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 ± 11˚ internal to 3 ± 9.5˚ external in the proximal group and from 9 ± 14˚ internal to 4 ± 12.4˚ external in the distal group. Correction of the foot progression angle was from a mean of 10.0 ± 17.3˚ internal to 13.0 ± 11.8˚ external in the proximal group (p < 0.001) compared with a mean of 7.0 ± 19.4˚ internal to 10.0 ± 12.2˚ 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.

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. This results in a pattern of gait which is inefficient and causes limitation of function. 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. 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. In-toeing may be the result of both dynamic and static problems including abnormal muscle tone, musculotendinous contractures and medial femoral torsion. 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.

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. 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. Soft-tissue procedures alone will not prevent dislocation of the spastic hip when the percentage of migration is greater than 40 to 50. 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. This may be relevant in the context of simultaneous multilevel surgery in spastic diplegia.
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. 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 children 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. 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 gonimeter. Measurement of femoral neck anteversion was by the direct palpation technique described by Ruwe et al. 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...
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’. 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. 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 femur and a technique similar to that described by Cooke, Carey and Williams. 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.

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. 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. The parametric and non-parametric tests used depended on the distribution of the data. Paired, two-tailed $t$-tests deter-
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 ± 9.7 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
mean of 10.0 ± 17.3° internal to 13.0 ± 11.8° external in the proximal group (p < 0.001) and from a mean of 7.0 ± 19.4° internal to 10.0 ± 12.2° 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 midstance, 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...
ostotomies were equally satisfactory, we conclude that the in-toed gait in spastic diplegia is usually caused by medial compensation and prolonged loss of extension of the hip and an increase in anterior pelvic tilt. Distal osteotomy using a vastus 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 strong as we thought. In retrospect, we almost certainly should have carried out more psoas lengthenings and less hamstring surgery.\(^58\)

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References