RELATIVE STRENGTHS AND EFFICACY OF FIXATION TECHNIQUES IN OSTEOTOMIES AND ARTHRODESIS OF THE FIRST METATARSAL

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OBJECTIVE

The purpose of this project is to relatively quantitate and compare the stress/strain characteristics of different internal fixation techniques for the first metatarsal. The authors will study techniques commonly utilized for fixation purposes in first metatarsal osteotomies, metatarsophalangeal joint fusion, and metatarsal-cuneiform fusion. In this study, the authors will also present and test several new different techniques for fixation of the oblique base wedge osteotomy.

METHOD

The following osteotomies of the first metatarsal will be tested with various fixation devices.

I. ANATOMICAL REGIONS
- A. Base of metatarsal
  1. Lapidus Arthrodesis (1st met-cuneiform fusion)
     - a. Staple (2 or more)
       1. Stapilizer vs. Blounts
     - b. Crossed K-wire (Pittsburgh Podiatry, 1989)
       1. 0.045, 0.062 Steinmann Pins
     - c. AO Screw (Rutherford)
       1. Single vs. Double
       2. 2.7-mm, 4.0-mm
     - d. Plate
       1. Semi-tubular vs. DCP (5 or 6-hole)
       2. Medial vs. Dorsal placement
     - e. Plate and Screws
       1. Podiatry Institute (Ruch)
       2. Semi-tubular plate and 4.0-mm screw
  2. Base Wedge Osteotomy (transverse vs. oblique)
     - a. Monofilament wire
       1. Dorsal vs. intra-osseus loop
       2. Variation in wire gauges
     - b. Kirschner wire
       1. Single vs. double
       2. Crossed
     - c. Staple
       1. 1 vs. 2
       2. Stapilizer vs. Blounts
     - d. Screw
       1. Single vs. double
       2. 2.7-mm, 4.0-mm
       3. Orientation

e. Plate
    1. Semi-tubular vs. DCP
    2. Positional
f. Screw and Monofilament wire
    1. Orientation: dorsal wire vs. plantar wire
    2. Variation in wire gauges
g. Tension Band - plantar
    1. Threaded K-wires
    2. Monofilament Wire

B. Metaphyseal and Head
1. McKeever Arthrodesis
    a. K-wires
        1. Single vs. crossed
        2. Smooth vs. threaded
    b. Staple
        1. 1 vs. 2
        2. Stapilizer vs. Blounts
    c. Plate
        1. With screws (Interfragmental and plate screws)
        2. Dorsal vs. Medial
    d. Screws
        1. Single vs. double
2. Scarf Osteotomy
    a. Traditional Cut - dorsal shelf
        1. Cortical screw fixation
    b. Inverted Osteotomy
        2. Cortical screw fixation

(Distal metaphyseal procedures will not be included in the study)

MATERIALS

1. Stress/Strain Device (Podiatry Institute) (Fig. 1)
2. Instron Stress/Strain Model (Philadelphia)
3. Internal fixation devices: K-wires, staples, screws, plates, monofilament wire
4. Plastic Foot Bones

DISCUSSION

For the podiatric physician, evaluation and surgical treatment of the first metatarsal is commonly encountered. An important aspect in a sound surgical approach is consideration to the fixation technique utilized to assure a stable intra-operative and postoperative result. Knowledge of the stress/strain characteristics and limitations these techniques possess is invaluable in dictating

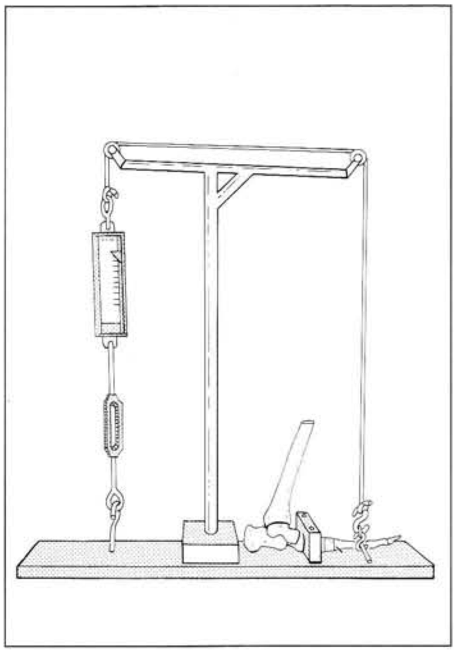

Fig. 1. Testing apparatus for quantifying strength of various internal fixation techniques. The midfoot is rigidly secured while dorsal forces at placed upon the first MPJ.

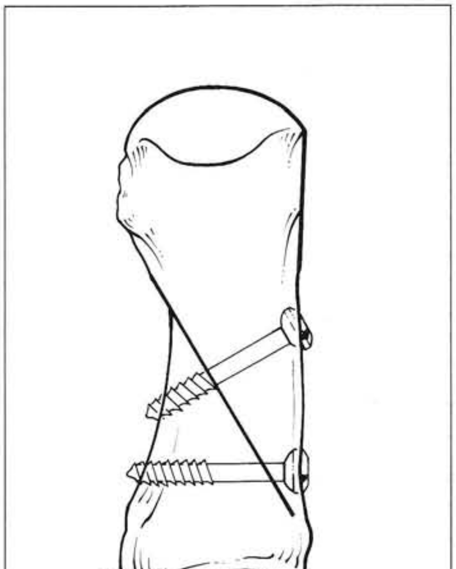

Fig. 2. Illustration of base wedge fixation technique utilizing a proximal "anchor" screw perpendicular to the metatarsal and a distal screw perpendicular to the osteotomy.

patient instruction and activity in the recovery period.

With proximal osteotomies of the first metatarsal, the goal of adequate stability in fixation techniques is more difficult to achieve. Traditionally, base wedge and met-cuneiform osteotomies have been treated with a non-weightbearing postoperative status. These osteotomies are inherently subject to increased disruptive forces and have relied on immobilization for proper osseous fusion.

Preliminary stress/strain trials have been run for different base wedge fixation techniques. Determination of the actual fulcrum or moment arm around which dorsal forces are transmitted is important in the potential design of a new fixation model. This can be determined with stress/strain evaluation of the present 2 x 4.0-mm cancellous screw fixation technique and studying the level of failure. The proximal screw is oriented perpendicular to the metatarsal shaft and the distal screw perpendicular to the osteotomy. (Fig. 2) Modifications to this fixation technique are described in Table 1.

TABLE 1

Model No.	Modifications	Failure
#1	None	7.5 lbs
#2	None	8.3 lbs
#3	Double Interosseus Loop: Dorsal-Proximal (Fig. 3) Plantar-Distal	6.5 lbs
#4	Double Interosseus Loop: Plantar-Proximal (Fig. 4) Plantar-Distal	6.5 lbs
#5	Circumferential Monofilament Wire Loop between the two screws	6.5 lbs
#6	Sagittal (Dorsal/Plantar) Interosseus Loop Proximal and Distal to the osteotomy site	9.0 lbs
#7	Threaded K-wire proximal and distal to osteotomy site with monofilament connecting K-wires plantarly	9.2 lbs
#8	Same as above except distal threaded K-wire placed between middle and distal 1/3 of metatarsal shaft	14.5 lbs
#9	Same as above	15.0 lbs
#10	Intact Bone model	18.0 lbs

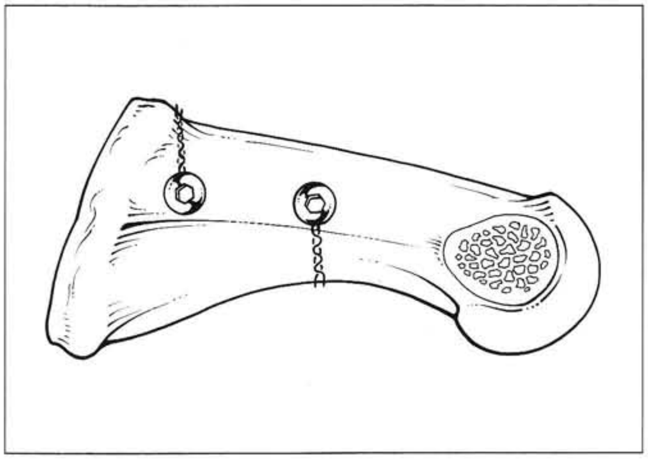

Fig. 3. Modification to the base wedge fixation. A double 28-Gauge mono-filament wire is wrapped around the screw heads medially and the threads laterally. This configuration attempts to stabilize the osteotomy against rotation around the distal screw.

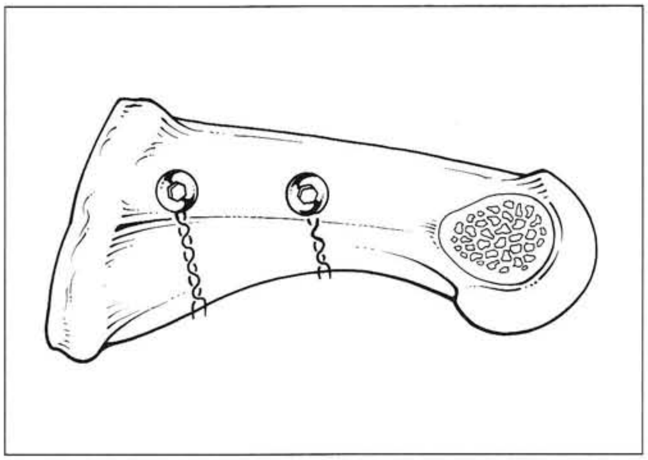

Fig. 4. Modification to this configuration attempts to stabilize the osteotomy against rotation around the proximal screw.

When the models failed in the stress/strain device, all the fractures originated through the plantar cortex from either the proximal or distal screw hole. (Fig. 5) Analysis of the preliminary data illustrates a bimodal distribution of stress failure. The first five models all failed at 6-8 pounds. A significant increase in stress failure in models 8 and 9 was seen.

After carefully evaluating the mode of failure in these models, attention is presently directed to controlling the dorsal movement/distraction of the plantar cortex across the osteotomy. Although the traditional base wedge fixation technique offers stability across the osteotomy site, this technique provides minimal mechanical ability to resist the dorsal/distal movement of the plantar cortex during dorsal stress. Even minimal dorsal movement afforded by displacement forces proves significant enough to cause failure of the fixation. While these modifications may provide additional stability to the osteotomy site, the modifications tested in models 3-5 provided minimal additional plantar cortex immobilization, showing no significant increase in stress resistance. Fixation providing added stability to the osteotomy may be considered "intrinsic" fixation; however, no additional stability is added to resist plantar tension leading to failure. The common limiting factor to failure of the base wedge fixation and modifications 3-5 is the strength of the bone. The bone is already at a disadvantage to resist dorsal forces because the plantar cortex (tension side) has been violated with the osteotomy.

Attempts to prevent even minimal dorsal/distal distraction of the plantar cortex (tension side) may provide insight to improvement of present fixation, and development of "extrinsic" fixation techniques. With the "extrinsic" techniques, the limiting factor is no longer the bone but now the fixation devices themselves. Theoretically, the strongest form of fixation to prevent even minimal plantar movement/distraction would be a plantar plate. This would effectively stabilize the tension side of the bone with weightbearing. However, due to incision planning and available exposure, placement of a plantar plate is not practical.

Initial tests performed with a "tension band" concept on the plantar cortex have demonstrated significant results (Models 8 & 9). (Fig. 6) The early experimental model #7 demonstrated increased stability, yet failed with a fracture pattern from the distal wire hole to the plantar osteotomy. With this discovery, modification to this model produced model #8. This model significantly demonstrated increased stress resistance for two reasons. The distal threaded K-wire is placed distal enough to minimize communication of the stress riser from the plantar K-wire hole to the osteotomy. Secondly, as the K-wire moves closer to the metatarsal head, the lever arm to this stress riser decreases.

Only after a careful analysis of the present techniques, will the authors make conclusions and recommendations from their findings.

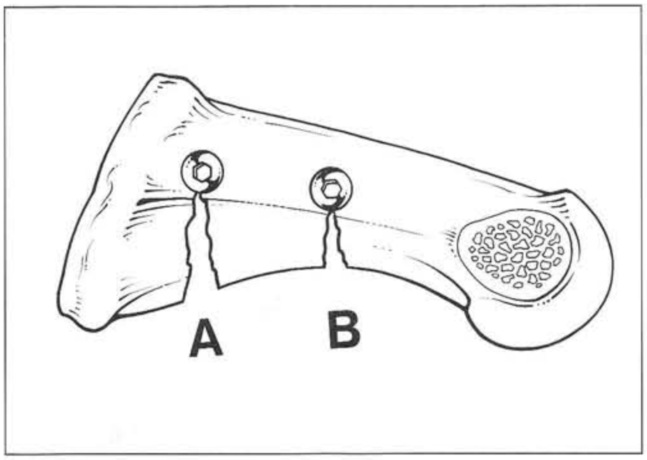

Fig. 5. Failure of the bone models occurred from the plantar osteotomy to either the proximal screw (A) or the distal screw (B). The more secure the screw placement, the osteotomy tends to fail towards the other screw.

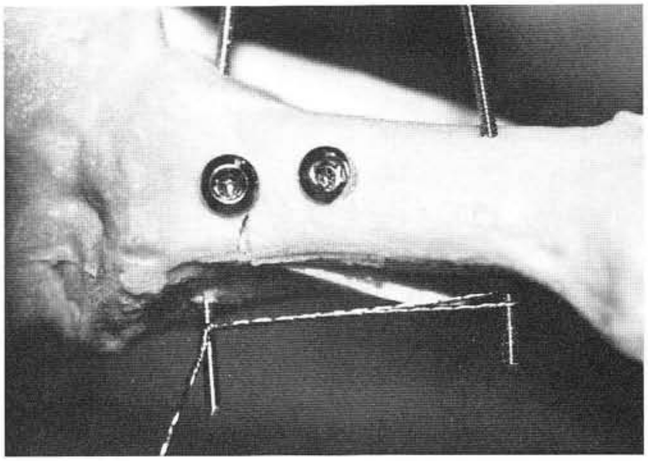

Fig. 6. Bone model illustrating the plantar "tension band" concept. This is an example of "extrinsic" fixation in which the limiting factor of failure is dependent on the fixation rather than the bone.