Isolated calf lengthening in cerebral palsy

OUTCOME ANALYSIS OF RISK FACTORS

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We assessed the medium-term outcome of three methods of isolated calf lengthening in cerebral palsy by clinical examination, observational gait analysis and, where appropriate, instrumented gait analysis. The procedures used were percutaneous lengthening of tendo Achillis, open Z-lengthening of tendo Achillis and lengthening of the gastrosoleus aponeurosis (Baker’s procedure).

We reviewed 195 procedures in 134 children; 45 had hemiplegia, 65 diplegia and 24 quadriplegia. We established the incidence of calcaneus and recurrent equinus and identified ‘at-risk’ groups for each. At follow-up, 42% had satisfactory calf length, 22% had recurrent equinus and 36% calcaneus. The incidence of calcaneus in girls at follow-up was significantly higher (p = 0.002) while boys had an increased rate of recurrent equinus (p = 0.012).

Children with diplegia who had surgery when aged eight years or younger had a 44% risk of calcaneus, while those over eight years had a 19% risk (p = 0.046). Percutaneous lengthening of tendo Achillis in diplegia was the least predictable, only 38% having a satisfactory outcome compared with 50% in the other procedures.

The incidence of recurrent equinus in hemiplegic patients was 38%. Only 4% developed calcaneus. The type of surgery did not influence the outcome in patients with hemiplegia or quadriplegia.

Severity of involvement, female gender, age at operation of less than eight years and percutaneous lengthening of tendo Achillis were ‘risk factors’ for calcaneus. Hemiplegia, male gender, and an aponeurosis muscle lengthening increased the risk of recurrent equinus.

Equinus is the commonest deformity in cerebral palsy1-6 and adversely affects standing balance and gait. Failure of conservative treatment such as physiotherapy, ankle foot orthoses, casting, and injections of botulinum toxin A may be an indication for surgical intervention.7,8 Many surgical procedures have been described for the treatment of this deformity including partial neurectomy of the gastrocnemius,9,10 lengthening of the origin of the gastrocnemius,11,12 recession of the proximal gastrocnemius aponeurosis,13 combined lengthening of the gastrocnemius/soleus fascia,14-16 and lengthening17-19 and translocation20 of tendo Achillis. Previous studies have reported recurrent equinus in approximately 10% to 30% of patients with hemiplegia5,21 and calcaneus in 3% to 30% of patients with diplegia20,22-27.

In an independent walker with an equinus gait, calf lengthening is commonly undertaken to improve gait. There are, however, many children with more severe cerebral palsy, who can only stand for transfers or walk with assistance, who may also benefit from surgery for a calf contracture and an equinus deformity. The indications for surgery in the more severely involved group are more difficult to define and the outcome more difficult to assess. There is a tendency for surgeons to view all children with cerebral palsy and an equinus deformity as being similar, and to manage the problem with their single preferred operation. We therefore undertook a study to test the validity of this assumption and to review the results of the preferred operation. All calf-lengthening procedures carried out over a five-year period in children with hemiplegia, diplegia and quadriplegia were included. Although gait analysis is the most sensitive and objective method of assessment,25 we accepted that not all patients would be suitable for three-dimensional gait analysis because of their limited functional abilities.

Patients and Methods

We aimed to assess the outcome of isolated operations on the calf in children with cerebral palsy who were considered appropriate for such surgery on clinical criteria alone. Children who had lengthening of the hamstrings or psoas at the same time, or in whom staged surgery was planned for proximal contractures, were excluded from the study.
Of the 161 patients with a confirmed diagnosis of cerebral palsy who had an isolated unilateral or bilateral calf-lengthening procedure between 1988 and 1993, 134 were available for study. Of the non-participants three had died, 12 had moved away and the remaining 12 could not be contacted. The 134 children had a total of 195 operations.

The indication for operation in this series was a fixed equinus deformity of more than 10° which interfered with standing balance, walking or wearing an ankle foot orthosis.

The procedure was performed using one of three techniques:

1) Percutaneous lengthening of tendo Achillis by a triple hemisection technique, taking care to dorsiflex the foot only to the plantigrade position; 18,28,29

2) Open lengthening of tendo Achillis by a sagittal plane Z-lengthening, with the tendon repaired using an absorbable suture and the foot in the plantigrade position. 28,30

3) Baker’s aponeurotic lengthening performed through a vertical midline incision in the middle-third of the leg, with a ‘tongue in groove’ lengthening of the conjoined gastrosoleus fascia. 1,14,31

The postoperative management was the same after all three procedures. The leg was immobilised in a below-knee plaster cast for six weeks with the foot in a plantigrade position. Immobilisation in dorsiflexion was strictly avoided. During the first three weeks after operation non-weight-bearing was advised and wheelchairs provided. This was followed by weight-bearing in a cast for three weeks as tolerated. When the cast was removed an ankle foot orthosis was prescribed and used for a minimum of six months. All children received preoperative and postoperative physiotherapy, according to their level of disability.

All patients were independently examined by one of the first two authors (DCB or KW) who had not been involved in the surgical procedures. Measurements of the joint angle were obtained using a goniometer. We measured plantar flexion and dorsiflexion of the ankle with the knee flexed to 90° and with the knee maximally extended. 32 We also assessed the length of the hamstrings (popliteal angle) 7 and the presence of a hip flexion contracture (Thomas’ test). 33

Observational gait analysis was undertaken during three consecutive walks. The patients, wearing shorts, walked the length of a large examination room. They were encouraged to use their usual assistive devices. Gait was classified according to the Physicians’ Rating Scale as described by Koman et al 34 and modified by Corry et al. 35 This is an ordinal, observational gait scale, which was first tested for repeatability by Corry et al, then modified to retain the discriminating categories and to discard categories with poor interobserver agreement. Relevant to this study was the original finding by Corry et al 35 that mild degrees of crouch gait were difficult to detect, but that severe crouch could be recognised with confidence.

Fig. 1

Variables assessed in the study.
In our study, two features of the Physicians’ Rating Scale were used: foot contact and crouch. Foot contact was described as toe-toe, toe-heel, flat, occasional heel-toe or heel-toe. Only the more severe degree of crouch, i.e., a range of ankle dorsiflexion, knee flexion and hip flexion all greater than 20° throughout stance phase, was classified as a calcaneus/crouch gait. The outcome was considered good or poor based on calf length and gait (Fig. 1). A good outcome was associated with a correct calf length with adequate dorsiflexion, a range of plantar flexion and a satisfactory gait. In a poor outcome the calf was either too short with an equinus deformity or equinus gait, or too long with a calcaneus deformity or calcaneus gait.

Patients for whom further surgery was being considered and those who were capable of walking unassisted (73 patients, 131 calf lengthenings) were referred to our gait laboratory where three-dimensional gait analysis was undertaken using a five-camera reflective marker system to record kinematics (VICON 370; Oxford Metrics Ltd, Oxford, UK), with two AMTI force plates (Advanced Medical Technology Incorporate, Newton, Massachusetts) to measure kinetic data. Sagittal plane kinematics of the knee and ankle were used as a functional measure of calf length, with the normal range for our laboratory defined as the mean value ± two standard deviations from a large group of normal children.

Those patients with quadriplegia or severe diplegia who were household walkers, or could only stand for transfer, were assessed by clinical examination and observational gait analysis because they were unable to complete a valid kinematic analysis.

All patients underwent radiological examination, and tibial-floor, tibiocalcaneal and calcaneal pitch angles were documented. Calcaneal pitch was defined as the angle subtended by lines drawn from the plantar aspect of the posterior calcaneal tuberosity to the anterior tuberosity of calcaneus and from the posterior tuberosity to the plantar aspect of the first metatarsal head.

The results were analysed according to the motor distribution, type of operation, outcome of surgery and age at the time of surgery.

**Statistical analysis.** This was undertaken using logistic regression models for hemiplegia and quadriplegia, and multinominal logistic regression models for diplegia using 95% confidence intervals, calculated using robust standard errors to account for intrasubject correlation and checked in the model to show that the age brackets chosen were parsimonious. Prior knowledge suggested dichotomising age at eight years and examining the outcome in the two age groups. Alternative age-outcome relationships were investigated by fitting different models and the most parsimoniously fitting model was chosen. Chi-squared tests were used to measure any difference in outcome between groups and the level of significance was set at 5%.

**Results**

There were 78 boys and 56 girls with a mean age at surgery of 7.6 years (2 to 18). The mean follow-up was 6.9 years (5 to 10). There was no significant difference in the length of follow-up in the three operative groups. The 45 patients with hemiplegia, had 45 calf lengthenings, the 65 with diplegia had 110 and the 24 with quadriplegia had 40. Half of the procedures (98) were percutaneous tendo Achillis lengthenings (PTAL) while 40 (21%) were open Z-lengthenings and 57 (29%) Baker’s operation.

Only 42% of patients had a good calf length: 22.6% developed recurrent equinus (equinus gait 13.9%, equinus deformity 8.7%) and 36% calcaneus (calcaneus gait 23.1%, calcaneus deformity 12.8%) (Figs 2 and 3).

**Influence of gender on outcome.** The male-to-female ratio was 58:42. The preponderance of boys was similar in all motor distributions (Table I). Girls had an increased chance of calcaneus (49% v 27%; p = 0.001) and when adjusted for age and motor distribution (p = 0.002). Boys had a greater chance of equinus (29% v 13%; p = 0.009)
and a much lower risk of calcaneus in group 3.

However, a significant difference between groups 1 and 2 was evident. There was no difference between the outcomes in groups 1 and 2. There was, however, a significant difference between groups 1 and 2 and group 3, with an increased chance of a good outcome and a much lower risk of calcaneus in group 3.

This pattern was even more pronounced in the diplegic group, with a sharp rise in good results and a dramatic fall in poor calcaneus results in those over eight years at surgery. In patients undergoing surgery at over eight years there was a good outcome in 70% and a calcaneus outcome in 17% compared with 37% and 46%, respectively, in those under eight years (p = 0.046).

**Surgical procedure and outcome.** The three surgical procedures were assessed according to outcome (Table III). There was an increased chance of recurrent equinus with Baker’s procedure and of calcaneus with PTAL lengthening. These increases, however, were not statistically significant.

Combining both types of procedure on tendo Achillis and applying the age groupings indicated that patients operated on younger than eight years of age had a 43% chance of a calcaneus outcome in comparison with a 30% chance in those who had a Baker’s procedure, but this was not statistically significant.

In patients with diplegia, PTAL was very unpredictable with only 38% having a satisfactory outcome compared with 50% of those who had one of the other procedures (p = 0.02). In hemiplegia, the type of operation had little effect on the final outcome. In quadriplegia, PTAL resulted in a calcaneus outcome in 80% of children compared with an incidence of 48% with either of the other two procedures (p = 0.046).

**Radiological assessment.** Standing lateral radiographs of the tibia, foot and ankle were used to obtain a proxy measure for calf length and were obtained in all patients who were unsuitable for three-dimensional gait analysis because of limited mobility, very slow or inconsistent gait, or dependence on assistive devices.

Patients with hemiplegia had values for the tibial-floor angles which were nearly normal, despite 22% having a recurrent equinus gait or deformity. Values for tibiocalcaneal and calcaneal pitch were also normal.

In diplegia, radiographs were of more value as those patients with a calcaneus outcome had a significantly lower tibial-floor angle than normal (Fig. 2).

In quadriplegia, radiological measurements were helpful in delineating severe structural calcaneus deformity. In both diplegia and quadriplegia, interpretation of the radiographs was further complicated in those children who could not extend their knees fully, since this gave spuriously lower readings of the tibial-floor angles. We found radiographs to have limited value in assessing calf length and radiology is no longer used for this in our unit.

### Table I. The gender distribution and the outcome by motor distribution

<table>
<thead>
<tr>
<th>Boys</th>
<th>Total (%)</th>
<th>Equinus (%)</th>
<th>Good (%)</th>
<th>Calcaneus (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemiplegia</td>
<td>28 (62)</td>
<td>11 (39)</td>
<td>17 (61)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Diplegia</td>
<td>64 (58)</td>
<td>14 (22)</td>
<td>30 (47)</td>
<td>20 (31)</td>
</tr>
<tr>
<td>Quadriplegia</td>
<td>21 (52)</td>
<td>8 (38)</td>
<td>3 (14)</td>
<td>10 (48)</td>
</tr>
<tr>
<td>Total</td>
<td>113 (58)</td>
<td>33 (29)</td>
<td>50 (44)</td>
<td>30 (27)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Girls</th>
<th>Total (%)</th>
<th>Equinus (%)</th>
<th>Good (%)</th>
<th>Calcaneus (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemiplegia</td>
<td>17 (38)</td>
<td>6 (35)</td>
<td>9 (53)</td>
<td>2 (12)</td>
</tr>
<tr>
<td>Diplegia</td>
<td>46 (42)</td>
<td>4 (9)</td>
<td>18 (39)</td>
<td>24 (52)</td>
</tr>
<tr>
<td>Quadriplegia</td>
<td>19 (48)</td>
<td>1 (5)</td>
<td>4 (21)</td>
<td>14 (74)</td>
</tr>
<tr>
<td>Total</td>
<td>82 (42)</td>
<td>11 (13)</td>
<td>31 (38)</td>
<td>40 (49)</td>
</tr>
</tbody>
</table>

### Table II. The age at operation as related to outcome, by percentage

<table>
<thead>
<tr>
<th>Group 1 (2 to 5 years)</th>
<th>Group 2 (6 to 8 years)</th>
<th>Group 3 (&gt; 8 years)</th>
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</thead>
<tbody>
<tr>
<td>Equinus</td>
<td>21.4</td>
<td>23.3</td>
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<tr>
<td>Good</td>
<td>41.1</td>
<td>36.0</td>
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<tr>
<td>Calcaneus</td>
<td>37.5</td>
<td>40.7</td>
</tr>
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</table>

### Table III. Operative procedure as related to outcome, by number and percentage

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Equinus</th>
<th>Good</th>
<th>Calcaneus</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baker’s</td>
<td>15 (26)</td>
<td>24 (42)</td>
<td>18 (32)</td>
<td>57</td>
</tr>
<tr>
<td>Z-lengthening</td>
<td>9 (22.5)</td>
<td>17 (42.5)</td>
<td>14 (35)</td>
<td>40</td>
</tr>
<tr>
<td>PTAL</td>
<td>20 (20)</td>
<td>40 (41)</td>
<td>38 (39)</td>
<td>98</td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td>81</td>
<td>70</td>
<td>195</td>
</tr>
</tbody>
</table>

and when adjusted for age and motor distribution (p = 0.012).

In the diplegic group boys operated on before the age of eight years, had less favourable results and girls showed this increased risk of a poor outcome up to the age of seven years. This may reflect earlier skeletal maturation in girls.

**Motor distribution and outcome.** The motor distribution of cerebral palsy significantly affected the outcome (Table I). As the severity of motor involvement increased, the chance of achieving a satisfactory calf length decreased. The worst outcome was in children with quadriplegia. The results in diplegia were intermediate and the best results were in hemiplegia (p = 0.001).

Of those with hemiplegia, 58% had a good outcome, 38% had a recurrent equinus deformity and gait pattern, but only two patients (4%) had a calcaneus gait pattern. In diplegia, 44% had a good outcome, 16% had equinus and 40% had a calcaneus gait or deformity. In quadriplegia, only 17.5% had a satisfactory outcome; 22.5% had a recurrent equinus deformity and gait pattern and 60% a calcaneus deformity or gait pattern.

**Age at surgery and outcome.** Age at the time of surgery was examined to see if this had an influence on outcome (Table II). The patients were divided into three groups: group 1 was aged two to five years; group 2 six to eight years; and group 3 over eight years. There was no difference between the outcomes in groups 1 and 2. There was, however, a significant difference between groups 1 and 2 and group 3, with an increased chance of a good outcome and a much lower risk of calcaneus in group 3.

This pattern was even more pronounced in the diplegic group, with a sharp rise in good results and a dramatic fall in poor calcaneus results in those over eight years at surgery. In patients undergoing surgery at over eight years there was a good outcome in 70% and a calcaneus outcome in 17% compared with 37% and 46%, respectively, in those under eight years (p = 0.046).
Discussion

Uncertainty of outcome is perhaps the most significant criticism levelled at orthopaedic procedures in children with cerebral palsy by parents and physiotherapists. We therefore undertook this study in the form of a ‘risk-factor’ analysis and included the entire population of children with cerebral palsy during the period of study who had isolated operations for calf lengthening.

Clinical estimation of muscle length in these patients using the Silfverskiold test confirmed that in most the gastrocnemius was more affected by shortening than the soleus. Many patients with diplegia or quadriplegia showed no evidence of soleal contracture. Delp, Statler and Carroll developed a computer model of the effects of surgical treatment for contracture of the triceps surae which allows description of the primary effect of calf lengthening on the gastrocnemius and soleus, respectively, and the secondary effect of lengthening on the strength of plantar flexion. They showed that lengthening of the gastrocnemius when only the gastrocnemius was shortened, resulted in a marked reduction in the strength of plantar flexion. Clinically, this may result in calcaneus. Many surgeons choose to lengthen both the gastrocnemius and soleus by a variety of procedures on tendo Achillis or at the level of the combined aponeurosis. The operations which lengthen both gastrocnemius and soleus include all lengthenings of the gastrocnemius such as the Hoke percutaneous lengthening and Baker’s procedure. Although the last is described as a lengthening of the gastrocnemius fascia, it is in fact a lengthening of the conjoined aponeurosis of the gastrocnemius and soleus.

A review of the patients’ case notes suggested that most calf-lengthening procedures achieved their stated goal in the short term. Most charts recorded that the foot was plantigrade after removal of the cast and, during interview, most parents or carers stated that there had been an improvement in the child’s gait for a variable period of time. Given the complexity of the motor disorder in children with cerebral palsy and the effects of growth, it is not surprising that the results deteriorated with time in a large number of children and that a single operation did not provide permanent correction.

Assessment of outcome after surgery for calf lengthening is difficult in such a diverse group. Sagittal plane kinematics and kinetics of the ankle are the most sensitive outcome measures, as both under- and overcorrection can be readily identified. More than 50% of the outcomes in our study were assessed by three-dimensional gait analysis. We were, however, evaluating the outcome in the whole series and not just in the independent walkers, who would be expected to have the best results. In an effort to assess the more severely involved children in an objective manner, we obtained long standing lateral radiographs of the tibia, ankle and foot. Although calcaneus deformity was easily recognised, the method lacked precision and reproducibility. In the children who were household or therapeutic walkers we found that observational gait analysis by two experienced observers was adequate for the method of outcome assessment which we used. In a previous study we have found observational gait analysis to have good inter- and intraobserver repeatability.

In children with hemiplegia there was little calcaneus deformity and a low incidence of calcaneus gait, but equinus deformity, equinus gait and further surgery for recurrent equinus were common. In hemiplegia, equinus deformity is usually ‘real’ and not ‘apparent’. Most children in this study had type-2 hemiplegia according to the criteria of Winters, Gage and Hicks, with little or no involvement at the hip or knee on either clinical examination or gait analysis.

Calf lengthening, by whatever means, will correct the length and improve gait in the short term. In some children, following this procedure, growth of the muscle-tendon unit gradually falls behind tibial growth and recurrent equinus develops. In the child with hemiplegia who is still growing, we should be more surprised by a lasting correction of equinus deformity than by recurrent equinus, which can be managed successfully by a repeat lengthening of the calf.

Management of calcaneus deformity is much more difficult and there is a greater need to avoid it.

In children with diplegia and quadriplegia the situation is more complicated. Equinus deformity is often more ‘apparent’ than ‘real’. Spasticity and flexion contractures at the hip and knee may dictate an equinus posture at the ankle when there is no calf contracture because of the need to achieve sagittal plane balance. This is a biomechanical response to control the direction of the ground reaction vector in relation to the centres of joint rotation. In diplegic and quadriplegic cerebral palsy, calcaneus deformity and crouch gait may be part of the primary pathology and not always the result of calf lengthening, a situation which is not seen in hemiplegia.

Progressive ‘crouch gait’ is characterised by marked overlengthening of the calf in relation to tibial length and to the length of the hip and knee flexors. Once the ground reaction force is behind the knee throughout stance, a persistent stretch is applied to the calf muscle. There is good experimental evidence to suggest that the calf muscle responds by adding sarcomeres and gradually becomes anatomically too long and biomechanically incompetent. In time, a calcaneus gait may progress to a calcaneus deformity.

The type of surgical procedure had only a limited effect on outcome. Percutaneous lengthening of tendo Achillis was the most unpredictable procedure, particularly in younger patients, possibly because the size of the tendon is very variable and complete transection is not uncommon. While the effect of complete transection is debatable, it is unlikely to improve the predictability of the outcome. Baker’s procedure was a safer alternative in our study with
a lower incidence of calcaneus and a slightly higher level of recurrent equinus. Aponeurotic lengthenings are inherently more stable than tendon lengthenings. This is probably the reason why in our study the Baker operation was associated with a slightly lower rate of overlengthening, despite the fact that it is not a selective gastrocnemius procedure.

We have identified a significant gender difference in outcome which has not been previously reported. Girls had an increased chance of a calcaneus outcome and boys an increased risk of recurrent equinus. Whether this can be explained by an increase in laxity of the connective tissues in girls remains to be determined.

In hemiplegia, the lessons are clear: operations to lengthen the calf are safe and calcaneus is rare, but maintenance of calf length until skeletal maturity may be difficult and parents should be advised about the possible need for further surgery. It is worthwhile, when possible, to postpone the age of the initial operation by conservative measures such as physiotherapy, casting, the application of an orthosis and injections of botulinum toxin. There are no convincing data to suggest that the use of orthoses or night splints affects the rate of recurrence, but controlled trials are required. 4,8,39,52

In the growing child with diplegic or quadriplegic cerebral palsy, isolated calf lengthening has few if any indications. Three-dimensional gait analysis may help to shift the focus more proximally where the more important contractions will be found. 53 Simultaneous surgery at the level of the hip, knee and ankle and a selective lengthening of the gastrocnemius rather than lengthening of tendon Achilles may reduce the incidence of calcaneus gait and deformity. 25,40,54

In diplegia the timing of surgery is important. Girls over seven years and boys over eight have much better results. This may be due to delayed development of gait, which in diplegia may not be mature until the age of six years 53 or to difficulty in predicting the final length and strength of plantar flexors of the ankle.

Risk factors for a calcaneus outcome are the severity of disease, female gender, age at operation of less than eight years, and percutaneous lengthening of tendon Achilles. Risk factors for a recurrent equinus outcome are hemiplegia, male gender and an aponeurosis calf lengthening. Familiarity with the risk factors may help surgeons in the assessment of patients and the timing and selection for operation. It will also allow improved informed consent to be given by patients and their parents.

Calf lengthening in hemiplegia by any of the above methods can be undertaken in a general orthopaedic practice with few risks and with acceptable results. The same cannot be said in diplegia and quadriplegia. If calf lengthening is necessary in diplegia, we recommend preoperative gait analysis, postponing surgery until after the age of eight years, carrying out simultaneous proximal lengthenings of the hamstrings and psosas when appropriate, and using a selective gastrocnemius lengthening procedure.

We wish to thank Rory Wolf, PhD of the clinical epidemiology and biostatistics unit in the Department of Paediatrics at the Royal Children’s Hospital for his assistance with the statistical analysis.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References


