

Box Fusion or Screw Fixation? A Comparative Study on Correcting Hallux Rigidus, Using an In-Vitro Biomechanical Model

Adnan A. Faraj¹, Asheem Naraen², Peter Twigg³

1- Orthopaedic Department, Airedale General Hospital, Keighley;
2- Orthopaedic Specilaist Registrar, Hull Royal Infirmary, Analby Rd, Hull,
3- Medical Engineering lab, university of Bradford, West Yorkshire, UK
E-mail: shevanfaraj@hotmail.com

Abstract: Fusion of the metatarsophalangeal joint (MTPJ) of the big toe for osteoarthritis involves fixation of the two ends of the bone. Ideally the fixation method should lead to a high rate of fusion with minimal complications. In this study, the current practice of screw fixation and circlage wiring for MTPJ fusion were evaluated, using an in-vitro biomechanical model.. The two fusion models proved to be remarkably similar. Whereas the former required to break or permanently deform the joint, the latter was stronger by almost an order of magnitude. The use of circumferential wire fixation for osteoporotic bones where screw hold is suboptimal, may offer some advantage. However, in the presence of quality bone, screw fixation may be preferable.

Keywords: Fusion, big toe, MTPJ, screw, wire, vitro, study

Introduction

Many operations have been advocated for hallux rigidus over the years. Some have shown very good results whereas others have not gained popularity. Excision arthroplasty, dorsal wedge osteotomy at the base of the proximal phalanx or the distal 1st metatarsal, cheilectomy, arthrodesis and replacement arthroplasty are some of the principles of dealing with hallux rigidus. Arthrodesis remains the most popular surgical procedure for hallux rigidus. Several methods are commonly used to stabilize the arthrodesis until its union [1,5,7,8,,11]. All these procedures can fail in some subjects, especially those with poor peripheral circulation. Indeed, up to 20% of patients require secondary surgery [10].

One of the predisposing factors for the failure of fusion is the method of fixation; there are over ten ways of fixation of arthrodesis, reflecting the true reality, that there is still no ideal method of fixation. Screw fixation and circlage wiring have been in use since the sixties for metatarsophalangeal joint (MTPJ) fusion [10]. In this study, the strength of first MTPJ fusion, using circumferential wiring technique (Box technique) and screw fixation, was evaluated.

Materials and Methods

The bones of the hallux were simulated using nylon 66 extruded rod, 25 mm in diameter. Fifteen millimeter wide flats were machined onto the top and bottom of this rod, giving a truncated circular section 20 mm thick. The distal bone analogue was 50 mm in length, with the ends cut perpendicular to the long axis. The proximal bone analogue was 75 mm in length and was clamped 50 mm from the fusion site by passing the nylon through a 25 mm diameter hole in a 20 mm thick steel bar, with retaining bolt acting on the superior surface of the bone analogue. This clamping bar was welded to a steel plate for stability and support. A shallow countersunk depression was made on the superior midline of each distal bone analogue, 20 mm from the fusion surface. This depression was the point of application of the applied load, resulting in a built-in-support cantilever loading mode (Fig. 1).

Holes were drilled for the fusions as per the surgical procedures and the bone analogues were wired or screwed as described above. The tests were performed using an Instron 430 hydraulic tensile testing machine, in compression mode, using a 1 kN load cell. The crosshead speed was 1 mm min⁻¹, with a sampling rate of 1 Hz and the tests were conducted in displacement control mode (Fig 1).

Results

Mechanical testing results, demonstrating joint displacement with applied load for the two fixation methods is shown in Fig 2. Table 1 shows results calculated from the force-displacement curves. Elastic stiffness was calculated from the initial straight line section of the load-displacement curves. By plotting stiffness gradients, shifted by 1 mm along the displacement axis, proof loads and proof displacements could be defined for 1 mm inelastic deflection, where these gradients cross the measured curves. It was noted that some slippage occurred on applying the load (below 0.05 kN) in the screw fixation test and this was allowed for in the calculations.

Discussion

The type of fixation of the MTPJ arthrodesis used for hallux rigidus and the biomaterial of fixation has become a point of discussion and controversy. The following points are of concern: the strength and rigidity of fixation, hence reliability in holding the arthrodesis together while osseous union takes place, the complications of the material used, and the complexity of revision surgery when required.

The methods available for MTPJ fixation involve procedures using intramedullary steinmann pins, crossed K-wires, staples, external fixation to induce compression across the arthrodesis, 4 mm cancellous screws or ante-grade Herbert cannulated screw fixations to dorsal tubular plates. Various rates of success following different techniques have been reported [1-6,8,10,11]. Several biomechanical experimental studies have been

conducted in-vitro on cadavers and laboratories to investigate the most effective method of fixation following fusion of the MTPJ. A simulated MTPJ arthrodesis was performed on 18 pairs of cadaveric great toes [7]. One toe of each pair was fixed with a 4.0-mm oblique AO (Associat osteosynthetic) cancellous screw. The contralateral toe was fixed with one of three techniques: 1) a dorsally placed miniplate; 2) a 4.5-mm Herbert cannulated screw placed from the metatarsal neck into the medullary canal of the proximal phalanx; or 3) a 3/32-inch Steinmann pin placed longitudinally. An oblique 0.045 Kirschner wire was added with each method. The specimens were tested to failure in dorsiflexion. The miniplate was significantly stronger than the AO screw in force to failure and initial stiffness. The Herbert cannulated screw was also significantly stronger in force to failure than the AO screw. There was no significant strength difference between the Steinmann pin and the AO screw [7].

In a study, Politi et al [6] used Instron materials testing device for loading of the first MTPJ in dorsiflexion. Liquid metal strain gauges were placed over the joint and micromotion was detected with varying loads and cycles, they compared the strength of fixation of five commonly utilized techniques of first MTPJ arthrodesis. These were surface excision with machined conical reaming and fixation with 1) a 3.5 mm cortical interfragmentary lag screw; 2) crossed 0.062 Kirschner wires; 3) a 3.5 mm cortical lag screw and a four hole dorsal miniplate secured with 3.5 mm cortical screws; 4) a four hole dorsal miniplate secured with 3.5 mm cortical screws and no lag screw; and 5) a single oblique (planar) 3.5 mm interfragmentary cortical lag screw. It was concluded that interfragmentary lag screw and dorsal plate was two times stronger than an oblique lag screw alone. Dorsal plate alone and Kirschner wire fixation were the weakest techniques.

Plate fixation is probably too invasive and associated with higher rate of implant related complication. Soft tissue stripping and associated infection if and when it does occur, jeopardizes the biology of bone healing across the fusion. Plate and screw fixation may especially be difficult to perform in patients with poor bone quality like rheumatoid patients or patients on steroids. Due to the decreased holding power of screws in osteoporotic bone, internal fixation failure rate is in the range of 10-25%. Screws placed in the cortical bone have better resistance to pullout than do those placed into adjacent trabecular bone. Tension band construct are better alternatives for osteoporotic trabecular bone. Our study has revealed that circumferential wire fixation is weaker than screw fixation. In vivo, with the help of plaster immobilization, the box fixation (simple technique) appears to give fairly stable fixation. Furthermore, circlage wire technique allows adjustment of the position of the toe by undoing the knot if need be; this is not as easy when a screw is used. Properly done, the boxed wire method can be much more effective than using a screw. With screw fixation, the center of rotation is no longer in the central portion of the fusion. Thus the outer portion of the fusion, as shown by hard-ware analogy, is free to open up when the muscle forces id applied, this is counteracted only partially by the rigidity of the screw. In addition screw is subjected to bending

stresses. Screws are not designed (or intended) to withstand significant bending stresses and the latter should be avoided and minimised.

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Figures

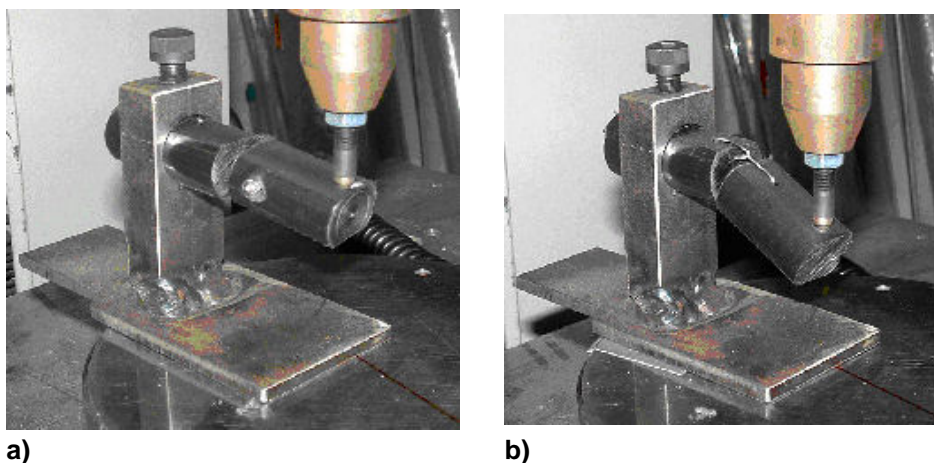


Figure 1: Mechanical testing method, showing the sample clamping and load application for a) screw fixation and b) wire fixation.

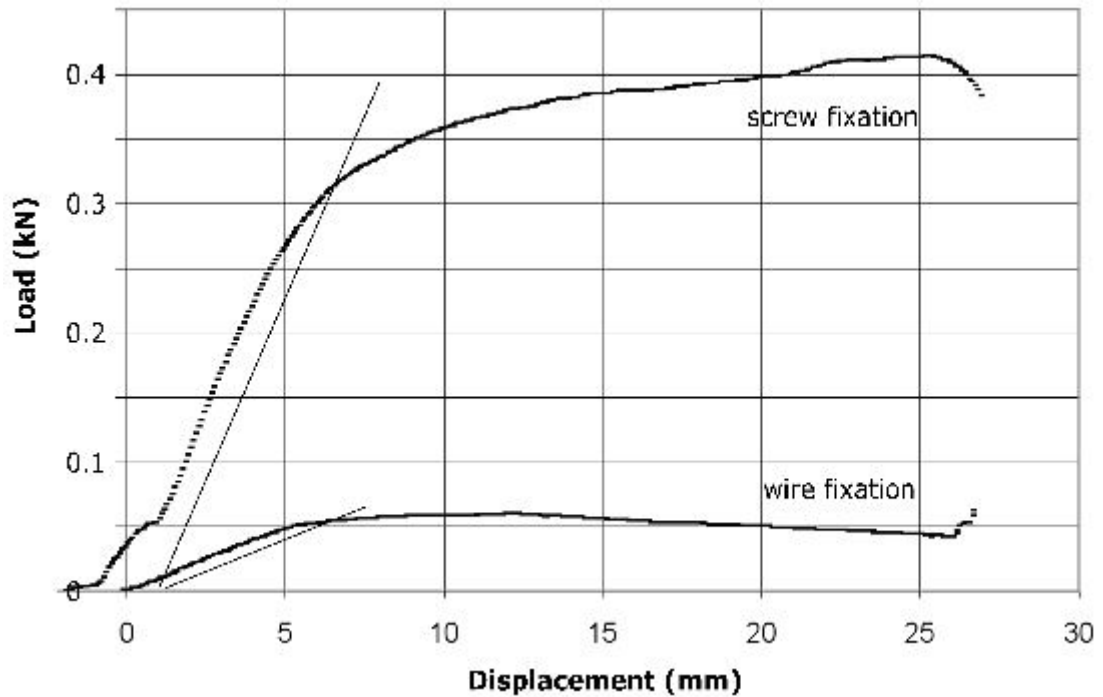


Figure 2. Mechanical testing results, showing joint displacement with applied load for the two fixation methods. The straight lines follow the elastic part of the deflection curve and are shifted by 1 mm along the displacement axis.

Table 1. Results calculated from the force-displacement curves

	Wire Fixation	Screw Fixation	
Elastic stiffness	0.0098	0.0565	kN mm ⁻¹
Peak load	0.060	0.413	kN
Extension at peak load	12.3	12.3	mm
Proof load (1mm)	0.054	0.315	kN
Proof extension (1mm)	6.55	6.57	mm