A Critical Analysis of the Eccentric Starting Point for Trochanteric Intramedullary Femoral Nailing

Robert F. Ostrum, MD, Andrew Marcantonio, DO, and Robert Marburger, RN

Objectives: Antegrade femoral intramedullary nailing through a greater trochanteric insertion site has been proposed for the treatment of subtrochanteric fractures. The currently available trochanteric nails have dissimilar characteristics, and the most appropriate insertion site for satisfactory subtrochanteric fracture alignment has not been determined. This study is an analysis of 5 different trochanteric femoral nails and 3 different insertion sites using a cadaveric model of a reverse obliquity subtrochanteric femur fracture to determine the optimal trochanteric entry site.

Setting: OSHA-approved cadaveric laboratory with an OEC 9800 (General Electric Company, Fairfield, CT) fluoroscopic C-arm.

Methods: Twenty-one embalmed human cadaveric femurs were stripped of soft tissues. Three different starting points on the anteroposterior radiograph were used: at the tip of the greater trochanter, and 2 to 3 mm medial and lateral to the tip. A reverse obliquity subtrochanteric fracture was created. The Trochanteric Antegrade Nail (TAN), Gamma nail (2nd and 3rd generations), Trochanteric Fixation Nail (TFN), and the Holland Nail were then inserted. The proximal bend and radius of curvature were calculated for each nail. Varus and valgus angulation as well as lateral gapping were measured on radiographs; also calculated were the mean, range, and standard deviation. Statistical analysis was performed on angulation and gapping at the fracture site by using Fisher least significant differences analysis, based on a 2-way ANOVA test.

Results: The Holland nail had a proximal bend of 10° and a radius of 300 cm. TAN was 5° and 350 cm, TFN was 6° and 150 cm, Gamma 2 was 4° and 300 cm, and Gamma 3 was 4° and 200 cm. The tip starting point led to the most neutral alignment regardless of nail. The lateral starting point led to varus with all nails. The medial starting point led to valgus of $>6°$ with the Holland and TFN; Gamma and TAN had better alignment with $<4°$ of valgus. Gapping of the lateral cortex was greatest with a lateral starting point.

Conclusions: An analysis of 5 trochanteric intramedullary nails with different proximal bends and 3 different starting points in the greater trochanter showed that the tip of the trochanter is close to the "universal" starting point. In this cadaveric subtrochanteric fracture model, the tip starting point led to the most neutral alignment regardless of nail used. The lateral starting point led to varus and gapping of the lateral cortex with all nails.

Clinical Relevance: Subtrochanteric fractures treated with a trochanteric antegrade nail should have an acceptable reduction before nail insertion. The tip of the trochanter, or even slightly medial, on anteroposterior fluoroscopy is recommended as the universal starting point for these nails. However, slight deviations from this point and nail geometry can cause fracture site malalignment. A lateral starting point led to varus alignment and should be avoided.

Key Words: trochanteric antegrade nail, subtrochanteric fracture, reverse obliquity

(*J Orthop Trauma* 2005;19:681–686). Reprinted with permission.

Accepted for publication July 27, 2005.
From Cooper University Hospital, Camden, NJ.
All orthopaedic devices used for this study are FDA-approved.
Reprints: Robert F. Ostrum, MD, Cooper University Hospital, 3 Cooper Plaza, Suite 411, Camden, NJ 08103 (e-mail: ostrum-robert@cooperhealth.edu).

Antegrade femoral nailing through a greater trochanter entry site using intramedullary nails with a proximal bend is gaining in popularity. The locations of the insertion sites differ according to the various nail manufacturers. The "tip of the greater trochanter" or "just lateral to the tip of the greater trochanter" are commonly used terms.[1,2] "The junction of the anterior third and the posterior two-thirds of the tip of the greater trochanter" also has been described.[2] The authors have noted clinically that some subtrochanteric femur fractures reduced on a fracture table can become malreduced with the introduction of a trochanteric nail.

Antegrade and retrograde centromedullary femoral nailing have been shown to have standard starting points that lead to excellent alignment. The piriformis fossa entry site for antegrade femoral nailing has been extensively studied and its location in line with the axis of the femoral shaft has been well documented.[3,4] The retrograde nail starting point has been shown to be anterior to Blumensaat's line on the lateral radiograph again in line with the axis of the femoral shaft. A cadaveric study showed that with proper nail insertion, there were no deleterious contact forces or pressures on the patellofemoral joint.[5] Tibial nailing starting at or near the tibial tubercle is eccentric to the midline axis of the tibial shaft. Carr et al[6] demonstrated a rigid tibial nail entry site just proximal to the tibial tubercle, which allowed implant insertion without generating high bursting strains in the proximal tibia. However, a study on proximal third tibia fractures showed that the proximal nail bend and geometry could lead to anterior tibial translation because of the eccentric starting location.[7] The eccentric starting point for trochanteric antegrade femoral nailing combined with the proximal nail bend and a fracture in the subtrochanteric region can lead to the same deformities seen with proximal tibial nailing.

The purpose of this study was to look at specific trochanteric entry sites to determine whether there is an optimal, universal starting point for antegrade trochanteric femoral nailing of subtrochanteric fractures. In addition, we examined the proximal bend, location of this bend, and radius of curvature of 5 commonly used implants.

MATERIALS AND METHODS

Nine matched pairs and 3 unmatched human cadaveric, embalmed femurs (21 femora) were stripped of soft tissues and stored frozen until ready for use. The femora were placed in neutral rotation, and they were radiographed using fluoroscopy.

Five intramedullary trochanteric nails of 12 mm in diameter and 340 to 380 mm in length were used: Trochanteric Antegrade Nail (TAN, Smith & Nephew, Memphis, TN), Gamma nail (2nd and 3rd generations, Howmedica/Osteonics, Mahwah, NJ), Trochanteric Fixation Nail (TFN, Synthes, Paoli, PA), and the Holland Nail (Biomet, Warsaw, IN). The location of the proximal bend on these nails and the radius of curvature were calculated. One of 3 entry points was used: at the tip of the trochanter, and 2 to 3 mm medial and lateral to the tip (Figs. 1A–C). The starting point was approximately in the midportion in the coronal plane and was determined by direct visualization of the greater trochanter and the tip; medial and lateral locations were determined on the anteroposterior fluoroscopy view. The entry hole of 12 mm was made over a 3.2-mm guidewire. After reaming, the entry site and the intact intramedullary canal to 12.5 mm, a reverse obliquity osteotomy was made with an oscillating saw from the base of the lesser trochanter to a point on the lateral cortex 4-cm distal. Using the 12-mm entry site, the Holland and TAN nails were inserted. The proximal entry site then was reamed to 17 mm before insertion of the TFN and the Gamma nails.

Each right femur was nailed successively with the Holland, TAN, Gamma (3rd generation), and TFN. The left femurs were nailed in the same manner except with the use of the 2nd-generation Gamma nail. The correct rotation, ie, anteversion, of the nail was obtained through external insertion devices. Six femurs were treated with a lateral starting point, 5 with a starting point just medial to the tip of the trochanter, and 10 with an entry site at the tip of the trochanter. Twenty-one data points were collected for each nail: 40 data points for tip nailing, 24 for lateral, and 20 for medial nailing.

Fluoroscopic radiographs were taken after each nail insertion and the displacement (gapping) and angulation were measured using a goniometer. The gap from the tip of the displaced distal portion of the proximal fragment to the intact shaft was measured in millimeters (mm). Statistical analysis was performed using GB-STAT version 5.30 from Dynamic Microsystems Incorporated. A completely randomized 2-way ANOVA was used to evaluate the data for angulation and gapping at the osteotomy site followed by the Fisher least significant differences test for the multiple comparisons between factors but also between cells when the interaction factor was significant.

RESULTS

The location and angle of the proximal nail bend and the radius of curvature was calculated for all 5 nails used (Table 1).

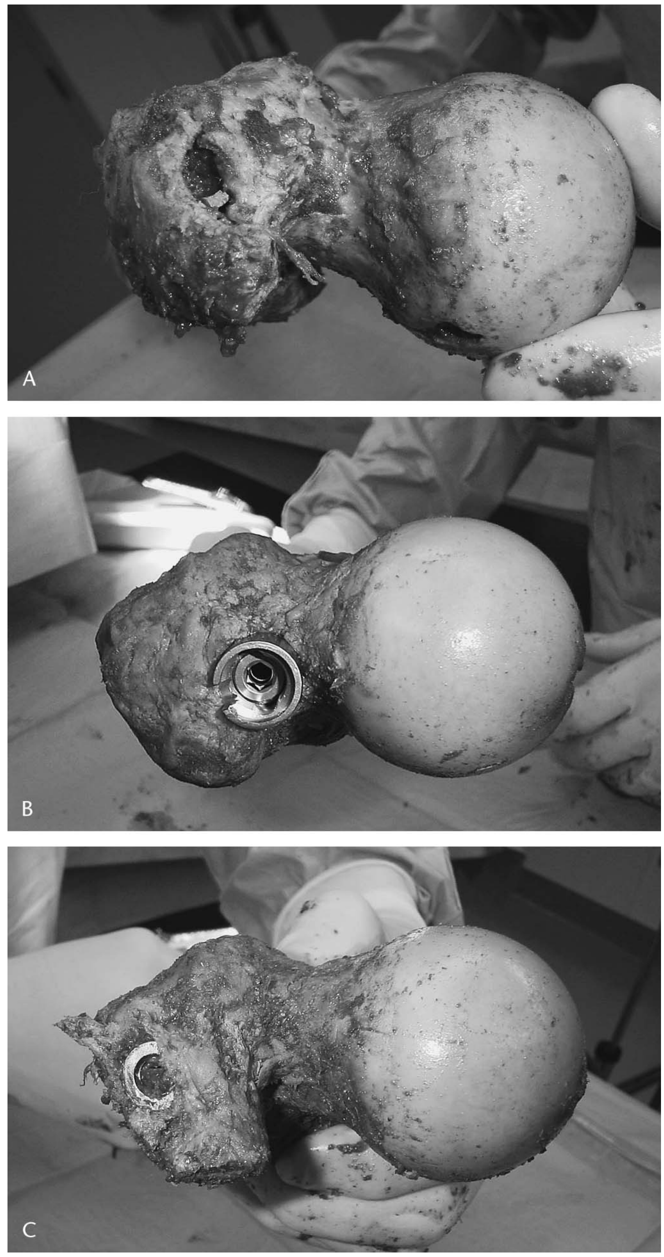

FIGURE 1. A, Trochanteric nail insertion site at the tip of the greater trochanter. B, Insertion site 2 to 3 mm medial to the tip of the trochanter. C, Trochanteric insertion site 2 to 3 mm lateral to the trochanter tip.

For the Holland nail (Biomet) with a lateral to the tip starting point, the mean angulation was 2.5° varus and gapping was 5.93 mm. For the medial starting point, angulation was 8.8° valgus with gapping of 3.56 mm. When the nail was started at the tip of the trochanter, the angulation was 2° varus with a mean gap of 3.47 mm (Tables 2 and 3; Fig. 2A).

Measurements for the Trochanteric Antegrade Nail (TAN) with a lateral starting point showed the mean angulation measured 4.43° varus with a gap measurement of 4.54 mm. For a medial starting point, the angulation was 3.2° valgus

TABLE 1. Geometry of Trochanteric Nails

	Holland	TAN	TFN	Gamma 2	Gamma 3
Proximal bend	10°	5°	6°	4°	4°
Radius of curvature	300 mm	350 mm	150 mm	300 mm	200 mm
Distance to bend	9.5 cms	7 cms	8.5 cms	9 cms	9 cms

with gapping of 2.16 mm and for a tip starting point angulation was 2.3° varus with gapping of 1.53 mm (Tables 2 and 3; Fig. 2B).

With insertion of the Gamma nail through a lateral starting point, the angulation was 7° varus and gapping was 6.27 mm. For a medial starting point, the mean angulation was 2.33° valgus and gapping measured 3.77 mm, whereas with an insertion point at the tip of the trochanter, angulation was 2.3° varus with a gap mean of 3.12 mm (Tables 2 and 3; Fig. 2C).

Using the Trochanteric Fixation Nail (TFN) with a lateral to the tip of the trochanter, starting point demonstrated 6.83° varus and a gap of 8.03 mm. A medial starting point resulted in 6.6° valgus with a mean gap of 3.88 mm and a tip starting point showed 0.3° varus and 3.56 mm of gapping (Tables 2 and 3; Fig. 2D). The mean angulation for all nails was 5.2° varus with a lateral starting point, 5.23° valgus with a medial starting point, and 1.4° varus when the nail was started at the tip of the trochanter.

Using Fisher least significant differences analysis based on a 2-way ANOVA test, the following results were obtained by using $P < 0.05$. For angulation after osteotomy and final nail seating, the entry point alone was significant for angulation ($P < 0.0001$). The nail geometry alone was not significant for angulation ($P = 0.1085$). The entry site + nail did have an effect on angulation ($P = 0.0366$). The lateral starting point for all nails led to varus. The medial starting point led to more valgus with Holland nail than Gamma nail and TAN, however, not statistically different than the TFN.

The tip starting point led to near neutral alignment for all nails ($P < 0.0001$). For TFN and Gamma, a lateral start led to more varus than the tip starting point ($P < 0.01$). For TAN and Holland, a lateral start was not significantly worse than tip insertion. The lateral entry point was significant for varus angulation independent of nail used ($P < 0.0001$).

TABLE 2. Angulation With Trochanteric Nail Insertion

	Angulation (degrees)	Standard Deviation
Holland		
Lateral start	2.5° varus (0–6° varus)	0.92
Medial start	8.8° valgus (5–11° valgus)	2.28
Tip start	2° varus (2° valgus–6° varus)	3.12
TAN		
Lateral	4.4° varus (0–8° varus)	2.44
Medial	3.2° valgus ((0–8° valgus)	4.38
Tip	1.25° varus (1° valgus–4° varus)	1.58
Gamma		
Lateral	7.0° varus (2–10° varus)	3.03
Medial	2.3° valgus (2°varus–10° valgus)	4.63
Tip	2.3° varus (2° valgus–8° varus)	2.98
TFN		
Lateral	6.83° varus (4–10° varus)	2.48
Medial	6.6° valgus (2–11° valgus)	3.36
Tip	0.3° varus (6° valgus–6° varus)	3.77

TABLE 3. Gapping at the Osteotomy Site After Trochanteric Nail Insertion

	Gapping (mm)	Standard Deviation
Holland		
Lateral start	5.93 (4–8)	1.48
Medial start	3.56 (1–7)	2.38
Tip start	3.47 (0–6.4)	2.37
TAN		
Lateral	4.54 (0–7)	2.44
Medial	2.16 (0–4.8)	1.71
Tip	1.53 (−2–4)	2.04
Gamma		
Lateral	6.27 (4–9)	1.77
Medial	3.77 (0–9)	3.61
Tip	3.12 (0–7)	2.63
TFN		
Lateral	8.03 (5.6–12)	2.55
Medial	3.88 (2–6.4)	1.63
Tip	3.56 (0–6.4)	2.38

When analysis of lateral cortex gapping was performed using Fischer least significant differences based on a 2-way ANOVA test, it was again found that the entry site alone was significant ($P < 0.0001$). The nail geometry was significant ($P < 0.05$) and the combined nail + entry site was not significant (NSS). The lateral entry site led to more gapping than the medial or tip entry sites ($P < 0.01$). The TAN nail produced less gapping than the TFN for all entry sites ($P < 0.05$). There was no difference in gapping between the medial and tip starting point (NSS).

Analysis of 12 lateral radiographs demonstrated that a starting point at the junction of the anterior one-third and posterior two-thirds of the greater trochanter led to the best alignment. A mid trochanteric start led to slight posterior displacement of the shaft fragment, whereas a more posterior start led to further translation and apex anterior angulation.

DISCUSSION

Trochanteric antegrade femoral nailing has gained popularity because of the ease of finding the trochanteric entry site versus the traditional piriformis fossa entry site for classic antegrade nailing. Centromedullary nailing—retrograde or antegrade—has led to high union rates, but more importantly the alignment with these reamed nails has been excellent.[8,9] Second-generation intramedullary nailing of subtrochanteric femur fractures through a piriformis fossa entry site has been shown to have a propensity toward a varus deformity.[10,11] The pull of the hip flexor and abductor muscles makes antegrade nailing of subtrochanteric femur fractures difficult, independent of starting point. The varus deformity commonly seen is worse in reverse obliquity fractures because of the very high proximal medial fracture line and the malalignment produced by the contraction of the gluteus medius musculature. This study did produce a worse-case

FIGURE 2. A, Femur #9, tip insertion site with Holland nail (Biomet). B, Femur #9, tip insertion site with Trochanteric Antegrade Nail. C, Femur #9, tip insertion site with Gamma 3 nail. D, Femur #9, tip insertion site with Trochanteric Fixation Nail. Note varus at osteotomy site with all 4 nails despite introduction from the tip of the greater trochanter.

scenario osteotomy with the reverse obliquity; however, the femur was reamed before the osteotomy. Therefore, no eccentric reaming was performed so alignment was anatomic during this canal preparation.

The surgical technique brochures for trochanteric antegrade femoral nails are basic and offer little insight. For the TAN, with a proximal bend of 5°,[1] the instructions state to advance a guidewire at the tip of the greater trochanter. The 10° proximal bend Holland nail description states, "The correct entry point is located at the junction of the anterior third and posterior two-thirds of the tip of the trochanter. The insertion site should be just lateral to the tip of the greater trochanter avoiding a more medial insertion site (piriformis fossa)."[2] The Gamma nail has a 4° proximal bend,[12] and the suggested entry point is "at the junction of the anterior one-third and posterior two-thirds of the tip of the greater trochanter and on the tip itself." For the TFN[13] with its 6° angle proximally, it is suggested "the entry point for the nail is in line with the medullary canal in the lateral view. In the AP view, the nail insertion point is slightly lateral to the tip of the greater trochanter, in the curved extension of the medullary cavity. The lateral angle of the nail is 6°, therefore, the 3.2 guidewire must be inserted at an angle 6° lateral to the shaft of the femur and intersect the centerline of the canal just distal to the lesser trochanter."

It becomes obvious that the exact location of not only the guidewire entry site but also the entry hole after reaming for the starting point is important. The tip of the trochanter may be where the guidewire starts, but with obese or muscular patients, eccentric lateral reaming can lead to a more lateral entry portal and thereby increase the final varus angulation. For the Gamma and TAN nails, a tip or even slightly medial to the tip starting point led to excellent results. For the Holland or TAN nails, the tip or slightly lateral worked well; however, lateral was not good for Gamma or TFN. TFN performed best with a tip starting point only, but yielded the best overall alignment results of all the nails used. The fact that TFN, TAN, and Gamma all performed differently despite having similar proximal bends of 4° to 6° demonstrates that possibly other variables, such as the location of the bend or radius of curvature of the nail, also may have an effect on fracture alignment. Furthermore, the anatomy of the trochanter itself, the femoral neck-shaft angle, and the depth of nail insertion into the proximal femur also may effect final alignment.

From this study the starting point seems to be the single most important factor; however, fracture reduction, reaming, and nail geometry also will determine the fracture alignment in the operating room. Whether surgeons can percutaneously, or through a small open procedure, determine the "exact" starting point is difficult to say. The anatomy of the greater trochanter is variable and the rotation, abduction, and flexion positions of the proximal femur associated with a subtrochanteric fracture can make this starting point difficult to visualize and at best a very "inexact" procedure. Often subtrochanteric fractures are well aligned on the fracture table, yet introduction of the nail with its proximal bend can produce a deformity.

It is suggested that the coronal starting point be located at the junction of the anterior one-third and posterior two-thirds of the trochanter to facilitate placement of the cephalomedullary device into the femoral head.[1,2,12] Although only a small number of specimens were examined on lateral radiographs, a trend was seen that this starting point did lead to better alignment as a result of the proximal radius of curvature of the nails.

Reverse obliquity intertrochanteric/subtrochanteric fractures are extremely difficult to treat with any method; however, intramedullary nailing seems to lead to more reasonable results than the sliding hip screw implants. Haidukewych et al[14] reported on 47 reverse obliquity fractures treated by various methods and had a 32% failure rate. The highest failure rate was with plate-screw devices and only 1 of 6 fractures treated with a cephalomedullary device failed. Honkonen et al[15] treated 72 reverse obliquity intertrochanteric fractures with a cephalomedullary nail and found a "near anatomic alignment and properly placed implant" in only 47 cases (65%). There were 5 reoperations, and a cable was used in 12 of 14 open procedures.

The deformities seen in this proximal femoral model are similar to those seen with nailing of proximal one-third tibial shaft fractures. The similarities include an oblique fracture with muscle pull to accentuate the deformity and an eccentric starting point for the intramedullary nail. In the tibia, Henley et al[7] and Lang et al[16] in separate articles demonstrated an anterior translation of the proximal tibia and a procuvatum deformity when these fractures were nailed. This deformity is predictable, and a malunion can lead to a possible nonunion as well.

In a study using the long Gamma nail in intertrochanteric/subtrochanteric fractures, Barquet et al[17] reported 2 of 52 patients who had a deformity of $>5°$ of varus but did not comment on their function. Borens studied 90 subtrochanteric fractures treated with a long Gamma nail and had 2 nail failures caused by varus malalignment.[18] The type of fracture, amount of varus, or other inciting factors was not described. This stresses the fact that besides a poor clinical result with a limp secondary to varus malunion, catastrophic implant failure also can be seen as a more serious complication. However, no study has shown a correlation between varus alignment of the proximal femur and poor clinical results. In fact the opposite is true: Barquet et al[17] found that a good radiologic result did not uniformly mean a good functional outcome.

Part of our original hypothesis was that the performance of the nail could be predicted by the angle of the proximal bend and the insertion site. A greater proximal bend would do better with a lateral starting point and a lesser-angled nail would do better with a more medial entry site. The Holland nail with the most pronounced 10° proximal bend did do better with a starting point lateral to the tip of the trochanter. This was predictable. Unfortunately, the other nails with a bend of 4° to 6° did not perform predictably with a starting point at or lateral to the tip of the greater trochanter. The TAN nail with a 5° proximal bend showed good alignment with a slight lateral starting point, but Gamma and TFN with 4° and 6° proximal bends did not fare well when started just lateral to the tip of the trochanter. Utilizing the tip of the trochanter as a starting point led to both varus and valgus malalignments with all 5 nails used; however, overall the tip led to the best final angular and gapping alignment and is to be recommended as the "universal" starting point.

This study further demonstrates the importance of entry site, femoral anatomy, and nail geometry as significant variables, because in this study there was no muscle pull and reaming was performed on an intact femur. Thus, even controlling these potentially negative variables that the surgeon faces in the operating room did not yield a consensus that all nails performed the same. This study found that slight deviations in the tip entry site can lead to final fracture malalignment.

CONCLUSIONS

An analysis of 5 trochanteric intramedullary nails with different proximal bends and 3 different starting points in the greater trochanter showed that the tip of the trochanter is the "universal" starting point. This tip starting point led to the most neutral alignment regardless of nail used. The lateral starting point led to varus with all nails and is to be avoided. Only the Holland nail with a 10° proximal and the TAN with a 5° proximal bend led to varus of $<5°$ with a lateral entry site. The medial starting point led to valgus with the Holland and TFN; Gamma and TAN had good alignment. Gapping of the lateral cortex, which was related to varus alignment, was greatest with a lateral starting point and is to be avoided. The TFN performed well at the tip only. The Holland nail did well at the tip or slightly lateral. The Gamma and TAN nails did better with a medial or tip starting point. These conclusions are applicable to all subtrochanteric femur fractures that occur near the proximal bend in the trochanteric nail.

Recommendation

The tip of the trochanter, or even slightly medial to the tip, should be the entry site of choice for antegrade trochanteric nailing of subtrochanteric fractures. The lateral starting point, even 2 to 3 mm from the tip of the trochanter, is to be avoided.

ACKNOWLEDGMENTS

The authors thank Mindy Hoffmann and Edward Dailey for their assistance and Eric Hume, MD, for the statistical analysis.

REFERENCES

1. Russell TA, Sanders RW, Trigen IM. *Nail System Surgical Technique*. Memphis: Smith and Nephew, Inc.; 2001.
2. *Holland Nail System Surgical Technique*. Warsaw, IN: Biomet Orthopaedics, Inc.; 2002.
3. Johnson KD, Tencer AF, Sherman MC. Biomechanical factors affecting fracture stability and femoral bursting in closed intramedullary nailing of femoral shaft fractures, with illustrative case presentations. *J Orthop Trauma*. 1987;1:1–11.
4. Gausepohl T, Pennig D, Koebke J, et al. Antegrade femoral nailing: an anatomical determination of the correct entry point.Injury 2002;701–705.
5. Morgan E, Ostrum RF, DiCicco J, et al. Effects of retrograde femoral intramedullary nailing on the patellofemoral articulation. *J Orthop Trauma*. 1999;13:13–16.
6. Carr JB, Sobba DB, Bear LL. Biomechanics of rigid tibial nail insertion sites. *Am J Orthop*. 1996;25:553–556.
7. Henley MB, Meier M, Tencer AF. Influences of some design parameters on the biomechanics of the unreamed tibial intramedullary nail. *J Orthop Trauma*. 1993;7:311–319.
8. Tornetta P 3rd, Tiburzi D. Antegrade or retrograde reamed femoral nailing. A prospective, randomized trial. *J Bone Joint Surg Br*. 2000;82:652–654.
9. Brumback RJ, Ellison TS, Poka A, et al. Intramedullary nailing of femoral shaft fractures. Part III: Long-term effects of static interlocking fixation. *J Bone Joint Surg Am*. 1992;74:106–112.

10. French BG, Tornetta P3rd. Use of an interlocked cephalomedullary nail for subtrochanteric fracture stabilization. *Clin Orthop*. 1998;348:95–100.
11. Wiss DA, Brien WW. Subtrochanteric fractures of the femur. Results of treatment by interlocking nailing. *Clin Orthop*. 1992;283:231–236.
12. *Long Gamma Locking Nail Surgical Technique for Femoral Fracture Fixation*. Mahwah, NJ: Howmedica Osteonics, 2002.
13. Trochanteric Fixation Nail Technique Guide. Paoli, PA: Synthes (USA); 2002.
14. Haidukewych GJ, Israel TA, Berry DJ. Reverse obliquity fractures of the intertrochanteric region of the femur. *J Bone Joint Surg Am*. 2001;83:643–650.
15. Honkonen SE, Vihtonen K, Jarvinen MJ. Second-generation cephalomedullary nails in the treatment of reverse obliquity intertrochanteric fractures of the proximal femur. *Injury.* 2004;35:179–183.
16. Lang GJ, Cohen BE, Bosse MJ, et al. Proximal third tibial shaft fractures. Should they be nailed? *Clin Orthop*. 1995;315:64–74.
17. Barquet A, Francescoli L, Rienzi D, et al. Intertrochanteric-subtrochanteric fractures: treatment with the long Gamma nail. *J Orthop Trauma*. 2000;14:324–328.
18. Borens O, Wettstein M, Kombot C, et al. Long gamma nail in the treatment of subtrochanteric fractures. *Arch Orthop Trauma Surg*. 2004;124:443–447.