Impact of the Distal Tibia Structural Properties on the Mechanical Strength of Interlocking Screws for Intramedullary Nails

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Introduction: Intramedullary (IM) nailing, successfully used for diaphyseal tibia fractures since 1970s, offered the least invasive approach possible[1]. Considering the limitations of distal static interlocking options with IM nails, treatment options of distal metaphyseal tibia fractures (AO Type 43A) have favored the use of open reduction internal fixation (ORIF). However, ORIF carries a high risk of complications such as wound problems, prominent hardware, and non-unions[2-4]. Newer tibial IM nails offer greater stability with a wider variety of distal interlocking options. Despite these changes in design, we know little regarding the optimal screw pattern[5] and the effects of the metaphyseal bone structure on the screws. Our hypothesis was, therefore, that higher biomechanical stability may be obtained by having the maximum number of screws in an orthogonal conformation. In this study, we used human cadaveric tibiae to evaluate the relationship between bone morphometric properties and load carrying capacity of distal interlocking screws for IM nail.

Methods: We harvested the distal quarter of 24 cadaveric tibial bones (12 individuals) by performing a transverse osteotomy 7 cm above the tibial plafond (Type 43A fracture). The embalmed tibiae were provided by the Laboratory of Gross Anatomy. We nailed each specimen with a Stryker T2 Tibial Nail using 3 types of configuration for the distal locking: Group I: 2 parallel medio-lateral (ML) screws, Group II: 2 cross with 1 antero-posterior (AP) + 1 ML screws, Group III: 3 cross with 1 AP + 2 ML screws. The mechanical testing was done in compression using the Instron machine (Instron Corp., model 8874). The constructs were loaded using a displacement rate of 1 mm/minute to a maximum of 3 mm (Fig. 1). The apparent density of the cancellous bone around and below the screws was calculated using the Mettler Toledo® - XS104 - Analytical Balance. We measured the cortical thickness by taking direct measurement with a digital precision caliper micrometer.

Results: Our study showed that the load carrying capacity of the Group III samples was higher than that for Groups I and II, although this difference was not statistically significant (Fig. 2). As seen in Figure 3, at 3 mm displacement, there was a direct linear relationship between cancellous bone density and load carrying capacity for each specimen from Group I (R² = 0.92). Group II had a quasi linear relationship (R² = 0.72), whereas Group III showed a very poor relationship (R² = 0.05). Cortical thickness showed weak but uniform correlations with load carrying capacity at 3 mm displacement. Variations in load at 3 mm correlated with gender (p = 0.00804) but not with age (p = 0.85909). In general specimens from male showed higher load carrying capacity than those from female (fig. 4). Samples with highest values for thickness and density were older than 90 year old.

Discussion: Although not statistically significant, we observed a trend toward higher load carrying capacity for specimens with 3 screws. The treating surgeon could have the option to choose any of these configurations depending on the wound or other patient care considerations. Therefore, cost, radiation exposure from the fluoroscope, and surgical time must be considered. One of the limitations of this study was the small sample size. Seven out of the 24 specimens were osteoporotic and very difficult to be accurately tested for cancellous bone density measurement. The average age of individuals before death was 87 and 78 for females and males respectively. We assume that the load carrying capacity of the constructs may increase for younger and less osteoporotic bone tissues. We are preparing a new set of cadaveric tibia constructs to study the biomechanical behavior of the complex tibia-nail in torsion. We will also examine the relationship between load carrying capacity and bone mineral content.

Significance: The results of this study showed a trend toward highest biomechanical stability with 3 orthogonal distal interlocking screws. Surgeons could use that to find the right balance between efficient use of surgical time and resources and the biomechanical stability of the IM nail for distal tibia fracture repair.

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Figure 1. Human bone construct before (left) and after (right) mechanical compression. Arrow shows the screw cutting through the cortical bone with a 3 mm displacement.

Figure 2. Average load carrying capacity of the 3 Groups. Specimens from Group I sustained a higher load than Groups II and III at 1 mm displacement. But, at 2 and 3 mm, specimens from Group III had a higher load carrying capacity.
Figure 3. Load vs. Density graph for the 3 Groups at 3 mm displacement. Load carrying capacity for constructs with 2 screws (Groups I and II) was strongly correlated with cancellous density. Constructs with 3 screws (Group III) showed no correlation between load and density.

Figure 4. Boxplots showing Load at 3 mm displacement and gender. On the horizontal axis is gender (sex): F for female, M for male. On the vertical axis is load at 3 mm displacement (load). We can observe male specimens have a significant higher load carrying capacity.