Closed, Locked Intramedullary Nailing of Pediatric Femoral Shaft Fractures Through the Tip of the Greater Trochanter

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Background: **Closed femoral nailing is universally accepted as the treatment of choice in almost all diaphyseal femoral fractures in adults. Numerous authors reported favorable results applying the same surgical technique in the adolescent patient group. Nevertheless, reports of complications such as avascular necrosis and alteration of the proximal femoral anatomy have dampened the initial enthusiasm. The purpose of this paper was to evaluate the possible effect of closed intramedullary nailing through the greater trochanter on the proximal femoral anatomy.**

Methods: **We report the results of intramedullary nailing in 20 skeletally immature patients (13 men and 7 women) with a mean age of 14.4 years (range, 11–16 years). All were treated with closed, reamed, percutaneously performed nailing, using the tip of the greater trochanter as the nail insertion point. The patients were followed for 29 months in average (range, 19–37 months).**

Results: **No major complication (limb length discrepancy, avascular necrosis, coxa valga) occurred during the observation period. All fractures healed clinically and radiographically within 9 weeks in average (8–13 weeks) and all patients returned to the preinjury activity level. The mean ATD difference was 1.10 ± 3.51 (range, −5–7 mm, 95% CI −0,54/2,74, $p = 0.177$). The mean LTA distance difference was 0.3 mm (range, −6–5 mm, $p = 0.158$), the mean femoral length difference was 1.9 mm (−9–12 mm, $p = 0.122$) and the overall limb length difference was 1.4 mm (−25–20 mm, $p = 0.178$). The mean neck-shaft angle difference was 0.20 ± 1.74 (range, −3–4, $p = 0.612$) and the mean neck width was 0.60 ± 1.50 (range, −3–3, $p = 0.09$). Fourteen nails (70%) were removed within 13 months in average (range, 10–18 months) without any complications.**

Conclusion: **This study showed that with strict adherence to a surgical technique that respects the growing proximal femur and its vascular anatomy, using the tip of the greater trochanter as an entry point to the femoral canal, the proven advantages of closed, intramedullary nailing can safely be offered to the adolescent patient population as well.**

Key Words: **Avascular necrosis, Greater Trochanter, Intramedullary nailing, Pediatric femoral fracture.**

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Femoral shaft fractures in the pediatric patient group are relatively rare injuries, accounting for just 1.6% of all fractures.[1] Nevertheless, it is the leading cause for hospitalization measured in days per year, for hospital stay longer than 5 days in pediatric patients.[2]

The management of femoral shaft fractures is age-specific. While in patients younger than 6 years, early reduction or traction followed by spica casting is considered the treatment of choice, in older patients conservative treatment provides less satisfactory results.[3,4] In adolescent patients nonoperative treatment does not always ensure complete fracture site rotational and translational stability, resulting often in angular and rotational deformities as well as in limb-length discrepancy.[5] The financial and social impact of conservative treatment is also considerable.[5,6]

Operative methods, which allow early and independent mobilization, are in principle more attractive. Among other operative treatment options, use of either rigid or flexible nails inserted intramedullary has been strongly advocated by many authors.[7–16]

Flexible intramedullary rods recently gained popularity among surgeons because they can easily be accommodated by the narrow femoral canal, are introduced away from growing areas and from areas with precarious blood supply. On the other hand, the flexible IM nailing technique performs poorly when there is fracture comminution, the fracture is located at either end of the femur, especially in overweight (>45 kg) patients.[17,18]

Rigid nailing in adolescents has been notoriously related to complications such as avascular necrosis and proximal femoral growth disturbance, especially coxa valga.[7,19–21] Use of the piriformis fossa as the entry point to the femoral canal may have harmed the proximal femoral vascular supply. This distinct anatomic location has been recognized as the area that nests the single stem artery that provides the blood supply to the femoral head.[22,23]

Newer reports on intramedullary nailing in adolescents through the tip of the trochanter revealed no serious complication.[8,13–15,24] These studies enhance the validity of the method that offers the merits of excellent fracture handling with minimal hospital stay and cost, yielding favorable radiographic and functional outcome.

Our study is merely a report on the use of a modified percutaneous technique placing the entry point for IM nailing

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at the tip of the greater trochanter. The possible effect of closed intramedullary nailing on the proximal femoral anatomy was also evaluated.

PATIENTS AND METHODS

From November 1999 to September 2001, 20 consecutive patients with a mean age of 14.4 years (range, 11–16 years) with the admitting diagnosis of a femoral diaphyseal fracture were treated with closed, reamed, statically locked intramedullary nailing. Patients with closed physes at the date of admission and patients with follow up shorter than 2 years were excluded from the study.

In 13 patients (65%) the fracture was the only injury, while the fracture was unilateral in all cases. In four patients the fracture was a grade I open, according to the Gustillo-Andersen classification. Closed intramedullary proximally and distally locked nailing was performed after a mean hospital stay of 2 days (0–5 days) depending on operating room availability. As far as the location is concerned, 9 patients (45%) sustained midshaft fractures, 6 (30%) proximal third, and 5 (25%) distal third fractures. Fourteen Russel-Taylor IM nails (Smith and Nephew, Memphis, TN) of mean diameter 10.8 mm (range, 10–12 mm) were used. In 6 patients, who were preoperatively considered having a medullary canal diameter of less than 10 mm a Targon nail (Aesculap AG, Tuttlingen, Germany), was used with a mean diameter of 8.6 mm (range, 8–9 mm). The mean overall length of the intramedullary rod was 350 mm (280–420 mm). The procedure was completed within 75 minutes in average (range, 50–110 minutes) and no patient required blood transfusion intraoperatively.

Regarding the surgical technique employed, the patient was placed supine on a fracture table, with adequate lateral bend of the torso on the frontal plane to allow direct linear access to the tip of the greater trochanter. A 2.2 mm threaded guide pin was introduced percutaneously reaching the tip of the greater trochanter. The pin was positioned in line with the femoral medullary canal and accurate positioning was verified with the image intensifier in both the anteroposterior and the lateral projections. The guide pin was advanced and the entry site was opened with over-reaming with a cannulated reamer, while 2 cm long incision was made around the guide pin to facilitate reaming. Routine fracture reduction, reaming and nail insertion followed. The distal end of the nail was proximal to the distal growth plate in all cases. Distal locking was performed with a free hand technique followed by proximal locking.

Postoperative clinical and radiographic assessment was performed at 4, 8, and 12 weeks as well as on a semi-annual basis after that (Figs. 1*A–C*). The fracture was considered clinically healed when full unprotected weight bearing was painless and was considered radiographically healed when there was bridging of all cortices in the AP and lateral fracture radiographs. During nail insertion careful selection of the nail length under fluoroscopic guidance is necessary to avoid distal femoral physis penetration (Fig. 2). The femoral nail was removed in 14 patients. Both hip MRI scan was obtained in 13 patients after nail removal to exclude the presence of asymptomatic AVN (Fig. 3). Weight bearing status and adjacent joint range of motion were recorded at the immediate postoperative period as well as the time to radiographic and clinical union.

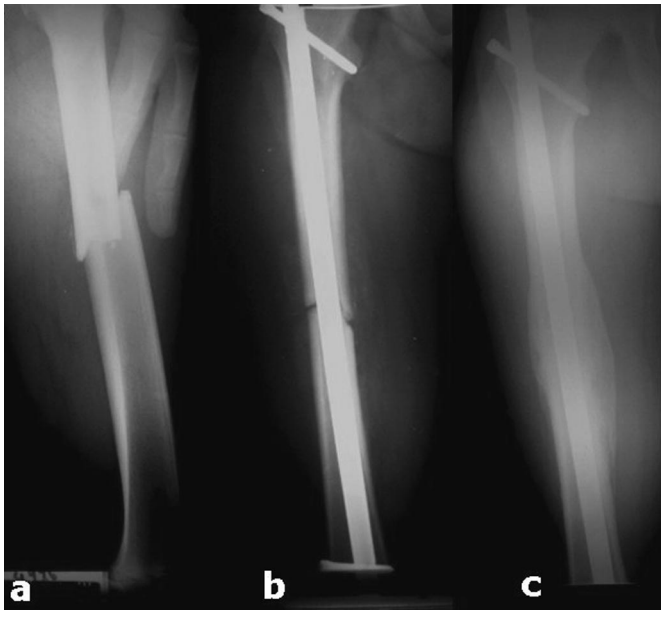

Fig. 1. *(A–C). Healing progression of a transverse midshaft fracture in a 14 year old patient. Radiographs at presentation (A), 1 (B), and 13 months after nailing (C).*

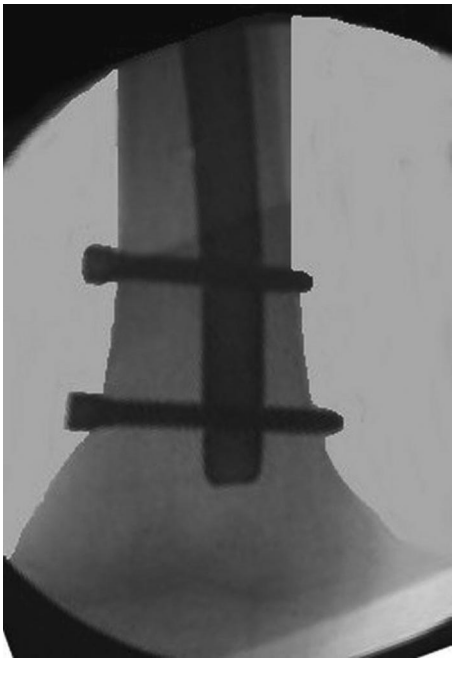

Fig. 2. *The appropriate length of the femoral nail is chosen intraoperatively under fluoroscopic guidance to avoid distal femoral physis penetration.*

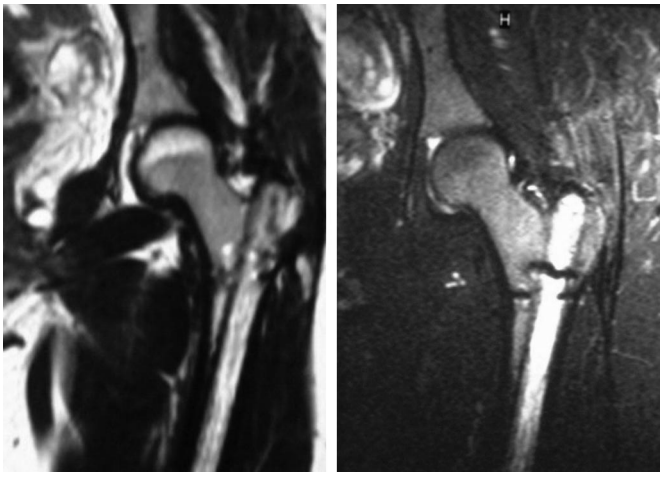

Fig. 3. *MRI scan of the left hip and proximal femur 3 days after nail removal. The nail was removed 15 months after the fracture had occurred. The position of the nail is clearly demarcated on T1 images, giving bright signal on T2 images. There is no evidence of femoral head pathology.*

The proximal femoral anatomy was assessed by comparing the affected with the contralateral side. The articulo-trochanteric distance (ATD) of Edgren, lesser trochanter articular distance (LTA), neck shaft angles and neck width were measured on plain AP pelvic radiographs (Fig. 4). Computed tomography scans were performed in all patients to detect length discrepancies at 1 year postinjury. Measurements were statistically evaluated with the paired *t* test, and the significance level was set at $p = 0.05$.

RESULTS

The mean follow up extended to 29 months postoperatively (range, 19–37 months). All fractures healed by secondary healing, with the development of callus, within 9 weeks in average (range, 8–13 weeks) and there were no delayed unions, nonunions or deep infections. The results are presented in Table 1. One patient developed a stitch abscess that responded to local care and p.o. antibiotics. At 6 weeks postoperatively all patients demonstrated lack of full knee and hip flexion, which were restored within the next 3 weeks. Within 6 weeks postoperatively, 16 patients (80%) were capable of full weight-bearing. At the latest follow up all patients had returned to their preinjury activity level and no patient had a limp. No clinical signs and symptoms indicative of hip osteonecrosis were observed, although two patients did not reach yet the full 2 year interval since injury and considered to be still at risk for development of ascular necrosis.

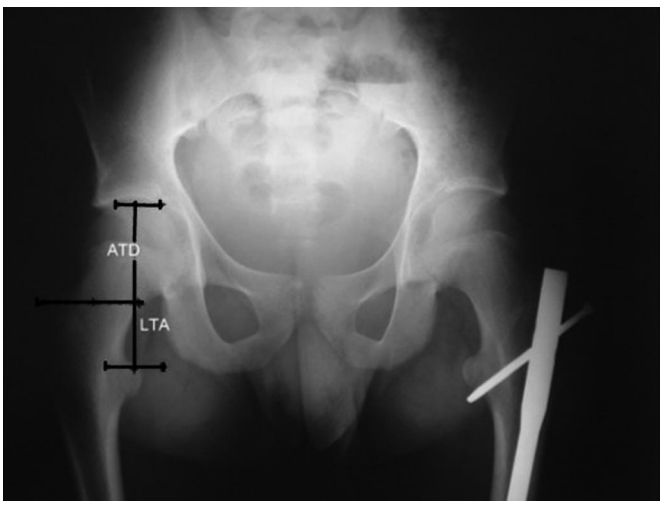

Fig. 4. *The morphology of the proximal femoral end was examined on plain AP pelvic radiographs. ATD, articulo-trochanteric distance; LTA, lesser trochanter articular distance.*

Plain radiographic examination was normal in all patients. In six patients, were a Russel-Taylor nail without a proximal plug was used, intramuscular calcifications around the proximal end of the nail were noticed. This was merely a radiographic finding with no concomitant clinical sequelae. Four patients demonstrated premature closure of the greater trochanteric apophysis, but their gait was normal and they were asymptomatic. There was no overall statistically significant difference between the radiographic parameters measured between the fractured and the contralateral side. The mean ATD difference was 1.10 ± 3.51 (range, −4–7 mm, 95% CI −0,54/2,74, $p = 0.177$), while the mean neck width difference was 0.7 mm (−3–3 mm). A sample size of 20 achieves 28% power to detect a difference of −1.1 between the null hypothesis mean of 0,0 and the alternative hypothesis mean of 1.1 with a known SD of 3.5 and with a significance level (alpha) of 0.050 using a two-sided Wilcoxon test. The mean LTA distance difference was 0.3 mm (range, −6–5 mm, $p = 0.16$), the mean femoral length difference was 1.9 mm (−9–12 mm, $p = 0.12$) and the overall limb length difference was 1.4 mm (−25–20 mm, $p = 0.18$). The mean neck-shaft angle difference was 0.20 ± 1.74 (range, −3–4, $p = 0.61$) and the mean neck width was 0.60 ± 1.50 (range, −3–3, $p = 0.09$). Fourteen nails (70%) were removed within 13 months in average (range, 10–18 months) without any complications.

DISCUSSION

Intramedullary nailing in adolescents has been linked to notorious complications, such as limb length inequality, avascular necrosis of the femoral epiphysis, thinning of the femoral neck and coxa valga.[7,19–21] Use of the piriformis fossa to establish the entry point leading to the femoral canal endangers the vascularity of the femoral head, i.e. the terminal branch of the medial femoral circumflex artery that branches off to the lateral epiphyseal vessels.[22,23] According to Siffert[28] up to the age of eight this area also represents an active growth center that affects the width of the femoral neck and the femoral neck shaft angle.

Use of the trochanteric approach avoiding the piriformis fossa and all pertinent complications, increases the safety of the procedure. The initially reported cases of postoperative

Table 1 Data for All 20 Patients Included in This Study

Patient	Age, years	Sex	Side	Injury Mechanism	Fracture Location	ATD #, mm	ATD, Normal mm	Diff. ATD, mm	NSA #, mm	NSA, Normal mm	Diff. NSA, mm	Neck Width #, mm	Neck width, Normal mm	Difference Neck Width mm	Accompanying Injuries	Hospital Stay days	Open #	Nail Removal
1	16	M	R	MVA	Proximal third	30	29	1	140	139	1	23	21	2	No	4	No	Yes
2	16	M	R	MVA	Proximal third	17	13	4	119	121	−2	25	26	−1	No	7	Grade I	Yes
3	16	F	R	Fall	Midshaft	13	15	−2	130	130	0	30	28	2	# Distal radius	5	No	No
4	15	M	L	Sports	Distal third	23	18	5	140	139	1	31	30	1	No	8	No	No
5	14	M	L	MVA	Midshaft	24	22	2	141	141	0	24	25	−1	# Ankle	7	No	No
6	13	M	L	Sports	Midshaft	18	14	4	130	131	−1	30	29	1	No	8	No	Yes
7	15	M	R	MVA	Midshaft	18	22	−4	135	131	4	33	33	0	No	4	No	No
8	16	F	R	MVA	Midshaft	13	17	−4	132	134	−2	35	37	−2	No	6	No	Yes
9	11	F	L	Fall	Distal third	23	20	3	124	126	−2	37	37	0	No	9	Grade I	Yes
10	14	M	R	Bike	Distal third	24	28	−4	143	142	1	35	32	3	No	9	No	No
11	14	M	R	MVA	Midshaft	30	30	0	149	147	2	36	36	0	# Elbow	10	No	No
12	15	M	R	MVA	Proximal third	26	23	3	139	140	−1	38	37	1	# Distal radius	6	No	Yes
13	12	M	R	MVA	Proximal third	19	18	1	136	136	0	34	32	2	No	5	No	No
14	15	M	R	MVA	Midshaft	23	19	4	143	143	0	29	27	2	No	5	Grade I	Yes
15	14	F	L	MVA	Proximal third	28	21	7	134	133	1	37	37	0	Tendon laceration	7	No	Yes
16	14	M	R	Sports	Distal third	26	29	−3	129	128	1	30	31	−1	No	5	No	Yes
17	16	M	R	MVA	Midshaft	30	25	5	137	137	0	41	38	3	No	6	No	Yes
18	15	F	L	MVA	Midshaft	24	25	−1	134	137	−3	27	29	−2	No	8	No	Yes
19	15	F	L	Sports	Proximal third	26	22	4	127	126	1	35	34	1	Head injury	17	Grade I	Yes
20	16	M	L	MVA	Distal third	22	25	−3	132	129	3	40	39	1	Abdominal trauma	13	No	Yes

ATD, articulo-trochanteric distance; NSA, neck-shaft angle; Diff., difference.

Fig. 5. *Correct placement of the femoral nail through the tip of the greater trochanter avoiding the piriformis fossa.*

growth disturbance of the proximal femur as well as the development of iatrogenic osteonecrosis of the upper femoral epiphysis after intramedullary nailing merely represent early phases of the learning curve and may be attributed to technical factors. These complications are not reported in all recent clinical studies that utilize the trochanteric approach.[8,13–15,24]

Moberger et al.[13] studied 48 patients with a diaphyseal femoral shaft fracture treated with intramedullary nailing performed through the tip of the greater trochanter and followed up to 60 months postoperatively. No patient developed any significant complications such as alterations in the proximal femoral anatomy or avascular necrosis. MRI scans detected two cases of sub-clinical avascular necrosis, which was bilateral in one of them.

Gordon and co-authors[24] looked specifically for proximal femoral changes in skeletally immature patients after antegrade intramedullary nailing. They concluded that for patients older than 9 years of age, this nailing does not alter proximal femoral anatomy. These findings are in accordance with reported data from authors that looked upon the effects of trochanteric epiphysiodesis on the growing proximal femur.[25–27] All authors agree that premature closure of the greater trochanter in patients older than 8 years of age is not expected to cause any change on the proximal growing femur.

Thus the vascular anatomy and the location of the growth centers in the proximal femur impose certain modifications on the standard "adult" intramedullary nailing technique, which are as follows:

1. Fashioning of the entry point to the medullary canal through the tip of the greater trochanter (Fig. 5).
2. Extensive surgical exposure of the entry point is not necessary. This can be localized in both anteroposterior and medio-lateral direction using a percutaneously introduced guide wire under fluoroscopic guidance.
3. Percutaneous insertion of all instrumentation and the nail through a 2 cm long incision.
4. Use of small diameter nails to minimize reaming. The industry has recently become adaptive to this technique releasing small diameter "pediatric nails" with a built-in offset to accommodate for the lateral entry point.
5. Static nail interlocking.
6. Removal of the nails at least 1 year postoperatively using an atraumatic technique.

We feel that intramedullary nails should be removed as soon as the fracture has remodeled, i.e. within 2 years after fracture fixation, especially in patients with a prominent proximal nail end accompanied with local symptoms. Prominence of the proximal or distal locking screws if symptomatic may also necessitate its removal. Removal of the nail should be postponed if fracture remodeling is not satisfactory. Additionally, removal of a nail, which is deeply seated in the greater trochanter may be significantly traumatic and may also represent a separate AVN risk factor if extensive dissection is required.

Treatment of femoral shaft fractures in the adolescents is still far from a consensus. Flexible nails appear to be a sound surgical method for young and lean children but are not suitable for proximal and distal fractures. Flynn et al.[17] reported 66.7% failure rate of flexible titanium nails used in such fractures. Lee et al.[18] demonstrated that these flexible nails can withstand only 40% of the body weight of a young adolescent (approximately of 45 kg). Rigid nailing on the other hand offers excellent fracture stability allowing early mobilization and joint motion. In light of the above it seems that in the older and heavier adolescents especially those with a comminuted fracture pattern, a "through the tip of the trochanter," locked intramedullary nailing should be preferred.

In conclusion, our study performed in a group of 20 adolescent patients with a diaphyseal femoral fracture, treated with intramedullary nailing, confirmed the safety and efficacy of the technique, providing excellent radiographic and functional outcome. A more extensive study including more patients with a longer follow up will be able to describe more explicitly the morphologic changes of the proximal femur after closed, locked intramedullary nailing.

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EDITORIAL COMMENT

Kanellopoulos and his colleagues from Athens have presented a small case series of older children in whom they successfully used locked femoral nails inserted through the tip of the greater trochanter.[1] They emphasized the use of such nails in children who weigh greater than 45 kg, but they did not report the weights of their patients. The authors carefully looked for signs of avascular necrosis and problematic proximal femur growth changes at an average follow-up of about 2 years and found none. The patients in their study were old enough to minimize their risk of growth-related complications of the proximal femur.[2]

Most (if not all) of the trochanteric nails used in this study are not specifically designed to be used in such a way; they are piriformis fossa nails. Force feeding femoral nails such as these through the tip of the greater trochanter leads to eccentric reaming (see radiographic images in Kanellopoulos et al.) as well as a strong tendency to create varus alignment (especially when treating proximal shaft fractures).[3] The authors state that their study has "confirmed the safety and efficacy of the technique", but this could not be further from the truth as uncontrolled case series do not establish safety and efficacy.[4] Such studies speak only to effectiveness and the specter of bias looms large in such small series. To their credit the authors acknowledge that their study was significantly underpowered (estimated 28% power).[1]

The concept of using a trochanteric entry point is old, dating back at least to the 1940 writings of Gerhard Kuntscher. The concept remains a noble one, the modern intention of which is to minimize the possibility of injury to the medial femoral circumflex artery and its important tributaries.[5] This may be vitally important in the growing child, and trochanteric entry nails are felt to significantly decrease the possibility of femoral head avascular necrosis (there has in fact been only one reported case of avascular necrosis following this procedure).[6] Many other authors have produced results similar to Kanellopoulos et al. using either standard piriformis fossa femoral nails or locked nails with a proximal bend aimed at better accommodating the trochanteric entry point.[7]

In conclusion, Kanellopoulos et al. have produced a well-documented case series that adds to the growing body of work that shows that locked femoral nailing through the greater trochanter can be effective in older (and in many cases heavier) children. The indications for such a treatment approach appear to be reflected by the present paper: patients greater than or equal to 12 years of age or those whose weight equals or exceeds 45 kg.[1] Until there is much wider availability of pediatric nailing systems specifically designed for trochanteric entry such "kid-friendly" use of standard locked nailing systems needs to be in the armamentarium of those who care for pediatric trauma patients. In the future we need larger controlled

clinical trials to confirm what we think to be the case; that this treatment is safe and effective.

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