

# The Baumann procedure for fixed contracture of the gastrosoleus in cerebral palsy

## EVALUATION OF FUNCTION OF THE ANKLE AFTER MULTILEVEL SURGERY

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**We treated 22 children (28 limbs) with diplegic cerebral palsy who were able to walk by the Baumann procedure for correction of fixed contracture of the gastrosoleus as part of multilevel single-stage surgery to improve gait. The function of the ankle was assessed by clinical examination and gait analysis before and at two years (2.1 to 4.0) after operation. At follow-up the ankle showed an increase in dorsiflexion at initial contact, in single stance and in the swing phase. There was an increase in dorsiflexion at initial push-off without a decrease in the range of movement of the ankle, and a significant improvement in the maximum flexor moment in the ankle in the second half of single stance. There was also a change from abnormal generation of energy in mid-stance to the normal pattern of energy absorption. Positive work during push-off was significantly increased. Lengthening of the gastrocnemius fascia by the Baumann procedure improved the function of the ankle significantly, and did not result in weakening of the triceps surae. We discuss the anatomical and mechanical merits of the procedure.**

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Equinus deformity is commonly encountered in children with cerebral palsy. Good function of the foot is essential for normal gait. The heel, ankle and forefoot rockers optimise the shock-absorbing, stabilising, and propulsive functions of the foot. Equinus causes a decrease in the stability

of the stance phase, loss of smooth transition of the body over the foot, and inadequate clearance of the foot in the swing phase.<sup>1</sup> Persistent deformity interfering with gait requires lengthening of the triceps surae. A wide variety of procedures has been described for the surgical correction of equinus (Table I).

Few studies have used gait analysis to analyse objectively the outcome of different methods of lengthening of the triceps surae. Sharrard and Bernstein<sup>2</sup> presented an eight-year follow-up of 57 patients treated either by lengthening of the tendo Achillis or by aponeurotic lengthening of gastrocnemius. They found a recurrence of equinus of 15% in aponeurotic lengthening compared with 23% in lengthening of the tendo Achillis. Their study did not include analysis of gait. Perry et al<sup>3</sup> reported a study of the function of triceps surae before and after surgery, using electromyography and clinical analysis of gait. They found simultaneous activity in the gastrocnemius and soleus to the quick stretch test, and suggested that the Silfverskiöld test, although unreliable in the conscious patient, can give consistent results when carried out under anaesthesia. Yngve and Chambers<sup>4</sup> compared ankle function after Vulpius lengthening of the gastrocnemius fascia for gastrocnemius contracture with Z-lengthening of tendo Achillis for contracture of the gastrosoleus. They found an equal improvement in the ankle moments and in push-off one year after surgery in both groups. Entyre et al<sup>5</sup> studied changes in ankle function after the Vulpius procedure and Z-lengthening using electromyography and ankle kinematics. They found no difference in the outcome between the procedures. DeLuca, Giachetto and Gage<sup>6</sup> compared the effects of Z-lengthening with those of the Baker procedure using plots of ankle movement and found better push-off after the latter operation. Rose et al<sup>7</sup> carried out a kinematic and kinetic evaluation of the ankle one year after Baker lengthening of the gastrocnemius fascia. Their results showed improvement in dorsiflexion in the stance and swing phases. Their kinetic results demonstrated a decrease in abnormal generation of energy in mid-stance and a significant increase in late stance for push-off. In most of these studies it was not specified whether the patient had a dynamic or a fixed contracture, and whether the contracture was isolated to the gastrocnemius or a combination of the gastrocnemius and soleus.

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**Table I.** Different procedures described for lengthening of the triceps surae in children with cerebral palsy

Study	Procedure
Vulpus and Strofel	Inverted "V" slide lengthening of the distal gastrocnemius/soleus aponeurosis
Silfverskiöld <sup>25</sup>	Transplantation of heads of origin of the gastrocnemius
Green and McDermott <sup>26</sup>	Lengthening of the gastrocnemius at its origin with/without neurectomy
White <sup>27</sup>	Slide lengthening of tendo Achillis
Strayer <sup>17</sup>	Recession of the gastrocnemius tendon distally where it blends with tendo Achillis
Baker <sup>16</sup>	"Tongue in groove" slide lengthening of distal aponeurosis of gastrocnemius
Banks <sup>28</sup>	Open slide lengthening of tendo Achillis
Silver and Simon <sup>29</sup>	Silfverskiöld procedure with selective neurectomy of gastrocnemius
Pierrot and Murphy <sup>30</sup>	Transplantation of insertion of tendo Achillis
Gaines and Ford <sup>31</sup>	Technique for determining adequate lengthening of tendo Achillis
Garbarino and Clancy <sup>32</sup>	Geometrical method for calculating lengthening of tendo Achillis
Baumann and Koch <sup>8</sup>	Intramuscular lengthening of the gastrocnemius and/or soleus

Intramuscular lengthening of the gastrocnemius and soleus was described by Baumann and Koch<sup>8</sup> in 1989. It involves multiple incisions in the anterior aponeurosis of the gastrocnemius and the adjacent fascia of soleus, over the muscle bellies. We have used this procedure during the past four years for surgical correction of equinus deformity in children with cerebral palsy and we now present our results.

## Patients and Methods

We studied 22 children (28 limbs) with diplegic cerebral palsy who were able to walk and who were undergoing single-stage multilevel surgery. Only those patients who showed a fixed contracture of the gastrocnemius and the soleus by a negative Silfverskiöld test (lack of dorsiflexion of the foot to neutral with the knee in flexion and in extension) under anaesthesia and who had a subsequent lengthening of the gastrocnemius and soleus by the Baumann procedure were included. The mean age at surgery was 12.6 years (7.4 to 16.6). A mean of 8.0 procedures (3 to 8) was carried out in each patient. All had good vision, ability to comprehend instructions and were able to walk without the use of walking aids.

**Patient assessment.** Clinical examination and analysis of gait were undertaken before (mean 1.0 month) and at a mean of 2.2 years (2.1 to 4.0) after surgery. Physical examination included assessment of the active and passive range of movement, as well as of fixed deformities in the joints of the lower limb. The power of various muscle groups in the leg was investigated by manual testing, and their tone was recorded according to the Ashworth scale.<sup>9</sup> Instrumented analysis of gait, using a six-camera video based on a movement-capturing system (Motion Analysis Corporation System, California) and a floor-mounted forceplate (Kistler Instruments Ltd, Winterthur, Switzerland), provided three-dimensional kinematics, kinetics and time-distance parameters. Kinematic and kinetic parameters in the sagittal plane and relevant findings from clinical examination were used for this study.

**Operative technique.** The procedure has been described by Baumann and Koch.<sup>8</sup> A medial incision, 8 to 12 cm long, is made at the junction of the upper and middle thirds of the lower leg (Fig. 1). By blunt dissection, the plane

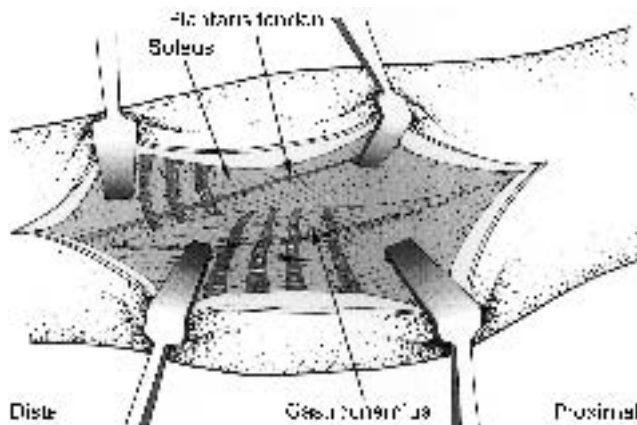


Fig. 1

Diagram to show the Baumann procedure for intramuscular lengthening of the triceps surae.

between gastrocnemius and soleus is opened. The plantaris tendon is resected. The ankle is dorsiflexed to put tension on the strong anterior aponeurosis covering the two muscle bellies of the gastrocnemius. Starting proximally the aponeurosis over the muscle bellies is divided by two or three parallel transverse incisions 1.5 cm apart. The septum between the medial and lateral head of the gastrocnemius is cut. The distal tendon sheet of the gastrocnemius which blends into tendo Achillis is preserved. Similar incisions for aponeurotic lengthening of the soleus are made distally to avoid overlapping with those in the gastrocnemius aponeurosis. The ankle is then gradually dorsiflexed until a neutral position is achieved with the knee in full extension, and separation of the gastrocnemius and soleus fascia can be seen. After careful haemostasis, the incision is closed in layers. Postoperatively, a short- or long-leg cast, depending on any additional procedures, is applied with the ankle in neutral.

The additional bony and/or soft-tissue procedures carried out which were specific for each patient are listed in Table II.

**Postoperative management.** A standard regime was used for rehabilitation after operation. Passive movement was started at four to seven days and standing in a frame and gait training by seven to ten days. Above-knee casts were applied in two patients in whom capsulotomy of the knee

**Table II.** List of surgical procedures carried out on the 22 children with cerebral palsy

Procedure	Total	Mean per patient
Intrapelvic psoas tenotomy	20	0.9
Adductor lengthening	6	0.3
Lateral hamstring lengthening	8	0.4
Medial hamstring lengthening	32	1.5
Distal rectus transfer	32	1.5
Gastrosoleus lengthening	28	1.3
Knee capsulotomy	2	0.1
Foot procedures	26	1.2
Tibial derotation osteotomy	8	0.4
Femoral derotation osteotomy	14	0.6
Total	176	8.2

had been carried out. The other patients were treated by below-knee casts. These were removed at three weeks and knee-ankle-foot orthoses (KAFO) fitted to maintain knee extension during resting periods, with walking ankle-foot orthoses (AFO) to provide passive knee extension in the stance phase of gait. A KAFO was used until muscle balance at the knee was established. The AFO was discontinued when the muscle power in the calf was sufficient to stabilise the knee during stance. Stay in hospital was for four to six weeks with daily physiotherapy, and gait training. After discharge, the patients continued physiotherapy on an outpatient basis, as required, and were seen once a month in the outpatient department.

The paired Student *t*-test was used to compare the relevant kinematic, kinetic and clinical observations which were measured before operation and at follow-up. We considered *p* values of less than 0.05 to be statistically significant.

## Results

At follow-up, clinical examination showed a significant improvement in active and passive dorsiflexion at the ankle, with and without knee flexion. There was no significant decrease in the power of plantar flexion of the ankle after surgery. The mean popliteal angle decreased from 55.6° before to 19.5° after operation.

Kinematics at the ankle showed a change in the angle at initial contact from a mean plantar flexion of 16.8° to 2.2°. The mean angle in single stance changed from 11.8° plantar flexion to 7.1° dorsiflexion.

The maximum dorsiflexion of the ankle in the swing phase improved by 17.7° (*p* < 0.0008). Although the ankle showed an increase in dorsiflexion of 21.9° at the beginning of push-off, the total range of movement at the ankle during this phase was not affected. In the stance phase there was an increase in extension at initial contact, on single-stance and at the beginning of push-off, with maintenance of flexion during the swing (Table III).

The kinetics of the ankle in mid-stance showed a change

**Table III.** The mean ( $\pm$  SD) kinematic and kinetic parameters evaluated

Parameter	Preoperative	Postoperative	<i>p</i> value
<b>Clinical*</b>			
Popliteal angle in degrees			
At knee extension (degrees)	55.6 $\pm$ 17.5	19.5 $\pm$ 11.3	0.0013
Passive ankle dorsiflexion	-16.9 $\pm$ 9.6	11.9 $\pm$ 7.5	0.0000
Active ankle dorsiflexion	-21.3 $\pm$ 7.4	4.4 $\pm$ 4.2	0.0001
At 90° knee flexion (degrees)			
Passive ankle dorsiflexion	-11.9 $\pm$ 8.8	16.3 $\pm$ 7.9	0.0003
Active ankle dorsiflexion	-18.8 $\pm$ 7.9	9.4 $\pm$ 4.2	0.0001
Ankle plantar flexion power	3.9 $\pm$ 0.8	3.5 $\pm$ 0.5	0.0796
<b>Kinematics in degrees*</b>			
Initial contact			
Ankle angle	-16.8 $\pm$ 11.7	-2.2 $\pm$ 6.0	0.0017
Knee angle	27.2 $\pm$ 9.7	18.9 $\pm$ 9.6	0.0424
Single-stance			
Ankle angle	-11.8 $\pm$ 13.7	7.1 $\pm$ 5.7	0.0007
Minimum knee angle (maximum extension)	9.3 $\pm$ 13.5	3.5 $\pm$ 9.5	0.0553
Onset of push-off			
Ankle angle	-16.2 $\pm$ 14.3	6.9 $\pm$ 8.7	0.0006
Knee angle	13.7 $\pm$ 12.6	8.9 $\pm$ 10.4	0.0329
Toe-off			
Ankle angle	-25.1 $\pm$ 12.5	-3.2 $\pm$ 9.0	0.0005
Push-off range of movement (ankle)	12.9 $\pm$ 5.0	13.7 $\pm$ 5.6	0.2782
Maximum in swing			
Ankle dorsiflexion	-16.0 $\pm$ 12.2	1.7 $\pm$ 6.2	0.0008
Knee flexion	59.6 $\pm$ 11.5	57.5 $\pm$ 7.4	0.7906
<b>Kinetics*</b>			
Positive work (W/kg)			
In single stance	5.7 $\pm$ 8.4	-7.1 $\pm$ 11.3	0.0020
For push-off	2.4 $\pm$ 1.9	5.5 $\pm$ 2.2	0.0005
Maximum extensor moment (Nm/kg)			
In first half of single-stance	0.9 $\pm$ 0.3	1.0 $\pm$ 0.3	0.2511
In second half of single-stance	0.7 $\pm$ 0.3	1.0 $\pm$ 0.1	0.0102

\* negative values indicate power absorption

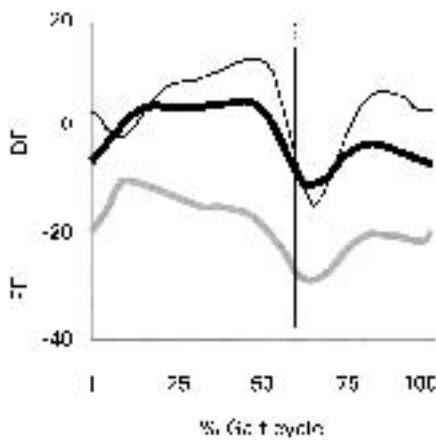


Fig. 2a

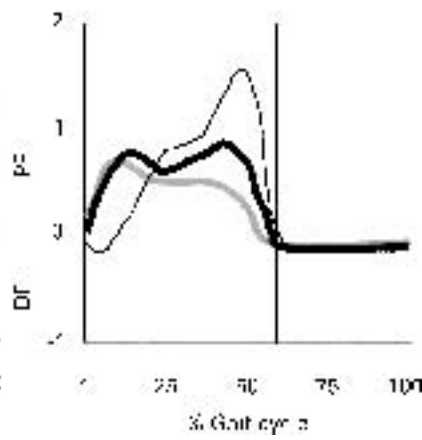


Fig. 2b

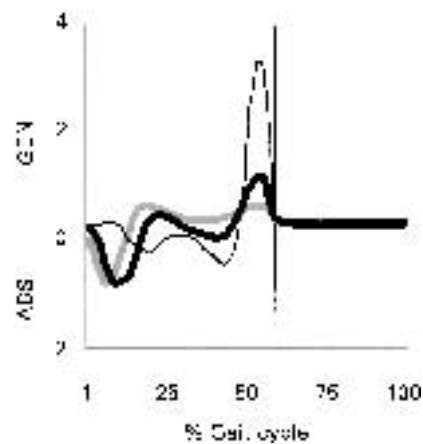


Fig. 2c

Mean curves depicting the a) ankle kinematics (degrees), b) moments (Nm/kg) and c) power (w/kg) before and after surgery (preoperative, grey line; postoperative, thick black line; normal, thin black line).

towards normal. Ankle moments showed better loading in the stance phase, manifested by significant improvement in the maximum extensor moment in the second half of single stance. After operation, there was a change from abnormal generation of energy to normal absorption of energy in mid-stance. Positive work during push-off was significantly increased.

Figure 2 shows mean curves of kinematics and kinetics of the ankle before and after operation. The mean values of parameters measured with their corresponding p values are shown in Table III. One of the patients required reoperation one week after surgery because of undercorrection of the equinus. Additional incisions were placed over the gastrocnemius and soleus fascia, and the deformity was corrected. No overcorrection, recurrence, or other complications, were observed during the study.

## Discussion

Improvement in ankle movement and function were seen after lengthening of the triceps surae by the Baumann procedure. The function of the ankle, however, could also be influenced by the improvement in other joints after multi-level single-stage surgery. Knee kinematics were assessed for two reasons. First, the triceps surae is a two-joint muscle and hence can affect function of the knee and, secondly, in most patients the hamstrings were lengthened; it is known that this can affect the function of the ankle.<sup>10,11</sup> The angle of the knee was evaluated at three points in the gait cycle, on initial contact which defines the position of the limb for weight acceptance, at mid-stance when the limb supports the full body-weight; and at the start of push-off which may influence the function of triceps surae. All three points in the gait cycle showed an improvement of knee extension.

Better positioning of the foot at initial contact was noted because of improvement in knee extension as well as ankle dorsiflexion. These changes allow normal acceptance of weight through the ankle and knee. Increased dorsiflexion

in the swing phase improved clearance of the foot resulting in better function. There was abnormal generation of energy in single stance before operation, possibly because of a premature stretch on the shortened spastic triceps.<sup>3</sup> This was replaced by normal absorption after the Baumann procedure. In spite of the increased ankle dorsiflexion in single stance and before the swing phase, there was no change in the range of movement of the ankle then or in the angle of the ankle at toe-off. This suggests a shift towards normality in ankle movements. These improvements in kinematics are reflected in changes in the moments acting at the joint, which demonstrate a better flexion moment in the late half of single support. This implies that lengthening the triceps improves the eccentric contraction of the muscle in stance and the function of the ankle rocker, allowing controlled rotation of the tibia over the ankle and a change in energy absorption in single stance. After operation, the energy generated for push-off was significantly improved.

Co-spasticity of muscles makes it difficult to test the power of a single muscle group in patients with cerebral palsy. Clinical examination showed significant improvements in passive and active dorsiflexion at the ankle. The improvement in the kinetics of the joint suggests that lengthening of the gastrosoleus fascia by the Baumann procedure did not result in weakening of the triceps surae. The clinical findings correlated well with dynamic assessment by gait analysis, and are reflected by the improvements in kinematics and kinetics.

Kawakami, Ichinose and Fukunaga<sup>12</sup> showed that the gastrocnemius and soleus have different lengths and angles of the fascicle and that both change differently on contraction. Based on a computer simulation study, Delp, Statler and Carroll<sup>13</sup> suggested that neither lengthening of the gastrocnemius aponeurosis nor lengthening of tendo Achillis was effective for contracture of the gastrosoleus. Lengthening the gastrocnemius aponeurosis did not decrease the excessive passive moment caused by the contracted soleus. Lengthening of tendo Achillis restored

**Table IV.** Recurrences and overcorrections from lengthening procedures described in literature

Level	Procedure	Recurrence (%)	Overcorrections (%)	Reference
Single	Aponeurotic	12 to 48	3	Olney et al <sup>23</sup> , Trusculli et al <sup>33</sup> , Damron et al <sup>34</sup> , Lemperg et al <sup>35</sup> , Conrad and Frost <sup>36</sup> , Rattey et al <sup>24</sup> , Damron et al <sup>34</sup> , Kerr Graham and Fixsen <sup>37</sup> , Frost <sup>38</sup> , Sharrard and Bernstein <sup>2</sup> , Trusculli et al <sup>33</sup> , Grant et al <sup>39</sup>
	Tendo Achillis lengthening	6 to 25	2 to 28	
Multiple	Aponeurotic	0 to 6	0	Rose et al <sup>7*</sup> , Javors and Klaaren <sup>40</sup>
	ATL	5 to 22	0 to 30	Gaines and Ford <sup>31</sup> , Sala et al <sup>1</sup> , Segal et al <sup>41*</sup>
	Aponeurotic or ATL†	0 to 12	0	Yngve and Chambers <sup>4*</sup> , Entyre et al <sup>5*</sup>

\* gait analysis used for evaluation

† Vulpius procedure was used for gastrocnemius contracture, and tendo Achillis lengthening (ATL) for combined contractures; level indicates whether the surgical correction reported was performed as an isolated procedure or a part of multilevel surgery

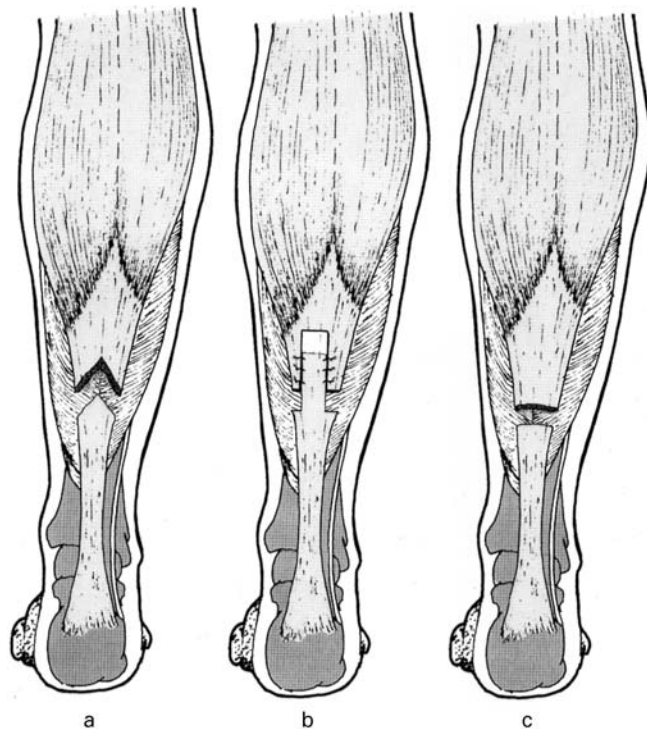


Fig. 3

Diagrams of other techniques of aponeurotic lengthening showing a) Vulpius b) Baker and c) Strayer. Note the proximity of surgery to the musculotendinous junction.

the normal passive range of movement, but substantially decreased the active force-generating capacity of the soleus. They suggested that independent lengthening of the contracted gastrocnemius and soleus, rather than lengthening of their common tendon, may be a more effective method of restoring range of movement and maintaining the strength of plantar flexion. Ziv et al<sup>14</sup> showed that in the gastrocnemius muscle of normal and spastic mice, 45% of growth occurs at the musculotendinous junction. They also showed that spastic muscle grows at only 55% of the rate of bone, and this may explain the development of equinus contracture. They termed the musculotendinous junction as the 'growth plate' of the muscle. It is therefore possible that operating at this site as in the Vulpius, Baker and Strayer procedures or lengthening of tendo Achillis could further compromise the retarded growth of spastic muscle (Fig. 3).<sup>15-18</sup> Since these procedures are not intramuscular

lengthenings, they could shorten the spastic muscle and further compromise the function.

The Baumann procedure has several advantages. The Vulpius, Strayer and Baker procedures are carried out at the musculotendinous junction and lengthen the posterior gastrocnemius aponeurosis (Fig. 3).<sup>15-18</sup> The Baumann procedure addresses the thicker and relatively inelastic anterior gastrocnemius aponeurosis (Fig. 1). If indicated, the soleus aponeurosis can also be lengthened. Multiple incisions spread the tension on the muscle fibres during subsequent stretching, and reduce the danger of stress concentration which could lead to rupture. This procedure respects the 'growth plate' of the muscle, and allows an individual correction of both muscles. The muscle power of the triceps surae after the Baumann procedure was not reduced after operation in our study. The results support the theoretical conclusions of simulation studies.<sup>13</sup>

Patients with cerebral palsy require prolonged rehabilitation and follow-up after surgery.<sup>19-20</sup> In our study, patients required dynamic AFOs for a mean of 9.4 months and rigid KAFOs were worn at night for up to one year after surgery. The orthoses were discontinued when they were able to walk with the knee unlocked, and extension of the joint occurred in stance phase.<sup>21</sup>

A review of the literature shows that there is a higher incidence of recurrence and overlengthening after lengthening of the tendon than after aponeurotic lengthening. Sala et al<sup>11</sup> found that increasing hamstring contracture was the major factor influencing recurrence of equinus. The age of the patient is also important, and several studies have documented a higher rate of recurrence after operation at less than six years.<sup>22-24</sup> Awareness of the interdependency of the deformity of joints and the concept of multilevel surgical correction have considerably improved the outcomes (Table IV). There were no recurrences or overcorrections in our study and our results compare favourably with those of Baumann and Koch.<sup>8</sup>

As a result of this study we would recommend the Baumann procedure for fixed equinus contractures in diplegic cerebral palsy. These conclusions, however, have some limitations. The effects of multilevel surgery and improvement of function at other joints undoubtedly influences the results. We rarely use other methods of lengthening of the triceps surae for equinus deformity and do not have sufficient data for a comparative study.

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