Current Concepts in Intramedullary Nailing

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The past decade has seen a dramatic increase in the use of intramedullary nailing for fracture management. Increased availability of new techniques and instrumentation have contributed to the continuing expansion of applications for intramedullary nailing. The introduction and availability of image intensifiers into American hospitals has also led to the popularization of closed intramedullary nailing techniques, and locking nails have expanded the indications of closed intramedullary nailing to unstable long bone fractures of the femur, tibia, and humerus. New classes of nails such as the second generation Reconstruction Nail have expanded the use of intramedullary nailing for more proximal femoral fractures. In addition, advances in biomechanical and locking designs have recently led to the use of intramedullary nailing in distal femur fractures and forearm fractures. There is continuing evolution of specialized nails including a self-guiding nail, nails for use in femoral lengthening, and nails used in conjunction with intramedullary osteotomies.

The advantages of intramedullary nailing include shaft realignment, decreased risk of pulmonary complications, decreased hospitalization, and early functional use of the involved extremity.[1,2] Intramedullary devices offer several biomechanical advantages over plates and screws and external fixators:

1. The intramedullary canal is closer to the mechanical axis of long bones; devices are therefore subjected to smaller bending loads than plates.[1,2]
2. Intramedullary nails have the ability to act as load-sharing devices; if the nail is not locked at both ends, it can act as a gliding splint, allowing fracture compression with loading of the extremity.[1-3]
3. With fractures at the midshaft level, intramedullary devices that fill the medullary canal will reestablish long bone alignment.[2,3]
4. Stress shielding is minimal with intramedullary implant devices.[2,4]
5. Refracture after implant removal is uncommon.[3,5]
6. Intramedullary implants do not usually require extensive dissection for exposure.
7. Closed techniques will theoretically reduce infection and nonunion rates.[2,5-9]
8. Debris created by reaming may act as

an osteoinductive agent.[2,5,10-12]

The disadvantages of intramedullary nailing include: (1) technical demands of insertion; (2) increased X-ray exposure with image intensifiers; (3) disruption of endosteal blood supply[5,10,12]; and (4) increased intramedullary pressures with the theoretical risks of pulmonary sequelae.[13,14] Implant complications after nailing are generally related to use of small-diameter nails or the use of intramedullary nailing of very proximal or distal fractures.[2] The mode of failure for most intramedullary devices is generally fatigue fracture.[2,15,16] Locking holes represent potential weak points and are sites of such failure.[2] Nail strength is directly related to the third power of the nail's radius; therefore, small changes in nail diameter result in a large change in nail strength.

Controversy remains over the importance of reaming prior to nail insertion. Reaming increases the contact length of the nail and endosteal surface and therefore provides better fracture stability.[5] Nail placement after reaming decreases the risk of nail incarceration and allows placement of a larger diameter nail.[5] An added advantage of reaming is the osteoinductive effect of the morselized bone left behind.[2,5,10-12] Reaming, however, increases risk of cortical comminution if the cortices are thin at the fracture site, and there is a resultant disruption of endosteal blood supply. It is felt that the blood supply is disrupted to a greater extent with reaming than with nail placement alone.[17-21] Rhinelander has shown that the endosteal blood supply rapidly reconstitutes itself after intramedullary nailing with non-reamed nails.[18-21] Although endosteal blood supply will eventually reconstitute itself, care must be taken not to disrupt the periosteal blood supply. This is an important consideration when undertaking treatment of open fractures with intramedullary nailing. Current treatment protocols for Gustillo grades I and II open fractures include placement of locked intramedullary nails.[22,23] These nails are placed without reaming the canal. Gustillo grade IIIA fractures have also recently been added to the group of open fractures treated in this manner.[22,23] An added reason for placing unreamed nails with these higher energy injuries is the risk of increased soft tissue swelling created by the reaming process which may contribute to a compartment syndrome.[24] In all cases of open fractures, the involved extremity should be monitored closely.

Recent attention has been given to the problem of decreased oxygenation associated with intramedullary reaming. It has been suggested that fat emboli are responsible for this pulmonary compromise.[13,14,25,26] For this reason, use of smaller diameter unreamed nailing should be considered for polytrauma patients with pulmonary contusions or ARDS. Reamed intramedullary nailing has also been associated with increased infection rates when used for the treatment of open fractures or after external fixation.[27] This may be related to avascular bone chips which are produced by reaming.

The newest nail designs have tried to address the problems related to placement of proximal and distal locking screws. Targeting devices have been developed for placement of proximal screws. These devices are attached to the proximal end of the nail and guide screw placement while minimizing radiation exposure to both the surgeon and the patient. The smallest displacement of these devices can cause failure to target properly; therefore, added care must be taken with nail insertion. With distal locking screws, a free hand technique is generally utilized, as no reliable targeting device has yet been developed. Radiolucent drill drives as well as laser-guided image intensifiers have been developed to aid in these techniques.

INTRAMEDULLARY NAILING AND THE FEMUR

The treatment of choice for the majority of femoral shaft fractures is intramedullary nailing. The results of closed nailing are superior to other treatment methods for both closed fractures and open types I, II, and IIIA fractures.[27-33] Union rates approach 95%, are associated with low infection rates, and almost complete return of knee and hip motion can generally be expected.[27-33] This method of treatment is also associated with a low overall complication rate.[27-33] Despite these excellent results, functional outcome studies are needed to better define the success of this procedure from the perspective of the patient. Although closed nailing is the preferred method, a small incision at the fracture site to facilitate reduction and guidewire passage may provide similar results.

Antegrade locked intramedullary nailing with prior reaming of the canal is the treatment of choice for closed fractures and open types I, II, and IIIA fractures.[30,31] Errors in decision making can occur over the question of dynamic or static interlocking. Locking provides rotational stability for very proximal or distal fractures, for spiral and long oblique fractures, and for those comminuted fractures with greater than 50% comminution. Brumback recently reported a 10.5% postoperative loss of reduction in a large series of dynamically locked femoral nails, and found that static locking did not interfere with fracture union. Loss of fixation was attributed to previously unrecognized fracture lines or those created at nail insertion.[28-30] The investigators concluded that all femoral shaft fractures should be statically locked,[28-29] that the need for dynamization is very uncommon,[28-29] and that hardware removal was not associated with an increase in refracture rate.[30]

Infection rates for closed nailing are extremely low (~1%).[27-33] Treatment includes thorough debridement of the fracture site, but the nail may be left in place if significant stability is still provided. If fixation is compromised, the nail should be removed, and a larger nail should be inserted after reaming the canal. Exchange nailing is usually successful with early intervention, minimal necrotic bone, and an intact soft tissue envelope.

Although uncommon, complications do occur with closed nailing. Reported complications have included angular deformity, malrotation, leg-length discrepancy and aseptic nonunion.[34] Heterotopic ossification occurs commonly, but hip motion is infrequently affected.[35] Nerve palsy involving the sciatic nerve and pudendal nerve are thought to be related to positioning on the fracture table and traction applied to the lower extremity.[36] The prognosis for these nerve palsies is good. Recent reports of reamed intramedullary nailing in patients with severe pulmonary injury have found an increased risk of adult respiratory distress syndrome.[13,14,25,26] Locked intramedullary nailing without reaming has shown some preliminary success and should be considered under these circumstances.

Antegrade locked intramedullary nailing may also be used for the stabilization of selected types of supracondylar femur fractures.[38] Best results with this procedure are obtained with AO/ASIF type A fractures.[37,38] If antegrade nailing is used for selected type C1 and C2 fractures (bicondylar fractures with minimal or moderate supracondylar comminution), supplemental lag screw fixation will be needed for the intra-articular component of the fracture.[37,38] Additional modifications which may be required include removal of the distal portion of the nail to allow purchase of the distal locking screws.

A new device, the Supracondylar Intramedullary Nail (Fig. 1), has recently been introduced for treatment of distal femur fractures. This nail is inserted in a retrograde manner through the intercondylar notch and allows closed locked intramedullary fixation. Applications include AO/ASIF type A and C supracondylar fractures[39,40] and those fractures above total knee replacements (Fig. 2). Retrograde nailing may also be indicated for those situations in which an antegrade technique is not possible or unwanted. These situations include the following: fractures associated with ipsilateral acetabular, pelvis, or femoral neck fractures; polytrauma patients who need simultaneous procedures (with multiple teams); fractures in pregnant women (to avoid pelvic irradiation for nail entry); and fractures distal to a prosthesis or plate.

TIBIAL SHAFT NAILING

Tibial shaft fractures are among the most common long bone fractures. Closed tibial shaft fractures have been successfully treated with intramedullary nailing and have been shown to result in a high healing rate, and low malunion and infection rate.[42-44] The availability of interlocking nails is one of the most significant technological advances for tibial fracture management, as it has extended their use to fractures which are rotationally or axially unstable, and has made postoperative casting unnecessary. Additionally, locking has enabled the nailing of fractures within 6 cm of the tibial plafond. Unacceptable malunion often results from attempted nailing of fractures in the proximal metaphysis.

The technique of closed tibial nailing is often performed under tourniquet. The tourniquet must be deflated during reaming in order to avoid heat necrosis and the possible increased risk of infection and nonunion. Although reaming with intramedullary nailing increases compartment pressures,[24] these changes are transient and compartment syndrome is uncommon. The use of small-diameter unreamed devices has been popularized by its use for open tibial fractures.[22,43,45] There is a lack of clinical data and prospective randomized studies regarding the use of these nails for closed tibial shaft fractures. As a result, this controversy remains unsettled. Some surgeons advocate the use of small-diameter unreamed nails for high-energy closed fractures[46,47] and those fractures associated with elevated compartment pressures. Avoiding elevated compartment pressures and added disruption of endosteal blood supply may be beneficial in these clinical settings.

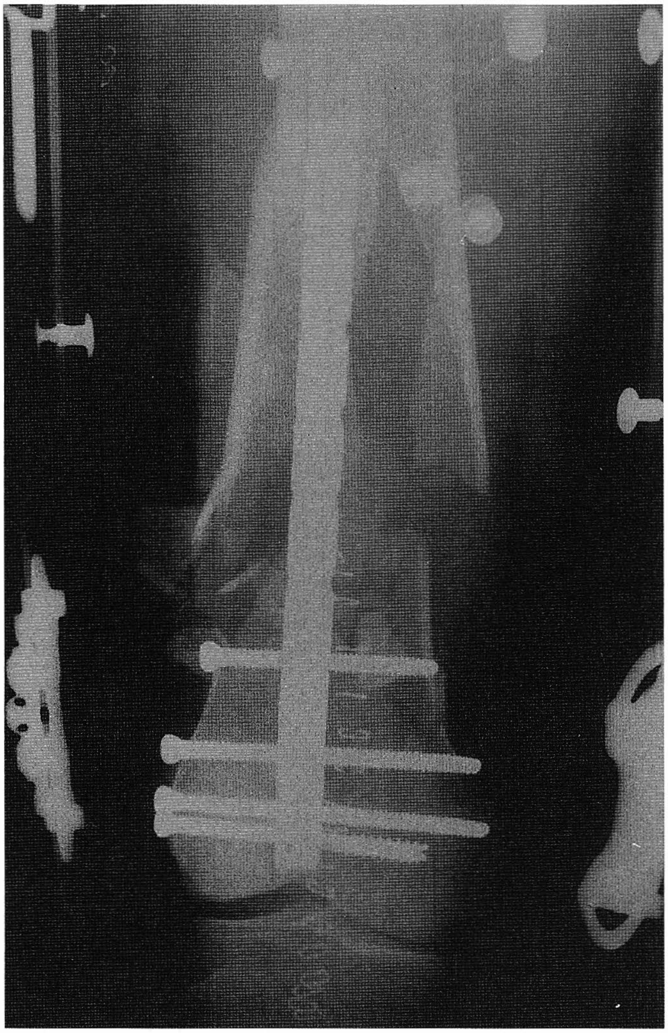

Figure 1. AP radiograph of a statically locked supracondylar intramedullary nail used to stabilize a highly comminuted distal femur fracture. The patient had an associated ligamentous injury.

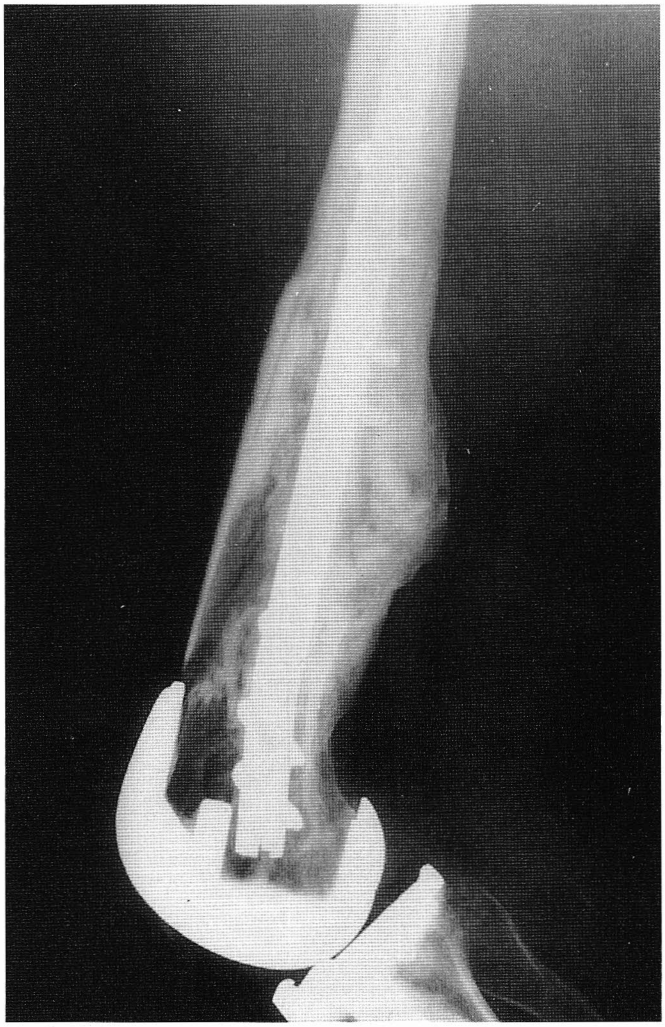

Figure 2. Lateral radiograph of a healed femur fracture above a total knee replacement at 1-year follow-up. The fracture was stabilized with a locked supracondylar intramedullary nail.

Open tibial fractures are managed with immediate debridement, fracture stabilization, and administration of systemic antibiotics. In recent years, the use of intramedullary nailing has been extended to Gustillo grades I, II, and IIIA fractures.[45] When a small-diameter unreamed nail is used, infection and union rates have been comparable to rates reported with the use of external fixation for the treatment of open tibia fractures.[22,23,45-47] Laboratory studies in animals have revealed a 70% versus 30% decrease in cortical circulation when comparing reamed to unreamed nailing.[48] Unreamed nails are smaller in diameter and some have been constructed with a solid cross section in order to increase their strength. Other nails have been constructed with an increased wall thickness for the same purpose. A recent study looking more closely at grade IIIB open fractures has found no significant difference between intramedullary nailing and external fixation with regard to union and complication rates.[23] There may be significant mismatch between endosteal diameter and outer nail diameter when smaller nails are used; consequently, the ability of these nails to prevent fracture malalignment is significantly reduced.[47] If small-diameter locking nails are inserted without reaming (Fig. 3), extra care must be taken to first achieve anatomic alignment. This is especially true for fractures above or below the level of the isthmus.

Surgical options for treatment of nonunions of tibial shaft fractures include fibulectomy, dynamic external fixation, dynamization, bone grafting, and stabilization. If primary nailing has not shown adequate consolidation by 12 to 14 weeks, an exchange reamed nailing with a larger diameter nail should be considered.[49] The osseous debris created by reaming may accelerate union with its osteoinductive effect.[2,5,10-12] Exchange nailing may be performed with immediate or delayed posterolateral bone grafting.

HUMERAL SHAFT NAILING

Fractures of the humeral shaft account for approximately 3% of all fractures.[50] Most humeral shaft fractures can be managed nonoperatively with a high union rate and good to excellent results expected. Operative indications for humeral shaft fractures include open fractures, those with an associated vascular injury, segmental fractures and floating elbows, pathologic fractures, polytrauma patients, fractures with intra-articular extension, and fractures that cannot be treated with an acceptable closed reduction.[50-54]

The success of intramedullary nailing for the treatment of fractures of the femur and tibia has led to the development of several types of locked intramedullary humeral nails. These nails are able to stabi-

Figure 3. Small-diameter locked tibial nail which was inserted without prior reaming for treatment of an open fracture.

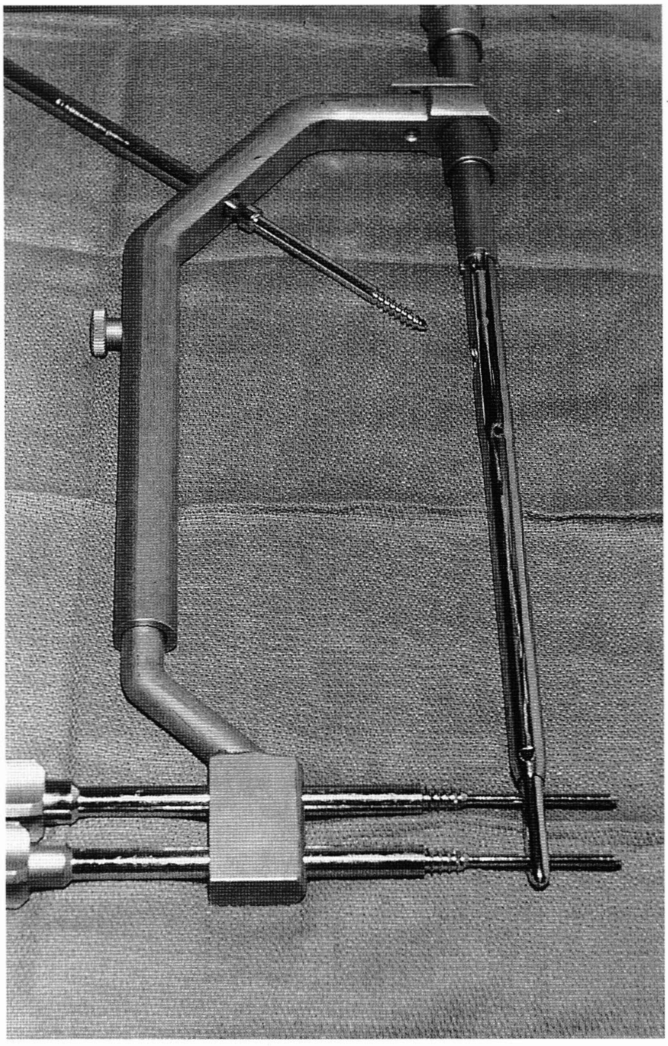

Figure 4. Photograph of the gradual lengthening nail with insertion and targeting device.

lize fractures 2 cm distal to the surgical neck to 3 cm proximal to the olecranon in both an antegrade manner, through the rotator cuff, or retrograde manner proximal to the olecranon. The nails may be inserted with or without prior reaming; however, it must be remembered that the humeral cortical thickness is much less than that of the femur or tibia, and therefore fracture comminution may result from excessive reaming. If a humeral nail is placed through the rotator cuff, it must be buried in order to prevent nail impingement on the acromion with arm elevation. The proximal locking screws must be inserted below the equator of the humeral head in a proximal-lateral to distal-medial manner, and can be inserted with a targeting device.[55] This will avoid subacromial impingement of the screw.[55] The axillary nerve is at risk during proximal screw insertion and caution should be observed during this part of the procedure.[55] The distal locking screws are inserted in either an anterior-posterior or posterior-anterior manner by a free hand technique. The decision of whether or not to ream prior to nail placement is often related to the age of the patient. Younger patients often have smaller diameter canals when compared to the larger canals of older patients. As such, prior reaming is often required with a younger population.

Successful treatment by locked nailing of acute humeral shaft fractures has been reported on the order of 95%.[56,57] Reamed nailing has also been used successfully for the treatment of nonunions with union rates approaching 87%.[58] Locked intramedullary nailing may also be considered for treatment of osteoporotic and pathologic fractures of the humeral shaft. If locked intramedullary nails are used for open fractures, they should be inserted without reaming so as not to disrupt the endosteal blood supply.

THE FEMORAL LENGTHENING NAIL

The use of external fixators for femoral lengthening has been well documented both in this country and in Europe.[59-61] There has been much success with these devices; however, there have also been many complications associated with the use of external fixation for femoral lengthening.[62] Pin tract complications with drainage result from the excursion of the thigh's muscle mass while walking. Other complications have included loss of hip and knee motion, knee subluxation, and femoral deformity. The intramedullary nail can serve as an attractive alternative for femoral lengthening and may avoid the potential complications encountered with external fixators. In addition to the previously discussed biomechanical advantages of intramedullary nailing, debris created by reaming may have an osteoinductive effect and accelerate regenerate consolidation.[11,12]

Previous applications of intramedullary fixation for lengthening have primarily involved treatment or limb salvage procedures for pediatric bone tumors and correction of deformity in osteogenesis imperfecta.[63] More recently, intramedullary nails have been used in conjunction with external fixators during limb lengthening in order to minimize the length of time the patient spends in the external fixator. Paley et al. have reported successful use of an external fixator for distraction osteogenesis performed over a dynamically locked nail.[64] The nail was then statically locked once the desired lengthening had been completed and the external fixator was removed. The average time spent in the external fixator was approximately half that of those patients undergoing standard Ilizarov lengthening.[64]

A gradual lengthening nail has recently been introduced in France. This nail is a telescoping device with a proximal outer cylinder and a solid distal inner rod, and is constructed of stainless steel (Fig. 4). The nail contains both proximal and distal locking holes and is equipped with an internal ratchet mechanism to actuate distal translation of the inner rod. This mechanism is activated by alternatively rotating the limb first internally, and then externally. The gradual lengthening nail is available for both left and right limbs in diameters ranging from 10 to 16 mm, and lengths of 120 to 240 mm. These devices have the ability to lengthen 2.5 to 4.0 cm depending on nail length chosen. The nail is placed in a standard fashion using the piriformis fossa as a starting point; however, a straight reamer must be used after the flexible reamers due to the nail's lack of an anterior bow. It is important that the nail be inserted without force so as not to damage the internal lengthening mechanism. Once the nail is locked in a standard fashion, both proximally and distally, the nail is lengthened 5 mm to separate the corticotomy site and to ensure proper functioning of the lengthening mechanism (Fig. 5).[65] Partial weightbearing is advanced depending on regenerate consolidation.

Mechanical studies of the gradual lengthening nail have been performed at

Figure 5. AP radiograph of femur after femoral lengthening prior to regenerate formation.

the Hospital for Joint Diseases.[65-67] It was found that bending stiffness with the nail in a shortened configuration was twice that in a lengthened configuration; however, both of these values were within the range measured for other standard intramedullary nails. Torsional stiffness also fell within the ranges obtained for other nails.

In the future, well-controlled clinical studies may prove the gradual lengthening nail an excellent alternative to standard methods of lengthening with an external fixator. STI

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