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MANUAL SENSING OF FRACTURE STABILITY: A BIOMECHANICAL STUDY

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In the closed management of fractures of long bones the physician must decide when the injured limb may assume normal function unsupported by external stabilization. This decision to remove the final cast is based on several criteria of healing such as: adequate elapsed time, a pain-free limb, a non-tender fracture site, firm localized callus, painless active function of local musculature, roentgenographic criteria of healing, and finally in appropriate cases, a test of fracture stability applied by the physician in the form of an attempt to evaluate bending of the fracture site under a manually applied bending moment (Figure 1).

While applying the moment, the physician judges patient discomfort and fracture segment stability both by "feel" and visual determination of angular deformation.

Frequently patients may feel pain during such a test while the physician reports that the fracture feels "springy". He may judge that there is insufficient stability; the patient must continue to wear a cast or be otherwise supported. A continuing feeling of instability even in the face of roentgenograms which show apparent solid union (Figure 2) may lead to a decision that the fracture is failing to unite solidly.

The judgement of relative stability is based on two variable factors; the applied moment force and the visual and manual sensitivity of the physician in detecting motion and angular deformation. Excessive bending force may cause a refracture while an inadequate test may lead to a premature decision to abandon the cast.

This study was designed to determine the magnitude of the moment force applied by a group of orthopaedic surgeons when testing fractures for stability, and to evaluate the variability within the group. In addi-

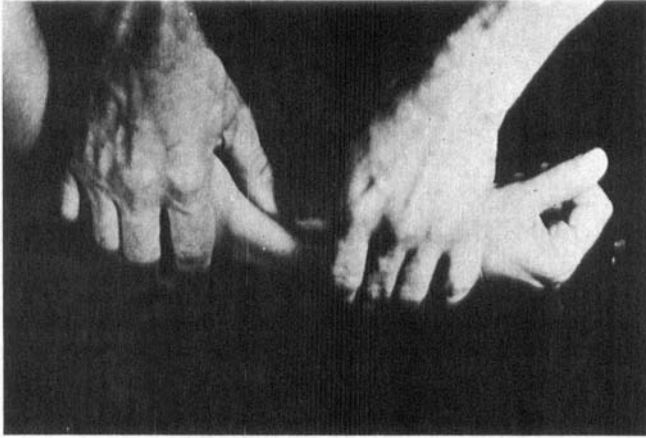


Figure 1. A typical manual test for forearm fracture stability.

tion, an effort was made to analyze the visual and manual sensitivity of the physician groups in detecting angular deformation, and to determine the relative stability present when the surgeon makes the decision that the fracture is healed. These results were sought in view of the difficulty in teaching residents what an appropriate moment force is when one surgeon knows precisely what testing force he usually applies or what level of stability is satisfactory for unsupported function.

METHODS

Design and Calibration

An instrument (Figure 3) has been designed to simulate a midshaft fracture of a long bone. The design includes two 28 centimeter lengths of 1.6 centimeter diameter steel pipe with a 3 millimeter wall thickness. A stranded steel cable, 3 millimeters in diameter, is positioned through the longitudinal axis of the aligned pipe segments. One cable end is attached to a sliding screw, pretensioning device. The opposite end is affixed to a strain gauge instrumented beam which provides continuous measurement of cable tension. Flanges at the interfacing pipe ends form the simulated fracture site. The flanges provide a fulcrum effect, whereby bending moments, and corresponding angulations, applied across the site yield appropriately measurable cable tension changes. A thin rubber sheet is interposed between the flanges to decrease a "mechanical" feeling and to eliminate noise when the device is employed. The length of the apparatus is covered with two layers of sponge rubber to duplicate the feeling of soft tissue over bone.

Cable pretension, as controlled by the sliding screw attachment, enables experimental variation of fracture site bending stiffness, defined to be the applied moment versus angulation relationship. Stiffnesses were determined for an appropriate range of cable pretensions by calibration in an Instron floor model testing machine.

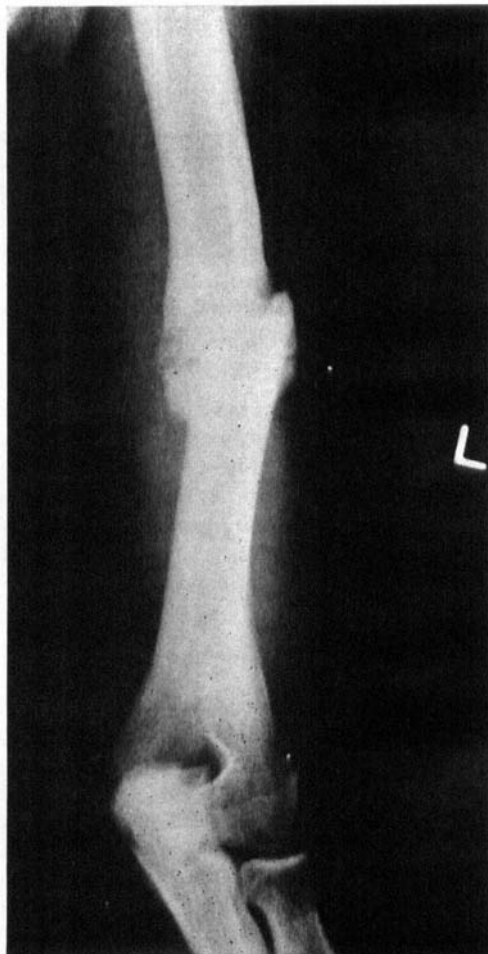


Figure 2. A clinically unstable humeral shaft fracture despite good roentgenographic evidence of healing.

Strain gauge instrumentation recordings made during calibration serve a two-fold function. The first is determination of cable tension settings prior to the application of fracture site bending moments; second, calibration of subsequent applied moment-angulation conditions as measured by cable tension increases. These combined results are shown in Figure 4, to be interpreted as follows. The values 150, 225, and 300 are strain gauge measures of three cable pretension settings. The three settings yield increasing fracture site stiffnesses as plotted to the left in the figure. For example, the 150, 225, and 300 settings subsequently require 80 kgf · cm, 100 kgf · cm, and 125 kgf · cm moment magnitudes, respectively, to produce a 3 degree angulation at the fracture site. Note that the pretension settings serve only to identify calibrated stiffness curves, and do not imply further signifi-

FRACTURE SIMULATOR

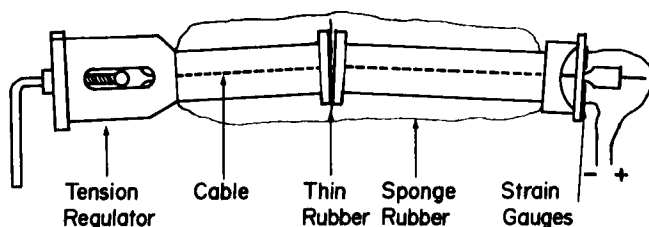


Figure 3. The fracture simulator.

cance. Figure 4 on the right shows calibrated strain gauge output readings which correspond to increased cable tensions caused by the application of fracture site bending moments. Thus an output reading of 78 denotes, for a 150 setting, the application of a 76 kgf·cm moment, and a resulting 2.5 degree angulation at the fracture site. The above outlined calibration procedure was conducted over a stiffness range from the simulation of a rubbery or springy fracture to progressively pretensed cable settings at which the stimulated fracture seemed to be solidly united.

Test Protocol

Ninety orthopaedic surgeons were tested. They were divided into three groups; residents (39); orthopaedic surgeons with 0-10 years experience after residency (26); and those with greater than ten years experience (25).

First, the subject physician was told to consider the instrument a nearly healed, undisplaced, midshaft fracture of both bones of the forearm which had been treated closed by long arm casts. The limb was to be considered pain free, and the roentgenograms had demonstrated satisfactory progression toward healing. The subject surgeons were asked to apply to the simulated fracture that moment force they would normally use for a test of the healing fracture at the time a decision to continue or discontinue cast treatment must be made. The instrument was pretensioned at the 150 stiffness setting for all subjects. The test was repeated approximately six times to insure device familiarity and to determine consistency. Characteristic test one recorded results are shown in Figure 5. The bending moment values to be reported are the averages of the three most similar individual test results.

To validate the chosen degree of controlled stability, subjects were asked in this test whether they felt that the fracture was sufficiently stable to discontinue cast treatment. Their responses were recorded, 25 per cent positive and 75 per cent negative, indicating that the pretension stiffness level indeed simulated that representative of a nearly or just healed fracture.

In the second test, the instrument was adjusted to provide gross angulation with a minimal bending moment, simulating a very unstable fracture. While the subject was asked to repeatedly test the simulated fracture for stability, the apparent fracture stiffness was progressively increased until the surgeon reported that the

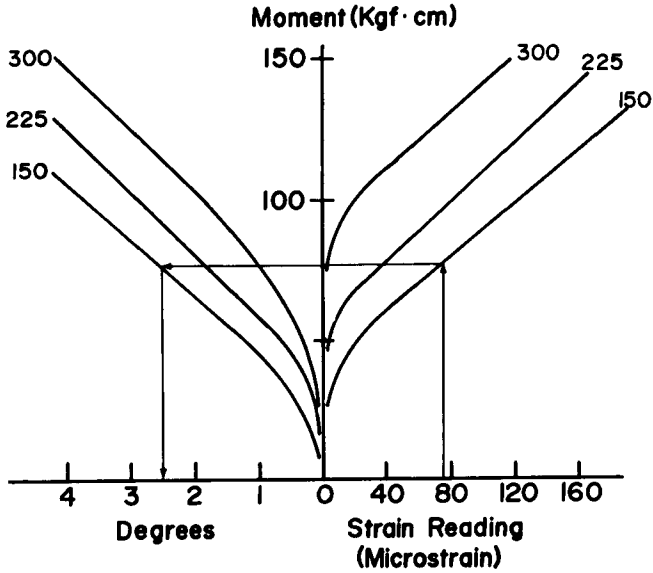


Figure 4. Nomogram used to determine test moment and angular deformation values at the three pretension levels.

fracture was sufficiently stable for unsupported function. The recorded cable pretension at the time of this decision measures the fracture stiffness required for a "healed" decision (Figure 5). Force and angulation at the "healed" decision were recorded. This bending moment force allows a comparison between the first test force magnitude and that actually used at the time of the simulated decision. Relative consistency was again evaluated. Lastly, the bending moment used by the subjects at the first test stiffness level was compared, when applicable, to that recorded when the simulated fracture stiffness passed the same level in the second test.

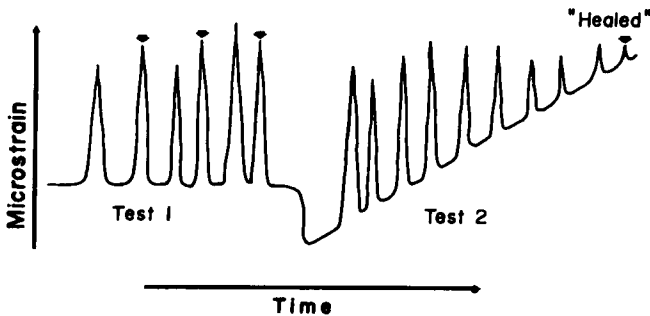


Figure 5. A sample test record. Arrows in Test 1 indicate the three test results chosen for further evaluation. The arrow in Test 2 is the recorded value when the surgeon declared the simulated fracture "healed".

Table 1. Bending moment and associated angular deformation for a simulated both bones of the forearm fracture tested for stability by orthopaedic surgeons.

Group	Number	Bending Moment (kgf·cm \pm 1 S.D.)	Range	Angular deformation (degrees, \pm 1 S.D.)	Range
Orthopaedic residents	39	104.3 \pm 25.9	55.0–155.9	3.3 \pm 0.3	1.8–4.0
Orthopaedic surgeons with 0–10 years experience	26	100.1 \pm 23.4	64.2–138.4	3.2 \pm 0.3	2.2–3.8
Orthopaedic surgeons with greater than 10 years experience	25	81.7 \pm 20.0	48.4–126.8	2.7 \pm 0.3	1.6–3.5
All groups	90	96.7 \pm 25.0	48.4–155.9	3.2 \pm 0.3	1.6–4.0

RESULTS

The average bending moment used by the physicians when testing a stimulated forearm fracture was 96.7 ± 25.0 kgf·cm (Mean \pm 1 Standard Deviation). The associated angular deformation was 3.2 ± 0.3 degrees (Mean \pm 1 Standard Deviation). Table 1 presents the average bending moments and associated angular deformations.

The first test as presented above investigates the bending moment applied by our 90-surgeon sample when testing a simulated, both bones of the forearm fracture for healing. Overall and experience grouping results are presented in Table 1. Although experienced physicians appear to use less bending force (81.7 ± 20.0 kgf·cm) than the other two groups, this impression is not substantiated by student t-tests at a $P = 0.1$ level of significance. Decreasing magnitudes of standard deviation values do demonstrate a trend toward uniformity with experience. A variance ratio test, using the F distribution, for residents compared to surgeons with greater than 10 years experience, shows a population variance difference exists at $P < 0.1$.

In test two (Table 2) the physicians declared the fracture stabilized at a 239 ± 75 cable pretension setting. Recall that this value is a measure of fracture site stiffness, and must be interpreted in the context of

Table 2. Stimulated fracture initial stiffness and test moment with the associated angular deformation at the time of the surgeons' decision "healed fracture".

Group	Number	Relative simulated fracture stiffness (Micro-strain)	Range	Bending moment (kgf·cm) \pm 1 S.D.	Range	Angular deformation (degrees)	Range
Orthopaedic residents	39	231 \pm 74	375-100	97.6 \pm 30.9	49.2-156.0	2.6 \pm 1.1	1.0-5.0
Orthopaedic surgeons with 0-10 years experience	26	254 \pm 85	450-100	98.4 \pm 29.2	44.2-138.4	2.3 \pm 0.7	1.0-4.0
Orthopaedic surgeons with greater than 10 years experience	25	224 \pm 70	350-90	87.6 \pm 24.2	45.9-138.4	2.1 \pm 0.5	1.0-3.5
All groups	90	239 \pm 75	375-90	95.0 \pm 29.2	44.2-156.0	2.3 \pm 0.8	1.0-5.0

Figure 4 calibration curves. There are no significant differences in means or variances for this stiffness measure as related to experience. The relatively small standard deviation indicates most physicians made the simulated decision to discontinue immobilization at approximately the same stage of healing. The limits of this range (90-375) do indicate, however, that a few physicians deviate considerably from the average.

At the decision "healed" the bending moment and angulation values were 95.0 ± 29.2 kgf·cm and 2.3 ± 0.8 degrees respectively. Averages of both are not significantly different for the group comparisons. As in test one, however, the variance ratio test again shows a trend toward uniformity with experience. Bending moment variances for residents compared to orthopaedic surgeons with more than 10 years experience, are significantly different at $P < 0.1$. Angulation variances, residents compared to the less than 10 years experience and the less than 10 years experience group compared to the more than 10 years experience group, are significantly different at $P < 0.05$.

The test two moment applied at the "healed" decision is not significantly different from the results of test one, demonstrating that the tested physicians do indeed apply a controlled standard bending

moment as fractures become more stable. In addition, the test one bending moment at the 150 pretension setting is not significantly different than that applied in test two as the stiffness setting was increased through the same value. There is thus a remarkable consistency in the moment used by individual surgeons and all groups in the two tests.

DISCUSSION

Although a manual test for long bone fracture stability is but one factor considered in the decision to discontinue external support, it is an important one. When the injured bone is sufficiently mechanically stable for normal function the fracture is functionally healed. It plays an equally important role in evaluating a possible non-union and in the decision to intervene surgically. The roentgenogram provides a two dimensional representation of the situation and even with multiple views, the vagaries of fracture geometry may hide a pseudoarthrosis. Decreasing local fracture tenderness and pain reflects the healing of injured tissue at the fracture site and is usually associated temporally with maturing callus. However, the absence of pain does not necessarily indicate a healed fracture. In fact, many non-unions are pain free. The functional common denominator is stability.

Mechanical stability of healing fractures was studied by Jernberger (1970) who applied a controlled bending moment directly to bone through pins *in vivo* in humans. Interestingly, the threshold bending moment value he determined for the clinically stable tibial fracture is approximately 104 kgf · cm if a 2.3 degree angulation is produced. The values he was able to record with extensive instrumentation when fractures were functionally healed are remarkably similar to the values determined manually by our group of orthopaedic surgeons.

CONCLUSIONS

These studies indicate that there is an appropriate bending moment force used by the majority of orthopaedic surgeons in testing for fracture stability. Most surgeons appear to be able to sense a 2.3 degree angular deformation at the fracture site and tend to further immobilize fractures which bend to a greater degree. There was an unexpected consistency in the bending moment utilized by each physician in the different tests and in the average moments for the different groups. This would appear to indicate that the ability to appropriately

test healing fracture stability is easily learned by experience early in the orthopaedic residency.

S U M M A R Y

An instrument simulating the feel of a fractured forearm was used to determine the average bending moment used by ninety orthopaedic surgeons in determining fracture stability. The relative stiffness, bending moment, and associated angulation at the decision "healed" were measured. Remarkable consistency in these values was observed from test to test by each physician and between groups of orthopaedists selected according to experience.

R E F E R E N C E S

- Jernberger, A. (1970) Measurement of stability of tibial fractures—A mechanical method. *Acta orthop. scand.*, Suppl. 135, 7-88.

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