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FAS 951 No. of Pages 7

ARTICLE IN PRESS

Foot and Ankle Surgery xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Foot and Ankle Surgery

journal homepage: www.elsevier.com/locate/fas

Arthrodesis of the first metatarsophalangeal joint—A biomechanical comparison of four fixation techniques

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ARTICLE INFO

Article history:
Received 21 February 2016
Received in revised form 17 June 2016
Accepted 11 July 2016
Available online xxx

Keywords:
Arthrodesis
First metatarsophalangeal joint
Biomechanical testing
Dorsal plate

ABSTRACT

Background: Arthrodesis of the first metatarsophalangeal joint is a commonly performed orthopaedic procedure. The optimum method of fixation and joint surface preparation has yet to be determined.
Methods: This study compared four fixation techniques:

* Crossed cannulated screws with cup-cone reaming of the joint surface;
* Dorsal plate with separate interfragmentary screw and cup-cone reaming of the joint surface;
* Dorsal plate with separate interfragmentary screw with planar preparation of the joint surface;
* Dorsal plate alone with cup-cone reaming of the joint surface.

Biomechanical grade sawbones were used. The dorsal plate used was a titanium, anatomically contoured locked plate.
Testing was performed using an Instron machine applying force from the plantar aspect of the fused joint. Each fused sample was tested to failure. Stiffness, as calculated from the force-displacement curve, and ultimate load tolerated were recorded for each sample. The method of failure of each sample was also documented.
Results: Constructs arthrodesed using dorsal plate with separate screw groups, regardless of method of joint preparation, were the stiffest ($p < 0.001$). The weakest construct was dorsal plate alone without interfragmenary screw. There was no difference in stiffness between planar and cup-cone joint preparation ($p = 0.99$).
Maximum load tolerated was similar when comparing Crossed Screws with dorsal plate with screw with either cup-cone or planar reaming ($p = 0.93$, $p = 0.89$ respectively). Dorsal plating alone tolerated a significantly lower maximum load than Plate with Screw Groups or Crossed Screws ($p < 0.001$).
Conclusion: This study confirms that an IFS combined with a dorsally positioned locked-plate is the ideal construct, with the joint preparation technique of little consequence.

1. Introduction

Arthrodesis of the first metatarsophalangeal joint (MTPJ) was first described by Clutton in 1894 for the treatment of hallux valgus. Today, it is a commonly performed procedure in the treatment of disorders of the great toe including hallux valgus, hallux rigidus, rheumatoid arthritis, neuromuscular instability and as a salvage option for failed procedures [1–3].

The primary aims are reduction of pain and restoration of function. The ideal fixation should be simple, reproducible, have a high rate of fusion and low incidence of complications.

A good outcome following arthrodesis is dependent on two factors: rigid fixation and compression to promote primary bone healing and maintenance of bony position for functional success. Therefore, the current literature focuses on rigid internal fixation. Furthermore, fixation strong enough to allow early weightbearing without compromising fixation would be highly desirable.

A number of techniques for both fixation and joint preparation have been described.

Joint preparation for arthrodesis has traditionally been performed using planar cuts of the bone ends. Planar excision is

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http://dx.doi.org/10.1016/j.fas.2016.07.005
1268-7731/

Please cite this article in press as: E. Harris, et al., Arthrodesis of the first metatarsophalangeal joint—A biomechanical comparison of four fixation techniques, Foot and Ankle Surgery (2016), http://dx.doi.org/10.1016/j.fas.2016.07.005

simple and allows fine adjustment of the proposed angle of fusion. Convex-concave reaming, initially proposed in the 1950s, is becoming increasingly popular [4–8] due to its inherent stability with large surface area, compressive properties and the possibility for improved bone preservation which is particularly helpful in salvage procedures [9].

Fixation methods described include external fixators, Kirschner wires, Steinmann pins, interfragmentary lag screws (IFS) in various alignments, dorsal plates, staples, sutures or a combination of these methods [1,3,7,8,10–16].

Biomechanical studies have shown that cup-cone reaming and fixation with a dorsal plate in combination with lag screw is the most stable construct [17–19]. Single or crossed interfragmentary screws also provide good fixation.

However, the incidence of non-union runs from 5.4% to 10% [3,10] and malunion and hardware removal rates comprise 6.1% and 8.5% of cases respectively [3]. As a result, there is still a need to determine the most effective method of fixation in order to minimise the incidence of these complications.

Therefore, understanding the biomechanical features of methods of arthrodesis may provide greater insight into what the most optimal osteosynthesis technique might be.

For many years, our personal practice has consisted of an IFS in compression combined with a dorsally positioned plate.

The aims of this study were to biomechanically compare the construct combining an interfragmentary lag screw with a dorsal plate, using two different joint preparation techniques, with the most popular construct (2 Crossed Screws) and also to emphasise the importance of the IFS in improving the stability and rigidity of the arthrodesis.

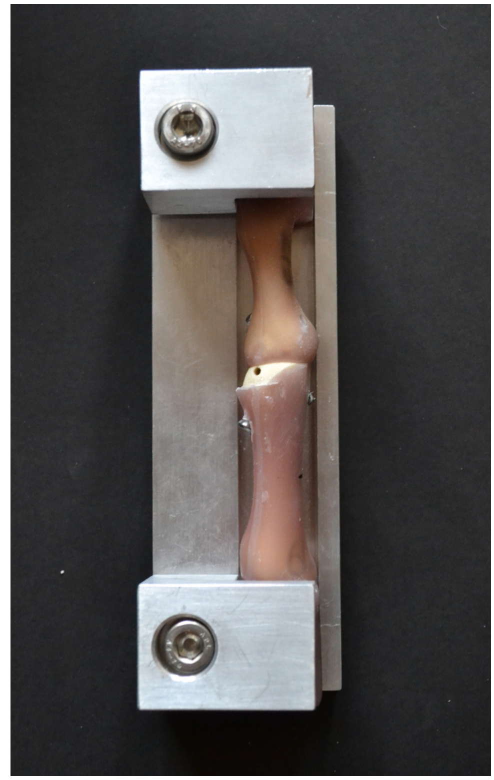

Fig. 1. Jig to ensure construct standardisation.

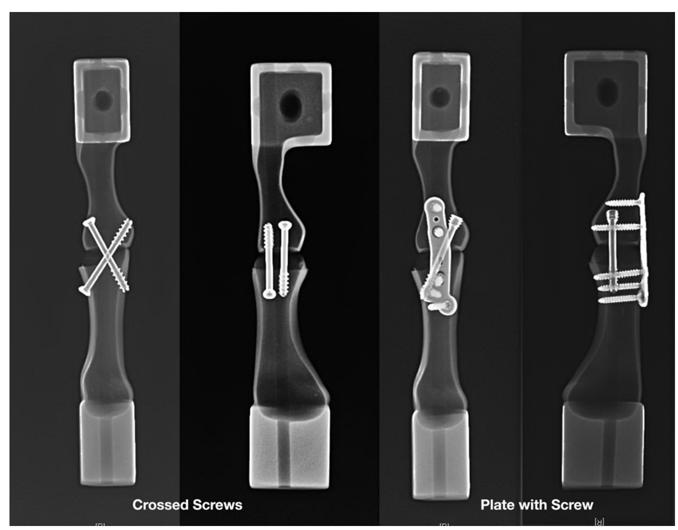

Fig. 2. Xrays of Crossed Screw and Plate and Screw fixation methods.

2. Materials and methods

2.1. Materials

- Four combinations of fixation and joint preparation were compared:

Technique 1: two crossed interfragmentary lag screws with cup-cone reaming of the joint surface ('**Crossed Screws**').

Technique 2: anchorage plate (Laboratoire Mémométal Stryker) with separate interfragmentary lag screw, and cup-cone reaming of the joint surface ('**CC Plate Screw**').

Technique 3: anchorage plate with separate Interfragmentary lag screw and planar reaming of the joint surface **('PL Plate Screw'**).

Technique 4: dorsal plate alone without interfragmentary screw and cup-cone reaming of the joint surface ('**Plate No Screw**').

- Twenty sets of metatarsal/proximal phalanx synthetic biomechanical grade bone models (Sawbones, Pacific Research Laboratories, Malmo, Sweden) were fused using the techniques outlined above. These synthetic bone models consist of a standardized left sided first metatarsal and proximal phalanx pair mimicking that of human cortical bone with a cancellous centre. They demonstrate similar compressive, tensile and shear strength and modulus of elasticity to human bone. They were chosen to reduce variability introduced by the use of cadaveric specimens. Four groups were tested, each containing five specimens.
- Joint surfaces were prepared by machine in one of two fashions: cup-cone reaming using 20 mm reamers supplied with the Anchorage plate or with laser guided planar cuts where the proximal phalanx was cut perpendicular to the shaft and metatarsal was cut in 25° dorsiflexion and 10° valgus relative to the metatarsal shaft. All reamed and planar cut constructs were the same total length.
- The position of the arthrodesis was standardised using a customised fabricated jig to ensure accurate plate, screw and bone positioning (Fig. 1).
  - In the first group the crossed interfragmentary screws used (Stryker® Asnis, 4.0 mm partially threaded) were placed obliquely 1 cm proximal to the arthrodesis site from the medial aspect of the proximal phalanx, across the MTP joint and through the lateral cortex of the first metatarsal. This was repeated in mirror image on the lateral side.
  - The second and third groups differed in the method of joint preparation but were stabilised using the same method: plate