Stable Fixation of Intertrochanteric Fractures

A Biomechanical Evaluation*

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ABSTRACT: The combined roles of three different positions of reduction and three different fixation devices in stabilization of a standard four-fragment intertrochanteric fracture were studied to determine which combination would best support the load of weight-bearing. Experimental four-part fractures were produced in forty-one pairs of embalmed adult femora. These fractures were stabilized using an anatomical reduction position, the Dimon-Hughston position of medial displacement, and the Wayne County General Hospital position of slight lateral and upward displacement of the femoral shaft fragment, combined with Jewett nail, telescoping screw, and Holt nail implants in all combinations. The stabilized specimens were loaded to failure and examined for the maximum load supported and for resistance to continued deformation under load. The implant device was found to play the major role in fixation stability. The three positions of reduction exerted only a minor influence on the maximum load supported.

The primary goal in the treatment of an elderly patient with an intertrochanteric hip fracture is to return the patient to his prefracture activity as soon as possible. Pain and proximal femoral instability and deformity are the important local problems which must be controlled. Rapid mobilization of a pain-free patient helps to prevent skin ulceration, pneumonia, urinary stasis, thromboembolic disease, and other complications of confinement to bed in the elderly. For these reasons, treatment of intertrochanteric fractures by reduction and internal fixation has become the standard procedure. Most fixation techniques alleviate the pain and permit the patient to be ambulatory although non-weight-bearing, or to be partially weight-bearing during assisted ambulation [1,4,5,8,10,16]. Unfortunately, the elderly patient frequently does not have enough strength or coordination to protect the hip from excessive stress while using a walker or crutches [7,12]. Many surgeons, therefore, have attempted to provide fixation of the fracture that is so stable that the patient may bear full weight on the fractured hip. Holt [7] and Sarmiento [14] have developed very strong hip nails for this purpose, while Dimon and Hughston [3], Massey [10], and others [12,14], with the same objective, have proposed altering the positions of the fracture fragments, hoping thereby to improve the mechanical resistance of the bone to the disruptive forces of weight-bearing.

When confronted with an unstable intertrochanteric hip fracture, it is important to know which combination of fixation device and position of fracture fragments will yield maximum stability. The present study was designed to evaluate the relative importance of the positions of bone fragments and type of fixation device in operative stabilization of

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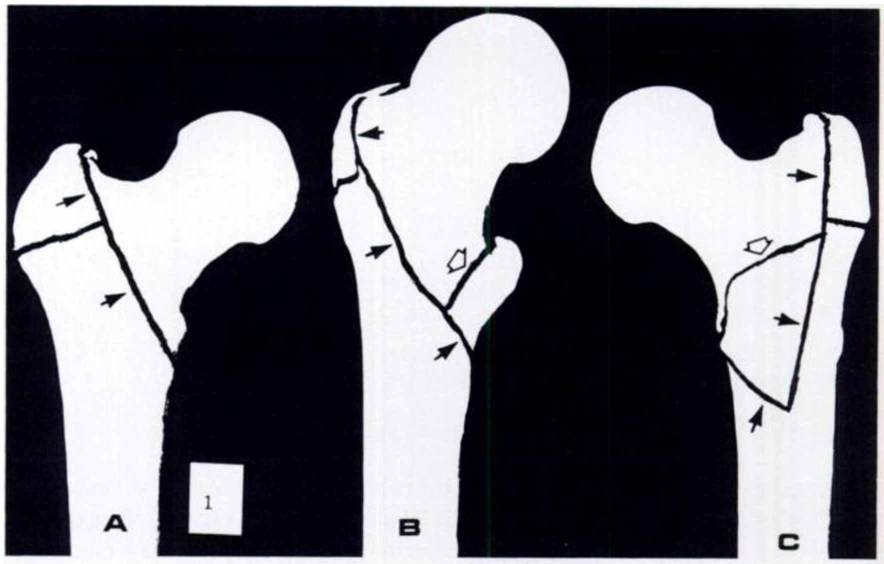


FIG. 1

The experimental four-fragment intertrochanteric fracture produced by a straight saw cut at the capsular attachment (solid arrows). The lesser trochanteric fragment is produced by a second straight saw cut made at right angles to the anterior capsular line and passing across the proximal base of the lesser trochanter (hollow arrows). A third straight saw cut at right angles to the anterior capsular line passing through the abductor tubercle releases the greater trochanter. *A*, anterior view; *B*, anteromedial view; *C*, posterior view.

unstable intertrochanteric fractures, and to determine the optimum reduction-fixation combination.

Maintenance of a clinically acceptable stable reduction is the most important factor in achieving satisfactory union of intertrochanteric fractures [1,16]. Because the fracture occurs through cancellous bone in an area of adequate blood supply, non-union and avascular necrosis rarely supervene.

Materials and Method

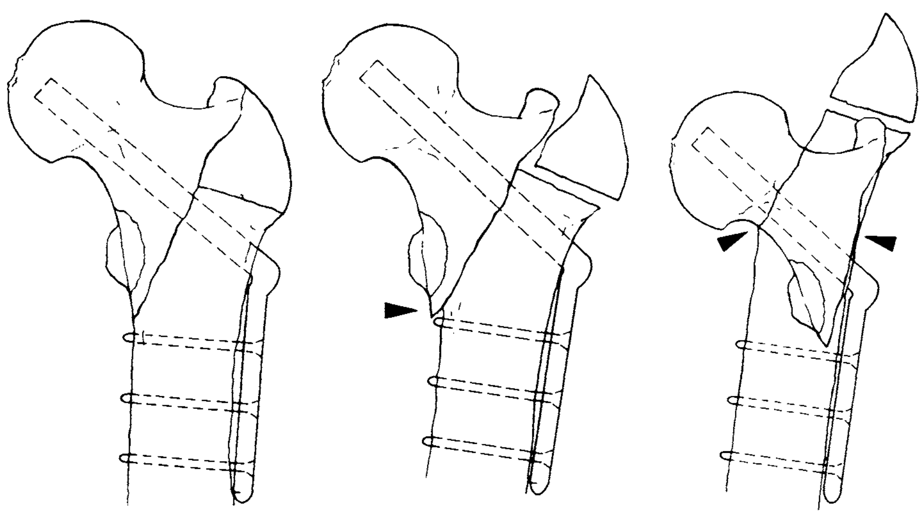
The specimens consisted of eighty-two (forty-one pairs) embalmed adult femora obtained from cadavera used in the Department of Anatomy, whose age averaged sixty-two years, an appropriate age for the present study. We excluded those specimens that showed evidence of previous fracture, contained orthopaedic devices, or demonstrated gross evidence of neoplastic disease or deformity. We tested sixty-nine specimens, used seven as controls (Fig. 4), and discarded six, as discussed below. A standard four-part fracture (Fig. 1) was made on all test specimens. A straight saw cut was made through the anterior femoral attachment of the hip-joint capsule (Fig. 1,*A*, arrows). The straight cut at its distal end crossed the medial femoral cortex (Fig. 1,*B*), and at its proximal end crossed the tip of the greater trochanter. This saw cut continued along the posterior femoral attachment of the hip-joint capsule, passing midway between the linea aspera and the base of the lesser trochanter (Fig. 1,*C*) and terminated at the point where it met the distal end of the anterior straight line saw cut (Fig. 1,*C*, solid arrows).

Another saw cut was made at right angles to the anterior capsular line and passed through the abductor tubercle of the greater trochanter, thus separating a large greater trochanteric fragment. A final straight saw cut was made at right angles to the anterior cut (Fig. 1,*B*, hollow arrow), crossing the base of the lesser trochanter at its junction with the femoral neck and terminating at the posterior cut (Fig. 1,*C*, hollow arrow). The fragment thus produced included a sizable portion of posterior and medial cortex as well as the entire lesser trochanter. The four-part fracture described resembled many naturally-occurring unstable intertrochanteric fractures. Since the location and direction of the saw cuts were determined by definite anatomical features of each specimen, variable sizes and shapes of specimens did not compromise our ability to produce standard, consistent, comparable four-part intertrochanteric hip fractures.

Because most intertrochanteric hip fractures are reduced anatomically [1,4,8,16], our first series of loading studies was performed on anatomically reduced intertrochanteric fractures (Fig. 2-A). To ensure precise anatomical reduction in this series, the fracture was made after the fixation device had been inserted.

Our second series of tests was performed on specimens as in Figure 2-B. For six years one of us (H. K.) has utilized this non-anatomical stable reduction position at the Wayne County General Hospital. The proximal fragment was medially displaced and the lateral surface of the proximal fragment impinged on the medial cortex of the distal fragment, providing bone contact to resist further shortening and varus displacement, thereby potentially increasing mechanical stability.

The third reduction technique evaluated was that described by Dimon and Hughston [3], in which the intertrochanteric portion of the proximal fragment was embedded in the distal fragment (Fig. 2-C). The femoral neck was supported by the medial cortex of the shaft and the base of the neck was buttressed against the lateral cortex to prevent further settling of the fracture. This method of reduction has gained considerable popularity. Clinical reports are generally favorable [3,12]. The Dimon-Hughston reduction was therefore selected as the third reduction variable for testing to determine load-bearing capacity.



ANATOMIC — FIG. 2-A | **WAYNE COUNTY** — FIG. 2-B | **HUGHSTON-DIMON** — FIG. 2-C

Reduction variables. Fig. 2-A, anatomical reduction; Fig. 2-B, Wayne County General Hospital reduction with medial calcar overlap designed to resist neck shortening and varus displacement; and Fig. 2-C, Dimon-Hughston reduction — the medial cortex of the shaft supports the femoral neck and the base of the neck rests against the lateral cortex.

Three commercially available hip-fixation devices were chosen for evaluation. A stainless-steel Jewett nail [8] was chosen (Fig. 3-A) because it is the appliance most often used for fixation of intertrochanteric fractures in this country. All Jewett nails tested were identical and were provided by the Richards Manufacturing Company, Inc. (catalogue number 381NH; with a 9.5-centimeter nail, a 7.6-centimeter plate, and a 135-degree angle). A stainless-steel telescoping screw device also provided by the Richards Manufacturing Company, Inc. (catalogue number 12-5835; with a ten-centimeter screw and No. 479P, 7.6-centimeter, 135-degree plate) was tested (Fig. 3-B)

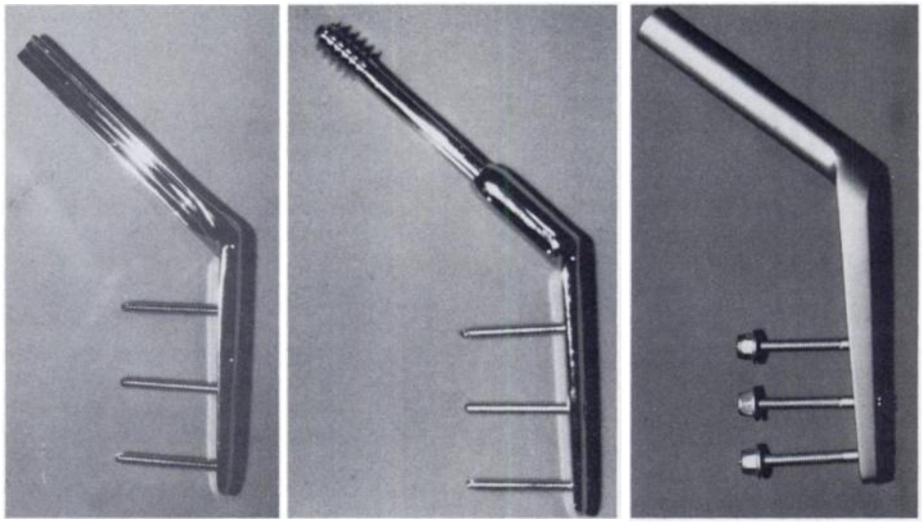


FIG. 3-A FIG. 3-B FIG. 3-C

Implant variables. Fig. 3-A, Jewett nail; Fig. 3-B, telescoping screw; Fig. 3-C, Holt nail.

to evaluate the effect of increased fixation in the femoral head and the potential advantages of telescoping [10,15]. A telescoping device, although potentially having less intrinsic strength, does not inhibit impaction and therefore allows the bone to maximize its stabilizing contribution. The third device tested was a Vitallium Holt nail [7] provided by Howmedica, Inc. (catalogue number 6410-0; 9.5-centimeter nail, 130-degree angle) (Fig. 3-C). The Holt nail is one of the strongest commercially available implant devices and was selected to study the role of the strength of the device in postoperative fixation stability. All possible combinations of the three reduction positions and devices were tested.

Following reduction and fixation, all fractures were vigorously impacted. Right and left specimens from the same cadaver were tested in sequence with different reduction-implant combinations. Previous studies showed that the strengths of bone from the right and left sides of the same individual do not differ significantly [2,11].

Specimens to be tested were potted in a support fixture with Vel-Stone mix, a dental casting material. The femoral shaft was placed at an angle of 66 degrees of inclination from the horizontal, to provide a proximal femoral force-distribution pattern which corresponded with that demonstrated by Rydell [13] in *in vivo* tests during unassisted ambulation. A control group of fresh and embalmed specimens loaded to failure in this manner produced subcapital compression fractures.

Test specimens were loaded to failure in an Instron floor-model testing machine. A large metal cup lined with hard rubber was placed over the femoral head to produce an even load distribution. A hemispherical wire screen was placed between the rubber and the femoral head and demonstrated an appropriate, even distribution of the applied load.

Electrical resistance between the screen and the hip-fixation device was continuously monitored during each test. A precipitous drop in electrical resistance indicated the instant when nail penetration of the head occurred.

During each test, at a deformation rate of 12.7 millimeters per minute, a continuous tracing of load versus deflection was made. Each specimen was loaded until the equivalent of anatomical failure of fixation was produced. Criteria for anatomical failure were: (1) penetration of the head by the fixation device; (2) a neck-shaft angle of 90 degrees or less; and (3) complete loss of fixation of either the shaft or the neck of the nailed femur.

Anteroposterior portable roentgenograms were made of all specimens prior to loading and after failure. Roentgenograms of selected specimens were made during loading.

Results

The load-deformation curve for intact control specimens (Fig. 4) demonstrated that increasing force was sustained to F_{max}, the maximum force supported, which averaged 1,040 ± 244 kilograms force for fresh specimens and 733 ± 169 kilograms force for embalmed specimens. At F_{max} a stable cervical compression fracture was generated. The force then dropped off and the specimens demonstrated resistance to continued deformation at force level F_{cd} for at least an additional 1.5 centimeters of further deflection. The average values of F_{cd} for fresh and embalmed specimens were 586 ± 143 kilograms force and 400 ± 144 kilograms force, respectively. The fragments then separated widely and all resistance to deformation was lost. An average F_{cd} was recorded for each specimen, since the region between F_{max} and complete failure in some specimens extended over several centimeters of further deflection.

Fresh and embalmed specimens yielded load-deflection curves of the same shape (Fig. 4). The average values of F_{max} and F_{cd} given are for four fresh and seven embalmed control specimens. The larger magnitudes of force for fresh specimens may reflect the lower average age of the fresh control specimens (twenty-two years) as compared with the embalmed control specimens (sixty-three years).

The average maximum load borne by the implant alone when tested at a 66-degree angle of inclination was 193 kilograms force for Jewett nails and 705 kilograms force for Holt nails. In order to obtain comparable data for an isolated telescoping screw, it was necessary to fix the screw length at 9.53 centimeters and eliminate the sliding action. Telescoping screw devices modified in this way failed at an average load of 330 kilograms force.

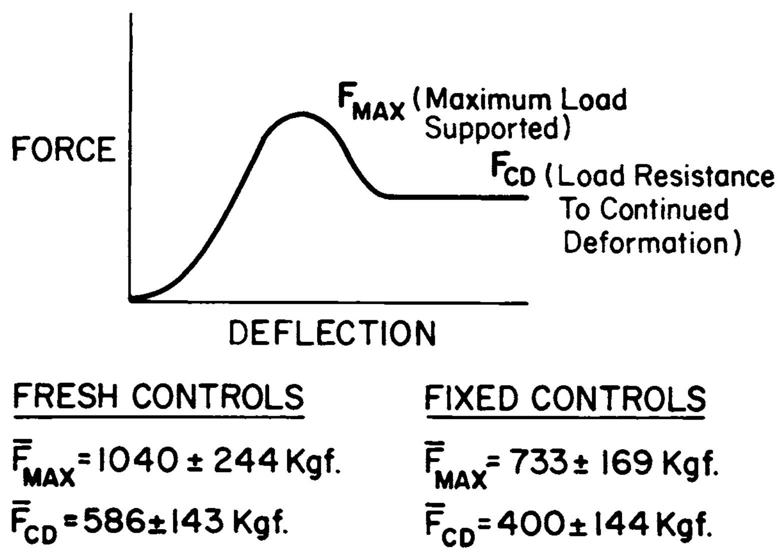
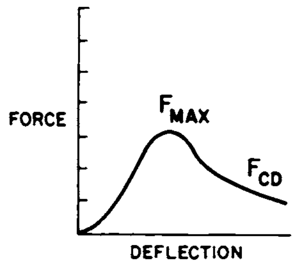


FIG. 4

Average load-deflection curve for control specimens. Average value of F_{max} and F_{cd} for both fresh and embalmed control specimens is listed.

Specimens stabilized with a *Jewett nail* in all three anatomical positions characteristically demonstrated bending of the nail at the fracture site and continued varus angulation at relatively low load levels. The Jewett nail-Wayne County General Hospital reduction position combination with medial calcar overlap characteristically developed an early fracture of the calcar spike, followed by nail bending at the fracture site and progressive varus angulation. The shape of the load-deformation curves for fractures fixed with a Jewett nail was constant for all three tested reduction configurations (Fig. 5). After the



	FMAX Kgm	FCD Kgm
18 ANATOMIC	285.3±111.1	147.9±59.9
5 WAYNE COUNTY	284.9±114.8	218.2±78.5
8 DIMON-HUGHSTON	331.1±165.6	281.7±112.9
AVERAGE	297.0±125.0	189.6±93.4

FIG. 5

An average load-deflection curve for specimens fixed with a Jewett nail. The average F_{max} and F_{cd} for each of the reduction variables is listed.

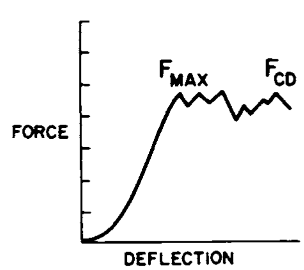
maximum load (F_{max}) was reached, rapid deformation occurred and continued at progressively lower force levels. The average values for F_{max} and F_{cd} are also shown in Figure 5.

When subjected to Student's t test of significance, the differences in F_{max} and F_{cd} for the various reductions fixed with a Jewett nail are not statistically significant.

During continued deformation the femoral head was penetrated by the nail in four of these specimens (12 per cent). Fracture of the femoral head occurred during insertion of the Jewett nail in seven specimens and six of these had to be discarded.

Anatomical reduction supported by a *telescoping screw* usually maintained the desired neck-shaft angle until the screw had telescoped completely. Continued loading then produced bending at the screw-plate angle. In no case did the screw fracture the femoral head during insertion or penetrate the head during loading. The telescoping screw was tested with each of the three reduction variables. A typical load-deflection curve is shown in Figure 6. The shape of this curve was constant for all three reduction variables. When the telescoping screw specimens were tested, loads rapidly rose to F_{max}. Continuing deformation (sawtooth region) (Fig. 6) then occurred at a load level F_{cd}, nearly as great as F_{max}. The average values for F_{max} and F_{cd} are shown in Figure 5. The differences in F_{max} and F_{cd} observed with the three reduction variables are not statistically significant.

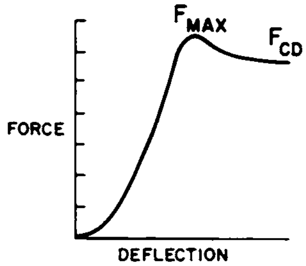
The sawtooth region of the load-deflection curve for telescoping screws usually continued through two or three centimeters of deflection, coinciding with the total telescoping excursion of the screw. During this phase of the test, the neck-shaft angle remained satisfactory. The load then gradually decreased as the plate bent at its angle and progressive varus deformity developed in the proximal end of the femur. Multiple audible cracks were heard during the so-called sawtooth portion of the force-deflection curve, a loud crack coinciding with the apex of each sawtooth. After each crack, the fragments settled with the telescoping screw until sound bone was loaded, whereupon the force level would rise to the next sawtooth.



	FMAX Kgm	FCD Kgm
10 ANATOMIC	387.4±64.9	325.2±74.4
10 WAYNE COUNTY	420.5±107.0	366.0±74.4
1 DIMON-HUGHSTON	430.0	——
AVERAGE	404.9±85.9	345.5±74.4

FIG. 6

An average load-deflection curve for specimens fixed with a telescoping screw. The average value of F_{max} and F_{cd} for all types of reduction tested with a telescoping screw is shown.



	F_{MAX} Kgm	F_{CD} Kgm
14 ANATOMIC	558.4±260.4	425.9±230.0
1 WAYNE COUNTY	624.0	——
2 DIMON-HUGHSTON	834.6	——
AVERAGE	594.4±253.7	425.9±230.0

FIG. 7

The average load-deflection curve for all specimens supported by a Holt nail. Average values for F_{max} and F_{cd} for all varieties of reduction tested with a Holt nail are shown. The Wayne County General Hospital and Dimon-Hughston reductions failed precipitously at F_{max} due to fracture of the femoral shaft distal to the side plate of the Holt nail. There are therefore no F_{cd} values for these reductions.

The desired telescopic action failed to occur in two tests, and then was associated with bending of the screw distal to the tube or bending of the plate at its angle, or both.

In clinical practice the *Holt nail* is seldom if ever used to support a Dimon-Hughston [3,7] or Wayne County General Hospital reduction. For this reason, we tested almost all specimens supported with a Holt nail in the anatomically reduced position. Only one specimen was tested with the Wayne County General Hospital reduction, and only two with the Dimon-Hughston reduction. When a femur fixed with a Holt nail was tested, the load rapidly rose to F_{max} (Fig. 7). The force curve then dropped off as a result of fracture of the trabeculae in contact with the nail. Fracture of these trabeculae allowed the proximal fragment to displace as the nail plowed through its substance, resulting in either a varus deformity or a shortened neck with a compressed plug of cancellous bone at the tip of the nail. As loading progressed, bending of the nail occurred and combined with trabecular failure to account for continued deformation.

Six specimens (37 per cent) stabilized with the Holt nail failed precipitously as the result of fracture of the shaft of the femur distal to the plate. There is no clinical parallel to this mode of failure. In three additional specimens, the nail penetrated the head during loading. However, F_{max} and F_{cd} for all modes of failure of a femur fixed with a Holt nail

	JEWETT	TELESCOPING	HOLT	AVERAGE
ANATOMIC	18 Specimens	10 Specimens	14 Specimens	42 Specimens
F_{MAX}	285.3±111.1	387.4±64.9	558.4±260.4	396.7±201.5
F_{CD}	147.9±59.9	325.2±74.4	425.9±230.0	267.2±176.6
WAYNE COUNTY	5 Specimens	10 Specimens	1 Specimen	16 Specimens
F_{MAX}	284.9±114.8	420.5±107.0	624.0	390.7±135.4
F_{CD}	218.2±78.5	366.0±74.4	——	321.1±101.4
DIMON-HUGHSTON	8 Specimens	1 Specimen	2 Specimens	11 Specimens
F_{MAX}	331.1±165.6	430.0	834.6	391.3±215.6
F_{CD}	281.7±112.9	——	——	282.0±113.1
AVERAGE	31 Specimens	21 Specimens	17 Specimens	
F_{MAX}	297.0±125.0	404.9±85.9	594.4±253.7	
F_{CD}	189.6±93.4	345.5±74.4	425.9±230.0	

Anatomic vs. Wayne County: $p > 0.10$ NOT SIGNIFICANT

Wayne County vs. Dimon-Hughston: $p > 0.10$ NOT SIGNIFICANT

JEWETT TELESCOPING HOLT

$p < .005$ $p < .005$

FIG. 8

A two-dimensional data matrix. Column data allows comparative evaluation with the device as a variable and the reduction as a constant. Row data allows comparative evaluation with the device as a constant and the reduction as a variable.

occurred at very high loads (Fig. 7). In no case was the head fractured during the insertion of a Holt nail.

Our data are shown in Figure 8, where the rows show the reduction configurations and the columns represent the three devices. Comparison of column averages shows that there is a highly significant difference for both F_{max} and F_{cd}, that is, the telescoping screw carried a significantly higher load than the Jewett nail and the Holt nail carried a significantly higher load than the telescoping screw. Comparison of row averages shows no statistically significant differences among the three reduction positions for either F_{max} or F_{cd}.

Discussion

In our specimens in which anatomical reductions were studied, the fracture was not created until after the fixation device had been inserted, so that the position of reduction was perfect. Moreover, the nails were consistently placed in the ideal location. Therefore, our experimental results cannot be considered representative of clinical situations where less-than-perfect anatomical reduction and less-than-ideal nail placement are the rule. A load-bearing comparison of what clinically is considered an anatomical reduction versus an experimentally perfect anatomical reduction was not part of this study, but is currently under investigation. In our study we used only slow single loads to failure. This in no way mimics the loads applied in patients. The data reported apply only to our test configuration of vertical load applied to a specimen angled 66 degrees from the horizontal and may not be valid for loading at other angles. The effects of torsional loading, impact loading, cyclic loading, and fatigue were not evaluated. These are a few of the obvious limitations of the study, if the data are to be considered representative of clinical situations.

One might assume that the use of embalmed bone is also a limitation in this study. However, carefully controlled studies by McElhaney and associates [9] showed that embalmed and fresh bone are remarkably similar in terms of mechanical properties, except for compressive strength in which they differ by about 12 per cent.

Another recognized difference between the conditions of this study and the clinical situation is the presence in patients of muscle forces across the fracture, altered by displacement of the greater and lesser trochanters. Therefore, while our direction of loading would be appropriate for the intact femur, it is probably at variance with the direction of loading following fixation of an intertrochanteric fracture in a patient. Recognizing the limitations and qualifications of this study, one must resist the temptation to apply the results directly to clinical fractures and their fixation.

Non-anatomical stable reduction (Dimon-Hughston, Wayne County General Hospital) has no advantage over a *perfect* anatomical reduction. Regardless of the reduction, telescoping-screw fixation will bear significantly larger loads than a Jewett nail. The Holt nail bears the largest loads of all, at levels which are highly statistically significant.

The average F_{max} for fractures fixed with a Jewett nail (296 kilograms) was only slightly in excess of the load on the femur observed by Rydell during unassisted walking and bed activity [13] (245 and 140 kilograms, respectively, for a man weighing seventy kilograms), and constitutes an inadequate margin for safety. The average F_{cd} for fractures fixed with a Jewett nail (188 kilograms) is much lower than the load which a proximal femur must bear during walking. Furthermore, fracture of the head during 22 per cent of Jewett nail insertions, and 12 per cent head penetration during continued deformation of Jewett nail specimens, is excessive. We conclude, therefore, that the tested Jewett nail is inadequate for intertrochanteric fracture fixation and should not be used.

The average F_{max} and F_{cd} for telescoping screws (406 and 343 kilograms force, respectively) and for Holt nails (590 and 422 kilograms force, respectively) exceed proximal femoral loads during both bed activity and unassisted walking [13]. Although the Holt nail is strongest of all, it is possible that the less rigid fixation of a telescoping screw is an advantage under cyclic or impact loading [15]. We conclude, therefore, that a telescoping screw and a Holt nail are both acceptable fixation devices for support of intertrochanteric fractures.

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