Femoral derotation osteotomy in spastic diplegia

PROXIMAL OR DISTAL?

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We describe the results of a prospective study of 28 children with spastic diplegia and in-toed gait, who had bilateral femoral derotation osteotomies undertaken at either the proximal intertrochanteric or the distal supracondylar level of the femur. Preoperative clinical evaluation and three-dimensional movement analysis determined any additional soft-tissue surgery.

Distal osteotomy was faster with significantly lower blood loss than proximal osteotomy. The children in the distal group achieved independent walking earlier than those in the proximal group (6.9 ± 1.3 v 10.7 ± 1.7 weeks; $p < 0.001$). Transverse plane kinematics demonstrated clinically significant improvements in rotation of the hip and the foot progression angle in both groups.

Correction of rotation of the hip was from $17 \pm 11^\circ$ internal to $3 \pm 9.5^\circ$ external in the proximal group and from $9 \pm 14^\circ$ internal to $4 \pm 12.4^\circ$ external in the distal group. Correction of the foot progression angle was from a mean of $10.0 \pm 17.3^\circ$ internal to $13.0 \pm 11.8^\circ$ external in the proximal group ($p < 0.001$) compared with a mean of $7.0 \pm 19.4^\circ$ internal to $10.0 \pm 12.2^\circ$ external in the distal group ($p < 0.001$). Femoral derotation osteotomy at both levels gives comparable excellent correction of rotation of the hip and foot progression angles in children with spastic diplegia.

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Although gait in children with spastic diplegia may be variable, the most common pattern includes problems in the sagittal, coronal and transverse planes. There is a characteristic anterior pelvic tilt with a compensatory lumbar lordosis, flexed, internally rotated and adducted hips, flexed, stiff knees and equinus deformities of the ankle.¹⁻³ This results in a pattern of gait which is inefficient and causes limitation of function.^{1,2} Additionally, parents and children have concerns about the cosmetic aspects of such an abnormal pattern of gait. In-toeing is a common and consistent feature of gait in spastic diplegia and contributes to poor cosmesis and function.²⁻⁴ The consequences associated with an in-toed gait include internal rotation of the hip with the knees knocking or rubbing, increased tripping and falling, and poor foot clearance with excessive shoe wear.^{5,6} In-toeing may be the result of both dynamic and static problems including abnormal muscle tone, musculotendinous contractures and medial femoral torsion.^{3,7-10} The last has been described by some as part of a spectrum of bony abnormalities collectively referred to as 'lever arm disease' and it may reduce the efficiency of muscles because the skeletal levers are not aligned with the line of progression.¹⁰⁻¹³

Femoral derotation osteotomy (FDO) may be indicated when it has been established that the in-toeing is principally due to medial femoral torsion, and interferes with gait and function. There is no evidence to suggest that medial femoral torsion and an in-toed gait in children with spastic diplegia will improve spontaneously or in response to non-surgical management.^{2,3} Proximal femoral osteotomy is obligatory when there is both in-toeing and subluxation of the hip. The proximal osteotomy allows varus angulation of the femoral neck to ensure stability of the hip with internal rotation of the femur proximal to and external rotation distal to the osteotomy.^{3,14-21} Soft-tissue procedures alone will not prevent dislocation of the spastic hip when the percentage of migration is greater than 40 to 50.^{22,23} The decision regarding the ideal site for femoral osteotomy is not as clear-cut when the hips are stable. Distal femoral osteotomy in this setting may afford a quicker, less invasive form of correction for in-toed gait, and may be as effective in functional and cosmetic terms as proximal osteotomy.^{24,25} This may be relevant in the context of simultaneous multilevel surgery in spastic diplegia.²⁶⁻²⁸

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Fig. 1a

Fig. 1b

Diagrams showing sites and effects of a) proximal and b) distal FDO.

There are few studies in which the kinematic outcome of proximal or distal FDO have been described and none in which the techniques have been directly compared.^{29,30} We have therefore compared the clinical, radiological and kinematic results of proximal and distal FDO in children with spastic diplegia in a prospective study.

Patients and Methods

Children with spastic diplegia, scheduled for the correction of in-toed gait by FDO as part of simultaneous multilevel surgery between 1997 and 1999, were recruited for this prospective consecutive study which was approved by our Institutional Review Board. We defined simultaneous multilevel surgery as at least two orthopaedic procedures at different anatomical sites in each limb, i.e. a minimum of four. Written informed consent was obtained from the parents or legal guardians. The criteria for entering the study included symptoms of in-toeing or of knocking of knees or rubbing, with the characteristic findings of femoral neck anteversion of 40° or more, internal rotation of the hip of 75° or more and external rotation of 15° or less. The indications for FDO on preoperative kinematics included rotation of the hip and/or an internal foot progression angle (FPA) of 10° or more, at mid-stance, on one or both sides. Patients were excluded from the study if there was subluxation of the hip on radiographs, a migration percentage of 20 or more, the need for other bony surgery such as tibial osteotomy or a stabilisation procedure of the foot, or if they had undergone a selective dorsal rhizotomy in the previous 12 months or intrathecal Baclofen therapy or injections of botulinum toxin A in the previous six months. We also excluded chil-

dren with very asymmetrical patterns of gait who required unilateral FDO.

Thus, 28 mobile children (19 boys and 9 girls) with spastic diplegia, were entered into the study. They had a mean age of 12.3 ± 2.4 years (7.6 to 16.2). Recruitment was consecutive and there were no refusals. Preoperative clinical and movement analysis determined the additional soft-tissue surgical procedures. The surgeon who referred the patients to the Gait Laboratory allocated the type of osteotomy with one surgeon assigning 14 children to proximal osteotomy and the other 14 children to a distal osteotomy. The two senior surgeons (GRN and HKG) operated simultaneously and both undertook an equal number of proximal and distal osteotomies.

The preoperative and postoperative assessment included a standardised, comprehensive, clinical examination by a physiotherapist and a surgeon. For the static rotational profile the child was prone with the knee flexed to 90° and the leg maintained at 0° of abduction.³¹ The hip was not forced into extremes of rotation. After the pelvis had been checked for tilting or rotational obliquity and with the child relaxed, we measured the angles using a standard long-arm goniometer. Measurement of femoral neck anteversion was by the direct palpation technique described by Ruwe et al.³² Radiological assessment included an anteroposterior (AP) radiograph of the pelvis in all patients and AP and lateral radiographs of the knees in the distal osteotomy group.

Each child also underwent a two-dimensional video recording of gait and a three-dimensional gait analysis before and 12 months after surgery with reflective markers placed about the pelvis and legs, according to the standard Vicon Clinical Manager protocol (Vicon; Oxford Metrics

Fig. 2

Radiograph showing bilateral, proximal FDO with 90° AO blade plate fixation.

Fig. 3

Radiographs showing bilateral, distal FDO with AO dynamic compression plate fixation.

Ltd, Oxford, UK). Six cameras, set at 50 Hz, collected three-dimensional movement data (Vicon 370 System, Oxford Metrics Ltd) for analysis using Vicon Clinical Management (Oxford Metrics Ltd). For ground reaction force, data were collected at 50 Hz using two AMTI force platforms (Advanced Mechanical Technologies Incorporated, Newton, Massachusetts) placed midway along a 10 m walkway. Children were asked to walk at a self-selected, comfortable speed. Multiple trials ensured consistency of the gait cycle. We estimated the location of the centre of the hip using the 'Davis hip model'.³³ Temperospatial parameters were recorded for further analysis. Pelvic, femoral and knee

rotation and FPA were measured at mid-stance. Pelvic tilt, extension of the knee and dorsiflexion of the ankle were measured at the point of maximum extension of the hip. After the 12-month postoperative visit, further six-monthly reviews included clinical examination, two-dimensional video analysis and radiographs of the osteotomy site.

Operative technique. Each child had bilateral FDOs at the same anatomical site (Fig. 1) as determined at the preoperative assessment. The two surgical teams worked simultaneously on their respective sides with the child prone. They undertook proximal FDOs in the intertrochanteric region by a previously described posterolateral approach to the proximal femur, using internal fixation.³⁴⁻³⁷ An AO 90° fixed-angle blade plate (Fig. 2) achieved stable fixation. With a guide wire and the blade of the fixation plate in the centre of the femoral neck, it was relatively easy to control precisely the amount of external rotation at the site of the osteotomy. We routinely externally rotated the femur in such a way as to maintain anteversion of 0° to 10°. After provisional fixation with a single screw in the side plate, we carefully checked the range of internal and external rotation aiming to leave only 20° of internal rotation and to match the arcs of rotation of both hips. Using a tourniquet with the child supine, the surgical team carried out distal FDO in the supracondylar area using the posterolateral approach to the distal femur³⁸ and a technique similar to that described by Cooke, Carey and Williams.³⁹ An AO large fragment six-hole dynamic compression plate provided stable internal fixation (Fig. 3). We made two marks with an osteotome on the exposed femur at the site of the proposed osteotomy. The first was directly anterior and the second in the midlateral line of the femur. We aimed to leave only 20° of internal rotation and 0° to 10° of anteversion. It is more difficult to check the range of movement of the hip and the amount of anteversion with the child supine and it is easy to undercorrect the medial femoral torsion.

Soft-tissue procedures included intramuscular lengthening of the psoas muscle at the pelvic brim, lengthening of the medial hamstrings, transfer of rectus femoris to semitendinosus, distal recession of gastrocnemius with soleal fascial lengthening and percutaneous lengthening of adductor longus.^{4,40-42}

The indications for, and selection of, the soft-tissue procedures followed published guidelines after evaluation of the range of movement of the static joint, movement analysis data and an examination under anaesthesia.^{1,2,11,12,40,41,43} A continuous epidural infusion, containing bupivacaine and fentanyl provided intraoperative analgesia and was continued for 72 hours after operation. The children also received antibiotic cover with a cephalosporin which was started at the induction of anaesthesia and continued for 24 hours after operation.

Statistical analysis. The key kinematic variables were identified from the preoperative patterns of gait.^{1,2,9,12,26,28-30} The parametric and non-parametric tests used depended on the distribution of the data. Paired, two-tailed *t*-tests deter-

Table I. The preoperative and postoperative results of the static clinical examination (mean $\pm$ SD; degrees) in the prone position, of the 14 children who underwent a proximal FDO and the 14 who underwent distal FDO

	Internal rotation of the hip		External rotation of the hip		Femoral neck anteversion	
	Preop	Postop	Preop	Postop	Preop	Postop
Proximal group	75 $\pm$ 12.0	44 $\pm$ 9.8*	7 $\pm$ 13.2	26 $\pm$ 10.0*	47 $\pm$ 8.8	20 $\pm$ 9.4*
Distal group	70 $\pm$ 12.0	43 $\pm$ 9.1*	10 $\pm$ 8.1	27 $\pm$ 10.0*	44 $\pm$ 10.4	21 $\pm$ 6.1

*p < 0.001

Table II. Number of soft-tissue surgical procedures tabled by side of the body and site of osteotomy for the 28 children with spastic diplegia and in-toed gait

Side of body	Psoas		Adductors		Hamstrings		Rectus		Calf	
	R	L	R	L	R	L	R	L	R	L
Proximal	4	4	4	4	14	14	5	5	12	12
Distal	6	6	4	4	14	14	1	1	6	6

Table III. The preoperative and postoperative mean ($\pm$ SD) transverse plane kinematics (degrees) at mid-stance for the 14 children who underwent a proximal FDO and the 14 who had a distal FDO

	Rotation of the hip		Rotation of the knee		Foot progression angle	
	Preop	Postop	Preop	Postop	Preop	Postop
Proximal group	17 $\pm$ 11.0	-3 $\pm$ 9.5*	-4 $\pm$ 10.7	1 $\pm$ 9.2	10 $\pm$ 17.3	-13 $\pm$ 11.8*
Distal group	9 $\pm$ 14.0	-4 $\pm$ 12.4*	-3 $\pm$ 13.4	-1 $\pm$ 11.1	7 $\pm$ 19.4	-10 $\pm$ 12.2*

*p < 0.001, a comparison between pre- and postoperative means

mined the significance of any change in outcome measures within groups. Two sample, two-tailed *t*-tests with equal or unequal variance compared changes in the outcomes between groups. The Wilcoxon rank-sum (Mann-Whitney) U test was used for non-parametric data. The level of significance was set at $p < 0.05$.

Results

Of the 28 children enrolled, 14 (9 boys, 5 girls) with a mean age at surgery of 11.9 ± 2.1 years (9.0 to 14.6) underwent proximal FDO and 14 (10 boys, 4 girls) with a mean age at surgery of 12.9 ± 2.6 years (7.6 to 16.2) had distal FDO. The two-sample Wilcoxon rank-sum test showed no significant difference between the two groups with regard to age or gender. Blood loss, assessed by weighing swabs, was 260 ± 57 cm³ in the proximal group. Because of the use of a tourniquet, there was significantly lower blood loss (22 ± 7 cm³, $p < 0.001$) in the distal group. No patient required a blood transfusion. Bilateral distal osteotomies were significantly quicker than the bilateral proximal osteotomies (52.6 ± 6.1 v 97 ± 7.7 min, $p < 0.001$). There were no superficial or deep infections.

All children were allowed to bear weight as tolerated after operation. Those in the distal group began assisted walking (4.5 ± 16 v 7.6 ± 1.5 weeks) and walked independently sooner (6.9 ± 1.3 v 10.7 ± 1.7 weeks) than those in the proximal group for both measures.

Both proximal and distal osteotomy achieved excellent correction of the medial femoral torsion and the in-toed gait

(Table I). There were no cases of delayed union, nonunion or malunion in either group. All osteotomies were clinically and radiologically united at three months after operation.

Soft-tissue surgery and sagittal plane kinematic outcome. Soft-tissue procedures undertaken to correct concurrent contractures in the sagittal and coronal planes and abnormalities of gait, were usually symmetrical with similar numbers of hamstrings and adductor procedures in both groups. Per child, the proximal FDO group had a mean of 5.57 soft-tissue procedures and the distal group a mean of 4.42. The number of calf lengthening and rectus femoris procedures differed significantly (Table I). The distal group had a large number of older children with severe crouching gait, as a consequence of isolated lengthening of tendo Achillis in early childhood.

In summary, there was an increase in anterior pelvic tilt in both groups, no change in hip extension in the distal group and a slight deterioration in the proximal group. In retrospect, we undertook too many hamstring lengthenings and too few lengthenings of the psoas tendon over the brim of the pelvis (Table II). Both the range of movement of the knee and dynamic function of the ankle improved in all children. Those with preoperative equinus had correction of equinus gait, improvement in ankle movements and increase in power of the ankle. Those with crouching gait also had improvement in dynamic ankle function, after correction of flexion contractures of the hip and knee.

Transverse plane kinematic outcome. There was a significant improvement in rotation of the hip and FPA in both groups (Table III and Fig. 4). The FPA was corrected from a

Fig. 4a

Fig. 4b

Fig. 4c

Fig. 4d

Kinematic graphs of mean foot progression angles a) before and b) after proximal FDO and c) before and d) after distal FDO. The x-axis represents the normalised gait cycle and the y-axis the angular deviation from neutral. A positive deviation represents an internal foot progression angle and a negative deviation an external foot progression angle. The continuous line depicts the left leg, the broken line depicts the right leg.

mean of $10.0 \pm 17.3^\circ$ internal to $13.0 \pm 11.8^\circ$ external in the proximal group ($p < 0.001$) and from a mean of $7.0 \pm 19.4^\circ$ internal to $10.0 \pm 12.2^\circ$ external in the distal group ($p < 0.001$). There were no significant differences between the two groups, pre- or postoperatively. All patients had correction of their in-toed gait with a change in FPA from predominantly internal before operation to neutral or external afterwards. No patient was significantly under- or overcorrected and satisfaction with the outcome was good. At mid-stance, there was no significant alteration of pelvic rotation or rotation of the knee. Postoperatively, there was a significant increase in walking speed in both groups (0.78 ± 0.21 to 0.93 ± 0.13 m/s for the proximal group, 0.82 ± 0.20 to 0.95 ± 0.14 m/s for the distal group; $p < 0.005$), but no significant difference between the groups.

Discussion

The synonyms for the characteristic femoral deformity in children with spastic cerebral palsy include persistent fetal alignment, increased femoral anteversion, inset hips and medial femoral torsion.^{3-7,11,14,17,20,22,31,32,44-46} Neither the site in the femur nor the cause of the torsion is well understood. We prefer the term medial femoral torsion because it provides an accurate description of the structural abnormality but does not imply a specific site or aetiology. In cerebral palsy, medial femoral torsion contributes both to subluxation of the hip and an in-toed gait, and both are traditionally managed by femoral osteotomy, either in isolation or combined with other procedures.^{15,18,47-49} When there is both in-toeing gait and subluxation of the hip, proximal

osteotomy is the logical procedure.^{3,17,18,20-22,47-49} The results reported for proximal osteotomy, when combined with other procedures for subluxation of the hip, are very good.^{3,15-21,47-49} The results for in-toed gait are also good and have been confirmed by studies which have incorporated preoperative and postoperative gait analysis.^{29,30}

In the child with spastic diplegia without subluxation of the hip, both proximal and distal osteotomies have been employed for the correction of the in-toed gait and medial femoral torsion.^{29,30} Ounpuu et al²⁹ described the results one and five years after FDO in 20 children with cerebral palsy; 27 procedures were carried out, of which 19 were proximal and eight distal, with multilevel soft-tissue surgery. They found a shift in static rotational profile of 23° towards external rotation with kinematic corrections of 18° for rotation of the hip and 16° for the FPA. The improvements in both static and kinematic parameters were similar to our results. Although their study was retrospective and follow-up was incomplete, in the patients who were available for study, correction was maintained at a follow-up at five years.²⁹ The only report describing the use of movement analysis to study the results of distal femoral osteotomy is in abstract form only.³⁰ The authors, Aiona et al,³⁰ showed a shift in the static rotational profile of 33° towards external rotation with consequent kinematic corrections of 12° for rotation of the hip and 18° for the FPA. Given the trend towards one-stage correction of deformities of the lower limb in children with spastic diplegia, we have prospectively studied proximal and distal FDO as well as the concomitant soft-tissue lengthening and transfers.

There are three studies comparing the rate of complications after proximal and distal FDOs.^{4,29,45} The proximal osteotomies were all fixed with blade plates and the distal osteotomies with pins and plaster. Each found superior results for proximal osteotomy, with stable internal fixation. From the earliest reports, proximal femoral osteotomy was described as a precise technique requiring stable internal fixation, and allowing early mobilisation. Distal osteotomy, using fixation by Kirschner wires and plaster immobilisation,^{24,25} has been associated with delayed mobilisation, stiffness of the knee, undercorrection, valgus deformity and persistent in-toed gait.^{24,29,44,50} More recently, the technique of distal osteotomy has changed with an emphasis on stable internal fixation using AO techniques.³⁹ A recent retrospective review of distal FDO reported good correction of in-toeing as measured by three-dimensional kinematics.³⁰

Given that our centre has extensive experience of both techniques of osteotomy using stable internal fixation, we felt that it was appropriate to study the outcome using instrumented gait analysis. We found that both yielded satisfactory clinical and radiological results with early mobilisation and no complications. Distal osteotomy was quicker to perform and had significantly less loss of blood. No child required a blood transfusion, but proximal osteotomy brought the child closer to the threshold for transfusion. Distal osteotomy was not associated with postoperative

stiffness of the knee. It is our practice to secure stable internal fixation, to avoid plaster immobilisation of either the hip or knee and to encourage early weight-bearing. Despite uniform encouragement, progress was more rapid in the distal osteotomy group, specifically the attainment of independent walking. The children in the proximal group, however, had a greater number of transfers of rectus femoris and calf-lengthening procedures than those in the distal group (Table II). This may have affected the speed of rehabilitation, although we think that it is the bony surgery which is the rate-limiting factor in rehabilitation rather than the soft-tissue procedures. This issue can only be fully resolved by better-matched groups, which will necessitate a randomised clinical trial.

The muscle dissection which is required for a proximal osteotomy is more extensive than that for a distal osteotomy and may interfere with abductor and extensor function of the hip.^{34,38} The delay in mobilisation may lead to decompensation and prolonged loss of extension of the hip and an increase in anterior pelvic tilt. Distal osteotomy using a subvastus approach seems to have minimal and short-term effects on the function of quadriceps. The radiological results of distal FDO were satisfactory with none of the reported angular deformities such as flexion or genu valgum.^{29,50}

Both techniques gave satisfactory correction of medial femoral torsion and in-toed gait. The correction of rotation of the hip and FPA was, however, approximately half of the derotation measured intraoperatively (45° for both proximal and distal osteotomy). We agree with Aiona et al³⁰ who suggested that a femoral derotation will result in internal rotation of the proximal femur as well as external rotation of the knee and leg distal to the osteotomy site. We are confident of our interpretation of the results of the transverse plane kinematics in this study because we undertook no other operative procedures which would affect the transverse plane. The effects of soft-tissue surgery on the transverse plane in general, and in-toeing in particular, are minimal.^{51,52} Given that the correction of rotation of the hip and the FPA were equally satisfactory, we conclude that the in-toed gait in spastic diplegia is usually caused by medial femoral torsion and that an external rotation osteotomy of the femur will correct both the static torsional deformity and the gait pattern, irrespective of the site of the osteotomy.

Preoperative planning, based on standard clinical examination and instrumented gait analysis, appears to be appropriate for this type of surgery. In our study and in that by Ounpuu et al,²⁹ the mean postoperative FPA was close to the normal external range of 12°, although there was some variation about the mean value.

Our interpretation of the outcome of the concomitant soft-tissue surgery, especially at the level of the hip, is complicated by many factors including the variability in the preoperative alignment of the pelvis and the different combinations of soft-tissue procedures used. The resulting subgroups were too small for analysis.⁵³

Internal rotation of the proximal femur may place the greater trochanter in a more advantageous position for the functioning of the abductors.^{1,2,7,13,43} Medial femoral torsion causes excessive internal rotation of the whole limb. The logic of undertaking femoral derotation is that the advantageous alignment of the proximal femur can be maintained without the whole limb being internally rotated during gait.

In the context of multiple surgical procedures and prolonged rehabilitation, a global measure of functional outcome is important in addition to clinical examination and selected kinematic and kinetic variables. Self-selected walking speed is the simplest and probably the most important functional outcome measure.⁵⁴ Preoperatively, the children walked slower than able-bodied peers.^{46,52,55-57} There was a clinically and statistically significant increase in walking speed after surgery, with no difference between the two groups. No patient lost independent walking or required increased use of assistive devices after surgery.

A proximal or distal FDO is equally effective for the correction of medial femoral torsion and in-toed gait in children with spastic diplegia. When derotation alone is required distal femoral osteotomy may be the technique of choice. In our hands distal osteotomy is more rapid with less blood loss and the children have a faster and easier rehabilitation. The inter-relationship of transverse plane (bony) and sagittal plane (soft tissue) surgery requires further investigation. There were improvements in dynamic ankle and knee function during gait, but no change at the level of the hip and pelvis. The indications for and the timing of lengthening of the psoas require investigation. It is probable that the hamstrings in some children in this study were stiff, but not as short as we thought. In retrospect, we almost certainly should have carried out more psoas lengthening and less hamstring surgery.⁵⁸

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