Proximal femoral osteotomy in children with cerebral palsy: the perspective of the trainee

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Abstract

Background There are a range of implants for fixation of proximal femoral osteotomies (PFOs) in children. We investigated the training experiences and preferences of orthopaedic residents and fellows who were learning PFO, using a fixed angled blade plate (ABP) or a locking, cannulated blade plate (LCBP). We also studied short-term technical and radiographic outcomes.

Methods This was a prospective, parallel-group, cohort study of 90 consecutive children and adolescents with cerebral palsy who underwent bilateral PFOs with ABP or LCBP. Surgical trainees completed a questionnaire to document the ease or difficulty of each operative step.

Results There were 48 boys and 42 girls, with a mean age of eight years and a mean follow-up of 25 months. Trainees preferred the LCBP system for: insertion of the guidewire, the seating chisel and the blade plate, as well as overall technical ease of use (p < 0.001). Radiographic outcomes were similar with no between-group differences for migration percentage (p = 0.996) or neck shaft angle (p = 0.849), but there was a higher prevalence of technical errors in the ABP group.

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Conclusions Trainee surgeons expressed a preference for LCBPs when learning PFO in children with cerebral palsy. Radiographic outcomes were similar in both groups, with close attending surgeon supervision.

Introduction

Proximal femoral osteotomy (PFO) is the most common major reconstructive surgery about the hip in children and adolescents.[1] There are many indications, the most common of which are to provide hip containment or correct internal hip rotation gait in children with cerebral palsy.[2–5] In our tertiary level paediatric teaching hospital, approximately 150 PFOs are performed each year. Residents and fellows who are training in orthopaedic surgery conduct many of these, under the supervision of an attending surgeon.

PFOs have frequently been performed with fixed angled blade plates (ABP) with several studies reporting good results.[6,7] The technique can be difficult to teach and the learning curve may be steep. A recent innovation in implant design is cannulation of the blade plate and locking screw technology for which limited reports exist in the literature.[1,8–10] Results from one small study demonstrated that the locking, cannulated blade plate (LCBP) provided good fixation, stability of the osteotomy and predictable union, with few adverse events, in children with a wide range of diagnoses and indications.[1] In comparison with conventional ABPs, the LCBP system allows for both the seating chisel and blade plate to be inserted over a guidewire into the femoral neck. This may result in more precise technique with greater intra-operative control and decreased margin for error.[1,8] In addition, most trainees in orthopaedic surgery are familiar with referencing internal fixation over a guidewire and with the use of locking screws. Alternative systems, which involve multiple points of fixation in the proximal femur with locking screws, include the paediatric locking compression

plate (LCP). The LCP system offers increased stability in osteoporotic bone.[11] The disadvantages include delayed union, increased operative time and increased blood loss, in comparison with the ABP.[11] It is therefore important for new implants and new technology to be compared with existing gold standards.

The aims of our study were:

1. To investigate trainee preferences and opinions on the use of the LCBP and ABP systems.
2. To compare the radiographic and technical outcomes of both systems.

Patients and Methods

This was a prospective, parallel-group, consecutive cohort study of children and adolescents with cerebral palsy who were scheduled for bilateral PFOs between 1 April 2013 and 31 December 2014 at a tertiary paediatric hospital (Fig. 1). Internal fixation was achieved with either the PediLoc Locking Cannulated Blade Plate System (Ortho-Pediatrics) or the Angled Blade Plate System (Synthes). The choice of implant was at the discretion of the attending surgeon. A randomised clinical trial was the preferred study design, but the attending surgeons lacked equipoise in their implant preference and choices.

Inclusion criteria were children with a diagnosis of cerebral palsy and registration on the Statewide Cerebral Palsy Register, bilateral PFOs performed by orthopaedic residents or fellows, supervised by one of three attending surgeons. Children at all levels of the Gross Motor Function Classification System (GMFCS) were included. Bilateral

PFOs were performed in the context of Single Event Multilevel Surgery (SEMLS) for gait correction (Fig. 2), as well as containment PFOs for non-ambulant children with hip displacement.[2–5] Bilateral medial hip muscle releases were allowed in hip containment procedures as were the typical muscle-tendon procedures utilised in SEMLS.[12,13] Children with diagnoses other than cerebral palsy were excluded, as were children who had unilateral surgery, pelvic osteotomy or surgery performed entirely by attending surgeons.

Procedure

Patient demographics including age at surgery, sex, weight, GMFCS level and medical co-morbidities, including the need for feeding tubes and medications for epilepsy, were entered on an Excel spreadsheet from the patient's electronic scanned medical record (ESMR).[14,15] Pre-operative radiographs were viewed on the Patient Archiving and Communication System (PACS) (Synapse, Fujifilm), which were then compared with sequential radiographs obtained at three, six and 12 weeks and at six and 12 months following surgery and yearly thereafter. Migration percentage (MP) and neck shaft angle (NSA) were measured according to a standardised method with good reliability.[16,17] Time to union was assessed and defined as the presence of bridging callus across more than 75% of the width of the bone at the level of the osteotomy surface, as well as external, medial bridging callus.[1]

Femoral derotation osteotomies (FDOs) for gait correction surgery were performed to correct internal hip rotation and intoed gait (Figs 2 to 4). The aim was to correct excessive femoral neck anteversion, by a single oblique
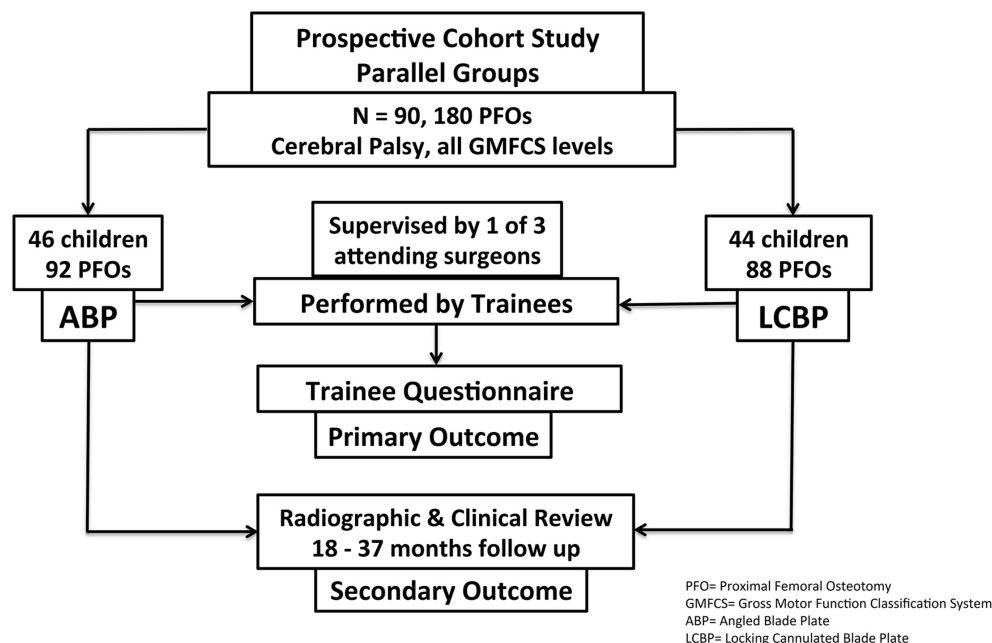
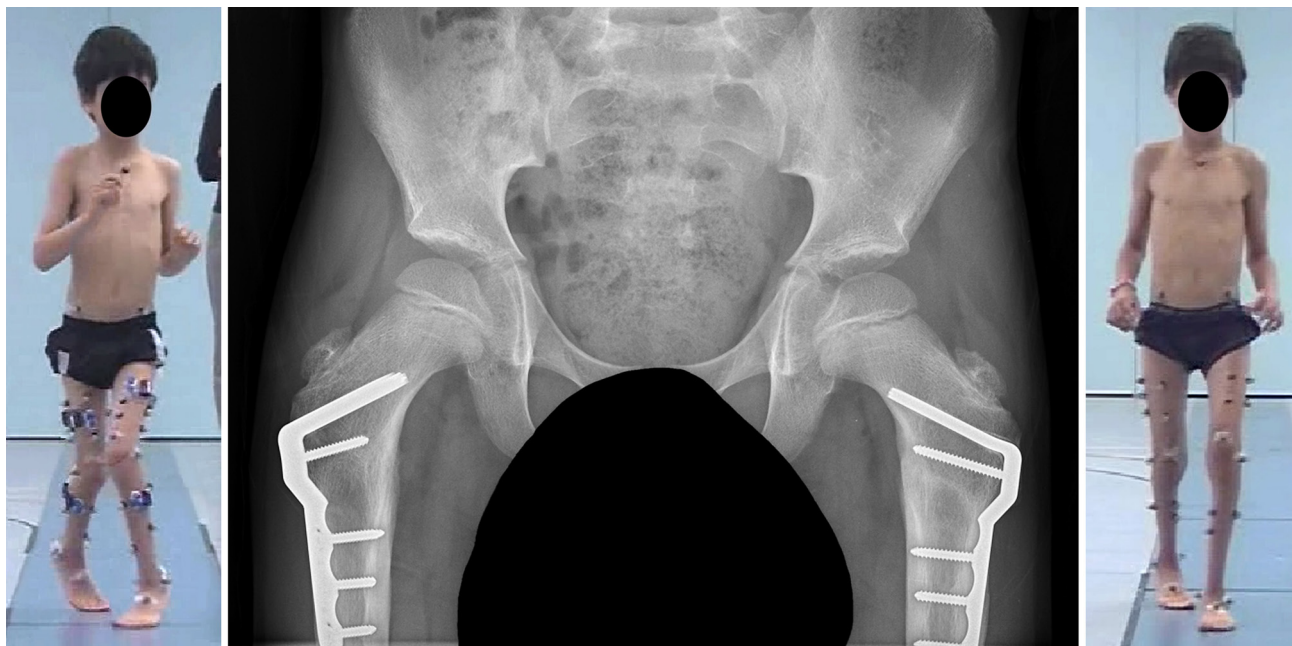

Fig. 1 Study design flow chart.

Fig. 2 Bilateral femoral derotation osteotomies (FDOs) with the 100° cannulated locking blade plate, in a ten-year-old boy with cerebral palsy, GMFCS level II, undergoing Single Event Multilevel Surgery (SEMLS). The operative aim was a 40° external rotation correction bilaterally without altering the neck shaft angle. Note the position of the tip of the blade in the solid bone of the calcar and inferior femoral neck. The patient mobilised full weight-bearing within one week of surgery with correction of internal rotation gait.

Fig. 3 Bilateral hip subluxation (right greater than left) in a nine-year-old girl, GMFCS III prior to Single Event Multilevel Surgery (SEMLS). There was coxa valga and increased femoral neck anteversion of 40° bilaterally. This resulted in hip displacement and intoed gait.
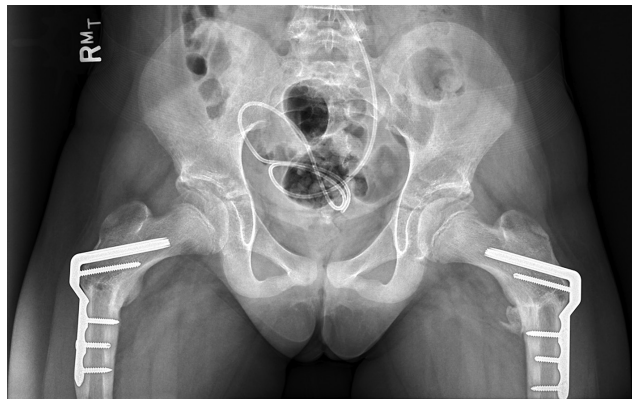

Fig. 4 Following bilateral VDROs, including bilateral distal hamstring lengthening, bilateral Strayer gastrocnemius recessions. The hips are now well contained and there has been extensive acetabular remodelling. Correction of both hip dysplasia and intoed gait was achieved.

osteotomy in the intertrochanteric region, to between 5° and 10°. Varus derotation osteotomies (VDROs) for hip displacement surgery were undertaken to correct excessive valgus and anteversion in the proximal femur, hip subluxation and to prevent dislocation (Figs 5 and 6). In some children, it was necessary to correct intoed gait and hip displacement simultaneously (Figs 3 and 4). The indications and techniques for both types of osteotomy have been previously described.[18,19] The range of hip abduction was assessed before PFO and adductor lengthening was

performed, following published protocols.[12,18] Osteotomies were performed in children at GMFCS IV and V, in a supine position.[18] Ambulant children had a full biomechanical assessment, including three-dimensional gait analysis and axial imaging prior to surgery, and underwent gait correction surgery in a prone position.[18,19] The indication and techniques for the SEMLS procedures have been previously published.[13,18] Intra-operative fluoroscopy was used in both groups and selected images were saved in PACS for subsequent analysis.

Fig. 5 Bilateral hip displacement, in an eight-year-old girl, GMFCS level IV, who missed out on hip surveillance and presented with hip pain and restricted abduction. Note the femoral head deformity and severe acetabular dysplasia.

Fig. 6 At 18 months after bilateral varus derotation osteotomies (VDROs) with angled blade plate (ABP) fixation, the hips are well contained; some remodelling of both the femoral head and the acetabulae has occurred, and the lateral acetabular epiphysis has appeared on both sides. However, there was penetration of the calcar in the left hip with type 3 avascular necrosis (AVN) changes in the femoral head, the significance of which will not be apparent until long-term follow-up. Penetration of the calcar may be a risk factor for AVN.

The degree of assistance provided to the trainee during surgery was at the discretion of the attending surgeon in the interests of patient safety and was not recorded. Following every operation, trainees were asked to complete a custom-designed questionnaire for each hip. Eight questions were asked using nine-point Likert scales. Five questions addressed sequential steps in the operation, with question 6 addressing the technical 'overall ease or difficulty' of the operation. Questions 1 to 6 were anchored at 1 (very easy) and 9 (extremely difficult).

Question 7 addressed the operating surgeon's assessment of the stability of fixation with 1 (very stable) and 9 (extremely unstable). Question 8 reviewed weight-bearing status at 1 (no restrictions) and 7 (six weeks in a hip spica) (Appendix 1).

Technical outcomes included the position of the implant in the proximal femur and stability of fixation. The angulation between the guidewire and blade plate was measured in hips where the ABP was used, in anteroposterior (AP) and lateral projections, from saved fluoroscopic images in PACS (Figs 7 and 8). Operating time was measured as the time required for bilateral PFOs. Anaesthetic time, surgical time for concomitant procedures and time required for cast application in the SEMLS group were excluded.

Adverse events were collected prospectively and reported using a modified Clavien-Dindo (MCD) classification reported by Sink et al.[20,21] Clinical and radiographic follow-up was conducted at three and six weeks after surgery, then at six and 12 months after surgery, and yearly thereafter. Patients who defaulted on follow-up appointments were contacted by the clinical nurse co-ordinator and rebooked to the next available clinic.

Avascular necrosis (AVN) was graded according to the criteria designed by Kruczynski et al.[22,23] Removal of implants was advised in all patients after 12 to 24 months.

Statistical analysis

Parametric data were reported for group comparisons using means, standard deviations, range and t-tests. Non-parametric data were reported as medians and interquartile ranges (IQR) with rank sum tests to assess group differences. Dichotomised results for the trainee questionnaire were reported with p-values from Fisher's exact tests (p < 0.05 was considered statistically significant). All calculations were performed in Stata version 12.1 (StataCorp., College Station, Texas).

Results

Between 1 April 2013 and 31 December 2014, 180 PFOs were performed in 90 children and adolescents with a diagnosis of cerebral palsy and registration on the Statewide Cerebral Palsy Register. There were 46 children in the ABP group and 44 in the LCBP group, 48 boys and 42 girls, with a mean age of 7 years 11 months (4 years 3 months to 13 years 9 months), and a mean weight of 25.8 kg (12 to 58). The minimum follow-up was 21 months (mean 28 months; 21 to 40), with no loss to follow-up.

The osteotomies were performed by eight trainees in orthopaedic surgery. Four were undertaking fellowships in paediatric orthopaedics and four were orthopaedic residents.

Age, gender, weight, GMFCS level and radiographic parameters (MP, NSA) were comparable at baseline between the two groups (Table 1). The mean PFO surgical time in the LCBP group was 71 minutes (SD 13.7; 45 to 97)
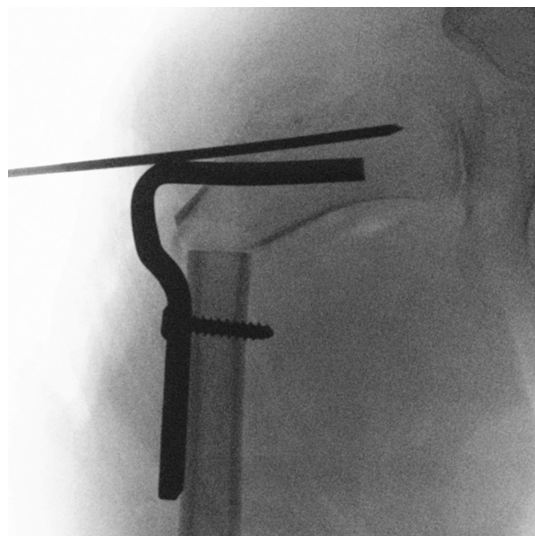

Fig. 7 When using the angled blade plate (ABP) system, the guidewire and blade may not be parallel in the frontal plane. The seating chisel and the implant are inserted distal to the guidewire, in the femoral neck. The space available between the trochanteric apophysis and the calcar is limited.
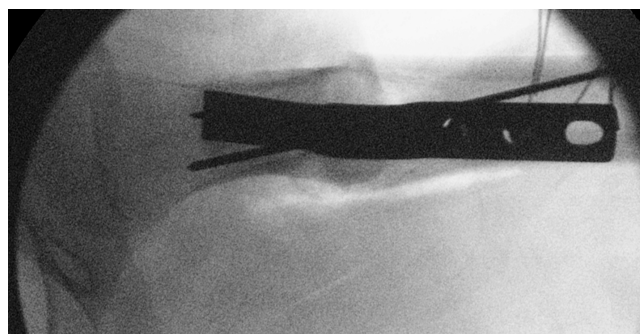

Fig. 8 In this hip, surgery proceeded after several failed attempts at placing the guidewire in a central position. Insertion of the blade plate was attempted in a more central position in the femoral neck. However, anterior angulation occurred with a 17° angulation between the angled blade plate (ABP) and the guidewire. The anterior cortex of the femoral neck was at risk of penetration by the ABP.

Table 1. Baseline demographic and radiographic parameters.

	LCBP n = 44 children (88 hips)	ABP n = 46 children (92 hips)	p
Age, years:months	7:11 (4:3 to 13:0)	8:1 (4:3 to 13:9)	0.684*
Gender, n (%)			
Male	23 (52)	25 (54)	
Female	21 (48)	21 (46)	0.844†
Weight, kg	25.5 (12 to 49)	26.2 (13 to 58)	0.741*
GMFCS, n (%)			
I	0 (0)	1 (2)	
II	11 (25)	11 (24)	
III	5 (11)	7 (15)	
IV	8 (18)	13 (28)	
V	20 (45)	14 (30)	0.471†
Follow-up time (mths)	28.3 (21 to 40)	28.1 (20 to 39)	
Migration percentage (%)	43.2 (12 to 100)	38.2 (8 to 100)	0.138*
Neck-shaft angle (°)	155.6 (138 to 175)	155.0 (135 to 179)	0.690*

Values are mean (range) unless otherwise noted

*t-test

†Chi-squared test

ABP, angled blade plate; GMFCS, Gross Motor Function Classification System; LCBP, locking cannulated blade plate

in comparison with 76 minutes (SD 18.1; 50 to 125) for the ABP. This difference was not significant (p = 0.137). The mean number of procedures performed during SEMLS was 7.4 (SD 2.1; 4 to 12) in the ABP group and 7.3 (SD 2.0; 5 to 12) in the LCBP group.

Technical outcomes

Both systems achieved the planned changes in containment and proximal femoral geometry according to MP and NSA (Table 2). In the ABP group, the mean angulation between guidewire placement and blade plate was 6° in both the coronal (SD 4.67, 95% confidence interval (CI) 5.21 to 7.11) and lateral planes (SD 5.25, 95% CI 5.00 to 7.15). However, the range was much wider – between 0° and 21° in the coronal plane, and between 0° and 23° in the lateral plane (Figs 7 and 8).

Trainee preferences

The questionnaire responses demonstrated floor effects with a majority of scores at the lower end of the Likert scales for both systems. Due to the skewed nature of these responses, results were dichotomised into 'easier' (Likert scale 1 and 2) and 'more difficult' (Likert scale 3 to 9), and then re-analysed (Table 3).

Table 2. Radiographic measurements comparing the locking, cannulated blade plate (LCBP) and angled blade plate (ABP) groups.

	LCBP (n = 44)			ABP (n = 46)		
	Pre-operative	Post-operative	Difference	Pre-operative	Post-operative	Difference
Migration percentage (%)	43.2 (12 to 100)	10.1 (0 to 55)	33.1 (1 to 100)*	38.2 (8 to 100)	5.1 (0 to 26)	33.1 (3 to 78)*
Neck shaft angle (°)	155.6 (138 to 175)	119.9 (92 to 155)	35.8 (2 to 77)*	155.0 (135 to 179)	119.8 (93 to 142)	35.1 (2 to 76)*

All values are mean (range)

*Differences reached statistical significance

Trainees reported that guidewire insertion was easier in the LCBP group (78%) compared with the ABP group (51%) (p < 0.001). Insertion of the seating chisel and the blade plate was also significantly easier in the LCBP group. The score for overall technical ease/difficulty also favoured the LCBP system (p < 0.001) (Table 3). No between-group differences were found for scores relating to performing the osteotomy cuts or reduction of the osteotomy.

Adverse events

Minor medical adverse events (MAEs, MCD I and II) occurred in just over half of the patients in both groups. The most common AEs were constipation, respiratory infections, skin irritation from casts or splints and problems with epidural infusions or morphine infusions, leading to incomplete pain and spasm control. All MAEs resolved with appropriate treatment.

There were four Grade III AEs requiring an unplanned return to the operating theatre. Two children had replacement of a poorly functioning epidural, one had injections of Botox to the hamstrings and adductor muscles for post-operative spasms and one required bladder catheterisation for acute retention. There were three Grade IV AEs. Two children (GMFCS V) had unplanned admissions to ICU for post-operative pneumonia and recovered fully. One child in the ABP group had an acute unilateral, post-operative dislocation. He had revision surgery with a San Diego pelvic osteotomy and hip spica casting.

In the ABP group, Grade I AVN was noted in six hips in four patients, Grade III AVN in one hip in one child and Grade V AVN in the patient who sustained the post-operative dislocation and revision surgery. In the LCBP group, six hips in three patients had Grade 1 AVN with no higher grade AVN. Seven children had mild asymptomatic, bilateral heterotopic ossification (MCD Grade II, four in ABP group and three in LCBP group).

Seven hips in four children had penetration of the calcar by the tip of the blade plate which was partial in six and complete in one. All were in the ABP group (three MCD II, one MCD IV). In the patient with complete penetration of the anterior femoral neck, the lateral fluoroscopic images were of poor quality. The error was not realised until post-operative radiographs were obtained. The AP radiograph was not conclusive (Fig. 9) and it was seen only on a cross-table lateral view (Fig. 10). The blade plate had not followed the track cut by the seating chisel. The patient was a 14-year-old boy weighing 52 kg with severe intellectual disability and could not reliably remain on protected weight-bearing. His parents refused revision surgery and the patient was managed by non-weight-bearing for six weeks until union was achieved, under inpatient supervision.

Table 3. Results of the trainee questionnaire with scores for each question dichotomised to two ranges.

Question	LCBP n = 88 hips	ABP n = 92 hips	p
1. Guidewire insertion			
Easier	69 (78%)	47 (51%)	
More difficult	19 (22%)	45 (49%)	< 0.001
2. Seating chisel			
Easier	88 (100%)	44 (48%)	
More difficult	0 (0%)	48 (52%)	< 0.001
3. Osteotomy cuts			
Easier	47 (53%)	59 (64%)	
More difficult	41 (47%)	33 (36%)	0.144
4. Insertion of blade plate			
Easier	87 (99%)	35 (38%)	
More difficult	1 (1%)	57 (62%)	< 0.001
5. Reduction of osteotomy			
Easier	59 (67%)	63 (68%)	
More difficult	29 (33%)	29 (32%)	0.837
6. Overall score			
Easier	76 (86%)	34 (37%)	
More difficult	12 (14%)	58 (63%)	< 0.001
7. Stability of fixation			
More stable	86 (98%)	88 (96%)	
Less stable	2 (2%)	4 (4%)	0.438
8. Weight-bearing status			
Earlier (< 3 weeks)	88 (100%)	90 (98%)	
Later (≥3 weeks)	0 (0%)	2 (2%)	0.164

Easier score, 1 to 2; More difficult, score 3 to 9; More stable, score 1 to 2; Less stable, score 3 to 9; Earlier score, 1 to 3; Later score, 4 to 7

LCBP, locking cannulated blade plate; ABP, angled blade plate

Fig. 9 Right proximal femoral osteotomy with an angled blade plate (ABP) in a 14-year-old boy, GMFCS level II, as part of Single Event Multilevel Surgery. Fluoroscopic images were of poor quality because of limited hip abduction. The post-operative anteroposterior radiograph showed what seemed to be a satisfactory position and stable fixation.
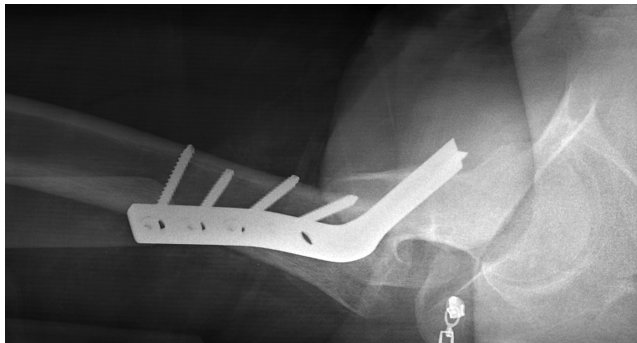
Fig. 10 When a cross-table lateral radiograph was obtained, complete penetration of the anterior femoral neck by the angled blade plate (ABP) was noted and the fixation was considered to be unstable. Non-weight-bearing was required for the next six weeks until union occurred.
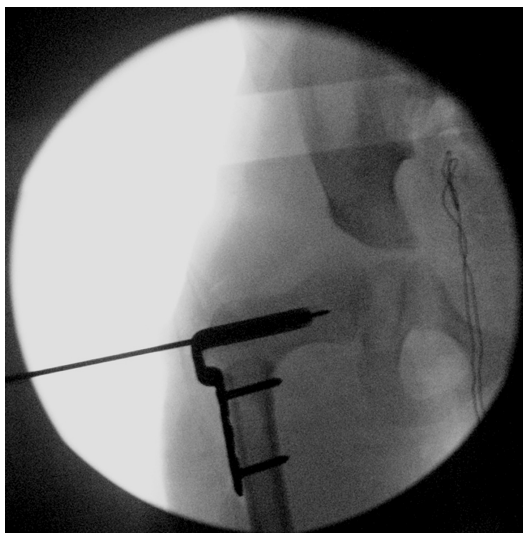

Fig. 12 The position of the locking cannulated blade plate (LCBP) over the guidewire is almost central, in the femoral neck, in the lateral projection. There can be no angulation between the LCBP and the guidewire.

Fig. 11 With the locking cannulated blade plate (LCBP) system, both the seating chisel and the implant are inserted over the guidewire. There can be no angulation between the seating chisel, or the LCBP, and the guidewire.

Discussion

A recent large study reported a 37% failure rate following bilateral VDROs in children with CP and found that this was related to surgeon volume as well as GMFCS level.[3] Even in high-volume tertiary centres, failures occur and surgeon experience and volume are important.[4–6,9,10] The challenge of teaching PFO is self-evident. Attending surgeons have to balance the competing demands of teaching surgery, patient safety and ensuring good clinical outcomes.

In this study, trainees reported that the cannulated system was easier to use in four of six domains.[1,9] Guidewire placement with the LCBP system is the most important step in PFO. The seating chisel and implant are passed directly over the wire (Figs 11 and 12), which thereby dictates the final blade plate position. This con-

trasts with the ABP system in which guidewire placement serves only as a reference plane for the insertion of the seating chisel and implant (Figs 7 and 8).[6,7] Deviation of the blade plate angle from the direction of the guidewire with the ABP introduces an uncontrolled variable, which has not been previously reported. Experienced surgeons are usually able to manage this angulation. After several guidewire placements, some surgeons may choose to accept a position which is less than perfect and to make a correction by altering the angle of the seating chisel to the guidewire (Figs 7 and 8). Trainees dislike this variability because it is unpredictable and makes it difficult to ensure that the pre-operative plan is correctly executed. These problems were not encountered with the cannulated system.

It may seem counterintuitive that trainees would rate insertion of the guidewire as easier in the LCBP system. Trainees expressed the view that insertion of the guidewire in the LCBP system could be identified precisely during pre-operative planning and the operative plan executed with precision. In contrast, the insertion of the guidewire in the ABP system is close to, but not in the same position as, the line of the seating chisel and the implant, necessitating an adjustment in pre-operative planning.

Experienced surgeons using the ABP system can usually avoid deviating from the track cut by the chisel during insertion of the blade plate.[6,7] Trainees are more prone to losing the track cut by the seating chisel and require high levels of concentration and supervision to ensure that the blade plate is inserted in the correct position, without cutting a false passage and penetrating the femoral neck or calcar (Fig. 10), which may result in intra-operative fracture and unstable fixation.[6,7] Any variability in the final

position of the blade plate will alter the desired correction, which will lead to a difference between planned correction and actual correction.

The floor effects in the trainee questionnaire was an unexpected finding. Close supervision from experienced surgeons allowed trainees to perform PFO in a controlled environment, conducive to patient safety and good outcomes. Trainees expressed the opinion that insertion of the guidewire, seating chisel, blade plate and the overall ease or difficulty of the procedure was easier with the LCBP system than the ABP system. Not surprisingly, no difference was expressed for the performance of the osteotomy cuts or the reduction of the osteotomy. These questions were included to look for evidence of systematic bias.

Although we did not record the time for individual operative steps, the trainee's impression was that the extra time required to insert the guidewire in exactly the right position in the LCBP group was recouped by the subsequent speed and certainty of insertion of the seating chisel and blade plate. In contrast, placing the seating chisel below the guidewire and in the proximal femoral metaphysis in the ABP system increased the risk of both calcar and femoral neck penetration. Penetration of the femoral neck resulted in unstable fixation in one hip and was associated with Grade III AVN in another hip (Fig. 10).

There was no difference in overall operating time for bilateral PFOs with the two systems. This is in contrast to a previous study in which the LCP hip plate and the ABP were compared.[11]

Implant systems, which make surgery more reliable, predictable and comfortable for trainees may offer significant advantages in terms of improved outcomes and lower revision rates.[1]

There was also no difference in the stability of fixation or in weight-bearing status. In this low-demand group, both implants were considered to be equally stable, allowing early weight-bearing, with no restrictions and no casts. There was no loss of position or revision surgery related to implant loss of position, implant breakage, delayed union or nonunion. This is in contrast to a previous study in which the ABP system was compared with the LCP system.[11] The rate of radiological consolidation at six weeks post-operatively with the LCP was lower than with the ABP with equivalent healing at three months.[11]

The strengths of our study included the prospective nature of the study, the large number of patients in both groups, standardisation of the operative procedures and follow-up, and the small number of supervising surgeons and trainees. Study limitations included lack of randomisation due to lack of equipoise and short-term follow-up. The questionnaire was designed for this study and has not been tested for validity or reliability. The reported outcomes were in technical domains and AEs, and did not include long-term clinical or functional outcomes.

Based on the findings of this study, both the ABP and LCBP systems are safe and effective for internal fixation of PFOs. However, the LCBP system may help trainee surgeons negotiate the learning curve with more confidence, fewer technical errors and improved outcomes. Finally, when choosing an implant for PFO in children, the difficulty of implant removal must be carefully considered. Removal of the titanium LCP has been associated with a high prevalence of fractures and retained hardware in children with CP.[24] In contrast, removal of both the stainless steel ABP and LCBP in this study has been easily achieved, without significant morbidity. Specifically, there have been no cases of cold welding of locking screws to the plate, no peri-operative fractures and no retained hardware.

COMPLIANCE WITH ETHICAL STANDARDS

ETHICAL STATEMENT
Ethical approval was granted by the hospital's Human Research Ethics Committee, Number: 35213A.

ICMJE CONFLICT OF INTEREST STATEMENT
H. Kerr Graham is a member of the OrthoPediatrics Surgeons Advisory Board. No funding received in support of this study.

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