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Intramedullary Screw Fixation of Jones Fractures

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ABSTRACT

Background: **Jones fractures of the fifth metatarsal can be stabilized using intramedullary screw fixation techniques. A range of screw diameters from 4.5 mm to 6.5 mm can be used, but the optimal screw for this procedure has yet to be defined. In clinical practice, we have observed that failure is more likely when smaller diameter screws are used.**
Methods: **Experimental Jones fractures were created in 23 pairs of human cadaver fifth metatarsals, which were fixed using either 5.0 mm or 6.5 mm screws. Fracture stiffness and pull-out strengths were measured for either screw type and their relationships with bone mineral density and medullary canal diameter were determined.**
Results: **There was no significant difference in the bending stiffness of fractures stabilized with 5.0 mm and 6.5 mm screws; however, different mechanisms of failure were noted for either screw type. Poor thread purchase within the medullary canal was noted with the 5.0 mm screws, while excellent purchase was noted with 6.5 mm screws. Pull-out strength testing revealed significantly higher pull-out strengths for the larger 6.5 mm screws. There was no significant difference in bone mineral density or medullary canal diameter between right and left metatarsals.**
Conclusions: **Fifth metatarsals can often accommodate a 6.5 mm screw for the stabilization of Jones fractures. Larger diameter screws did not result in greater fracture stiffness in our model, but did result in significantly greater pull-out strengths.**
Clinical Relevance: **Larger diameter screws may be more appropriate for intramedullary screw fixation of Jones fractures.**

INTRODUCTION

Fractures of the base of the fifth metatarsal are categorized into three types, namely tuberosity avulsion fractures, Jones fractures, and diaphyseal stress fractures.[8] Jones fractures are transverse fractures at the proximal metaphyseal/diaphyseal junction that involve the 4/5 intermetatarsal articulation, also called zone II fractures.[6,14] They are typically seen in the young athlete, presenting with acute pain following an adduction injury to the foot. These fractures are often undisplaced and can usually be managed non-operatively with a non-weight bearing cast.[17,18] However, non-operative management of Jones fractures is associated with an increased risk of delayed and non-union for a variety of reasons, not least because these fractures occur at a vascular-watershed.[3,13,15,16] Consequently our indications for operative intervention include acute fractures in the athlete where time to union is paramount and delayed or non-unions in the non-athlete.[3,4]

A variety of fixation techniques for Jones fractures have been described, including percutaneous pinning with a below knee cast,[1] medullary curettage and grafting,[17] and intramedullary screw fixation.[4,5,7,9] Currently, intramedullary screw fixation is considered the operative treatment of choice. Screw diameters of 4.5 mm to 6.5 mm are commonly used, but the optimal screw type has yet to be defined.[5] Unfortunately, intramedullary screw fixation does not ensure union,[5] and we have encountered fixation failures following the use of 4.5 mm malleolar screws and cannulated 5.0 mm titanium screws. This contrasts with good results when using larger diameter 6.5 mm stainless steel screws. We hypothesize that fixation failure occurs because the smaller diameter screws provide less stability than 6.5 mm screws. To test this hypothesis, we performed a biomechanical study analyzing the bending stiffness and pull-out strengths of fractures repaired with 5 mm and 6.5 mm screws, in 23 matched pairs of fresh frozen human cadaver fifth metatarsals.

MATERIALS AND METHODS

Specimens and specimen preparations

Twenty-three pairs of fresh, previously frozen fifth metatarsals were retrieved from cadavers. There were 15 male and eight female donors with an average age of 74.6

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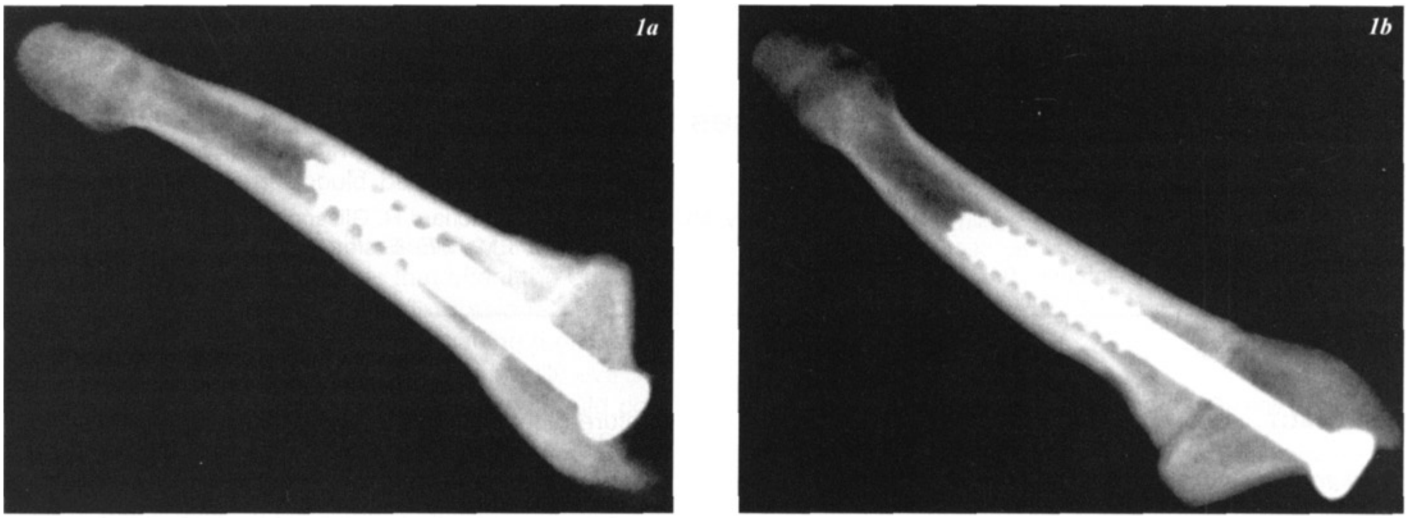

Fig. 1: (a) Anteroposterior DEXA image of Jones fracture of fifth metatarsal stabilized with a 6.5 mm screw. **(b)** Anteroposterior DEXA image of Jones fracture of fifth metatarsal stabilized with a 5.0 mm screw.

(+/- 15) years. The metatarsals were denuded of soft tissue and incomplete transverse fractures at the metaphyseal-diaphyseal junction, extending into the 4/5 intermetatarsal articulation (Jones fractures) were fashioned using a sagittal saw. All right metatarsal fractures were fixed using 6.5 mm short-threaded stainless steel screws (Synthes (USA), Monument, CO) (Fig. 1a). A guide-wire was inserted medial to the tip of the tuberosity avoiding the articular surface and keeping the guide wire parallel to the medullary canal. The canal was drilled with 3.2 mm and 4.5 mm cannulated drills and then tapped with a non-cannulated 6.5 mm tap. Screw length was selected by superimposing the screw over the metatarsal such that the threads were distal to the fracture site and located primarily in the proximal diaphysis. The screw was inserted and the fracture completed before tightening the screw to achieve visible compression at the fracture site. The left metatarsals were fixed with 5.0 mm short-threaded cannulated titanium screws (ACE Surgical Supply, Brockton, MA) (Fig. 1b). The medullary canal was drilled using a 3.8 mm drill over a guide-wire, and screw length was determined in the same fashion as for the right metatarsals. Again, the fracture was completed and the screw was tightened until good compression was visible at the fracture site. All operative procedures were performed by a single surgeon with extensive experience using intramedullary fixation techniques.

Bone Densitometry

The bone mineral density (BMD) of each metatarsal was measured using a LUNAR PIXImus small animal densitometer (Lunar Corp., Madison, WI). The system provides a point resolution of 0.186 mm. Standard PIXImus software (version 1.45.021) was used for scans and analysis. Quality assurance tests were performed prior to each scanning session using a phantom of known BMD. The isolated metatarsals were placed on a Delrin plate to substitute for soft tissue (according to the manufacturer's guidelines) and scanned separately in an anteroposterior direction. Measurements and data analysis were performed by a single observer.

Measurement of medullary canal dimensions

The diameters of the medullary canals of all 46 metatarsals were measured digitally on the DEXA scan images at the proximal diaphysis (Fig. 2).

Lateral cantilever bending stiffness

Twelve pairs of metatarsals were used for stiffness testing (specimen pairs one to 12). Four 0.062" K-wires were inserted transversely through the tuberosity in the medial-lateral plane and their lengths trimmed to project 5 mm from the outer cortices. The wires were placed such that they would not encroach on the trajectory of the screw as it cut through the bone during subsequent failure testing. The base of the metatarsal was then degreased with acetone and embedded in an aluminum pot using polymethylmethacrylate cement. Prior to embedding, the exposed screw head was covered with modeling clay to prevent contact between the head and surrounding cement. A 2 mm screw was inserted into the lateral cortex of the metatarsal head to provide a discrete contact point for subsequent load application. The effective lever arm between the contacting screw and the fracture site was recorded for each metatarsal. The aluminum pot was then rigidly mounted, with the metatarsal projecting in a horizontal orientation, in an Instron model 1321 servohydraulic materials testing machine. Displacement was applied to the distal contact point at a rate of 0.1 mm/second in a lateral-to-medial direction until failure was observed. A lateral-to-medial direction was chosen because Jones fracture non-unions are typically seen on the lateral cortex. Stiffness was calculated from the slope of the resulting load-displacement curve and expressed as newtons/mm (N/mm) of deflection.

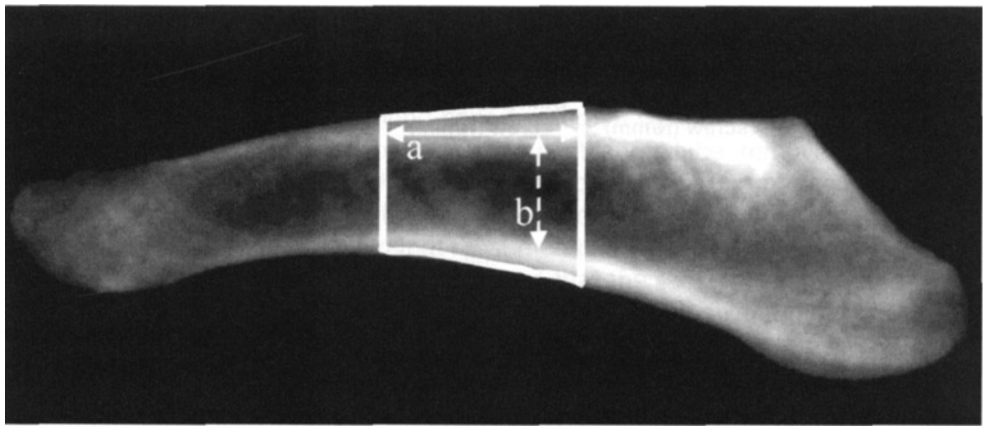

Fig. 2: DEXA image of a right metatarsal. **(a)** BMD was calculated for the proximal 18.6 mm of the metatarsal shaft. **(b)** Measurement position of the diameter of the medullary canal.

Pull-out strength

Pull-out strength testing was performed on 11 matched pairs of metatarsals (specimen pairs 13 to 23) to confirm the subjective impression of poor purchase with the 5.0 mm screws when compared with the 6.5 mm screws. A #8 self-tapping screw was inserted transversely through the distal shaft, such that its head and tip protruded from the cortices. The metatarsal tuberosity was removed with a rongeur to expose the head and shank of the fixation screw. The distal end of the bone was then degreased and embedded in a cylindrical aluminum pot using polymethylmethacrylate cement such that the fixation screw and pot were coaxial. The specimen was rigidly attached to the table of an Instron model 1321 servohydraulic materials testing machine and the head of the fixation screw was grasped by a specially designed tool attached to the testing machine's load cell and actuator. The screw was extracted from the metatarsal at rate of 0.1 mm/second while recording load and displacement. The maximum tensile load developed during screw pull-out was recorded for each specimen.

Statistics

Paired Student's t-tests were used to compare stiffness, and pull-out strength, BMD, and medullary canal diameter between right and left metatarsals. Regression analysis was performed to correlate donor age and BMD. Mixed effect analysis of variance (ANOVA) was performed to analyze the effects of age, BMD, and medullary canal diameter on stiffness and pull-out strength. All calculations were performed using a SAS/STAT® (Cary, NC) statistics program ($\alpha = 0.05$).

RESULTS

Bone mineral density

There was no significant difference ($p > 0.05$) in BMD between right and left metatarsals. The average BMD of the right metatarsals ($n = 23$) was 0.39 (+/- 0.14) g/cm^2. The average BMD of the left metatarsals ($n = 23$) was 0.40 (+/- 0.12) g/cm^2. Individual BMD values are displayed in tables 1 and 2. There was no significant correlation between BMD and age ($r = -0.193$ right, $r = -0.157$ left).

Medullary canal diameters

The average medullary canal diameter at the proximal diaphysis of the right metatarsals ($n = 23$) was 6.1 (+/ 1.3) mm. The average medullary canal diameter of the left metatarsals ($n = 23$) was 6.0 (+/- 1.3) mm. The canal diameters ranged from 4.8 mm to 8.9 mm. There was no significant difference ($p > 0.05$) in canal diameter between left and right metatarsals. No metatarsals fractured during insertion of the 5.0 mm screws, while two metatarsals sustained longitudinal fractures upon insertion of the 6.5 mm screw. Both of the fractured metatarsals had the smallest medullary canal diameters of 4.8 mm.

Fracture stiffness

Because the lever arm varied between specimens, stiffness results were normalized to a standard lever arm of 40 mm for comparison. There was no significant difference ($p > 0.05$) in fracture stiffness between the metatarsals fixed with 6.5mm and 5.0mm screws ($n = 12$ pairs) (Table 1). Age, BMD, and intramedullary diameter did not show a significant effect ($p > 0.05$) on stiffness for either screw size. Different mechanisms of failure were noted to occur with each screw type. During insertion of the 6.5 mm screws, excellent purchase was appreciated subjectively in all cases. When the right metatarsals (6.5 mm screw) were loaded, the fracture opened laterally due to collapse and crushing of the medial metaphyseal bone in the proximal fragment. During insertion of the 5.0 mm screws, good purchase was appreciated in seven of twelve metatarsals, while poor purchase was noted in five cases. When the left metatarsals (5.0 mm screws) were loaded, the metatarsal shaft translated distally along the screw secondary to loss of thread purchase, enabling the fracture to open at variable loads.

Pull-out strength

The pull-out strengths of the 6.5 mm screws were significantly greater ($p < 0.05$) than the pull-out strengths of the

Table 1: Fracture stiffness results, bone mineral density, and medullary canal diameters for specimen pairs one to 12. Because the lever arm varied between specimens, the stiffness values have been normalized to a standard lever arm of 40 mm.

Specimen pair	Stiffness: 6.5mm screw (N/mm)	Stiffness: 5.0mm screw (N/mm)	BMD: right (g/cm2)	BMD: left (g/cm2)	Diameter: right (mm)	Diameter: left (mm)
1	12.6	40.9	0.536	0.490	5.2	6.0
2	9.5	0.5	0.279	0.243	6.0	6.3
3	15.1	39.1	0.505	0.591	4.8	4.8
4	25.1	7.4	0.372	0.352	8.6	7.8
5	7.6	1.9	0.421	0.486	6.0	5.6
6	14.8	35.8	0.633	0.500	4.8	5.2
7	18.8	34.5	0.512	0.521	4.8	5.2
8	5.2	6.0	0.303	0.350	4.8	4.8
9	16.3	1.2	0.632	0.570	5.2	4.8
10	1.2	4.5	0.162	0.121	8.6	8.9
11	1.6	3.4	0.430	0.498	8.6	8.6
12	1.3	1.4	0.206	0.317	6.3	6.3

Table 2: Pull-out test results, bone mineral density, and medullary canal diameters for specimen pairs 13 to 23.

Specimen pair	Pull-out: 6.5mm screw (N/mm)	Pull-out: 5.0mm screw (N/mm)	BMD: right (g/cm2)	BMD: left (g/cm2)	Diameter: right (mm)	Diameter: left (mm)
13	1588.0	608.2	0.338	0.307	5.6	5.2
14	342.1	137.3	0.290	0.287	7.1	6.7
15	266.1	355.6	0.266	0.392	8.6	7.8
16	416.9	166.8	0.496	0.548	6.7	7.1
17	429.2	304.1	0.234	0.268	6.0	5.2
18	588.6	258.7	0.296	0.313	4.8	4.8
19	2006.1	1167.4	0.420	0.428	4.8	4.8
20	2019.6	849.8	0.573	0.540	5.2	5.6
21	1448.2	6.1	0.495	0.464	7.1	7.1
22	1861.4	164.3	0.308	0.362	6.3	5.6
23	445.1	566.5	0.297	0.363	5.2	4.8

5.0 mm screws ($n = 11$ pairs), confirming the subjective impression of poor purchase with the 5.0 mm screws. Screw diameter and BMD had a significant ($p < 0.05$) effect on pull-out strength, while the effects of medullary canal diameter, age and sex were not significant ($p > 0.05$). In two specimens, the 5.0 mm screws had greater pull-out strengths. In both specimens, the difference in pull-out strength was small, and both left metatarsals had a greater BMD and a narrower medullary canal diameter than their opposite right metatarsal. This combination of factors may explain the superiority of the smaller screw in these two cases. The one fractured right metatarsal still had a stronger pull-out strength than its opposite left metatarsal.

DISCUSSION

Jones fractures of the fifth metatarsal can be treated non-operatively with a non-weight bearing cast. However, non-operative treatment carries a significantly higher risk of delayed or non-union,[2,7] while operative treatment can shorten healing time and enable athletic patients to return to their sporting activity sooner.[3,4] The indications for surgery include acute fractures in athletes and painful delayed or non-unions in the non-athletic population. Since intramedullary screw fixation of Jones fractures was originally described, many favorable reports have been published.[4,5,7,9] DeLee and co-workers reported on ten athletes, all of whom returned to sports in an average of 8.5 weeks following surgery.[4] They used the 4.5 mm ASIF malleolar screw and recommended the longest screw which fit into the medullary canal of the individual. Mindrebo et al. reported on nine athletes with acute Jones fractures treated with percutaneous intramedullary screw fixation. Their patients also returned to full competition in an average of 8.5 weeks following surgery. Despite these good results, intramedullary screw fixation does not ensure union.[5] Glasgow and co-workers reported on the failure of surgical management of Jones fractures in eleven patients, six of whom had intramedullary screw fixation. They noted that the use of a screw other than the 4.5 mm malleolar screw correlated with failure.

Recently, investigators performed a biomechanical study comparing 4.5 mm cannulated with 4.5 mm non-cannulated screws for the fixation of Jones fractures.[12] They noted no difference between screw types in three-point bending tests with the superior contact point on the dorsal surface of the metatarsal, 2 mm distal to the fracture site. The metatarsals were loaded in a dorsal-to-plantar direction and failure occurred at the dorsal surface of the distal fragment or the plantar surface of the proximal fragment. When we evaluated this fracture model in preliminary testing, we noted a predominantly shearing force at the fracture site with no opening of the lateral cortex. Because non-unions are visible on the lateral cortex clinically, we opted to perform cantilever bending in a lateral-to-medial direction in an attempt to more closely simulate clinical failure. The methods applied for biomechanical testing are critical and may be responsible for the different findings between studies. The shortcomings of our study include an average donor age of 74.6 years. Likewise testing with cyclical loading and torque forces as opposed to pure cantilever bending would have simulated the clinical situation more closely. The different pitch and thread diameter of the two screws types could not be standardized, but do introduce a margin for error.

Cantilever bending stiffness testing revealed two mechanisms of failure. The lateral cortex of the right metatarsals (6.5 mm screws) opened during loading because the metaphyseal bone proximal to the fracture collapsed under load. The lateral cortex of the left metatarsals (5.0 mm screws) opened during loading because the metatarsal effectively slid off of the 5.0 mm screw which had achieved a poor purchase. The greater pull-out strengths of 6.5 mm versus 5.0 mm screws supports this mechanism of failure. BMD had a significant influence on pull-out strength, but did not correlate significantly with donor age. This highlights the importance of BMD measurements in biomechanical studies using cadaver bone.[10,11]

In clinical practice, we use a variety of screw types for the intramedullary fixation of Jones fractures, but the most common screw type reported in the literature is the 4.5 mm short-threaded lag screw or "ASIF malleolar screw" (Synthes (USA), Monument, CO).[3-5,7,9] Based on clinical experience and the experience gained through this study, we believe that 4.5 mm and 5.0 mm screws may often be too small to achieve optimal fracture stabilization. If the medullary canal is large, the cancellous bone is poor, or the screw purchase is weak, a larger diameter screw should be considered. We suggest the use of a short, wider diameter screw rather than the use of a longer screw as has been previously recommended.[4] The fifth metatarsal has a lateral curvature, and a long screw will attempt to straighten the curved bone, opening the lateral cortex at the fracture site, potentially predisposing to non-union. We feel that the appropriate screw length is the shortest screw capable of having all its threads distal to the fracture site. The starting point for the screw must be medial to the tuberosity tip while remaining extra-articular, to ensure a straight passage into the medullary canal. Inserting the screw perpendicular to the fracture site creates compression rather than shearing forces as the screw is tightened. In the 23 metatarsals fixed with the 6.5 mm screws, we encountered two longitudinal fractures during screw insertion. Both metatarsals had small canal diameters of 4.8 mm, indicating that one must be prepared to adapt the screw diameter to the size of the medullary canal of the metatarsal, not unlike reaming a long-bone fracture. If the 4.5 mm or 5.0 mm screw has poor purchase, it should be removed, the canal drilled with a 4.5 mm drill, and a 6.5 mm screw inserted after tapping the canal with a 6.5 mm tap. We have shown that most metatarsals can safely accommodate a 6.5 mm screw and that the larger diameter screw provides better pull-out strength. Despite the biomechanical advantages of the 6.5 mm screws, their usage is not recommended for canal diameters of less than 5 mm.

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