Femoral derotation osteotomy in children with cerebral palsy using the pediatric proximal femoral nail

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We designed a pediatric proximal femoral nail (PPFN) to overcome fixation method-related complications when performing femoral derotation osteotomy in cerebral palsy patients. Preliminary results of cerebral palsy patients who underwent femoral derotation osteotomy fixed using PPFN to treat in-toeing were evaluated. Sixteen patients with a mean age of 10 years were included. Mean follow-up duration was 36 months. There was no significant difference in the follow-up neck-shaft angle and articulotrochanteric distance values (P=0.2 and 0.3). PPFN provides stable fixation, early weight-bearing, reduces soft-tissue disruption while limiting the complications due to fixation technique. *J Pediatr Orthop B* 29:15–21

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Introduction

Gait function is often disturbed by severe in-toeing in growing children with cerebral palsy (CP) [1–4]. One of the major causes of in-toeing is increased internal hip rotation (IHR), and femoral derotation osteotomy (FDO) is often required to improve the gait [5–9]. Different fixation techniques were used for FDO, like external fixator, plate, and nailing, and successful outcomes for each have been reported [10–21]. However, each technique carries some disadvantages like cosmetic concerns, discomfort with walking and physical therapy, superficial or deep pin tract infections, and loosening of pins with external fixation techniques [1,22,23]. Plate fixation was reported to be associated with prominent hardware, infection, hematoma, implant failure, and subsequently prolonged immobilization [12–16].

To overcome hardware related problems in FDO, a pediatric proximal femoral nail (PPFN) with an improved design was used to address the above lists shortcomings. As they are located closer to the mechanical axis of the femur and intramedullary nails function as internal splints which allow for osteotomy healing while sharing compressive, bending, and torsional loads through the osteotomy site. In addition, intramedullary nails stimulate medullary blood supply by reaming and therefore support bone healing and decrease soft-tissue and bony disruption [24–27].

Advantages of nailing in adult patients were extensively reported; less blood loss, lower wound infection rates, shorter length of hospital stay, eliminated need for additional fixation, such as a cast, earlier mobilization, success in osteoporotic bones, and high healing rates are among these advantages. With higher functional scores when compared to sliding hip screws, nailing has become the most preferred method in treating hip fractures. A PPFN, which is specially designed for the pediatric proximal femur, would allow for secure stabilization at the osteotomy site and early weight-bearing. Hence PPFNs can provide a better alternative to other fixation methods for FDO and we conducted this retrospective analysis to evaluate and report the results of nailing in FDOs with PPFNs in CP patients.

Patients and methods

CP patients who were operated between 2013 and 2015 for in-toeing along with the characteristic findings of femoral neck anteversion of 40° or more and internal rotation of the hip of 45° or more were included in the study. Patients were excluded from the study if they had a subluxation of the hip on radiographs, a migration percentage more than 25%, or concomitant surgical procedures on the same extremity that prohibited postoperative full weight-bearing.

A uniquely designed PPFN for the proximal femur anatomy of pediatric patients was used (Fig. 1). The nail has an 18° apex medial proximal bend, and the proximal segment is hexagonal to improve rotational stability at the intertrochanteric area. The neutral-shaped proximal screw hole directs the screw into the medial calcar. The elliptical proximal screw hole allows for the insertion of a 15°–45° proximal screw (a 4.5 mm locking screw) through the femoral neck. Distally, the fixations are performed using locking screws over a guide wire (3.5 or

4.5 mm). These nails are manufactured from titanium (PPFN; PediFIN, Ilerimed, Istanbul, Turkey), and nails with a proximal segment having an external diameter of 8–12 mm and a distal segment having an external diameter of 7–10 mm are available.

To perform the nailing, patients were placed at 30° lateral on a radiolucent table, and a bolster was placed under the ipsilateral hip. A guide wire was inserted percutaneously through the lateral aspect of the greater trochanter ~1 cm below the tip of the trochanter using fluoroscopy control and advanced to the lesser trochanter (Fig. 2). Then, reaming was performed over the guide wire and the awl was placed into the prepared canal and left in the proximal femur. Next, two Kirschner wires were used to apply a preoperatively planned external rotation to correct the femoral medial torsion as follows. A Kirschner wire was placed posterior to the awl laterally according to the degree of femoral anteversion, and another Kirschner wire was inserted parallel to the posterior femoral condyles. A 3–4 cm longitudinal skin incision, which was wide enough to fit the oscillating saw, was made on the lateral side of the femur at the osteotomy level (Fig. 2). The osteotomy was performed perpendicular to the femur diaphysis using an oscillating saw or osteotome ~10 mm distal to the lesser trochanter. In the next step, the medullary canal was reamed with a rigid reamer that was 0.5 mm wider than the selected nail. Then, the preoperatively selected nail was inserted into the femur with a nail guide and placed ~1 cm below the level of the trochanter but above the trochanteric physis (Fig. 3). Proximal locking was performed over the nail guide using locking screws, and then the leg was rotated externally, guided by Kirschner wires, according to the preoperative plan. Finally, distal locking was performed over the nail guide using locking screws.

Physiotherapy was initiated immediately after the surgery to mobilize the hip and knee joints. Weight-bearing was allowed on the first postoperative day, as tolerated, using crutches or a walker, and intravenous, patient-controlled analgesia was used. The patients were discharged the day after surgery.

Any concomitant operations and the preoperatively Gross Motor Function Classification System (GMFCS) levels were recorded [28]. Hip range of motion was measured clinically with particular regard to hip rotation.

Anteroposterior radiographs of the pelvis and lateral radiographs of the hip joint were obtained preoperatively, immediately postoperatively, every 3 weeks until healing, and then every 3 months until the last follow-up (Figs 4–6). Neck-shaft angle (NSA), the articulotrochanteric distance (ATD), evidence of femoral head avascular

Fig. 1

The appearance of pediatric proximal femoral nail.

Fig. 2

The insertion point of the proximal guide and the level of skin incision.

Fig. 3

The insertion of the nail.

Fig. 4

Preoperative anteroposterior radiographs of the pelvis.

Fig. 5

Postoperative anteroposterior radiographs of the pelvis.

Fig. 6

Follow-up anteroposterior radiographs of the pelvis.

Table 1 **The number of concomitant surgical procedures**

Concomitant surgery	Number of cases
Adductor tenotomy	1
Hallux valgus surgery	2
Achilloplasty	2
Lateral column lengthening	8
Tibia derotation osteotomy	2
Supracondylar femur extension osteotomy	1
Tibialis anterior transfer	2
Hamstring tenotomy	2
Pronator tenotomy	3

necrosis (AVN) and healing time of the osteotomy were assessed from radiographs [29]. During the follow-up period, all surgical complications (wound infection, delayed union or nonunion, implant failure, etc.) were recorded. Delayed union was defined as a lack of bone healing after 6 months or nonunion after 12 months.

Statistical analysis was performed with Statistical Package for the Social Sciences, version 15 (SPSS Inc., Chicago, Illinois, USA). Data for continuous variables were reported as mean ± SD (minimum – maximum) and data for categorical variables reported frequency. The Friedman test and the Wilcoxon rank test for binary comparisons were used to compare the continuous variables at different times. The results were evaluated at a 95% confidence interval and at a significance level of P value of less than 0.05.

Results

Sixteen patients (seven girls and nine boys) who underwent FDOs using PPFNs were included in this study. The mean age of the patients was 10 ± 2.5 years (range: 7–14 years), and the mean follow-up period was 36 months (range: 26–52 months). In total 24 FDOs were performed, eight patients had unilateral procedures and eight had single-stage bilateral procedures. All patients were ambulatory and 11 patients had concomitant surgery addition to the FDO, and Table 1 shows these 23 concomitant surgical procedures.

Five patients were classified as level 1, eight as level 2, and three as level 3 according to GMFCS preoperatively.

On the follow-up gait evaluation, which was based on retrospective review of clinical examination, visual gait assessment, in-toeing was improved in all cases; two patients were evaluated out-toeing and the others in neutral alignment.

Table 2 Preoperative, postoperative, and follow-up neck-shaft angle and articulotrochanteric distance values

	Preoperative	Postoperative	Follow-up
Neck-shaft angle	145.2°±8.6° (130°–160°)	137.7°±9.1° (122°–165°)	137.3°±7.1° (123°–150°)
Articulotrochanteric distance	0.9±0.1 (0.5–1.3)	0.9±0.3 (0.4–1.8)	1.0±0.3 (0.5–1.7)

Data are represented as mean±SD (range).

The average hip internal rotation was 83.7°±5.8° preoperatively and 53.9°±5.9° at follow-up (P=0.0001). Hip internal rotation was significantly improved following surgery. The average hip external rotation was 12.4°±2.8° preoperatively and 42.9°±5.3° at follow-up (P=0.0001), which was statistically significant.

There was no significant difference among the preoperative, postoperative, or follow-up NSA and ATD values (P=0.2 and 0.3, respectively; Table 2). The average healing time for the osteotomy was 9 weeks (range: 8–12 weeks).

No patient had AVN of the femoral head on the follow-ups.

Complications associated with the surgeries included one case of proximal screw irritation, which required additional surgery for removal. We performed one PPFN removal because of family long-term concern about 'foreign material inside body' during the first year of the index operation. There was no wound infection, delayed union, or implant failure.

Discussion

Although there are different alternatives to it in the literature, FDO is the accepted treatment method for improving excessive femoral anteversion and in-toeing gait in CP [30–35]. However, when it comes to the choice of fixation for FDO, none of them was shown to be superior, and complication rates up to 9% have been reported [12,13,36]. When FDO is performed in the proximal region of the femur, the plate is the standard fixation device, it requires an extensile exposure with periosteal damage and increased blood loss [16,37]. In addition, the loss of strength due to the non-weight-bearing immobilization period postoperatively causes significant rehabilitation problems and delays patient's return to the preoperative physical activity level, which was already low [11,31,38–41]. However, when PPFNs is used for fixation, it allows immediate weight-bearing and avoidance of extensile soft-tissue damage, in addition to stable fixation provided by it.

In growing children, AVN of the femoral head and disruption in the growth of the greater trochanter are the leading complications associated with intramedullary nailing. Other reported complications were unequal limb lengths and coxa valga [42–46]. An open physis creates a barrier to blood flow from the metaphysis to the femoral head, meaning that the primary blood supply to the femoral head is provided from the medial femoral circumflex artery, and any damage to this vessel can result in AVN [47,48]. Using the piriformis fossa to place the entry point for the intramedullary nailing imperils the blood supply to the femoral head through the terminal branch of the medial femoral circumflex artery [48,49]. O'Malley *et al.* [46] performed intramedullary nailing of the femur through the piriformis fossa and one patient developed AVN 15 months postoperatively. Therefore, using the greater trochanter as an insertion point for the intramedullary nail has been recommended to decrease the risk of AVN [42,50–52]. After 32 months of follow-up, Elgohary *et al.* [42] found no cases of AVN of the femoral head in children and adolescents when the trochanteric tip was used as the entry point. In the present study, the nails were inserted through the tip of the greater trochanter to avoid the piriformis fossa, thus preserving the blood supply to the femoral head. The patients were followed for a mean period of 36 months, and no cases of AVN or deformity of the proximal femur were detected.

Greater trochanteric entry was associated with complications such as damage to or premature closure of the greater trochanteric apophysis and increased femoral neck valgus [42,47,51]. Gage *et al.* [53] reported premature greater trochanteric epiphysiodesis and progressive valgus of the femoral neck secondary to intramedullary nailing. In addition, they reported that intramedullary nailing does not affect the trochanteric growth when performed after the age of 8 years. Likewise, Gordon *et al.* [54] claimed that when patients are operated older than 9 years of age, intramedullary nailing does not disrupt proximal femoral anatomy. However there is no consensus in the literature about the lower age limit for rigid intramedullary fixation of the proximal femur, lower age is an important factor for the occurrence of trochanteric growth arrest [42]. In the present study with a limited number of patients, we did not experience a deformity of the proximal femur at the end of 36 months follow-up. The mean NSA was measured at 137° immediately postoperatively and at the follow-ups. Likewise, the ATD was unchanged after PPFN using the greater trochanteric entry point. However, the mean age of our patients was 10 years (range: 7–14 years) and in younger patient population it is possible to experience coxa valga and loss of ATD due to using the greater trochanteric entry point. In addition, we believed that there is a need for studies with longer follow-up until skeletal maturity.

Although locking plates contribute significantly to the mechanical stability at the osteotomy site, the need for revision because of hardware failure is common [36,48,55,56]. According to Haefeli *et al.* [38] when locking compression plates on subtrochanteric extending or derotational femoral osteotomies in ambulatory neuro-orthopedic patients were used, full weight-bearing was limited in the immediate postoperative period and implant failure was a significant complication with increasing varus deformity through the osteotomy. However, in our study, no loss of fixation in any CP child was developed, including those who were at high risk of postoperative bone loss. This seems to be an advantage when compared with traditional fixation techniques, particularly to those which uses plates and the loss of fixation has been an accepted drawback, especially in osteoporotic bones [14,16,36,57]. In our experience with a limited number of patients, PPFN provided secure stabilization and allowed early mobilization in CP patients with osteoporotic bones.

We used two distal screws to increase stability when performing PPFN until now, as we believe that only one screw can cause failure when early weight-bearing is allowed. However, stress shielding may be an important issue due to press-fit fixation into the canal and use of two distal locking screws. However, we ream the medullary canal with a rigid reamer that was 0.5 mm wider than the selected nail, so the size of the device is in an acceptable range. We also use proximally two screws to prevent loss of correction, one is inside the femoral neck trabecular bone, and the other is more distal at the level of the calcar. Finally, we achieved complete bone healing and did not detect any fracture or complaint due to stress shielding during 36 months of follow-up that can be accepted short. However, we think that single proximal and distal screw use as can be used and this is optional depending on the surgeon's preference.

Non-weight-bearing in children with CP after FDO to allow time for consolidation of the osteotomy has been an ongoing discussion, and it is not accurate to leave the impression that non-weight-bearing or immobilization is required for children using standard devices [11,31,57–59]. Beauchesne *et al.* [12] who performed 157 proximal femoral osteotomies by fixation with blade plate in 101 children with a mean age of 10 years claimed that weight-bearing immediately after proximal femur osteotomy in children with CP is a safe procedure and does not cause implant failure. On the contrary, Stasikelis *et al.* [57] suggested cast immobilization for 3–8 weeks after proximal femur osteotomy of 71 CP patients with an average age of 6 years. However, the prolonged immobilization period increases complications in children both with and without neuromuscular disease [41]. Szalay *et al.* [60] reported a postoperative bone loss of as much as 34% after at least 4 weeks of either not bearing weight or casting. Early weight-bearing and fast recovery are among the advantages of using intramedullary fixation devices especially in children with CP [61] and in this present study, by using PPFN enough primary stability was achieved with minimally invasive procedure, and we were more confident in weight-bearing and complications related to prolonged immobilization or casting were avoided. Hereby, we recommend early weight-bearing after FDO like many authors nowadays.

Long femoral intramedullary nails with greater trochanteric entry had been used for fixation for a long time [29,42,47,50–52,54]. However, we used proximal femoral nail in which proximal segment is hexagonal to improve rotational stability. In addition, the neutral-shaped proximal screw hole directs the screw into the medial calcar and the elliptical proximal screw hole allows for the insertion of varying angles proximal screw through the femoral neck. The available nail lengths differ from 100 to 125 and 150 mm.

The recurrence of IHR is a significant complication of FDO [5,30,32,62,63]. de Morais Filho *et al.* [30], who treated excessive IHR in CP patients using FDO, reported a 9.5% recurrence rate after a mean follow-up of 53 months. Likewise, Kim *et al.* [5] showed that hip external rotation deteriorated progressively over time following FDO. Younger age, increased GMFCS level, a high degree of spasticity, slow gait speed, and reduced hip joint abduction are among the factors that increase the rate of recurrence but there is no consensus in the literature [62–66]. The present study achieved correction of hip internal rotation of ~30° without experiencing any recurrence during a mean follow-up of 36 months. However, the mean age of our patients was 10 years and most of them were GMFCS I and II who were more ambulatory with a lower risk of recurrence in consistence with the literature so far. Probably, more studies will be needed to assess the recurrence rates of the deformity in longer follow-up periods.

The main limitations of this study are retrospective design and the limited number of patients included. However, it is known that the need in CP for derotational osteotomy alone is an infrequent situation, which restricted the number of patients included in the study. Also, follow-up period reported here can be considered to be short, especially given that it is known that this type of clinical outcome can deteriorate over the long term and recurrence of the rotational deformity can occur. Here, with this study, we shared the preliminary results for a newly designed PPFN, but larger studies that report long-term results are required to validate our findings.

Conclusion

Fixation of proximal femoral osteotomies using PPFN to treat rotational deformities in CP patients is a safe procedure that allows for stable fixation, minimal soft-tissue disruption, and full weight-bearing in the early postoperative period.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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