent displacement of the six specimens completing 20,000 cycles was 4.70 ±1.79 mm linear (shear) and 4.26 ± 1.35° angular (tilt).

Discussion

Fracture displacement during failure showed a remarkable resemblance between the different devices once a failure occurred, with an increase in elastic tilt and rotation followed by a permanent rotation and finally failure by the fracture going into varus. Because the implants had different designs, the failure mechanism probably differed. For the rigid triflange Jewett nail-plate, fatigue of the cancellous bone surrounding the nail and wear of the fracture surfaces are prerequisites for rotation to take place, whereas for the Nolok™ and Hansson systems, rotation should be prevented by compression of the fracture surfaces causing interlocking of the fragments. For the Nolok™ system the mechanical compression initially gained by the compressing screw was neutralized after approximately 1,000 cycles. The possible benefit of a temporary mechanical compression should be weighed against the risk of pulling out the lag screw by the compressing screw at surgery (Frandsen and Madsen 1983).

In the unstable fracture, it seems that rotation, once it occurs, will decrease stability. This is probably due to the lack of bony support on the medial aspect of the lesser trochanter and/or posterior aspect of the greater trochanter. In a previous study describing stable trochanteric fractures (Larsson et al. 1988), the number of failures was less and displacement was smaller when compared with the present study. In the stable fracture, a secondary displacement as rotation will not inevitably decrease fracture stability because adequate bony support is provided due to the medial and posterior parts of the trochanteric region being intact. It might be that prevention of rotation by functional compression, together with the possibility of a controlled elastic displacement, is the main reason why sliding systems give better results than rigid fixation devices in the treatment of unstable trochanteric fractures (Jacobs et al. 1976, Jensen 1981, Høgh 1982, Heyse-Moore et al. 1983).

By telescoping, a number of biomechanical advantages are achieved. Fracture stability is improved, and the bone will be able to absorb more load due to secondary impaction. The mechanical strength of the implant will improve because of reduced moment arms (Massie 1962, Jensen 1981), and the resistance to fatigue of the implant and of the interface bone-implant will also be improved by a controlled telescoping.

A rigid device such as the Jewett nail-plate depends on the fracture being totally immobilized, a condition hard to fulfill in unstable trochanteric fractures. Even in the present study with anatomic reduction, the impact achieved at fixation was insufficient to withstand repeated loading. Once fracture displacement occurs, fatigue of the bone-implant interface will cause failure.

Bending of a dynamic screw/pin is important to notice. Apart from the risk of implant failure due to stress concentration (Martz 1964), bending will obstruct telescoping so that the dynamic devices are converted to rigid systems not allowing secondary impaction. In the present study, both failures that occurred among the dynamic devices showed bending of the screw/pin. The telescopic action in a sliding screw system being prevented by bending of the lag screw and/or barrel was also demonstrated by Kaufer et al. (1974) and Sonstegard et al. (1974). If the lag screw is not fully engaged in the barrel, there is also a risk of inhibited sliding due to jamming (Kyle et al. 1980).

The strength of the dynamic screw/pin must be sufficient to withstand physiologic loading; otherwise, the results will not be better than with rigid devices. The functional strength of the implant can be improved either by using a stiffer metal or by increasing the plate angle, thus reducing the bending moment on the screw/pin. By an increased plate angle, sliding will also be facilitated (Kyle et al. 1980).

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