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Avoiding deformity in proximal tibial nailing: risk factors, deformity rules, tips, and tricks

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Summary: Malalignment is one of the most common problems linked to nailing of proximal tibial fractures. This review will cover technical aspects of intramedullary nailing and will help explain the various risk factors. Deformity rules aid in identifying the likely deformity and help to develop management strategies. Various tools and techniques are discussed which can help optimize the outcome.

Level of Evidence: Therapeutic Level V

Keywords: tibia, intramedullary nailing, IMN, malalignment, deformity

1. Introduction

Extra-articular short-segment proximal tibial fractures can be stabilized using a variety of implants including plates and screws, external fixators, and intramedullary nails. Although intramedullary nails reliably restore alignment of diaphyseal tibial fractures, management of proximal tibial fractures with nails presents challenges. Fractures in the proximal third of the tibia have a high risk of malalignment, and various nailing techniques have been described for these fractures (Table 1). The most common resultant deformity is valgus and apex anterior procurvatum[30]; however, varus deformity may also occur.[30–33] One of the reasons why deformity is so common after nailing of proximal tibial fractures is that surgeons lack detailed understanding of the various factors that contribute to deformity. This article provides a comprehensive review of the causes of deformity after short-segment proximal tibial nailing and describes new techniques to mitigate those risks. Angular deformity is most commonly a result of various anatomical and surgical factors; however, patient comorbidities can contribute.

2. Risk Factors of Deformity

Described risk factors of sagittal plane deformity include pull of the extensor mechanism,[1,5,32] pull of the anterior compartment muscles,[31] lack of a posterior cortex,[31] "wedge effect" of the bent nail in the distal fragment,[34] and a medial[1] or distal nail starting point.[1] Factors contributing to coronal plane deformity include a medial starting point, a laterally directed nail insertion angle,[1,31,32] and pull of the lateral compartment muscles[31] (Table 2).

2.1. Anatomy

In the proximal tibia, osseous anatomy and muscle distribution are different from other metaphyseal areas of the human body.

2.1.1. Bone Shape.

Medullary cavity diameter and nail diameter discrepancy: In diaphyseal fractures, diameter discrepancy between the nail diameter and the inner diameter of the medullary cavity in nongeriatric patients is low.[13,14] However, in metaphyseal regions such as the proximal tibia, the discrepancy between the nail diameter and the inner diameter of the cortical rim increases when approaching the articular surface (Fig. 1). The large medullary canal proximally allows for nail malposition and capacity to toggle (Fig. 2). This can result in malposition of the fragment, instability of the fragment, and malalignment of the limb.[30]

Proximal tibial asymmetry/eccentricity: Anatomic research has shown that the center of the medullary cavity does not align with the middle of the tibial plateau and instead is shifted laterally[35] (Fig. 2A and B). This means that to directly align with the center of the medullary cavity of the tibial shaft distally, the osseous starting point for tibial nailing needs to adapt accordingly and be shifted slightly laterally. Furthermore, the proximal medullary cavity is asymmetric, with the lateral aspect of the proximal medullary cavity being larger than the medial aspect. Hence, if a nail is inserted and aimed toward the narrower medial side, it may affect the cortical bone and be deflected laterally, potentially resulting in an undesired valgus deformity.[1] The surgeon must also be aware of imaging considerations that can contribute to incorrect assessment of the nail starting point and, therefore, contribute to nail malposition. In particular, because the starting point of the nail is not in the center of the tibial plateau in the sagittal plane, but instead on the anterior edge of the proximal tibia, small amounts of rotation around the longitudinal axis of the tibia can result in a significant shift of the desired starting point, which is not easily recognized on the image intensifier. Using a cadaver model, Walker et al[36] showed that the proximal

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TABLE 1

Nailing Options for Proximal Tibial Fractures

Positions/approaches	
Nailing in flexion	Patellar tendon–splitting approach[1,2]
	Medial parapatellar tendon[3]
Extended/semiextended nailing[4]	Medial parapatellar[5]
	Suprapatellar/retropatellar[6,7]
	Extra-articular[8]
Tools	
Reduction clamp[2,9,10]/Schanz screw[1,10]/External fixator[9,11]/Large femoral distractor[1,9]	Unilateral[1,12]
	Bilateral[12]
Poller screws[13–28]	Temporary[13,14,25]
	Permanent[13,14,25]
Supplemental plate[2]	Temporary[29]
	Permanent[2,29]

tibia can appear as a correct anteroposterior image in a 30-degree arc of tibial rotation, but that the ideal tibial starting point can vary by up to 15 mm of translation within this arc.

External rotation of the tibia can result in an apparently correct starting point that is actually medial to the correct starting point and will create malposition of the nail and possible malreduction of the fracture if this is not recognized. These investigators recommend using the fibular bisector line as a guide to correct assessment of the tibial starting point.

Triangular cross-section: The cross-section of the cortical bone at the metaphyseal level has a triangular shape with an asymmetric density distribution of the cancellous bone in the anterior recess. This cancellous bone is not difficult to penetrate during nail insertion, but difficult to compress when the nail is already placed in the posterior aspect. Therefore, it is easier to aim for a steep insertion parallel to the anterior tibial cortex.[1] The nail should be positioned as anterior as possible because it is easy to correct from a too anterior position to one more posterior, rather than to correct from too posterior later (Fig. 3). Because the tibia is triangular in cross-section with the apex anterior, there is limited capacity within the medullary canal to move the nail anteriorly because it will eventually impinge on the cortical bone; hence, familiarity with the tibial geometry and surgical judgment is important. The surgeon should aim to have the nail anterior, but its precise location will be influenced by the bony architecture.

TABLE 2

Deformity Risk Factors of Nailing a Proximal Tibial Fracture

Deformity Risk Factors	Modifiers
Anatomy	
Bone shape	Medullary cavity diameter >> nail diameter[1]
	Asymmetry/eccentricity
	Triangular cross-section
Fracture plane	Transverse
	Oblique/wedge lateral open
	Oblique/wedge medial open
Muscle forces	Asymmetric +++ lateral and posterior
	Extensor muscles
	Pes anserinus
Surgical factors	
Skin incision level	Too distal
Bone starting point	Too distal[30]
	Opposite from fracture plane orientation
Nail insertion vector	Too flat[1]
Nail insertion depth	Below anterior edge
Lack of deformity neutralization	Poller screws, reduction plates, temporary external fixation and others
Comorbidity	
Poor bone stock	Osteoporosis, etc.

2.1.2. Fracture Plane.

Only a small portion of proximal tibial fractures are transverse (26%), and most of the fractures are oblique with complex fracture patterns.[30] The length of the proximal fragment and the obliquity and orientation of the fracture plane define the "area of toggle." Increasing fracture obliquity leads to less cortical support and allows the nail on the short side of the segment to "escape" from the ideal nail path (Fig. 4).

The orientation of the fracture plane plays an important role in predicting the likely deformity and subsequently the choice of the osseous starting point and in the planning of additional surgical techniques to avoid deformity, such as Poller screws. When the fracture plane extends proximally on the posterior cortex, there is a risk of the nail approaching and entering this space. When this occurs, the proximal fragment is extended and the nail position lies obliquely from anterior to posterior in the sagittal plane. A procurvatum deformity is created.[32]

2.1.3. Deformity Rule.

The fracture tends to deform to the side with the blunt fracture angle or the short side of the segment (deformity rule). Because most oblique fractures have the short side lateral, they are, therefore, prone to develop valgus deformity, but there are also fractures with the short side medial, and they deform into varus. This behavior can be influenced by diminishing the functional diameter of the proximal tibia with Poller screws and with the strategic placement of the starting point. The tendency of a fracture with the short side lateral (fracture plane open lateral) is to deform into valgus; this can be compensated by a lateral Poller screw and a more lateral starting point. The tendency to deform into varus can be compensated with a medial Poller screw and by a more medial starting point (Table 3, Table 4).

2.1.4. Asymmetric Muscle Distribution.

The natural bony anatomy and muscular attachments of the proximal tibia create an environment to "set the scene" for several common deformities after fracture, with subsequent malalignment during nail placement.[9,15] Muscular forces through tendinous attachments contribute considerably to produce these deformities.[1] The dynamic forces through the patellar tendon pull the proximal fragment into a procurvatum deformity, whereas the attachment of the leg extensor muscles commonly cause valgus deformity at the fracture site[32,37] (Fig. 5). The lateral-based extensor muscles have no equivalent and opposing muscle on the medial side to act against them and prevent valgus.

Lang et al demonstrated poor results with conventional techniques for IMN of proximal third tibial fractures: 84% with >5-degree frontal or sagittal plane deformity; 59% with 1-cm or greater displacement; 25% with loss of fixation; and 28% required exchange nailing. In part, these undesirable results have been attributed to the dynamic deforming forces of the natural anatomy.[9,32] When the deforming forces are fully understood and appropriate surgical measures are undertaken, deformities can be avoided and results can be much improved.[35]

2.2. Surgical Factors

In addition to these anatomical factors, surgical factors including a soft-tissue approach, osseous starting point, nail insertion vector, insertion depth, and the lack of deformity-compensating surgical measures can contribute to alignment problems.

TABLE 3

Correct Starting Point, Fracture Plane, and Deformity Risk of Nailing of Proximal Tibial Fractures

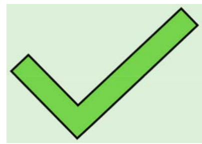
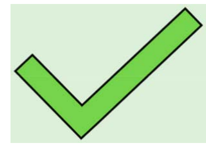
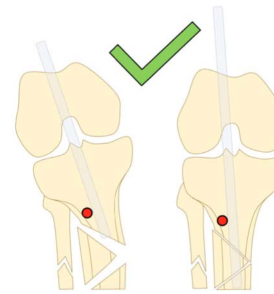
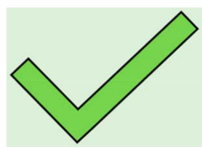
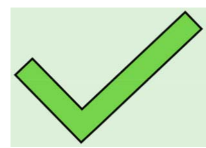
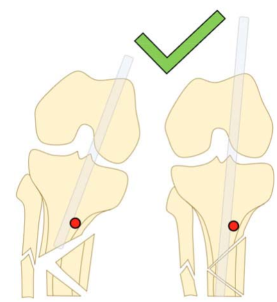
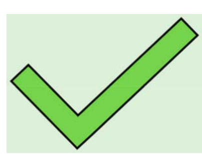
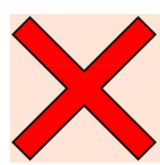
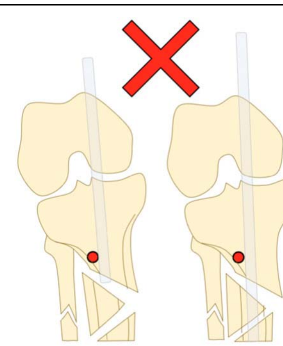
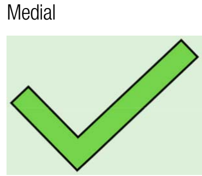
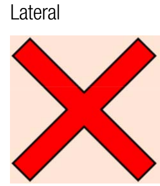
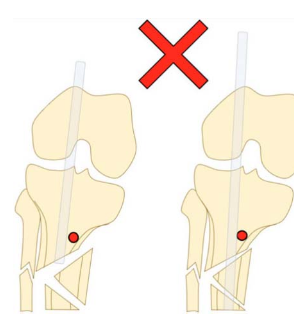
Fracture Plane	Deformity Rule	Poller Screw Placement Relative to Nail Position	Nail Starting Point	Deformity Risk: Low
Lateral open	Valgus	Lateral 	Lateral 	
Medial open	Varus	Medial 	Medial 	

TABLE 4

Incorrect Starting Point, Fracture Plane, and Deformity Risk of Nailing of Proximal Tibial Fractures

Fracture Plane	Deformity Rule	Poller Screw Placement Relative to Nail Position	Nail Starting Point	Deformity Risk: High
Lateral open	Valgus	Lateral 	Medial 	
Medial open	Varus	Medial 	Lateral 	

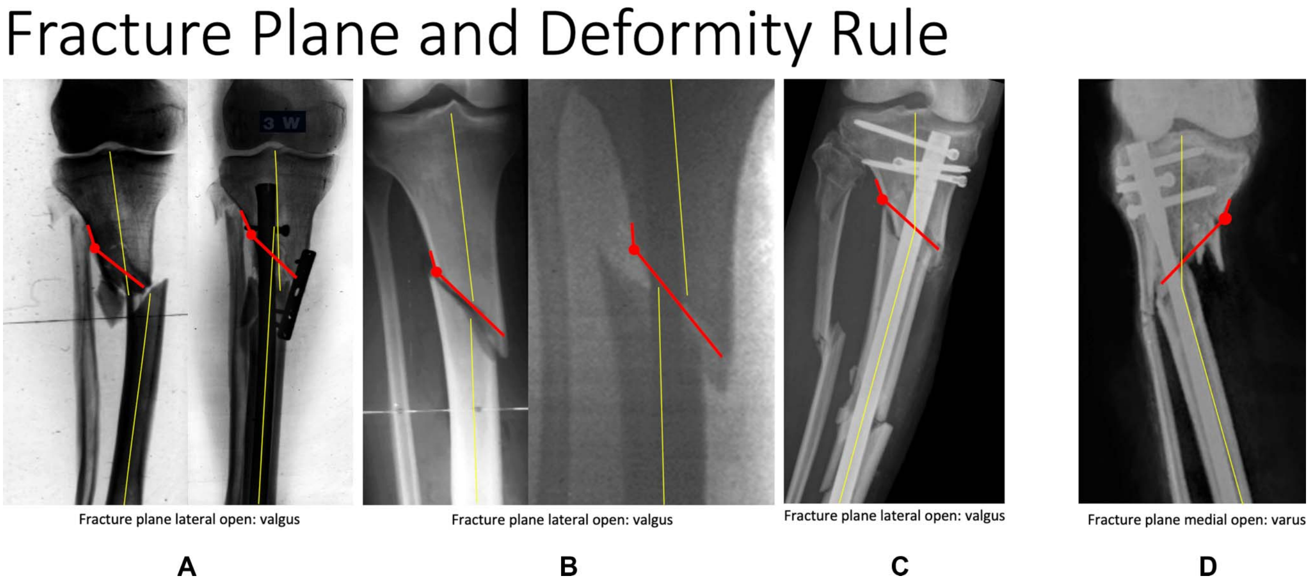


Figure 1. Radiographs demonstrating bone and implant diameter discrepancy, the role of fracture plane orientation, and the deformity rule. A–C, Radiographs of 3 cases with a lateral open fracture plane (common). According to the deformity rule, fractures tend to deform to the side where the fracture plane is open. This is the side where the fracture line ends more proximally and where the fracture angle (red) is >90 degrees ("blunt angle"). In most cases, this is on the lateral side with significant risk of valgus deformity. D, A case with a medial open fracture plane (rare). According to the deformity rule, the fracture tends to deform to the side where the fracture plane is open, which in this case is medial. This was not addressed with any deformity avoidance technique (eg, Poller screws or a small plate), and a varus deformity has resulted.

2.2.1. Skin Incision Level. Skin incisions for extended/semiextended nailing techniques[4–8] differ from the patellar tendon–splitting approach.[1,2] For the patellar tendon–splitting approach, it is important to start high, that is, at the level of the distal third of the patella, to be able to create a steep bone channel and keep the incision limited (Figs. 3, Figs. 5, 6).

There is no "one fits all—starting point" for proximal tibial fractures. In the past, the recommendations and discussions about

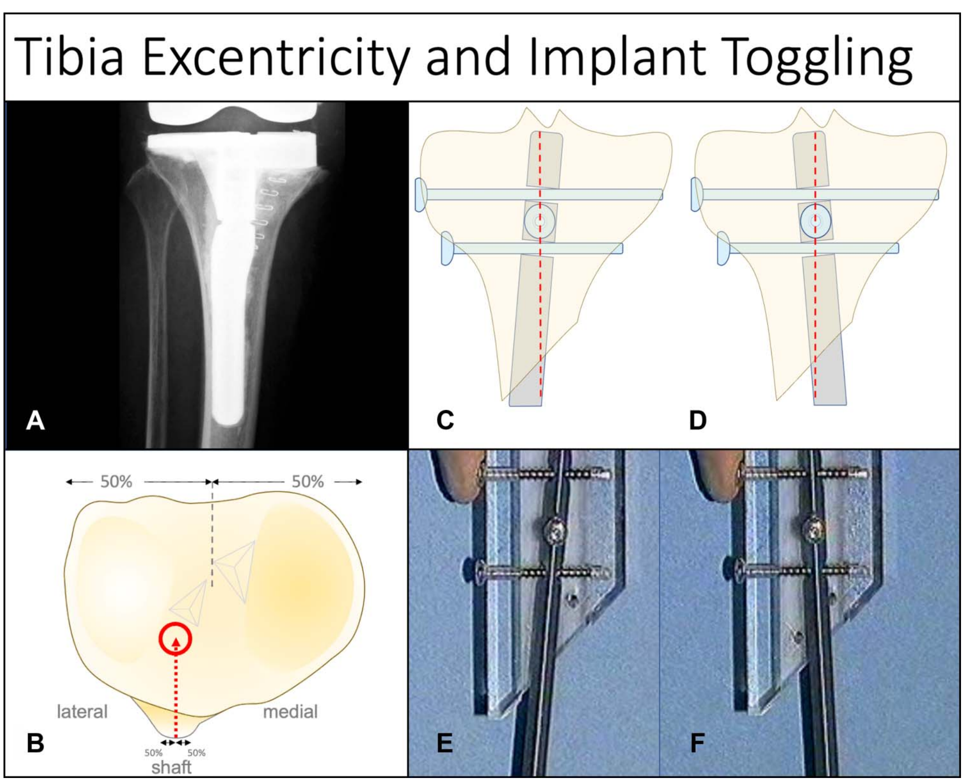


Figure 2. Anatomic factors favoring malalignment and instability. A, Radiograph demonstrating a stemmed tibial tray in a total knee replacement. They almost always have an offset coupler because the tibial shaft does not project to the center of the tibial plateau. B, Illustration demonstrating the eccentricity of the tibial shaft relative to the plateau. A central starting point at the plateau level would lead to a deformity. In schematic illustrations (C, D) and in a plexiglass model (E, F), toggling-related instability is demonstrated.

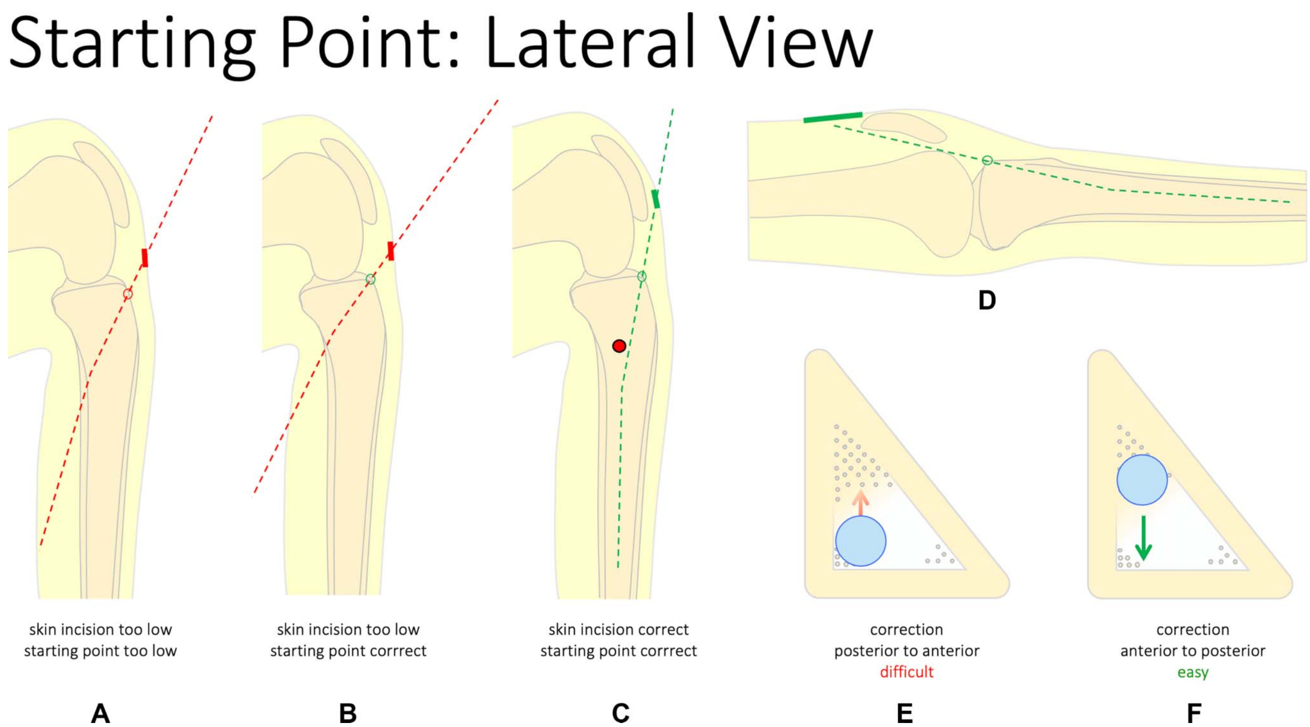


Figure 3. Considerations for the starting point in the lateral view, risk factors of procurvatum deformity, and solutions. A–C, An infrapatellar transligamentous approach requires knee flexion of more than 100 degrees to reach the medullary cavity at the correct (steep) angle. A, Skin incision and starting point too distal. B, Starting point correct, but skin incision too distal. (A) and (B) result in a too posterior vector orientation. C, Skin incision and starting point correct, resulting in a correct steep vector. A Poller screw, K-wire, or Schanz screw can prevent a too posterior nail vector and the related risk of a procurvatum deformity. D, A supraparapatellar approach allows surgery with the knee extended. E, F, If the insertion vector is not sufficiently steep, the nail will be placed in the posterior part of the wide medullary cavity. This is difficult to correct, because the cancellous bone in the anterior tibia is dense and hard, and difficult to compress. It is much easier to target very steeply from the beginning. If too steep, this is easy to correct because the cancellous bone in the posterior part of the wide medullary cavity offers little resistance.

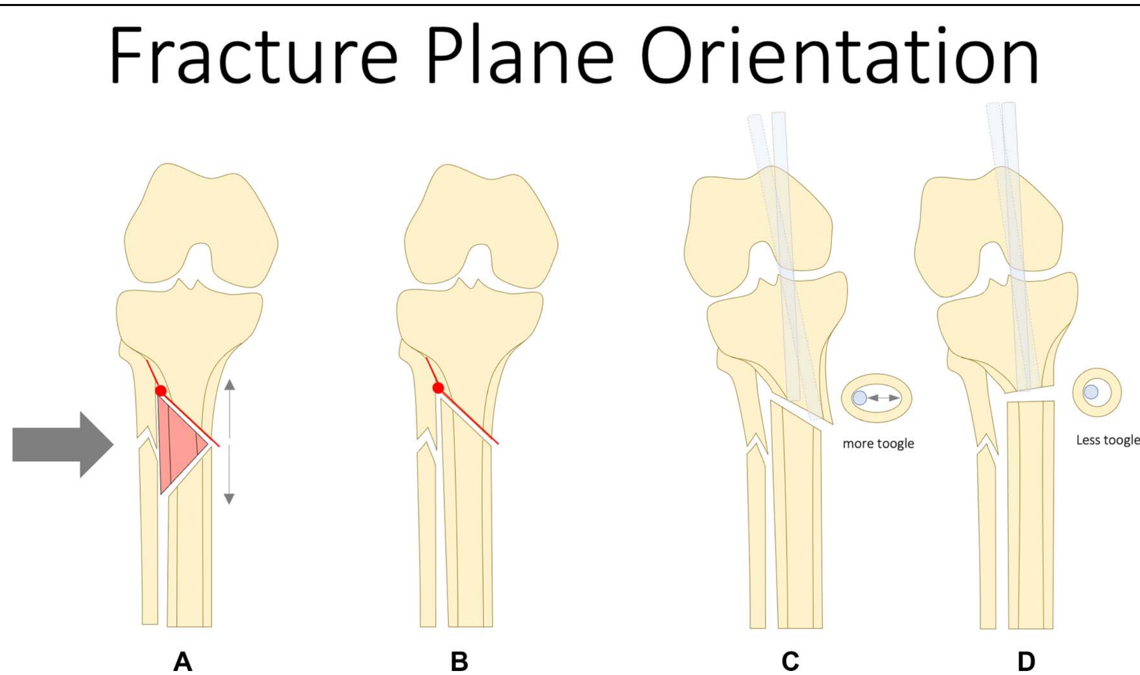


Figure 4. Fracture plane orientation. A, B, Oblique fractures result in a larger cross-sectional area of the distal end of the proximal fragment and more implant toggling–related instability (C) and (D) compared with transverse fractures. According to the deformity rule, fractures tend to deform to the side where the fracture plane is open. This is the side where the fracture line ends more proximally and where the fracture angle (red) is >90 degrees (blunt angle). In most cases, this is on the lateral side, resulting in valgus deformity.

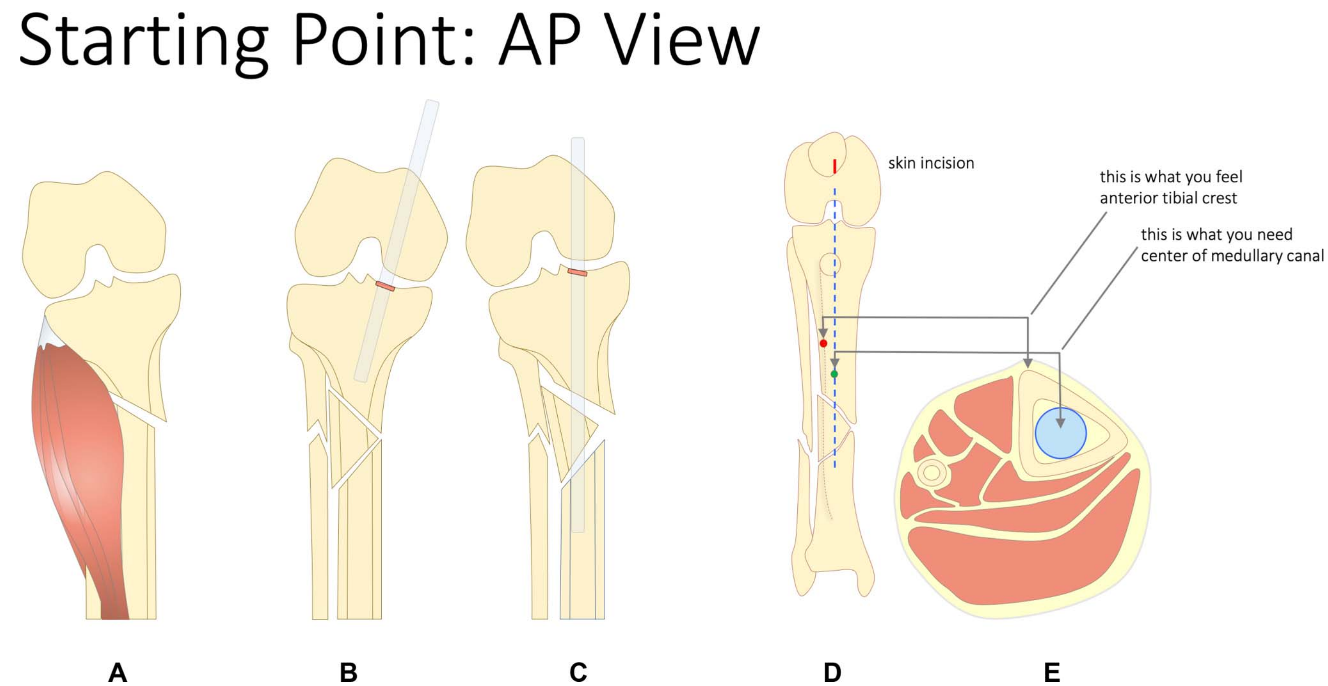


Figure 5. Considerations for the starting point in the AP view, and risk factors of valgus deformity. A, All the leg extensor muscles are on the lateral side of the tibia, favoring valgus deformity. B, C, In a lateral open fracture, a too medial starting point is an additional risk factor of valgus deformity. D, E, When determining the proximal starting point, it is essential to know exactly where the center of the distal medullary cavity is because the nail is centered in the usually tight tube of the diaphysis. The anterior tibial crest is often mistaken as the center of the medullary cavity; however, the medullary cavity is always medial to the anterior tibial crest.

starting point did not address fracture configuration. The attempts to define a "one-fits-all" starting point ignore that there is a common but not uniform fracture pattern. Therefore, it is more a "one-fits-most" starting point because most fracture planes are lateral open, where the short side is lateral. These fractures are at risk of valgus malalignment.

Only for these fractures, a starting point—based on the true AP radiograph—located in line with the medial aspect of the lateral intercondylar eminence is recommended[1,2] (Fig. 1A–C, and Table 3 and Table 4). However, if the oblique fracture pattern is medial open, the starting point needs to be placed more medially, ie, aligned with the medial intercondylar eminence, to compensate for the risk of varus deformity (Fig. 1D and Table 3). The correct starting point is dependent on a true AP projection. It is, therefore, critical to carefully observe radiologically the precise tibial rotation when determining the entry point for the nail, ensuring a true AP view. The presence of a true AP image can be assessed using several radiological criteria: The tibial plateau should appear symmetrical; the fibula head should be 50% obscured by the tibia; and the intercondylar notch of the femur should appear smooth and symmetrical.

2.3. Nail Insertion Vector

The nail insertion vector from the starting point in a lateral view is an important risk factor of procurvatum deformity. A steep angle is critical.[1] The infrapatellar transligamentous approach requires knee flexion of more than 100 degrees to reach the medullary cavity sufficiently steep enough. When the skin incision and starting point are too distal, this cannot be achieved, and the nail

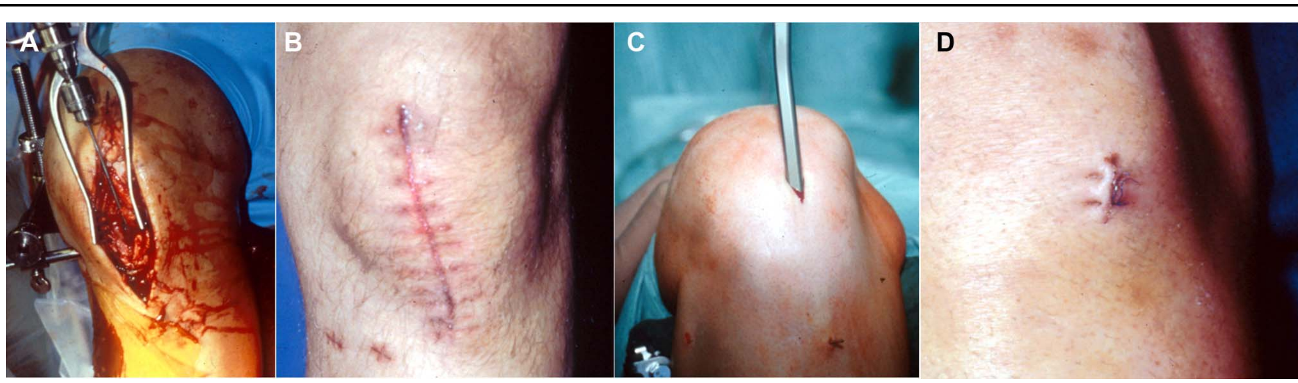


Figure 6. Conventional and minimally invasive nailing approach. There is no need for extensive skin incisions. A, B, Unnecessary long approach for the split patellar tendon approach, in which only the most proximal part is used during the procedure. C, Nailing with minimized soft-tissue dissection through a stab incision. The short K-wire was inserted as a reference under C-arm control, representing the center of the medullary cavity in AP projection. D, Skin incision a few days after the nailing procedure.

vector is directed too posterior (Fig. 3). A Poller screw (permanent or temporary) or a temporary K-wire or Schanz screw[2] can prevent a too posterior nail vector and the related risk of a procurvatum deformity (Fig. 3C). The starting instruments and IM nail, when viewed on the lateral image intensifier view, should appear almost parallel to the anterior cortical bone.

2.3.1. Nail Insertion Depth.

Especially in short-segment proximal tibial fractures, it is important to have as much nail length as possible in the proximal main fragment. With increasing insertion depth, the length of the nail segment within the proximal segment diminishes, resulting in some loss of mechanical control of that segment. The ideal situation is to have the proximal nail end flush with the anterior-superior cortical edge.

2.3.2. Locking Screws.

All nail designs will allow for at least 2 locking screws in the proximal segment. Some designs will allow for up to 5 screws. Every additional screw offers increased stability against late or gradual deformity.[38] Screws orientated at 90 degrees provide more resistance to varus/valgus angulation than parallel screws.[34] In general, it is recommended to use several[1,32,33] of the available locking screw options provided by the manufacturer, with preference given to 90-degree orientated screws, especially because implant toggling is frequently underestimated (Fig. 2).

2.4. Comorbidity

Most of the risk factors identified are amplified when the mechanical conditions of the bone are impaired, such as osteoporotic/osteopenic bone, which exists frequently in elderly patients. In these patients also, the diaphyseal bone diameter can be very wide, which can further increase the risk of deformity. In these cases, deformity-compensating measures have a particularly important role.

3. Tips and Tricks to Avoid Deformity

3.1. Patient Positioning and Surgical Approach

Extended or semiextended position: Since its first description, nailing in the extended or semiextended position has gained wide popularity.[4–8] A recent systematic review analyzing 16 studies with a total of 1750 operations showed that the suprapatellar approach demonstrates superior Lysholm knee scores, greater entry point accuracy, and reduced fluoroscopy exposure with equivalent risk of developing complications when compared with the IP approach.[4]

The first description of this technique was by Tornetta using a medial parapatellar incision, lateral subluxation of the patella, and significant exposure of the knee joint.[5] He subsequently reported a less invasive technique using a limited superomedial retinacular incision and a much lesser skin incision.[39]

In a modification of the study by Kubiak et al, the authors used an extra-articular semiextended parapatellar technique where the patella is medially or laterally subluxated. He suggested that the surgical approach be based substantially upon the mobility of the patella - if medially mobile, then approach laterally and vice versa. However we recommend that a more important consideration is the fracture configuration and associated deformity rule as outlined above and in Table 3. Hence a lateral open fracture (common variety) requires a slightly lateral entry point which is potentially achieved with medial subluxation of the patella.

More recently (2014), a transarticular approach has been recommended by Sanders et al,[40] using a suprapatellar incision through the quadriceps tendon and specific instruments to protect the joint surfaces. This may prove difficult in the “tight” patellofemoral joint, but does provide a “direct shot” toward the correct starting point on the tibia when compared with approaches requiring patella subluxation.

Patellar tendon–splitting approach: The avoidance of the fracture table significantly reduces setup time. In polytrauma patients, it also allows ipsilateral and/or bilateral tibial and/or femoral fractures to be treated with a single positioning and draping technique.[41] If desired, a simple frame constructed from a tubular external fixator and 4 tube-to-tube clamps can be used.

A 15-mm “stab” incision using a large blade is made in line with the medullary cavity of the tibia (Fig. 6). The incision passes through skin and the patellar tendon beginning at the inferior pole of the patella while the knee is flexed greater than 90 degrees (Fig. 3).[42] The proximal anterior edge of the tibia (seen laterally) can be easily identified by palpating with the tip of the opening pin, so the additional radiation related to a lateral C-arm shot can be avoided.

Medial parapatellar tendon approach: The radiographic center of the proximal metaphysis is in line with the medial border of the patella tendon.[43] Depending on the desired starting point, it may be possible to avoid transgressing the patella tendon by undertaking a medial parapatellar tendon approach. This has risks of being “too medial” but with appropriate selection of fracture configuration and careful radiological monitoring of position, avoidance of a patella tendon incision can be achieved.

3.2. Reduction Tools

Reduction can be facilitated by any form of controlled traction. Although the use of a fracture table in proximal tibial fractures results in limited manipulative flexibility, temporary tibiotibial external fixation using an external fixator[9,11] or distractor[1,9] (Fig. 6A) can be of great help. The application can be either unilateral or bilateral using unilateral, bilateral, or perforating Schanz screws. In the sagittal view, the Schanz screw can be placed proximally and posterior in a way to allow nail passage but also act as a temporary Poller screw (Fig. 3C). Large reduction clamps,[2,9,10] colinear clamps, Schanz screws,[1,2,10] or temporary K-wire fixation may also provide support and provide additional help for reduction and stabilization.

3.3. Plate-Assisted Nailing

The use of a supplemental provisional or permanent small plate with uni- and/or bicortical screws is another option to address the deformity risk.[2,44] The technique not only allows achievement and maintenance of reduction in displaced fractures but also helps avoid further displacement in the case of nondisplaced or minimally displaced fractures. The approach for the plate is either an open or minimally invasive percutaneous approach and can be placed medial[45] or lateral. Plates may also be useful in situations where techniques such as Poller screws are risky or contraindicated, such as osteoporosis, severe comminution, articular extension, and others.[9,46] The orientation of the plate should be selected to counteract the known deforming forces expected at the time of nailing.

3.4. Poller Screws

Since the very first description,[47] Poller screws have gained wide popularity. Tennyson et al conducted a systematic review and identified 75 publications dealing with the topic of Poller screws.

Figure 7. Clinical case with a distally open segmental tibial fracture demonstrating the use of a Poller screw for correction of malalignment and instability. A, C-arm image of a proximal tibial fracture with a typical misfit between nail diameter and inner diameter of the medullary cavity. According to the deformity rule, this results in valgus malalignment and instability. B, Revision of the case with temporary implant removal (old nail path visible, yellow arrows) and blocking of this wrong nail path in the proximal fragment with a Poller screw (red arrow). Because the fracture plane is lateral open, the Poller screw must be on the lateral side (blunt angle, >90 degrees). C, Reinsertion of the nail (same starting point). The nail is now forced to stay medial to the Poller screw, which functionally narrows the medullary cavity of the proximal fragment. D, When the nail then enters the distal main fragment, the fragments are aligned. With further progress of the nail, the stiffness of the bone-implant complex is further increased. E, F, Follow-up at 1 year demonstrates the integrity of the soft tissues, good alignment, and healed fractures.

Thirteen publications, with a total of 371 patients were included with a mean follow-up time of 21.1 months. The results showed a lower complication rate of IM nailing augmented with Poller screws for nonunion and coronal plane malunion when compared with nailing alone.[48]

For proper placement, it is important to understand the fracture pathobiomechanics and deformity rule and realize the important role of the appropriate starting point (Figs. 3–5, and Fig. 7, Table 3 and Table 4).

The underlying principle for Poller screw placement is to identify the likely incorrect direction/location that the nail may adopt and then place a screw to “block” that incorrect nail placement from occurring. Screws will generally be placed in the proximal segment but may, in large medullary cavities, additionally be required in the distal segment. The most common placement is in the AP plane to prevent coronal malalignment; however, screws will frequently be placed in the M-L plane to prevent sagittal malalignment. When considering the proximal segment, valgus deformity is prevented by a laterally situated AP screw (to direct the nail toward varus) and varus is prevented by a medial situated AP screw (to direct the nail toward valgus).

4. Conclusions

In the past 25 years, clinical research and the development of various techniques have resulted in substantial improvement in the outcome after nailing of proximal third tibial fractures, especially regarding alignment. Both better understanding of the very specific anatomy of the proximal tibia and better knowledge of the surgical risk factors have contributed to various technical improvements. Patient positioning, surgical approach, reduction tools, definition of deformity rules, and new and better understanding of a fracture specific rather than a “one-fits-all” starting point as well as additional temporary or permanent implant components, such as Poller screws or plates, have contributed to the avoidance of frontal and sagittal plane malalignment and instability. The level of the mostly retrospectively obtained evidence is low; larger and prospective clinical trials are necessary to get a more uniform and standardized protocol in the future.

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