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Stability of reamed and unreamed intramedullary tibial nails: a biomechanical study

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We examined the correlation of bone mineral density and bone strength in the cadaver tibia, and looked in vitro *at the relative stability of tibial fractures fixed with either reamed or unreamed tibial nails. Bone-mineral density correlated well with bone strength ($r = 0.946$), but paired tibias did not correlate closely. The unreamed nail–bone construct was less stable than the reamed construct in each pair tested ($P < 0.05$), and a comparison of all bones showed it to be less stable at all levels of our testing regimen, including failure ($P < 0.01$). Bending and breakage was seen in four of the smaller unreamed interlocking screws (4 mm).*

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Introduction

The tibial intramedullary (IM) nail is the implant of choice for the fixation of unstable closed midshaft fractures of the tibia. With the advent of interlocking, IM nails can be used for fractures within 5 cm of the bone ends. However, the management of open fractures of the tibia is controversial. Most authors would agree that it is essential to stabilize completely the fracture to create optimal conditions for both soft tissue and bony healing, and allow rehabilitation of joints and muscles about the fracture, preventing 'fracture disease'[1]. A small, stronger solid nail can be inserted into the tibia without reaming, and because of its intramedullary position it allows soft-tissue closure or cover. It is an attractive alternative to external fixation in the treatment of open tibial shaft fractures. In addition to having a smaller diameter, the unreamed nail utilizes smaller diameter screws for interlocking. The aim of this study was to examine the biomechanical stability of the unreamed nail–bone construct compared with the reamed nail–bone construct in compression and torsion, in paired tibias of a variety of bone-mineral densities.

Materials and methods

Fresh human cadaver tibias were harvested from the Maryland State Anatomy Board in matched pairs, stripped of soft tissue, and anteroposterior and lateral X-rays were taken to exclude osseous abnormality. They were scanned to determine bone-mineral density with a Hologic QDR-1000 dual energy X-ray absorptiometry (DEXA) scanner. For DEXA scanning, the tibias were placed in a customized perspex bath of 0.9 per cent saline that allowed accurate and repeatable positioning, so that orientation did not affect the result. All tibias were scanned in true anatomical anteroposterior orientation three times to ensure accuracy, and the mean of the measurements was used. Specimens were wrapped in saline-soaked towels, sealed in a polyethylene bag, and stored at −20°C.

Prior to testing all specimens were thoroughly thawed and mounted in specialized jigs. Six cadaver tibias were tested to failure (shaft fracture). Three pairs were randomly chosen to ascertain if there was a close correlation between bone-mineral density and bone strength, and to compare left and right bones of the pair. The tibias were preloaded with 100N axial compression and then angular deflection at a rate of 1°/s was applied until failure. Ten tibias (paired) were then chosen on the basis of a similarity in their bone-mineral densities, normal gross anatomy and radiographs. They were measured to ensure suitability for a 13 mm reamed nail. One side of each pair was internally fixed with either an unreamed (10 mm) or reamed (13 mm) nail after creation of an unstable fracture pattern. This was produced by removal of 15 per cent of the mid-diaphyseal length. Internal fixation was performed according to the manufacturer's instructions, and all tibias were statically interlocked utilizing the appropriately sized fixation screws. Screw position was checked with X-ray image intensification. The intramedullary nails and the screws were not re-used. The tibias were mounted in special jigs and proximal and distal ends embedded in resin. Care was taken to ensure that resin did not bind either proximal nail entry or screw fixation sites, so that no extra stability was conferred by the resin. The specimens were axially preloaded to 100N. The specimens were tested in torsion in clockwise and anticlockwise direction under load control with displacement the measured variable. A run of 175 cycles at 5 N/m torque at 1 Hz established the inherent stability, at low load, of the bone–nail construct. Load was increased at 2.5 N/m increments after every 25 cycles until failure of the specimen (*Figure 1*). Failure was taken as loss of bony integrity, screw cut-out or breakage, or an oscillatory displacement of ± 25° or greater. Testing was performed using an MTS Bionix 858 Servo controlled materials testing device (MTS Minneapolis, MN, USA).

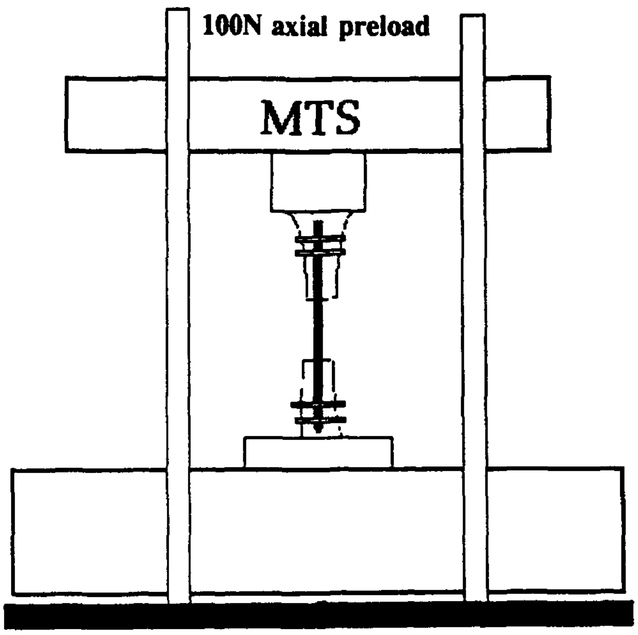

Figure 1. Configuration of biomechanical testing.

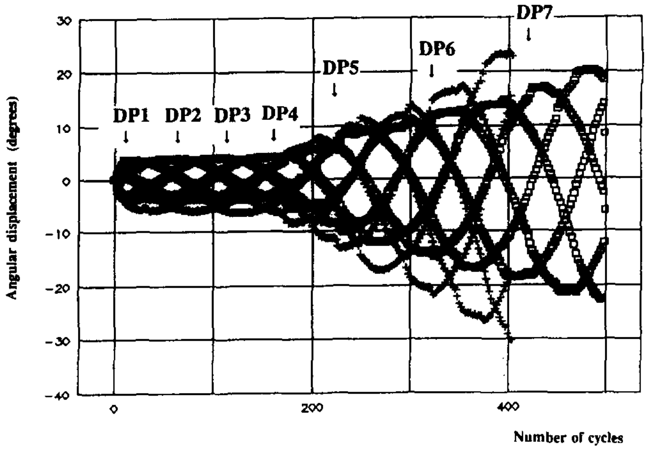

Figure 2. Seven data points (DP) isolated for comparing results from the test profile. ☐ reamed, + unreamed nails.

Table I. Comparison of bone mineral density and load to failure in intact cadaveric tibias

Bone-mineral density (g/cm^2)	*Load to failure (N/m torsion)*
0.459	11.5
0.543	14
0.751	46.5
0.781	59
0.88	55.7
0.992	61.7

Correlation, $r = 0.946$.

Table II. Comparison of five pairs of 'fractured' cadaveric tibias fixed with reamed or unreamed nails

Specimen	*Bone-mineral density (g/cm^2)*	*Mean torsion (N/m)*	*SD*
Reamed			
1	0.579	9.27	0.52
2	0.778	10.49	0.34
3	0.81	7.52	0.36
4	0.812	7.72	0.44
5	1.21	6.62	0.14
Unreamed			
1	0.629	14	0.47
2	0.797	14.81	0.3
3	0.887	9.93	1.17
4	0.909	9.96	0.95
5	0.15	7.98	0.18

Table III. Comparison of all specimens at increasing torsional load

	Reamed		*Unreamed*		
Data point (N/m)	*Mean deflection (rad)*	*SD*	*Mean deflection (rad)*	*SD*	*P*
±10	15.86	1.0	19.65	3.37	0.045
±20	28.6	5.11	39.7	4.04	0.000
±30	37.79	7.07	54.18	4.5	0.002

This machine has the advantage of being able to test specimens in both compression and torsion simultaneously. Results were analysed using Labtech Notebook Software (Labtech, Wilmington, MA, USA), and graphs prepared utilizing Lotus 123 spreadsheet (Lotus Development Corp, MA 02142, USA). Seven components of the test profile were compared between the reamed and the unreamed nail bone construct (*Figure 2*). Data points 1–4 established the angular deflection at low torque (100N compression, and 5 N/m angular torsion). Data points 5–7 were equivalent to axial compression of 100N and 220 cycles (± 10N/m), 320 cycles (± 20N/m) and 420 cycles (± 20N/m) or failure, respectively. Statistical analysis of the results was performed between each pair of reamed and unreamed tibias by unpaired *t* test and between all the specimens by repeated measures ANOVA.

Results

The first three pairs of human cadaver tibias were tested in torsion after quantification of the bone-mineral density of each bone. The results from these tests displayed in *Table I* show that there is a good correlation between the bone mineral density, and the load to failure. Osteoporotic bone with a bone-mineral density of 0.459 g/cm^2 failed in torsion at 11.5 N/m, and bone of moderate or good quality (bone–mineral density = 0.992 g/cm^2) failed at a higher torque 61.7 N/m.

This proved to be a close correlation, utilizing a Pearson correlation coefficient ($r = 0.946$). Tibias of similar bone mineral densities ($r = 0.974$) were chosen for testing with the intramedullary nails. In all specimens tested, the tibia fixed with the unreamed nails showed greater angular displacement, under 5 N/m torque and 100N axial preload, than their reamed counterparts ($P < 0.01$) (*Table II*). With increasing torque, the degree of displacement was greater in the unreamed constructs than in the reamed system. At ± 10N/m torsion, $P = 0.045$; ± 20N/m, $P = 0.000$; and at ± 30N/m or failure, $P = 0.002$ (*Table III*). In two cases, the smaller diameter screws failed. Three screws bent and one screw fractured. Vertical fractures were seen in four specimens extending from the distal screw holes (one reamed, two unreamed).

Discussion

The treatment of open fractures of the tibia remains controversial. Although excellent stability of the fracture may be obtained with plate osteosynthesis, infection rates are unacceptable[2,3]. In cases of severe open tibial injuries with contamination, the 'gold standard' treatment is with an external fixator[4,5]. This device provides adequate biomechanical stability for bone healing not seen with some other devices[6] yet allows access for soft tissue procedures as its inherent stability prevents the need for external splintage (e.g. plaster cast)[7]. However, external fixation is associated with certain risks. It is associated with an increased risk of delayed or non-union over fixation with IM nails[8] and also, after a preliminary treatment with an external fixator, conversion to an IM nail or use of a plate at a later stage attracts an increased infection rate[2,9,10]. Complications such as Schanz pin loosening with pin site infection and subsequent osteomyelitis are also worrying[8]. The reamed nail is deemed unsuitable for contaminated fractures as the reaming process causes bone devascularization, an increased local pressure, microthrombi and thermal necrosis[1,11–18]. The unreamed nail is associated with a lessened risk of infection[12], perhaps due to the preservation of medullary vasculature. Recently we have become aware of a few cases of non-union developing in fractures treated with the unreamed nail, and one contributory factor might be excessive motion at the fracture site. Although the device is now in current use, and satisfactory analysis of implant geometry has been performed, there is little investigation into the stability of the unreamed construct or the effect of partial weight bearing on a tibia fixed with the smaller diameter IM nail with smaller diameter locking screws *in vivo*. This study, directly compares the bone nail construct of the reamed and the unreamed system *in vitro* with an unstable fracture pattern. The results of this study suggest that the smaller diameter unreamed nail may not afford the same stability of the reamed nail in this fracture model and this testing methodology. This might contribute to an increased incidence of infection or non-union in the clinical situation. Of concern was the breakage and bending of the smaller screws – clinical studies will reveal if this is indeed a problem. The early failure of the unreamed construct in severely osteoporotic bone *in vitro* should be noted for clinical practice.

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