The effect of injections of botulinum toxin type A combined with casting on the equinus gait of children with cerebral palsy

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Our aim was to evaluate the effect of adding inhibitory casting to the treatment of young children with cerebral palsy who received injections of botulinum neurotoxin A (BoNT-A) to gastrocnemius for equinus gait. Of the 20 patients in the series, 11 in group A had inhibitory casts applied on the day of the first set of BoNT-A injections and nine in group B did not have casting. Both groups received another BoNT-A injection four months later. The patients were followed for eight months and examined at five intervals.

Both groups showed significant improvement in gait parameters and function (p < 0.0001) and selective motor control (p = 0.041, - 0.036) throughout the study. Group A had significantly better passive dorsiflexion of the ankle (p = 0.029), observational gait score (p = 0.006) and selective motor control (p = 0.036). We conclude that the addition of inhibitory casting enhances and prolongs the results of treatment and mainly influences the passive range of movement, while BoNT-A mostly influences the dynamic motion. The second injection further improved the results of most parameters. The gross motor function measure, the selective motor control test and the modified Tardieu scale correlated well with the results of treatment.

We recommend the use of inhibitory casting whenever augmentation of the effect of treatment with BoNT-A is needed.

In clinical trials both inhibitory casting and injections of botulinum neurotoxin A (BoNT-A) are effective treatment for equinus gait. Acting on the neuromuscular junction, it has a local and temporary effect. The effect of repeated injections declines with time. Immobilisation in short-leg casts reduces tone and improves the range of movement (ROM) of the ankle. The combined use of injections of BoNT-A and inhibitory casting has been found by some authors to be advantageous, others have shown that casting alone gave better results than BoNT-A alone or in combination with casting.

We therefore designed a prospective study to test the hypothesis that the addition of inhibitory casting of the ankle to injection of BoNT-A into gastrocnemius would enhance the effect of treatment by BoNT-A alone. Although the outcome of these treatments seems similar, their effect on the muscle may be different and therefore this combination may be advantageous. In order to assess our hypothesis we analysed the effect of treatment on parameters of gait, on active and passive movement of the ankle and on specific tests such as measurement of the gross motor function, the selective motor control test and the modified Tardieu scale.

Patients and Methods

Our series included children with cerebral palsy who were aged between three and five years and who walked with an equinus gait. After clinical examination they had their first BoNT-A treatment to gastrocnemius alone. We excluded those referred for injections to other sites, those who had previous BoNT-A treatment, those with fixed contractures in the lower limbs, and those who had previously had surgical treatment or who had received spasticity-reducing medication. We recruited 22 patients to the study, which was approved by the Institutional Review Board of our hospital. Participation was voluntary, and the parents gave informed consent.

The children were alternately allocated to one of two groups. Group A (11) received injections of BoNT-A plus casting while group B (11) had only injections of BoNT-A. Two group-B patients failed to complete the follow-up and were omitted from the study. In group A there were eight boys and three girls and in group B three boys and six girls. Their age, weight, diagnosis and level of gross motor function are given in Table I. The two groups did not differ statistically in gender, age or...
weight (p = 0.078, p = 0.393, p = 0.445 respectively, all independent sample t-test) or initially in gait or ROM except for knee flexion (Table III).

Protocol. Both groups received two injections of BoNT-A to gastrocnemius four months apart. In group A inhibitory casts were applied on the day of the first injection and retained for two weeks. These were below-knee casts with the ankle in a neutral position. The injections were given after the application of a local anaesthetic cream. A total dose of 20 IU of BoNT-A (Dysport; Ipsen, Slough, United Kingdom) per kg/body-weight divided equally was injected to both heads of gastrocnemius guided by known anatomical landmarks. Treatment was followed by enhanced physiotherapy, given three times a week in the community by the regular physiotherapist of each child, and the parents were instructed to encourage the child to walk with or without the cast. Those using braces on a regular basis before the study continued to do so. The gross motor function level was determined for each child.

The outcome was measured at five intervals (phase 0 to phase 4) over a period of eight months (Fig. 1). Outcome measures included video-based observational gait analysis and measurements of muscle tone, ROM, selective motor control and functional levels which were all carried out by the same physiotherapist (AG).

Gait analysis was based on two-dimensional (2D) video recordings in a gait laboratory. Seven markers were applied to each leg. The data collected included kinematic values (measured by goniometry on the computer screen), spatiotemporal values and gait-pattern ratings using the observational gait scale. Clinical measures included mobility functioning according to the gross motor function-66 dimension E (GMF-E), ankle tone according to the modified Ashworth scale, selective motor control of the ankle and passive ROM of the ankle. Goniometric measurements of the dynamic and static ranges of the ankle and knee were carried out according to the modified Tardieu scale. The data were collected from the affected

### Table I. Background parameters in the two groups

<table>
<thead>
<tr>
<th></th>
<th>Group A (n = 11)</th>
<th>Group B (n = 9)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (girls/boys)</td>
<td>3/8</td>
<td>6/3</td>
<td>0.078</td>
</tr>
<tr>
<td>Mean (range) weight in kg</td>
<td>13.8 (11.0 to 19.0)</td>
<td>12.9 (10.0 to 16.0)</td>
<td>0.445</td>
</tr>
<tr>
<td>Mean (range) age in years</td>
<td>3.9 (2.1 to 5.2)</td>
<td>4.1 (3.0 to 5.3)</td>
<td>0.399</td>
</tr>
<tr>
<td>Hemiplegia/diplegia</td>
<td>7/4</td>
<td>3/6</td>
<td>0.178</td>
</tr>
<tr>
<td>Gross motor function score 1/2/3</td>
<td>7/3/1</td>
<td>5/2/2</td>
<td>0.399</td>
</tr>
</tbody>
</table>

### Table II. Details of the baseline measurements in both groups

<table>
<thead>
<tr>
<th></th>
<th>Group A (n = 11)</th>
<th>Group B (n = 9)</th>
<th>value of t-test</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gait speed (m/s)</td>
<td>0.6</td>
<td>0.068</td>
<td>0.63</td>
<td>0.076</td>
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<tr>
<td>Stride length (cm)</td>
<td>28.9</td>
<td>5.763</td>
<td>28.0</td>
<td>7.961</td>
</tr>
<tr>
<td>Gross motor function-66 dimension E score</td>
<td>54.0</td>
<td>15.427</td>
<td>52.2</td>
<td>15.570</td>
</tr>
<tr>
<td>Passive DF* (°)</td>
<td>3.5</td>
<td>12.517</td>
<td>8.7</td>
<td>7.596</td>
</tr>
<tr>
<td>Active DF (°)</td>
<td>-28.1</td>
<td>19.637</td>
<td>-27.1</td>
<td>13.654</td>
</tr>
<tr>
<td>Ankle modified Tardieu scale - R1† (°)</td>
<td>-20.0</td>
<td>13.932</td>
<td>-21.0</td>
<td>12.580</td>
</tr>
<tr>
<td>Knee - R1† (°)</td>
<td>-52.9</td>
<td>9.481</td>
<td>-54.2</td>
<td>8.80</td>
</tr>
<tr>
<td>Knee - R2‡ (°)</td>
<td>-39.4</td>
<td>9.512</td>
<td>-44.4</td>
<td>4.216</td>
</tr>
<tr>
<td>DF at IC§ (°)</td>
<td>-12.7</td>
<td>12.760</td>
<td>-12.9</td>
<td>10.216</td>
</tr>
<tr>
<td>DF at mid-stance (°)</td>
<td>-7.1</td>
<td>14.06</td>
<td>-4.0</td>
<td>8.062</td>
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<tr>
<td>Maximum DF in stance (°)</td>
<td>0.5</td>
<td>15.488</td>
<td>-2.2</td>
<td>9.471</td>
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<tr>
<td>DF at terminal stance (°)</td>
<td>-8.3</td>
<td>19.895</td>
<td>-3.1</td>
<td>28.581</td>
</tr>
<tr>
<td>DF at mid-swing (°)</td>
<td>-17.9</td>
<td>16.337</td>
<td>-14.4</td>
<td>11.0</td>
</tr>
<tr>
<td>Knee flexion at IC (°)</td>
<td>34.4</td>
<td>12.119</td>
<td>26.7</td>
<td>12.60</td>
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<tr>
<td>Knee flexion at LR (°)</td>
<td>35.7</td>
<td>7.94</td>
<td>22.6</td>
<td>12.89</td>
</tr>
<tr>
<td>Knee flexion at mid-swing (°)</td>
<td>21.0</td>
<td>8.955</td>
<td>16.9</td>
<td>10.67</td>
</tr>
<tr>
<td>Knee flexion at initial swing (°)</td>
<td>63.3</td>
<td>17.833</td>
<td>59.8</td>
<td>14.478</td>
</tr>
</tbody>
</table>

* DF, dorsiflexion
† R1, dynamic range
‡ R1, the range of motion when a quick passive motion is applied to the joint
§ R2, the range of motion when a slow passive motion is applied to the joint
¶ IC, initial contact
**LR, loading response
side in the hemiplegic children and from the right side of diplegic children when both sides were injected.

**Statistical analysis.** This was performed using SPSS for Windows, version 14.1 software (SPSS Inc., Chicago, Illinois). All the variables were analysed by repeated-measures analysis of variance (ANOVA), using the confidence interval adjustment by Bonferroni for post hoc comparison tests. The ANOVA was used to analyse the effect of time and type of intervention (main effect and interaction) on the clinical measurements, functional performance, walking parameters and quality of gait. The results were considered to be significantly different at a p-value of ≤ 0.05.

**Results**

**Spatiotemporal parameters.** Gait speed was similar in groups A and B at the beginning of the study (independent sample t-test, p = 0.872) with a significant variance within groups (degrees of freedom of 18; p < 0.001). After treatment, the walking speed was significantly increased in both groups (p = 0.0001), but there was no significant difference between them (F = 0.423; p = 0.774) (Table III).

Figure 2 shows that the gait speed increased significantly at phase 2, reached the highest level in phase 3 and remained high in phase 4. There was a positive correlation between age and gait speed, step length and the baseline gross motor function score (p = 0.008, p = 0.014 and
Calculation of the effect of age before intervention showed that every year added a mean of 0.016 m/s to the gait speed, 0.43 cm to the step length and one point to the gross motor function score. This influence of age was not seen after the interventions had been initiated.

Step length was increased during the course of the study in both groups (F = 7.829; p < 0.0001) and there was no significant difference between them (F = 0.054; p = 0.9953). The mean increase in step length was between 6.4 cm and 9.4 cm in group A and 3.4 cm and 8.5 cm in group B. It was significantly longer at phase 2 than at phase 0 (p = 0.004), and this result remained constant to the end of the study (Fig. 3, Table III).

**Mobility and gait scores.** The GMF-E score which deals with mobility improved in both groups (F = 15.237; p < 0.0001) with no significant difference between them (F = 0.210; p = 0.5685). It was significantly elevated in phase 2 (p = 0.025) and kept rising by phase 4 (p = 0.028). The mean score rose by 4.0 to 9.7 points in group A and by 2.5 to 7.7 points in group B (p < 0.0001; Table III).

There was no significant difference between the two groups in the gait pattern according to the observational gait scale, with both showing significant overall improvement (F = 19.380; p < 0.0001). However, the groups demonstrated different patterns of improvement. As seen in Figure 4, group A showed a significant improvement starting at phase 1 (p < 0.0001) which remained constant during the following phases. Group B also had an improved gait pattern in phase 1 (p < 0.0001), but it declined in phase 2, returning almost to baseline levels (p = 0.154), only to rise again after the second intervention in phase 3 and to decline again four months later in phase 4.

**Range of movement.** Passive dorsiflexion of the ankle (Fig. 5, Table III) improved significantly (F = 18.037; p < 0.0001) only in group A. While the mean passive dorsiflexion before treatment was not significantly different between the groups (p = 0.287), group A had a mean increase of 12.2° in phase 1 and of 8.3° in phase 4. The mean change in ROM in group B was between 2.87° and 4.0°, which was not significant throughout the study (F = 0.923; p = 0.464). Active dorsiflexion improved significantly (F = 9.163; p < 0.0001) in both groups to a similar extent (F = 1.01; p = 0.409), remaining constant throughout the study (Fig. 6). It increased by a mean of 13.7° to 15.8° in group A (p < 0.0001) and by a mean of 4.9° to 12.7° in group B (p < 0.0001; Table III). There were no significant changes in the ROM of the knee and hip.
Muscle tone and spasticity. The muscle tone as measured by the modified Tardieu scale improved significantly in both groups (F = 6.589; p < 0.0001) and this was maintained throughout the study. No significant difference was found between the groups (F = 0.402; p = 0.807). A comparison of paired results showed improvement in tone after the first intervention (p = 0.012) as well as in phases 2 and 3, followed by a decline at the end of the study (p = 0.449).

The mean change in angles measured by the modified Tardieu scale was similar in both groups, 7.4° to 11.8° in group A and 7.5° to 11.56° in group B. Ankle tone as measured by the modified Ashworth scale showed no significant difference between the groups and no significant improvement throughout the study (chi-squared test, p = 0.2768 for group A and p = 0.6023 for group B).

Selective motor control. We found a significant difference in this between the groups only in phase 3 (chi-squared test, p = 0.04), with group A having better results than group B (Fig. 7). This was only marginally true for the other phases. Measurement of the selective motor control in phase 0 showed no significant difference between the groups (Mann-Whitney U test, p = 0.656).

The validity of the GMF-E score, the modified Tardieu scale and the selective motor control test. There was a positive correlation between walking speed and the GMF-E test. The mean walking speed increased from 0.63 m/s in the...
initial phase to 0.90 m/s in phase 4 at six weeks after the second intervention. The correlation between the GMF-E test and the walking speed was significant in all phases (in phase 1 \( r \) (Pearson’s product-moment coefficient) = 0.787, in phase 3 \( r = 0.687 \)).

In order to find out if those who had higher muscle tone correlated with a better response to treatment,\(^{18,19} \) we compared the modified Tardieu scale in phase 0 with that in phase 1 and correlated this with the dynamic range of the ankle, active dorsiflexion of the ankle and maximal dorsiflexion in stance. We found positive significant correlations between the modified Tardieu scale and active dorsiflexion \( (r = 0.312, p = 0.025) \) and between the dynamic range of the ankle \( (r = 0.603, p < 0.0001) \). We validated the selective motor control test by using Spearman’s rank correlation coefficient to compare the motor control findings and clearance at the swing phase.\(^{16} \) There was a significant but low correlation \( (r = 0.405, p < 0.0001) \) between the latter score and the angle of dorsiflexion of the ankle in mid-swing. This angle rose by 4.2° for each grade of the selective motor control score. The correlation between the motor control score and active dorsiflexion of the ankle was also significant in all phases \( (r = 0.867, p < 0.0001) \).

**Discussion**

The use of injections of BoNT-A to correct equinus gait is well-recognised, as is inhibitory casting.\(^1 \) Our results show that the combination of both treatments gave significant benefits in three parameters, namely the range of passive ankle dorsiflexion, the selective motor control and the observational gait scale.

Passive dorsiflexion of the ankle in group A (combined treatment) was significantly improved from phase 1 in contrast to that in group B (BoNT-A injections only) which showed no improvement throughout the study. Although from Figure 5 it appeared that the mean dorsiflexion in group A was lower than that in group B at the initial phase of the study, and the maximal amount of dorsiflexion reached in both groups was similar, statistically the difference between the groups at baseline was not significant while the improvement gained in group A was significant. A similar result was found in a retrospective study\(^{10} \) in which the ROM was analysed: those children who had a combined protocol of injections of BoNT-A and casting had the best results. Those children who had been treated by casting only also had significant improvement, but those treated only with BoNT-A had no significant benefit.\(^10 \) A difference in the treatment outcome was also reported by Ackman et al,\(^7 \) who showed that the combination of BoNT-A and casting was preferable to the use of inhibitory casts and placebo injections or to BoNT-A injections without additional intervention. Desloovere et al\(^{20} \) and Molenaers et al\(^{21} \) found improvement in the ankle kinematics after combined treatment. Both studies found a decrease in the ‘double-bump’ pattern of ankle movement and an increase in the plantar movement at push-off. Both groups treated all their patients with inhibitory casts and injections of BoNT-A, with the casts being applied at different times. They found that application of the casts immediately after the injections was slightly more effective. They did not compare these results with BoNT-A treatment without casting.\(^{20,21} \)

In our study, the observational gait scale and the selective motor control in group A differed from those in group B mainly in the duration of the effect of treatment. Group A had an improved observational gait scale and maintained this throughout the study, while group B showed initial improvement which declined after four months and rose again after the second injection of BoNT-A. The improved selective motor control in group A compared with group B was significant towards the end of the study. These results suggest that the addition of casting augmented the effectiveness of the BoNT-A treatment by maintaining the effect for a longer period. This augmentation and improved duration of influence has been observed in several other studies.\(^2,7,20-26 \) Boyd et al\(^2 \) found that the combined treatment of BoNT-A and casting improved ankle dorsiflexion for more than 12 weeks, while it declined in the patients who received only injections of BoNT-A. Ackman et al\(^7 \) examined the kinematics of the ankle and found that the combined treatment gave better results after the second and third treatments. Desloovere et al\(^{20} \) and Molenaers et al\(^{21} \) were able to prolong the intervals between treatments to one year when adding casting to the BoNT-A treatment. Bottos et al\(^{23} \) studied a group of ten children with spastic diplegia, all of whom had been treated with injections of BoNT-A and five of whom also had inhibitory casts. Both groups had similar results after the first month, but the combination group showed better results in muscle tone, overall function, gait speed and step length compared with the BoNT-A-injection-only group after four months.

The single parameter in which group B was found to have better results than group A was in maximal dorsiflexion of the ankle at the mid- and terminal stance. The dynamic tone of the ankle at other phases of the gait cycle was similar in both groups. Dynamic tone is the main inhibitor of a normal gait pattern in young children with cerebral palsy. These results suggest that it is mainly affected by the action of botulinum toxin, while inhibitory casting mainly influences the passive ROM. This combination of passive and dynamic influences around the ankle may be the reason for the advantage of the dual treatment.

Most of the parameters in both groups improved significantly and continuously throughout the study without a decline after the first four months. Given the age of the children and the duration of the study, some of the outcome measures might have been expected to improve under the influence of natural history. We found that age correlated positively with walking speed, step length and the baseline gross motor function score before the initial treatment, but the influence of age was eliminated after the interventions began, suggesting that the improvement resulted from the interventions. Other parameters which would have been
expected to decline with age in such children, such as passive dorsiflexion and selective motor control, improved and were significantly relevant.

The second treatment with BoNT-A had no less an influence than the first on all parameters with two exceptions, namely, dorsiflexion in swing and the dynamic muscle tone of the ankle. It is therefore impossible to separate the influence of the second intervention from that of the first, although the spatiotemporal parameters, the observational gait scale in group A, the dynamic tone of the ankle and the gross motor function score were shown to peak six weeks after the second treatment, suggesting a cumulative influence.

The influence of repeated injections of botulinum has been addressed in several studies. Both Sutherland et al and Metaxiotis et al showed an increasing effect of additional injections on the gait analysis of children with cerebral palsy. Sutherland et al repeated the injections at three-monthly intervals and reported that continued improvement even after the third and fourth injections. In the study of Metaxiotis et al, the influence of the injections began to decline 18 weeks after the third and fourth treatments, and the authors concluded that repeated injections could be given at intervals of longer than 18 weeks. These studies did not include casting, but others which have done so have shown that intervals may be as long as one year. From the results of our study and from those in the literature, we conclude that the interval between injections of BoNT-A may be extended beyond four months, and that this interval can be increased when casts are used.

The selective motor control score is a relatively new test which was devised by Boyd et al in 1998 to evaluate the influence of treatment with BoNT-A, a new intervention at that time. This score was found to be effective in predicting improvement in gait. The subjects who received high scores (3 or 4) had better ankle dorsiflexion and better clearance in swing. Our study is one of the few which did not find any positive change in the selective motor control when BoNT-A was used without casting. It was only when casting was added that the change was significant.

The modified Tardieu scale was also introduced by Boyd et al who showed, as we did, that the passive ROM of the ankle improved only when a combined treatment was given and not as a result of BoNT-A alone. The dynamic range, on the other hand, was equally improved in both treatment modalities. Drouin et al found that GMF-E test correlated with the gait velocity of children walking slower than 0.45 m/s but not with that of those walking at normal speeds. This was referred to as the ‘ceiling effect’ which reduced the sensitivity of the gross motor function test in nearly normal children. All except three children in our study walked independently. The mean walking speed was 0.63 m/s before treatment and rose to 0.90 m/s six weeks after the second injection. The correlation of the GMF-E test was positive and significant throughout our study. We found this test to be sensitive enough to indicate improvement in gait and function in both groups, as reported by others.

We did not encounter a ‘ceiling effect’ and were able to use this parameter even in children with relatively good function.

Our study had some limitations. There were only 20 patients and a larger series is probably needed to substantiate some results which did not reach a level of significance. Enhanced physiotherapy was given by different therapists at different centres. We had no means of measuring this treatment, but considered it to be equal in both groups. The physiotherapist recording the outcome measures was probably not blinded to the treatment protocol since the children were accompanied by parents who may have revealed this information. The height was not measured in our children, and therefore we could not normalise our results. The follow-up in our study was limited to eight months. A longer follow-up period would allow investigation of the effects of repeated injection and casting protocols, and of longer periods between treatment sessions.

We found a significant advantage in treating equinus gait with BoNT-A combined with inhibitory casting compared with treatment with BoNT-A alone, and suggest that this may be due to the different influence which each modality has on the muscle. Both groups showed significant improvement throughout the study which was sustained, in most parameters, for more than four months, with some evidence of an enhanced effect of the second treatment. The selective motor control test, the modified Tardieu scale and the GMF-E test were confirmed as good predictors of changes in gait after treatment. We recommend the use of inhibitory casting for two weeks in younger patients whenever augmentation of the effect of injection of BoNT-A is needed.


