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Preoperative Evaluation of Intramedullary Tibial Nail Measurements—A Review of the Literature and a New Technique Using Contralateral Radiographs and Digital Planning

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Abstract

Introduction: An accurate selection of tibial nail and screws measurements is paramount in purpose to achieve proper tibial fracture reduction and fixation, avoid irritation of the soft-tissue envelope, and enable extraction of the nail in the future, if needed. To this date, many methods were suggested to determine the length and diameter of an intramedullary tibial nail, preoperatively and intraoperatively. Each method has its disadvantages, and most are lacking in accuracy. Digital aids are currently available for preoperative planning for many types of surgeries.

Methods: Retrospectively, 27 patients operated for diaphysial tibial fracture intramedullary nailing were selected. The contralateral leg was imaged using AP and lateral radiograph views. Six orthopaedic trauma surgeons used the TraumaCad program (Voyant Health) to plan the appropriate nail and distal locking screws measurements, while blinded from the actual hardware used in the operation. Later, they also conducted quality review regarding the operation carried out and suggested correction in measurements of the hardware. Intra-observer and inter-observer reliability was calculated.

Results: The inter-correlation coefficient for the planned nails was 0.97 and 0.84 ($P < 0.001$) in AP view for length and diameter, respectively, and similarly 0.98 and 0.86 ($P < 0.001$) in lateral view. The interclass correlation coefficient (ICC) for the locking screws length was 0.7 ($P < 0.02$) and 0.82 ($P < 0.01$) for the proximal and distal medio-lateral screws, respectively, and 0.9 ($P < 0.001$). The ICC between AP and lateral views was 0.98 for length and 0.96 for diameter ($P < 0.001$). The scores and corrections given by the examiners to the actual selected nail were ICC of 0.98 and 0.96 ($P < 0.001$) for length and diameter, respectively. The examiners suggested they would correct, post-factum, the length of the nail in average 28% and the diameter in average 30%. The average observer resulted in ICC of 0.94 and 0.91 ($P < 0.001$) in length and only 0.77 and 0.67 ($P < 0.001$) in diameter (AP and lateral views, respectively) when comparing the actual nail used and the post-factum plan.

Conclusion: Preoperative planning of tibial fractures' nailing using imaging of the contralateral leg and a digital graphic planning program is an accurate and reliable method. It may serve to reduce errors, surgical time, and radiation dose in the operating room. This method could also be applied for surgical debriefing.

Tibial diaphyseal fractures are the most common fractures of the long bones, estimated to an incidence of 20 to 26:100,000 cases per year.^{1,2} These fractures are three times more common in men, typically of younger age (average age of 37 years). A common mechanism of injury is high-energy injuries, for example, motor vehicle accidents or falls from height; another common mechanism is indirect impacts during sport, for example, ski accidents. Nevertheless, an increase in occurrence has been noticed in the elderly population, especially osteoporotic women because of low-energy trauma.¹

Treatment options range from conservative treatment to surgical fixation. Surgical treatment includes external fixation, intramedullary nailing, or plating. Treatment selection depends on the type of fracture, the energy of the trauma, open fractures, the surgeon's preference, and the patient's previous functional status and treatment preferences. Because of its minimally invasive insertion technique and load-sharing properties, intramedullary nailing is most commonly used.³ Another advantage is the possibility and relative safety of early weight bearing.⁴

Proper nail length and diameter are of major importance for fracture fixation, patient's recovery, and final outcome. An overly long nail might disrupt proper reduction, causing malrotation or distraction of the fracture line. It could also protrude proximally and irritate the patellar tendon or, although rarely, penetrate the distal tibial plafond. On the other hand, a nail that is too short may be over-sunk into the medullary canal, which

could make nail extraction a daunting task, if required in the future. An overly thick nail requires over-reaming of the medullary canal, which may weaken the bone and possibly cause an iatrogenic secondary fracture. A nail that is too thin will not gain a stable reduction and in addition will not allow load sharing along the nail—an important principle of the intramedullary nailing technique. Accurate length of the interlocking screws is also important to achieve a hold of two cortices, while avoiding unnecessary irritation of the soft-tissue envelope.

Various methods are available for preoperative or intraoperative estimation of nail length. Previous publications on this subject have tried to find an external measurement reference during physical examination. Methods described include the “knee-ankle distance” in which nail length should be approximately 20 mm shorter than the distance between the knee and ankle joint lines.⁵ Other methods include similar approximations by calculating the distance between the medial knee joint line and the medial malleolus, the distance between the tibial tuberosity and the medial malleolus,⁶ or the distance between the olecranon to the head of the fifth metacarpal.⁷ Other methods described include a formula calculating the nail length based on patient's height⁸ or weight.⁹ None of these methods provided a highly reliable result. Moreover, an anthropomorphic analysis revealed some variance and rated the inconsistency of each of these methods, although a formulation of them was suggested.¹⁰

Other methods to estimate nail measurements include radiograph imaging using a designated ruler

or template (preoperatively or intraoperatively), radiograph imaging on a Kramer splint¹¹ and radiograph imaging of the suggested nail itself placed in its sealed box next to the patient's leg. Magnification must be taken into account because different models and manufacturers use different magnification estimation, and these were also published to be inaccurate.¹² A preoperative CT scan would be accurate to examine the length and diameter of the intramedullary canal but exposes the patient to a high radiation dose.⁸ If CT is not performed for a different indication, for example, vascular insult, it is not recommended for routine use. Of note is the adverse advantage of CT for estimating tibial torsion.¹³ A study performed on cadavers using a simple AP view with a scale ruler was 100% accurate in length measurement compared with a CT scan.⁸ However, the scale correction applied on cadavers and skeletons is not applicable in live patients.

The common method for intraoperative measurement uses a designated ruler to measure the length of the guidewire remaining outside of the tibia, assuming a known length of the whole wire. Alternatively, another identical guidewire can be used similarly. This method is relatively accurate but is not error proof. Possible pitfalls include failure to direct a bended guide's end exactly to the distal end of the medullary canal, the use of a non-standard guide, or improper introduction of the ruler, especially when using a suprapatellar approach. As mentioned, most manufacturers supply a designated ruler inside the sterile kit, allowing length and diameter measurement using fluoroscopy intraoperatively.⁸ This may require several trials for accurate

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positioning and must account for magnification. Diameter is also estimated while reaming, but this is inapplicable when using an unreamed nail.

Currently, no method was described to determine the length of the interlocking screws preoperatively. The measurement is carried out intraoperatively, using a depth gauge, and can require repeated trails of fluoroscopy screening until achieving exact positioning, thus exposing the patient and staff to radiation. Another method is enabled by a magnetic probe and a special drill, such as Trigen Sureshot (S&N). This method mandates the introduction of the distal locking nails before the proximal ones, due to the probe inside the nail.

Our hypothesis is that acquiring an accurate method for preoperative planning of the nail and screws size is advisable. It will ensure the availability of proper implants, prevent unnecessary opening of multiple expensive implants, narrow the intraoperative error margin, reduce the radiation dose to both the patient and the operating team, and decrease the operation time.

Methods

During postoperative follow-ups in our institutes' outpatient clinic, we have collected 27 cases of intramedullary nail fixation of unilateral tibial diaphyseal fracture in patients aged 18 to 80 years. The hardware used was either Trigen Meta-Nail (S&N) or T2 Tibial Nail (Stryker Orthopedics). In purpose to avoid bias due to poor surgical technique, before requirement, two senior orthopaedic surgeons examined the surgical result to be grossly satisfactory. After obtaining proper consent in accordance with our hospitals review board requirements, we attained AP and lateral radiograph

images of the ipsilateral (operated) and contralateral (healthy) leg. The radiograph image included the tibia as a whole (from the knee to ankle), while the beam was focused on the middle part. We used a designated 25-mm calibration ball which was placed adjacent to the leg to avoid magnification inaccuracies. Data of the nails implanted during the operation were obtained from the hospital medical records.

Six independent orthopaedic trauma surgeons analyzed the images digitally (Figure 1) using the TraumaCad program (Voyant Health). With the exception of the nail's manufacturer and model, the surgeons were blinded to any other information regarding patient history or implant used during surgery. Each surgeon evaluated the following variables:

- (1) Appropriate nail's length and diameter (in mm), defined as *planned nail*. The analysis was performed twice, once in the AP view and once in the lateral view of the healthy leg, selecting the closest sizes available with the specific nail's manufacturer portfolio.
- (2) Appropriate length (in mm) of the distal medio-lateral locking screws (using the AP view) and the distal AP locking screw (using the lateral view).
- (3) Quality of the operation ex post facto, regarding the actual used nail's measurements (length and diameter), was graded by a categorical scale (perfect match, too short/long, too thin/thick, respectively). The use of end-caps was taken into account. If the surgeon figured he would have altered the nail's measurement, in respect, the corrected nail's measures were calculated to the next manufacturer's available size (length or diameter), defined as *corrected nail*.

Inter-observer reliability for the following measurements, between all six

examiners, was calculated using interclass correlation coefficient (ICC):

- (1) Appropriate nails' length and diameter (planned nail) using an AP view.
- (2) Appropriate nails' length and diameter (planned nail) using a lateral view.
- (3) Appropriate distal locking screws length (two medio-lateral screws using an AP view and one AP screw using a lateral view).

Intra-observer reliability for the following variables for each examiner was calculated using ICC:

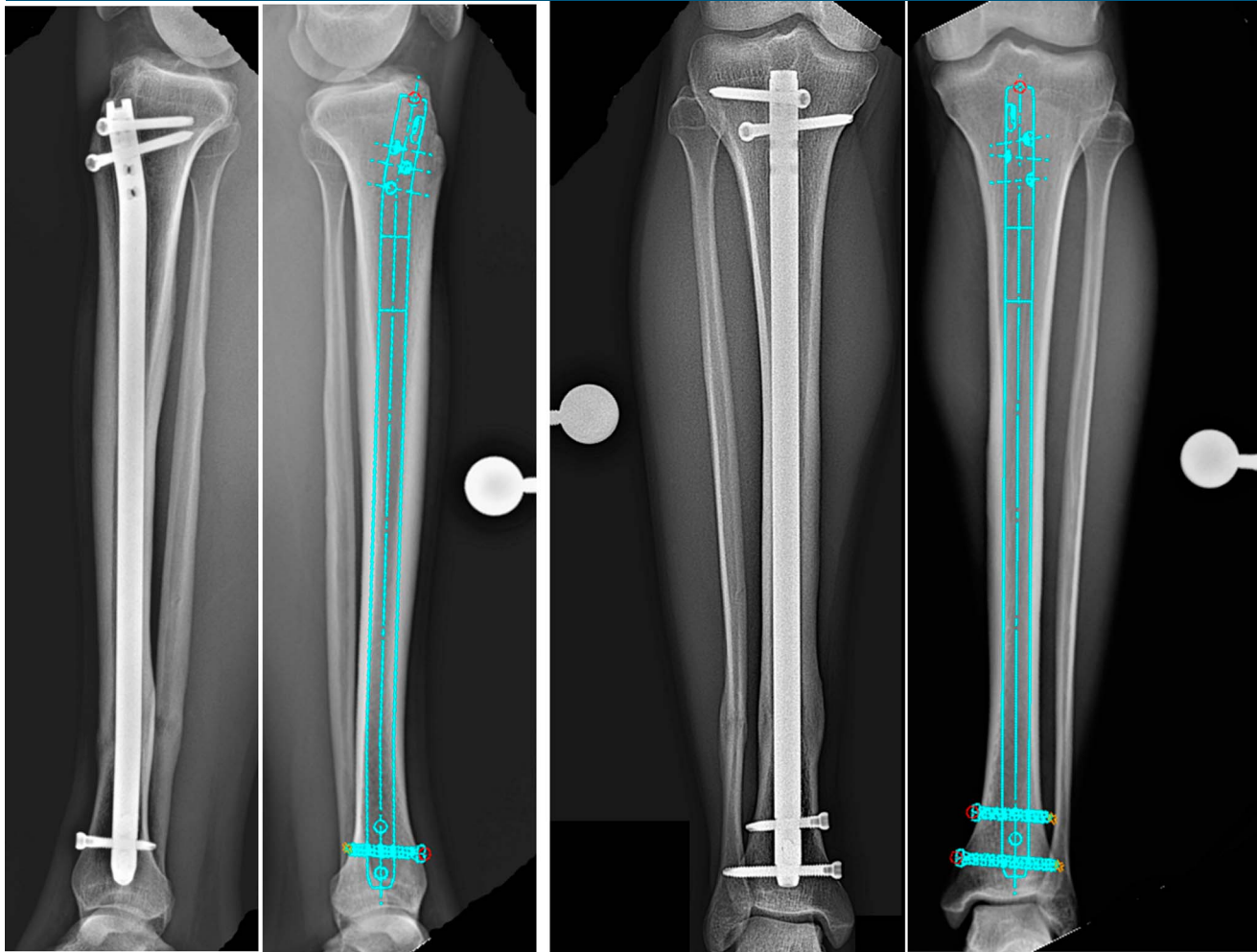
- (1) The planned nail length and diameter versus the actual used nail measures.
- (2) The planned nail length and diameter versus the calculated corrected nail measures.
- (3) The match between each examiner's planning using AP views and lateral views.
- (4) Means for the planning measures (length and diameter using AP and lateral views, separately) were computed. In addition, means for the corrected length and diameter of the actual nail used were computed. An ICC analysis was performed to compare each observer's planning to the mean corrected calculated measures. In addition, an ICC analysis was performed to compare the mean measurements of all observers and the mean corrected calculated measures.

All statistical analyses were performed using SPSS software (version 20). Significance level was set to 0.05. An ICC of more than 0.75 is considered good to excellent (Fleis 1986).

Results

The ICC for the planned nails according to an AP view was 0.97 for the length and 0.84 for the diameter ($P < 0.001$). The ICC for the planned nails

Figure 1



Radiograph showing the surgical result of the right leg tibial diaphyseal fracture fixated using the S&N Trigen nail, and digital planning using the left leg radiograph views, demonstrating a good match.

according to a lateral view was 0.98 for the length and 0.86 for the diameter ($P < 0.001$) (Figure 2). The ICC for the locking screws length was 0.7 ($P < 0.02$) and 0.82 ($P < 0.01$) for the proximal and distal medio-lateral screws, respectively, and 0.9 ($P < 0.001$) for the AP screw (Figure 3). The match between each examiner's AP and lateral planning was excellent, resulting in an average ICC of 0.98 for length and 0.96 for diameter ($P < 0.001$). The scores and corrections given by the examiners to the actual selected nail retrospectively were also mostly

reproducible, with an ICC of 0.98 and 0.96 ($P < 0.001$) for length and diameter, respectively (Figure 2).

In a retrospective analysis of the surgical results, the examiners suggested they would correct, post-factum, the length of the nail in average 28% (range 7% to 41%) and the diameter in average 30% (range 4% to 70%). When comparing the planning each examiner performed, using the healthy leg's radiographs and the actual nail that was used, the average rater resulted in ICC of 0.94 and 0.91 ($P < 0.001$) in length and only 0.77 and 0.67 ($P < 0.001$) in

diameter (AP and lateral views, respectively). This score did not improve much when comparing the planning each examiner performed and the corrected nail's measures (meaning the nail the same examiner would have used, given the postsurgical radiographs of the operated limb, knowing the measurements of the nail that was actually used). The average rater resulted in ICC of 0.96 and 0.94 ($P < 0.001$) in length and only 0.71 and 0.62 ($P < 0.001$) in diameter (AP and lateral views, respectively).

Discussion

Intramedullary nailing for tibial fractures is a common and effective treatment method. Preoperative planning of the nail and screws size could ensure proper equipment preparation, save costs, avoid gross intraoperative errors, reduce the surgery time, and radiation dose. Reducing surgical time might also contribute to surgical site infection prevention.¹⁴

We find that preoperative planning using radiograph imaging of the healthy leg is a very reproducible method. The inter-observer reliability of both AP and lateral view based planning was found to be high, with a slight advantage to lateral view-based planning. The diameter measurements were slightly more difficult to agree on. This could be because of the relatively large size of the variance in reaming, which is millimeters, comparing the measurement which is ranged usually 9 to 13 mm. However, the reproducible measure of length is not a trivial result because no distinct rules exist regarding where the nail should end distally. Yet, good inter-observer reliability was achieved. Moreover, excellent intra-observer reliability was demonstrated between the use of AP and lateral views of the healthy limb in planning both length and diameter, suggesting that a plan based on a single view could be sufficient. Based on these results, after meticulous preplanning, the nail length may be chosen in advance, but several nail diameters should be available on the shelf, and the final diameter should be determined intraoperatively. The inter-observer reliability in planning the locking screws was also good, with the exception of the proximal medio-lateral screw (ICC of 0.7, which is also considered fair), possibly because of its location in the distal metaphysic flare and the high variance which would result from different lengths or positions of nails in the planning.

Figure 2

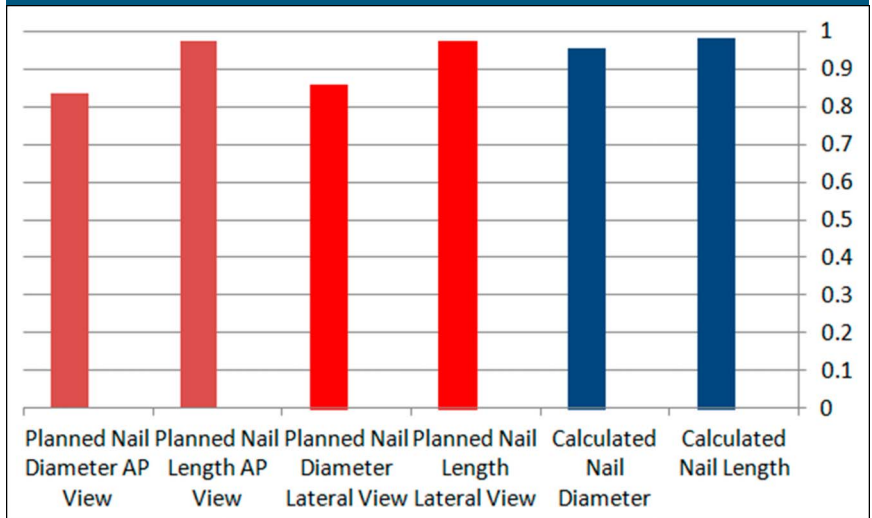


Chart showing the inter-correlation coefficient between the six raters, concerning the planning using AP and lateral views (planned nail) and the nail they would have used in retrospect, once examining the surgical result (corrected nail).

Figure 3

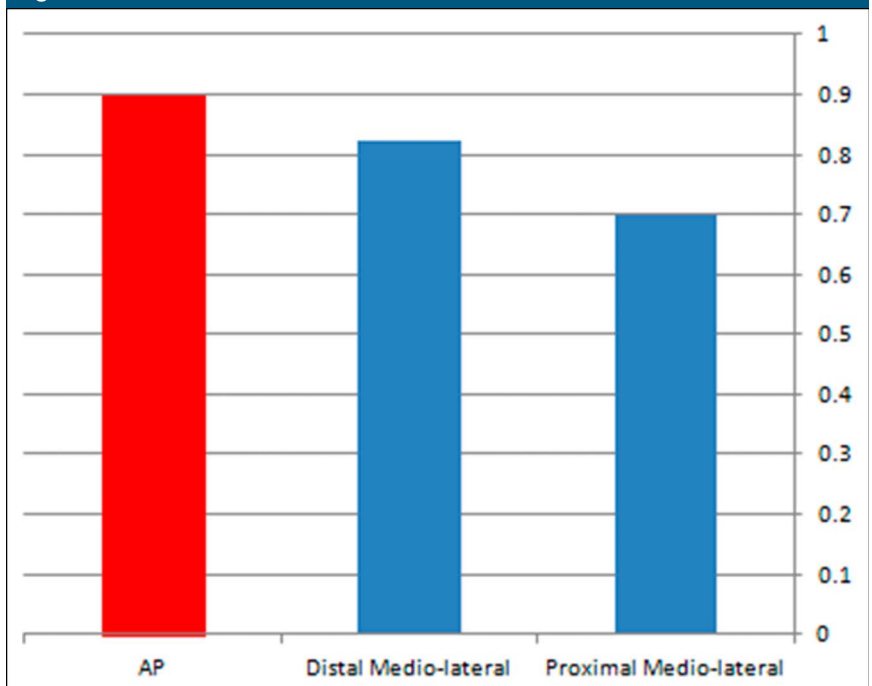


Chart showing the inter-correlation coefficient between the six raters, concerning the planning of the distal locking screws.

The accuracy of this planning method (using the radiographs of the healthy leg) is demonstrated clearly, with an average ICC higher than 0.9 (range 0.79 to 0.94) for length (which is considered excellent). However, the

results for diameter preoperative planning are more modest (yet reasonable), with an average ICC around 0.7 (range 0.37 to 0.81). The numbers improve slightly when analyzing the ICC for each examiner between the planned and the calculated nail, after reviewing the results postoperatively. Thus, we suggest that our method could serve for post-factum surgery debriefing, especially if the clinical outcome turned unsatisfactory.

Limitations

Only two models of tibial nails are available in our institute. Possibly, having more options of sizes could have created less agreement between examiners regarding the perfect nail. However, we had tried to neutralize this effect by limiting the examiners to the same manufacturer as was used by the surgeon.

This series is a retrospective one, with a selection bias for cases that were successfully operative for tibial intramedullary nailing. A prospective randomized controlled trial should substantiate our conclusions.

Conclusion

According to our series, preoperative planning of tibial fractures' nailing using imaging of the contralateral leg and a digital graphic plan-

ning program is an accurate and reliable method, especially concerning the length of the nails. Idealization of nail measurements should prevent future surgical complications, and several minutes spent on preplanning may serve to reduce surgical time and radiation exposure of both the patient and the surgical team. Yet, adequate caution should be taken in redundancy of nails available, especially in different diameters. This method could also be applied to surgical debriefing.

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