Corrective Bandage for Conservative Treatment of Metatarsus Adductus: Retrospective Study

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Background. Metatarsus adductus (MA) is the most common congenital foot deformity observed in children.

Objectives. The aims of this study were: (1) to analyze the evolution of a corrective bandage for semirigid MA in newborns and (2) to recommend the age interval at which to start treatment of MA with the corrective bandage alone, without the need of splints.

Design. An observational clinical study was conducted.

Methods. The study was conducted at Virgen Macarena University Hospital in Seville, Spain. Children born with semirigid MA at the hospital during the years 2010–2011 were included. Corrective bandaging was applied to all children until clinical correction of the deformity. Sex, laterality of the deformity, weight and length of the newborn, age at the start of treatment, antecedents related to the pregnancy and birth, type of treatment (bandaging, splints), and correction or no correction with bandaging alone were recorded. Age differences at the start of the bandaging treatment between children whose deformity was corrected with and without the need of splints were examined. The receiver operating characteristic curve method was applied to analyze the predictive ability of the age at the start of bandaging treatment relative to whether the deformity was corrected or not corrected with bandaging alone.

Results. The bandage achieved complete correction in 68.1% of the children and corrected the deformity more frequently in girls compared with boys. Of the 56 children who began the treatment within the first month of life, 92.8% achieved correction of the foot deformity with the corrective bandaging alone.

Limitations. Patients’ follow-up time was only 2 years, so it was only feasible to analyze the corrective bandaging method over the short term and medium term.

Conclusions. Corrective bandages showed high effectiveness, particularly in girls, and overall when started within the first month of life.
Metatarsus adductus (MA) is the most common congenital foot deformity observed in children, and its frequency has increased in recent years (1–3 cases per 1,000 newborns). It is a complex deformity that requires knowledge of its causal components prior to correct treatment, as treatment and expected outcomes will differ accordingly. In people with MA, there is a disorder of the alignment of the foot, with varying degrees of adduction and supination (Fig. 1). Moreover, the outer side edge of the foot is convex, with a lateral and dorsal prominence at the base of the fifth metatarsal and cuboid bone. Although the calcaneus is in a valgus position, there is no equinus deformity, in contrast to a clubfoot. In some cases, the deformity improves or corrects itself spontaneously. However, if these outcomes do not occur and the deformity is not treated, the child will have an altered gait (ie, he or she will walk with the toes pointed toward the midline [in-toeing]) and may experience recurrent tripping, which could have a significant impact on both the child and parents. This dysfunction results in an increased number of falls due to the child’s consequent psychomotor retardation. Furthermore, in the long term, the pressure exerted by the shoe may be a predisposing factor for the development of hallux valgus.

The classification used for years at Virgen Macarena University Hospital (Seville, Spain) for this deformity is the following: (1) grade 1, where there is adduction of the forefoot without inversion and the individual is able to perform abduction passively or by means of stimulation of the peroneal musculature; (2) grade 2, where the foot is slightly short-ended, the forefoot is in addition and inversion, the external border of the foot is convex (with prominent base of the fifth metatarsal), and the internal border is concave, with normal longitudinal arc, and the deformity can be partially corrected; and (3) grade 3, which corresponds to feet with more structured deformity because we have to add kidney-shaped form to the features reported above, with transversal sulci in the medial region of the foot, increased internal longitudinal arc, and marked longitudinal shortening of the foot, and passive correction of the forefoot is not possible. Cases of grade 3 deformity require surgery, whereas grade 1 and 2 cases can be corrected traditionally.

Treatment of the foot with MA varies depending on the degree of misalignment, ranging from observation and monitoring in mild cases to the placement of serial casts, thermoplastic splints, and even surgery in the most severe cases. Many authors agree that the best therapeutic option will depend on the initial flexibility of the foot, which ranges from a waiting attitude in mild cases to surgery for the stiffest feet. There is general consensus that, in the most flexible cases (grade 1 MA, according to the Virgen Macarena University Hospital classification), a vigilant attitude should be adopted, or parents should be taught foot flexibility exercises for the child to perform regularly at home. However, to our knowledge, there is little scientific literature supporting successful treatments of more severe cases of MA. Thus, determining the most appropriate treatment remains controversial. Several studies of semirigid (grade 2) MA have shown that treatment with serial casts below the knee is the most common therapy. This treatment is followed, in frequency, by the placement of position-correcting splints and parental control of the child's sitting and sleeping postures. Although this is a rather aggressive treatment, in our opinion, simpler and more cost-effective techniques could be developed (ie, by means of corrective bandages). To our knowledge, only a few studies have recommended treatment with corrective bandaging as the primary conservative treatment option. This technique has the advantage of allowing daily manipulation and correction of the foot, as well as reducing treatment time and cost.

The main aim of this study was to ascertain the effectiveness of a corrective bandaging treatment for semirigid (grade 2) MA in newborns at Virgen Macarena University Hospital. Another aim was to establish the most recommended age interval at which to start this treatment to achieve correction of the deformity with bandaging alone, without applying splints.

Method
Design
A retrospective study was designed with children born with semirigid (grade 2) MA during the years 2010–2011 who were treated with corrective bandaging. The study was performed at Virgen Macarena University Hospital.

Participants
The inclusion criteria included having been diagnosed with grade 2 MA according to the Virgen Macarena University Hospital classification and having received no prior treatment. The exclusion criteria were patients with skeletal dysplasia, neuromuscular pathology, or other abnormalities of the foot and children whose medical records were incomplete or who had not completed treatment. The final number of patients who met the selection criteria was 94.

Tests and Measures
The variables recorded were: sex (male or female), laterality of the deformity (unilateral right or left, or bilateral), weight (in grams) and length (in centimeters) of the newborn, age (in days) at the start of the treatment, antecedents related to the pregnancy and birth (normal vaginal, cesarean section, vacuum suction, or forceps), type of treatment (bandaging, splints), and the duration of treatment. The final number of patients who received no prior treatment. The exclusion criteria were patients with skeletal dysplasia, neuromuscular pathology, or other abnormalities of the foot and children whose medical records were incomplete or who had not completed treatment. The final number of patients who met the selection criteria was 94.

Procedure
Treatment with corrective bandaging was performed by physical therapists with more than 20 years of experience in the children’s physical therapy unit at our hospital. Treatment sessions were conducted 5 days a week for approximately 15 minutes per foot and consisted of corrective manipulation to flex the
retracted structures of the foot and stimulation of the peroneal muscles with a toothbrush. Subsequently, corrective bandaging was applied, using cotton bandages and strips of adhesive dressing placed from the base of the first metatarsal to the top of the leg. Bandaging was done in a distal-to-proximal direction. After several layers of cotton bandage, strips of adhesive dressing were placed over the head of the first metatarsal and on the plantar surface of the remaining metatarsals ending on top of the leg, under the knee (Fig. 2). Thereafter, several layers of bandage were applied to maintain plaster strip tension and correction achieved during manipulation. The bandage was not so tight as to compromise circulation and was examined before the child left the physical therapy unit. If necessary, it was removed and replaced with another bandage.

The bandaging was renewed every other day until the deformity was clinically corrected. Correction criteria included complete correction of the external convexity of the foot, no protuberance of the fifth metatarsal base, and balance in the musculature of the foot. The children were followed up at 2 years after treatment initiation.

Data Analysis
The data were analyzed using IBM SPSS Statistics for Windows version 20 (IBM Corp, Armonk, New York). The analysis included a general descriptive analysis with determination of the means and standard deviations of the quantitative variables measured and absolute and relative frequencies (as percentages) of the qualitative variables. Next, the potential associations of the variables of laterality, sex, and type of birth with the effectiveness of the bandaging treatment were evaluated using the chi-square test or Fisher exact test (in the case of 2 × 2 contingency tables). Age differences at the start of the bandaging treatment between children whose deformity was corrected without splints and those who needed splints were examined using the Mann-Whitney U test. A subsequent test of potential age differences was performed by grouping the ages at the start of treatment into 4 intervals and comparing the cases that did or did not require splints using the chi-square test. Finally, the receiver operating characteristic (ROC) curve method was applied to analyze the predictive ability of age at the start of the bandaging treatment relative to whether the deformity was corrected with bandaging alone or whether splints would be required. Values of the area under the curve (AUC), sensitivity, and specificity as well as positive predictive value (PPV) and negative predictive value (NPV) were determined. In all of the analyses, significance level (α) was established at .05, with a confidence...
Descriptive Data
A total of 94 children with grade 2 MA were studied. Of these children, 54.3% (51/94) were girls, 45.7% (43/94) were boys, 80.9% (76/94) were affected bilaterally, and 19.1% (18/94) were affected unilaterally. In the unilaterally affected cases, 38.8% (7/18) were left feet and 61.1% (11/18) were right feet. Regarding the type of delivery, 69.1% (65/94) were normal vaginal delivery, 18.1% (17/94) were cesarean section, 8.5% (8/94) were vacuum suction, and 4.3% (4/94) were forceps delivery. The values of the remaining quantitative variables recorded are listed in Table 1.

Effectiveness of Corrective Bandages
Importantly, regarding the effectiveness of the treatment with bandaging, the foot deformities of 68.1% (64/94) of the children with MA, regardless of whether unilaterally or bilaterally affected, were corrected with bandaging alone. In addition, in the remaining 31.9% (30/94) of the children, it was necessary to apply a posterior splint. The bandaging treatment was more effective in girls compared with boys: 78.4% (40/51) of the girls did not need a splint versus 55.8% (24/43) of the boys ($P=0.017$). As shown in Table 1, the mean number of bandages required for clinical correction was 7.74. The nearest round number would be 8 bandages. As the bandages were changed every other day, it could be upheld that the mean time required for treatment was 16 days.

Recommended Age Interval at Which to Start Treatment With Corrective Bandages
Comparison of the time from birth to the start of treatment between children for whom the correction of the deformity was obtained with bandaging alone and those for whom it was necessary to apply splints showed that a favorable outcome was more likely to occur the earlier the treatment was initiated (Mann-Whitney $U$-test $=151.5$, $P<.001$). The mean age at which treatment was started was 23.41 days (SD=21.07) in children for whom the correction was achieved with bandaging alone (n=64) and 107.63 days (SD=64.41) in children for whom splints were necessary (n=30).

The ages at the start of the treatment were binned into 4 intervals: (1) up to 2 weeks (28 children; 2 required half-cast plaster splints), (2) between 2 weeks and 1 month (28 children; 2 needed splints), (3) between 1 and 3 months (26 children; 14 needed splints), and (4) more than 3 months (12 children; all needed splints) (Tab. 2). There was a significant difference between the children who had started treatment before 1 month of age and the remaining children, independent of the need for splints ($\chi^2=41.17$, $P<.001$).

The ROC curve was calculated to obtain a predictive value for age (in days) at the start of treatment as a predictor of whether a splint would be needed. In this study, 30 children needed splints, and 64 children did not need splints. For the children who needed a splint, the ROC curve values were selected to be positive, and the value of the AUC was computed ($\bar{X}=0.921$; standard error=0.034; 95% confidence interval $[CI]=0.855, 0.987$; $P<.001$) (Fig. 3).

The optimum value of the age at which to start the treatment was obtained for a value of AUC equal to 0.921. This optimum value corresponded to the sensitivity. In particular, the sensitivity at this optimum was 0.933 (95% CI=0.787, 0.982), and the specificity was 0.719 (95% CI=0.599, 0.814). Using these data, the optimal age for starting treatment was 4 weeks ($\approx 27.50$ days). The results with this criterion, as well as the odds ratios derived from these data, are listed in Table 3. The corresponding PPV (true positives/[true positives + false positives]) was 61% (95% CI=46.5%, 73.6%), and the NPV (true negatives/[true nega-

### Table 1.
Descriptive Statistics of the Quantitative Variables Used in the Study

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\bar{X}$</th>
<th>SD</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age from birth at start of treatment (d)</td>
<td>50.29</td>
<td>56.15</td>
<td>24</td>
<td>3</td>
<td>300</td>
<td>94</td>
</tr>
<tr>
<td>Number of bandages applied</td>
<td>7.74</td>
<td>3.11</td>
<td>8</td>
<td>1</td>
<td>14</td>
<td>94</td>
</tr>
<tr>
<td>Weight at birth (g)</td>
<td>3,373.53</td>
<td>456.80</td>
<td>3,307.50</td>
<td>2,060</td>
<td>4,500</td>
<td>94</td>
</tr>
<tr>
<td>Length at birth (cm)</td>
<td>49.61</td>
<td>1.98</td>
<td>49.50</td>
<td>43</td>
<td>54</td>
<td>94</td>
</tr>
</tbody>
</table>

### Table 2.
Distribution of Children Who Needed and Who Did Not Need Half-Cast Plaster Splints, by Intervals of Age at the Start of the Bandaging Treatment

<table>
<thead>
<tr>
<th>Age (d) at Which Treatment Was Started (N=94)</th>
<th>Was a Splint Needed?</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Up to 2 wk (n=28)</td>
<td>26</td>
<td>2</td>
<td>4.06%</td>
</tr>
<tr>
<td></td>
<td>6.7%</td>
<td>6.7%</td>
<td></td>
</tr>
<tr>
<td>Between 2 wk and 1 mo (n=28)</td>
<td>26</td>
<td>2</td>
<td>4.06%</td>
</tr>
<tr>
<td></td>
<td>6.7%</td>
<td>6.7%</td>
<td></td>
</tr>
<tr>
<td>Between 1 and 3 mo (n=26)</td>
<td>12</td>
<td>14</td>
<td>18.8%</td>
</tr>
<tr>
<td></td>
<td>46.7%</td>
<td>46.7%</td>
<td></td>
</tr>
<tr>
<td>More than 3 mo (n=12)</td>
<td>0</td>
<td>12</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>40%</td>
<td></td>
</tr>
</tbody>
</table>
Discussion
In this article, a new method of treatment based on the application of corrective bandaging is described. This technique was performed on 94 patients with MA of grade 2 severity according to the Virgen Macarena University Hospital classification. Only a few references using this approach have been found in the literature. The present study showed that the feet were completely corrected with this treatment in 68.1% of the patients and that the mean time required for treatment was 16 days, which clearly indicate the effectiveness of the treatment, both clinically and in terms of cost-effectiveness. The clinical correction was maintained during the 2 years of follow-up.

Many authors agree that the best therapeutic option will be dependent on the initial flexibility of the foot, which ranges from a waiting attitude in mild cases to surgery for the stiffest feet. There is general consensus that, in the most flexible cases (grade 1 MA, according to the Virgen Macarena University Hospital classification), a vigilant attitude should be adopted, or the parents should be taught foot flexibility exercises for the child to perform regularly at home.

Different treatment possibilities have been proposed, such as in cases where the deformity is semirigid (grade 2). In the literature, the treatment of choice is usually serial casts, as reflected in studies from the mid-20th century in which acceptable results for the correction of the MA foot deformity were found after the placement of serial casts, with treatment duration from 6 to 12 weeks.

Another commonly proposed treatment method is the application of corrective splints. This treatment has been advocated by Votta and Weber and Chong, and recently by Herzenberg and Burghardt, who performed a clinical trial using 43 feet with MA and compared the correction obtained with serial casts with that obtained using splints. The results of the latter study showed that the 2 methods provided similar corrections. Moreover, although the cost was much less with a splint, the treatment time was 6 weeks with casts compared with 12 weeks with a splint.

Table 3. Prediction of the Need for Plaster Half-Cast Splints for the Treatment of Metatarsus Adductus

<table>
<thead>
<tr>
<th>Splint Needed?</th>
<th>Age at Which Treatment Was Started</th>
<th>Total (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age ≤27 d (n)</td>
<td>Age ≥28 d (n)</td>
</tr>
<tr>
<td>No</td>
<td>46 (true negatives)</td>
<td>18 (false positives)</td>
</tr>
<tr>
<td>Yes</td>
<td>2 (false negatives)</td>
<td>28 (true positives)</td>
</tr>
<tr>
<td></td>
<td>N=48</td>
<td>N=46</td>
</tr>
<tr>
<td>Likelihood ratio</td>
<td>35.78</td>
<td>7.71, 165.99</td>
</tr>
<tr>
<td>Positive likelihood ratio</td>
<td>3.32</td>
<td>2.22, 4.97</td>
</tr>
<tr>
<td>Negative likelihood ratio</td>
<td>0.09</td>
<td>0.02, 0.36</td>
</tr>
</tbody>
</table>

*Based on lower cutoff point of 27.5 days in age at the time of starting the bandaging treatment (sensitivity=93.3%, specificity=71.9%) and odds ratios derived from those data. CI=confidence interval.

Surgical treatment in the most severe or most rigid cases has been advocated by some authors, although this approach has more secondary complications and longer recovery times. The procedure may involve adductor tenotomy of the abductor hallucis muscle, an anteromedial release of the foot, or even a percutaneous correction, as described by Knörr et al in a study on 34 feet with MA treated using this technique.

Analysis of the results in the present study showed that the feet with MA that were not completely corrected with ban-
daging and required the use of splints were those for which treatment was initiated relatively late. Of the 56 children who began treatment within the first month of life, 92.8% achieved correction of the foot deformity with bandaging alone. Of the 25 children whose treatment began between the first and third months of life, only 48% achieved correction with bandaging alone. In addition, all 13 children whose treatment began after the third month of life needed splints and corrective bandaging.

The AUC is equivalent to the probability that if we were to choose 2 children at random, one who needed a splint and the other not, the test would classify them correctly. Therefore, the AUC estimates the capacity to differentiate whether a splint is needed in the future. The diagnostic test would have more capacity for discrimination the greater the AUC. In our study, we obtained an AUC of 0.921 (95% CI = 0.855, 0.987), and because 0.500 is not included in the confidence interval, we can interpret that the test provides positive information on the diagnosis. The cutoff obtained was 27.50 or greater, and the prediction of whether a splint is required, according to the age at which the child commenced treatment with bandages, using data from this cutoff point, is shown in Table 3.

These results confirm the importance of the early diagnosis and treatment of MA. Although most published studies indeed advocate early treatment of MA and recommend starting treatment within the first year of life, they do not comprehensively analyze the potential differences that may exist within this time period. Some previous studies did not find any statistically significant relationship between the patient’s age and the treatment outcome. This finding contrasts with the present results, which showed a clear relationship between the age at the start of the treatment and the type and duration of treatment required for final correction.

One limitation of the present study is that it was only feasible to analyze the corrective bandaging method over the short term and medium term, as the patient follow-up time was 2 years. We believe that it would be appropriate for future research to analyze the corrective bandaging method in the long term, particularly at the end of the child’s growth period.

In summary, the corrective bandaging method studied in the present work achieved a complete correction in 68.1% (64/94) of patients with MA. The other 31.9% (30/94) of patients needed the application of a posterior splint. All corrections were maintained to at least the 2-year follow-up. The bandaging treatment corrected the deformity more frequently in girls than in boys (78.4% of the girls and 55.8% of the boys did not need splints). The age at the start of the bandaging treatment influenced the likelihood of success in these cases of grade 2 MA. Of the 56 children who began treatment within the first month of life, 92.8% achieved correction of the foot deformity with the corrective bandaging alone.

Mrs Utrilla-Rodríguez, Professor Albornoz-Cabello, and Mrs Guerrero-Martínez-Cañavate provided concept/idea/research design. Mrs Utrilla-Rodríguez and Dr Munuera-Martínez provided writing. Mrs Utrilla-Rodríguez provided data collection. Professor Albornoz-Cabello and Dr Munuera-Martínez provided data analysis and consultation (including review of manuscript before submission). Professor Albornoz-Cabello provided project management and institutional liaisons.

This study was approved by the Ethics Committee of Virgen Macarena University Hospital.


References
The first group (age $\leq 27$ days) has a proportion of patients ($p$) who require a splint of $\frac{24}{46+2} = 0.04167$. The second group would obtain a proportion of $\frac{28}{18+28} = 0.6087$. Therefore, by applying these data to the power calculation formula for 2 proportions, we obtain the following result:

$$z_1 - \beta = \frac{|p_1 - p_2| \sqrt{n - z^2}}{\sqrt{p_1(1 - p_1) + p_2(1 - p_2)}}$$

where $p_1 = 0.04167$, $p_2 = 0.6087$, $n = 94$

$$z_1 - \beta = 1.96,$$  because $\alpha = 0.05$

$$p = \frac{p_1 + p_2}{2} = \frac{0.04167 + 0.6087}{2} = 0.3252$$

$$z_1 - \beta = \frac{|0.04167 - 0.6087| \sqrt{94 - 1.96 \sqrt{2 \times 0.3252(1 - 0.3252)}}}{\sqrt{0.04167(1 - 0.04167) + 0.6087(1 - 0.6087)}} = 7.96$$

By obtaining a $z$ score value greater than 4, we can state that for the power of the study, $1 - \beta$ is greater than 0.8 and approximate to the unit. We consider that this is an optimal result.