Assessment of Appropriate Ankle-Foot Orthoses Models for Patients with Charcot-Marie-Tooth Disease

ABSTRACT

Objective: The purpose of this study was to demonstrate to what extent ankle-foot orthoses improve posture and gait control in patients with Charcot-Marie-Tooth disease and to identify the most appropriate characteristics of ankle-foot orthoses for patients regarding their clinical characteristics.

Design: Twenty-six Charcot-Marie-Tooth patients were recruited. Clinical data (such as levels of sensory and muscular deficits) and posture and gait capacities were collected in three randomized experimental conditions (wearing ordinary shoes or with plastic and elastic orthoses). Several subgroups of patients, constituted using predictive value analysis, were associated using the probabilities of enhancing posture and gait control while wearing the various models of orthoses.

Results: Compared with ordinary shoes alone, adding plastic ankle-foot orthoses partially improved both gait and posture control, whereas wearing elastic orthoses only partially affected the more dynamic gait control. Furthermore, the choice between the two models can be clarified by taking into account distal lower limb muscle capacity.

Conclusions: Ankle-foot orthosis prescription appears relevant for improving balance and gait performance in Charcot-Marie-Tooth patients, particularly when the model adequately compensates for specific muscle deficits. This study also provides objective arguments for making adequate bracing.

Key Words: Ankle-foot Orthoses, Charcot-Marie-Tooth Disease, Gait, Posture Control
Ankle-foot orthoses (AFOs) are commonly prescribed and used for patients with a dorsiflexion muscle deficit and for limiting foot drop. This deficit, caused by distal muscle weakness and sensory reduction, is frequently observed in clinical practice and reflects an early muscle deficiency in Charcot-Marie-Tooth (CMT) disease.1

Orthopedic shoes have been traditionally prescribed for CMT patients because of the orthopedic deformities of the feet. As reported in a case study, falling and pain disappeared and walking speed increased when made-to-measure orthopedic shoes were worn.2 However, AFOs, whether or not combined with orthopedic insoles in ordinary shoes, are an interesting alternative,3 allowing the patient to wear ordinary shoes. Whereas CMT patients are generally not well suited to AFOs,4 adapted devices may satisfy their needs and improve compliance with orthosis wear for foot drop.5

Different mechanical characteristics can be observed among the numerous models of existing AFOs (Fig. 1). For instance, the plastic AFO (P-AFO), which is the most widespread model, can inhibit plantar and dorsal flexion ankle movements. When distorted during motor tasks, a corrective bending moment is generated to make the orthosis return to the neutral position.6 P-AFOs are therefore prescribed to correct gait abnormalities such as foot drop during swing and/or insufficient push-off during stance.7 Comparatively, the more recent AFO with its elastic band (E-AFO) only assists dorsal flexion movement (Fig. 1).

To the best of our knowledge, only three studies, two of them case studies, have compared the effects of different AFO models on CMT patients. Comparing various models endowed with different mechanical characteristics—kinematic,8 spatiotemporal,9 or physiologic9—reported specific effects during gait. In addition, the limited number of patients involved in these studies precludes any agreement between the clinical and mechanical data. Because one important goal of rehabilitation is to improve the control of upright stance and gait, improved knowledge on AFO’s effects on these two common motor tasks appears relevant. Interestingly, the biomechanical constraints of these two tasks seem quite complementary; although one of the main goals of postural control is to limit center-of-gravity motion as much as possible, gait requires displacing it. As a result, the horizontal accelerations, and therefore the muscle activities these two tasks require, are incommensurable.

The purpose of this study was (1) to verify that AFOs with different mechanical characteristics improve posture and gait control in CMT patients and (2) to identify the most appropriate AFO model for patients depending on their clinical characteristics. More specifically, considering that the elastic model does not assist plantar flexion movements, it can be hypothesized that only patients with preserved muscle plantar flexion strength will benefit from this model.

**METHODS**

Subjects

Twenty-six CMT patients (15 men, 11 women) with a mean age of 50.7 ± 16.0 yrs (mean ± SD), a height of 167.2 ± 10.8 cm, and weight of 64.8 ± 12.5 kg were recruited during consultation in a physical medicine and rehabilitation outpatient unit and included after having been given informed consent. All were able to stand quietly over 1 min and walk alone barefoot without assistance. This study was approved by the local ethics committee (March 11, 2009). Patients were tested in three randomized conditions, with their own ordinary

![FIGURE 1](image)  
P-AFO and E-AFO worn with ordinary shoes. P, plastic; E, elastic; AFO, ankle-foot orthoses.
shoes (OS) with or without their usual brace (usual conditions) and with their own ordinary shoes associated with P-AFO and elastic AFO (E-AFO; Fig. 1). Fourteen subjects (eight men, six women), with a mean age of 46.4 ± 18.4 yrs, a height of 167.8 ± 12.1 cm, and weight of 63.3 ± 11.0 kg, were wearing only shoes in the OS condition.

Considering that a heterogeneous disorder is observed in plantar flexor muscles and that dorsal flexor muscles are most often impaired, strength capacities (mean scores between the two lower limbs according to the Medical Research Council [MRC] 0–5 scale) were tested for ankle dorsal (1.2 ± 1.4) and plantar (2.5 ± 1.8) flexor muscles, and knee extensor (4.8 ± 0.4) and flexor (4.8 ± 0.4) muscles, and toe flexor (1.5 ± 1.7) and extensor (1.2 ± 1.4) muscles. In addition, superficial and deep sensibilities were assessed through the perceived sensation consecutive to the smooth touch of a cotton ball over the foot soles and a loss in the joint sense at the level of the ankle joint, respectively.

**Posturography**

Upright standing was assessed using a force platform (PF02, Equi+, France). The subjects were asked to stand quietly with the eyes open in a standardized position (heels 9 cm apart, toes pointing out at 30 degrees), arms hanging freely at the sides. Three trials lasting 32 secs (64 Hz) and separated by sitting for 2 mins were recorded. The upright quiet stance was quantified by classical parameters such as center-of-pressure trajectory area (CP area, in square millimeters), CP displacements along the mediolateral and anteroposterior axes were also processed through a frequency analysis using the root mean square (CP amplitude, in millimeters) and median frequency (CP frequency, in hertz) parameters.

**Gait Analysis**

Gait was assessed using an 8.3- × 0.89-m electronic mat (GAITRite, CIR Systems, Clifton, PA). To limit variability caused by acceleration and deceleration, the subjects covered a longer distance than the mat at a self-selected velocity (two trials separated by sitting for 2 mins). Gait was assessed through velocity, step time, step length and support initial contact, that is, the percentage of time (in relation to the required time for the whole length of the foot to be on the ground) during which the rear third of the foot was on the ground (heel off-on). In addition, considering that muscle strength might contribute to gait variability, the coefficients of variation of step time and length were also computed. The GAITRite application software was used to process the data and calculate spatial and temporal gait parameters.

**Predictive Analysis**

Considering that one of the objectives was to identify patients who gained from one of the two AFO models, a predictive analysis was conducted. Although regression analysis is traditionally performed to achieve prediction, this method is poorly adapted to the issue studied herein. Interestingly, predictive value theory may provide physicians with clues (in terms of probability) for objectively choosing the best AFO model regarding the patients’ clinical characteristics. The analysis consists of separating patients depending on the presence or absence of deficit (based on sensory data or on their muscle strength, for example) in relation to a variable threshold, hence allowing for a computation of predictive values. These values correspond to the probability that the subjects have the best posture and gait control with either the P-AFO or E-AFO model, depending on whether they have a sensory deficit or when their muscle capacities are below or above the threshold. For nonbinary variables such as the strength scale, the threshold was objectively determined using the highest Youden index (ranging necessarily between −1 and 1, the latter expressing the highest level of strength), inducing the best predictive validity.

**Statistical Analysis**

Because all posture and gait parameters were demonstrated to be Gaussian (using the Kolmogorov-Smirnov tests), a parametric one-way analysis of variance with repeated measures, followed, when necessary, by Newman-Keuls comparison tests, was computed to highlight the effects of wearing various AFO models (in the 14 patients who were wearing shoes without a brace in the OS condition). In addition, a predictive analysis was performed with P-AFO and E-AFO data. Predictive values were thus calculated only when χ² tests were significant (i.e., goodness of fit of the observed distribution to the theoretical one found). Considering that predictive analysis was originally designed to apply to binary variables, paired Student t tests were then computed to compare the effects of orthotic models in each subgroup of patients. The first significance level was set for all parameters at P < 0.05.
RESULTS

Effects of Wearing AFO Models

Figure 2 shows that wearing AFOs influence posture control ($F = 3.76, P = 0.037$) because a significant decrease in CP area was observed but only with the P-AFO compared with the OS condition ($P < 0.05$). Gait was also partially improved, as demonstrated by the step length increase ($P = 4.99, P = 0.013$) when patients wore P-AFOs ($P < 0.05$) or E-AFOs ($P < 0.05$) compared with the OS condition.

Predictive Analysis

For each clinical parameter, Table 1 presents the parameter's ability to predict, through the Youden index and $\chi^2$ values, a difference in posture or gait when patients (with various clinical characteristics) wore the AFO models. It is worth noting that only the strength of ankle and toe muscle groups gave significant clues.

For significant $\chi^2$ values, Table 2 presents the best muscle capacity thresholds inducing the highest probabilities that patients had of improving their posture or gait control with one of the two orthosis models.

First, patients with an MRC score of ankle plantar flexors less than 4 had a higher probability of displaying higher velocity (73%), step length (93%), heel off-on percentage (79%), and lower coefficients of variation step length (73%) with the P-AFO than with the E-AFO model. Conversely, patients with a plantar flexor MRC score greater than or equal to 4 improved their gait with the E-AFO (Table 2). A significant difference between the models of orthoses was found only for velocity ($t = 3.096, P = 0.008$ and $t = 2.359, P = 0.04$ for patients above and below the threshold, respectively) and step length ($t = 6.322, P < 0.001$ for patients below the threshold) (Table 2). A lower threshold (<2 or ≥2) of the same muscle group differentiates patients having a lower CP frequency along the anteroposterior axis with the P-AFO (89%) than the E-AFO (69%; Table 2). However, no significant difference between the two models in each group of patients was found ($P > 0.05$).

Table 2 presents the groups of patients for whom the most appropriate device during quiet stance was determined through the ankle dorsal flexor muscle score. Patients with an MRC score of 2 or higher were characterized by a lower CP frequency along the mediolateral axis with the E-AFO compared with the P-AFO ($t = 5.706, P < 0.001$).

The strength in toe flexors also appears relevant to identify the patients who benefited from one of the two AFO models (Table 2) during posture and gait. When the MRC score was less than 2, wearing P-AFO induced increases of CP frequency along the anteroposterior (in 79% of cases) and mediolateral (in half the cases) axes, gait velocity (in 67% of cases), and step length (in 87% of cases) compared

---

**FIGURE 2** Mean (SD) for the various parameters aimed at characterizing upright stance and gait performance. Patients included in these results were not accustomed to wearing orthoses (14 patients) and were evaluated in their OS. The AFO conditions consist in wearing plastic and elastic ankle-foot orthoses. Note that step length is increased while wearing both AFO models, whereas posture control is only significantly improved with the plastic model. P: plastic; E: elastic; AFO: ankle-foot orthoses; OS: ordinary shoes; CP: center of pressure; AP: anteroposterior; ML: mediolateral; CV: coefficients of variation. *$P < 0.05$. 

622 Guillebaastre et al. 

with wearing the E-AFOs. Conversely, the other patients benefited from the E-AFO model with only one significant difference between the orthoses for the CP frequency parameter along the mediolateral axis (t = 3.387, P = 0.007).

Finally, a significant improvement in gait parameters was found in the toe extensor muscle score (Table 2); 87% of the patients with an MRC score less than 2 produced longer steps with the P-AFO (t = 3.43, P = 0.004) compared with the elastic model. The latter model was more appropriate (in 86% of cases) in improving the heel off-on percentage in patients with an MRC score of 3 or higher (t = 3.038, P = 0.023).

---

**TABLE 1**

<table>
<thead>
<tr>
<th>Muscular strength</th>
<th>CP Area, mm²</th>
<th>CP Amplitude AP, mm</th>
<th>CP Amplitude ML, mm</th>
<th>CP Frequency AP, Hz</th>
<th>CP Frequency ML, Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Youden Index</td>
<td>χ²</td>
<td>Youden Index</td>
<td>χ²</td>
<td>Youden Index</td>
</tr>
<tr>
<td>Hip</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensors</td>
<td>0.01</td>
<td>0.01</td>
<td>0.08</td>
<td>0.25</td>
<td>0.13</td>
</tr>
<tr>
<td>Flexors</td>
<td>0.15</td>
<td>1.01</td>
<td>0.08</td>
<td>0.25</td>
<td>0.08</td>
</tr>
<tr>
<td>Abductors</td>
<td>0.15</td>
<td>1.01</td>
<td>0.12</td>
<td>1.22</td>
<td>0.12</td>
</tr>
<tr>
<td>Adductors</td>
<td>0.21</td>
<td>2.12</td>
<td>0.04</td>
<td>0.04</td>
<td>0.34</td>
</tr>
<tr>
<td>Knee</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensors</td>
<td>0.22</td>
<td>1.96</td>
<td>0.14</td>
<td>0.69</td>
<td>0.12</td>
</tr>
<tr>
<td>Flexors</td>
<td>0.23</td>
<td>3.15</td>
<td>0.19</td>
<td>1.92</td>
<td>0.12</td>
</tr>
<tr>
<td>Ankle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plantar flexors</td>
<td>0.10</td>
<td>0.36</td>
<td>0.15</td>
<td>0.51</td>
<td>0.07</td>
</tr>
<tr>
<td>Dorsal flexors</td>
<td>0.07</td>
<td>0.29</td>
<td>0.28</td>
<td>1.72</td>
<td>0.04</td>
</tr>
<tr>
<td>Toes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensors</td>
<td>0.36</td>
<td>3.38</td>
<td>0.27</td>
<td>2.05</td>
<td>0.23</td>
</tr>
<tr>
<td>Flexors</td>
<td>0.13</td>
<td>0.43</td>
<td>0.27</td>
<td>2.05</td>
<td>0.28</td>
</tr>
<tr>
<td>Superficial sensory</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.18</td>
<td>0.31</td>
</tr>
<tr>
<td>Deep sensory</td>
<td>0.02</td>
<td>0.01</td>
<td>0.14</td>
<td>0.43</td>
<td>0.12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Velocity, cm/sec</th>
<th>Step Length, cm</th>
<th>Step Time, secs</th>
<th>CV Step Length, cm</th>
<th>CV Step Time, secs</th>
<th>Heel Off-On (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Youden Index</td>
<td>χ²</td>
<td>Youden Index</td>
<td>χ²</td>
<td>Youden Index</td>
<td>χ²</td>
</tr>
<tr>
<td>Hip</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensors</td>
<td>0.08</td>
<td>0.25</td>
<td>0.05</td>
<td>0.46</td>
<td>0.10</td>
</tr>
<tr>
<td>Flexors</td>
<td>0.23</td>
<td>2.23</td>
<td>0.08</td>
<td>0.25</td>
<td>0.28</td>
</tr>
<tr>
<td>Abductors</td>
<td>0.23</td>
<td>2.23</td>
<td>0.17</td>
<td>1.15</td>
<td>0.28</td>
</tr>
<tr>
<td>Adductors</td>
<td>0.31</td>
<td>2.60</td>
<td>0.37</td>
<td>3.29</td>
<td>0.01</td>
</tr>
<tr>
<td>Knee</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensors</td>
<td>0.08</td>
<td>0.38</td>
<td>0.12</td>
<td>2.34</td>
<td>0.17</td>
</tr>
<tr>
<td>Flexors</td>
<td>0.15</td>
<td>1.18</td>
<td>0.12</td>
<td>2.34</td>
<td>0.22</td>
</tr>
<tr>
<td>Ankle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plantar flexors</td>
<td><strong>0.54</strong></td>
<td>7.72*</td>
<td><strong>0.65</strong></td>
<td>9.67*</td>
<td>0.25</td>
</tr>
<tr>
<td>Dorsal flexors</td>
<td>0.23</td>
<td>1.53</td>
<td>0.36</td>
<td>2.89</td>
<td>0.29</td>
</tr>
<tr>
<td>Toes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensors</td>
<td>0.23</td>
<td>1.38</td>
<td><strong>0.47</strong></td>
<td>5.06*</td>
<td>0.18</td>
</tr>
<tr>
<td>Flexors</td>
<td><strong>0.38</strong></td>
<td>3.94*</td>
<td><strong>0.47</strong></td>
<td>5.06*</td>
<td>0.25</td>
</tr>
<tr>
<td>Superficial sensory</td>
<td>0.22</td>
<td>1.11</td>
<td>0.20</td>
<td>0.68</td>
<td>0.34</td>
</tr>
<tr>
<td>Deep sensory</td>
<td>0.04</td>
<td>0.03</td>
<td>0.09</td>
<td>0.14</td>
<td>0.01</td>
</tr>
</tbody>
</table>

*For each gait and posture parameter, a pair of data (including Youden index and χ²), which indicate the level of predictive validity and the agreement between the predictive test and reality, respectively, were computed for each clinical characteristic. Boldface, Youden indexes associated with a significant χ².

*Considering that the first significance level was set at P < 0.05, the χ² value was considered significant for values above 3.84.

CP, center of pressure; AP, anteroposterior; ML, mediolateral; CV, coefficients of variation.

www.ajpnr.com

Orthoses in Charcot-Marie-Tooth Disease 623
### TABLE 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Score 0</th>
<th>Score 0.5</th>
<th>Score 1</th>
<th>Score 1.5</th>
<th>Score 2</th>
<th>Score 2.5</th>
<th>Score 3</th>
<th>Score 3.5</th>
<th>Score 4</th>
<th>Score 4.5</th>
<th>Score 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MRC score of ankle plantar flexors</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| CP-frequency AP, Hz | 89% (P-AFO) | 0.49 ± 0.10
E-AFO: 0.51 ± 0.12 ns | 69% (E-AFO) | P-AFO: 0.47 ± 0.15
E-AFO: 0.46 ± 0.16 ns |
| Velocity, cm/sec | 73% (P-AFO) | P-AFO: 93.9 ± 17.3
E-AFO: 91.3 ± 16.1 * | 82% (E-AFO) | P-AFO: 108.4 ± 18.6
E-AFO: 112.0 ± 17.9 |
| Step length, cm | 93% (P-AFO) | P-AFO: 55.9 ± 9.1
E-AFO: 54.1 ± 8.3 | 64% (E-AFO) | P-AFO: 62.7 ± 8.6
E-AFO: 62.9 ± 8.5 ns |
| CV Step length | 73% (P-AFO) | P-AFO: 4.7 ± 1.9
E-AFO: 5.3 ± 2.0 ns | 73% (E-AFO) | P-AFO: 3.5 ± 1.6
E-AFO: 3.4 ± 1.7 ns |
| Heel Off-On, % | 79% (P-AFO) | P-AFO: 5.22 ± 2.89
E-AFO: 4.78 ± 2.49 ns | 75% (E-AFO) | P-AFO: 5.50 ± 3.71
E-AFO: 6.18 ± 2.43 ns |

| **MRC score of ankle dorsal flexors** |
| CP-frequency AP, Hz | 71% (P-AFO) | 0.48 ± 0.12
E-AFO: 0.50 ± 0.11 ns | 71% (E-AFO) | P-AFO: 0.48 ± 0.16
E-AFO: 0.44 ± 0.19 ns |
| CP-frequency ML, Hz | 50% (P-AFO) | P-AFO: 0.43 ± 0.10
E-AFO: 0.44 ± 0.11 ns | 100% (E-AFO) | P-AFO: 0.50 ± 0.09
E-AFO: 0.43 ± 0.09 |

| **MRC score of toe flexors** |
| CP-frequency AP, Hz | 79% (P-AFO) | 0.48 ± 0.13
E-AFO: 0.50 ± 0.11 | 82% (E-AFO) | P-AFO: 0.48 ± 0.16
E-AFO: 0.44 ± 0.18 ns |
| CP-frequency ML, Hz | 59% (P-AFO) | P-AFO: 0.43 ± 0.10
E-AFO: 0.44 ± 0.11 ns | 91% (E-AFO) | P-AFO: 0.49 ± 0.09
E-AFO: 0.44 ± 0.08 | * |
| Velocity, cm/sec | 67% (P-AFO) | P-AFO: 94.8 ± 19.2
E-AFO: 92.7 ± 19.2 * | 73% (E-AFO) | P-AFO: 107.1 ± 17.0
E-AFO: 110.1 ± 15.9 ns |
| Step length, cm | 87% (P-AFO) | P-AFO: 55.7 ± 8.8
E-AFO: 54.1 ± 8.3 * | 54% (E-AFO) | P-AFO: 63.1 ± 8.7
E-AFO: 62.9 ± 8.5 ns |
| Heel Off-On, % | 82% (P-AFO) | P-AFO: 5.61 ± 2.62
E-AFO: 5.09 ± 2.33 ns | 67% (E-AFO) | P-AFO: 4.73 ± 3.58
E-AFO: 5.56 ± 3.93 |

| **MRC score of toe extensors** |
| CP-frequency AP, Hz | 67% (P-AFO) | 0.51 ± 0.14
E-AFO: 0.52 ± 0.14 ns | 86% (E-AFO) | P-AFO: 0.38 ± 0.07
E-AFO: 0.35 ± 0.09 ns |
| Step length, cm | 87% (P-AFO) | P-AFO: 54.6 ± 8.5
E-AFO: 53.3 ± 8.4 * | 54% (E-AFO) | P-AFO: 64.5 ± 7.5
E-AFO: 63.9 ± 7.8 ns |
| Heel Off-On, % | 68% (P-AFO) | P-AFO: 4.87 ± 2.75
E-AFO: 4.73 ± 2.25 ns | 86% (E-AFO) | P-AFO: 5.73 ± 4.35
E-AFO: 7.08 ± 5.03 |

For each parameter identified as having a significant predictive validity (see Table 1), two subgroups of patients were constituted according to the MRC strength score obtained in (a) ankle plantar flexors, (b) ankle dorsal flexors (no patients had a score of ≥4), (c) toe flexors, and (d) toe extensors (no patients had a score of ≥4). The percentages correspond to the proportion of patients, above or below the threshold, for whom the posture or gait parameters were improved with the orthosis model indicated in parentheses. Note that despite the high proportion of patients improving posture or gait parameters, significant differences between plastic and elastic orthoses were not consistently found. *P < 0.05.

CP, center of pressure; AP, anteroposterior; ML, mediolateral; CV, coefficients of variation; MRC, Medical Research Council.
DISCUSSION

This study aimed to verify that various models of AFOs contribute to improving, in different proportions, posture and gait control in patients with CMT disease and to provide insights to help prescription givers choose the optimal orthosis model more objectively.

Even though poor compliance between CMT disease and AFOs is generally reported, the results of this study demonstrate that wearing a plastic or elastic AFO in association with ordinary footwear improves, at least partially, upright stance and gait, both tasks being significantly impaired compared with healthy subjects (B. Guillebastré, MS, et al., unpublished data). However, as a whole, the effects of AFO wear are not as numerous as expected and could be related to the various needs of CMT patients, stemming from a heterogeneous deficit. These needs might be met with the varying mechanical characteristics of different orthosis models.

Although numerous AFO models exist, their functional consequences are still poorly known. The orthoses used in this study differ substantially depending on their mechanical features. Dorsiflexion movements are only restrained by plastic model, even though both models limit plantar flexion movements. Therefore, our study was aimed to identify, through clinical scores such as muscular strength and sensory deficit, the orthosis model incurring the greatest improvements in standardized tasks such as upright standing and gait.

As reported by the present results, the relevance of using sensory or proximal muscular strength data has not been proven to identify the patients who benefit the most with one or the other of the two orthosis models. The fact that a rough sensory assessment is made and that these muscle groups are not really impaired may partially contribute to the lack of significant results. In contrast, the predictive analysis results underline that wearing E-AFOs is more effective for patients with a substantial muscle deficit, whereas P-AFOs are more appropriate for patients with relatively well-preserved muscle strength in the distal part of the lower limbs. Moreover, it is worth noting that the optimal thresholds for ankle muscle strength, distinguishing patients on their motor improvement with one of the two AFO models, vary depending on the motor task. Indeed, the thresholds are higher when greater strength is required, such as in gait compared with upright stance.

When wearing the plastic AFO model, CMT patients unable to perform an ankle plantar flexion movement against resistance (MRC score, <4) had the best gait performance, as pointed out by the increase in comfortable velocity and step length. As previously described, this feature is mainly explained by the corrective force of the P-AFO, which assists weak plantar flexor muscles in the middle and last parts of the stance phase, that is, when maximal dorsal flexion occurs. When patients are able to perform a plantar flexion movement against resistance (MRC score, ≥4), the use of E-AFO is therefore more appropriate for improving gait velocity; assisting this muscle group, therefore, appears ineffective in this type of patient. The same reasoning applies for the toe muscle values, even though the threshold is lower.

The initial contact of the foot with the ground (particularly crucial with a foot drop deficiency) is mainly controlled by dorsal flexor muscle activity but also depends on the length of the step. Indeed, the shorter the step, the shorter the braking action of the downward foot. Quite surprisingly, the criterion reflecting the most appropriate AFO to be recommended (with a significant difference between the models) is toe muscle strength. Our results point out that patients able to generate a complete toe extension (MRC score, ≥3) perform the best heel rolling on the ground with E-AFO.

Postural control improvement with one of the two orthosis models might be explained by considering flexion and extension muscle capacity, even though the latter is not usually solicited. Considering that balance control along the anteroposterior axis is problematic for CMT patients, our predictive analysis highlights that patients unable to perform a flexion movement with their toes (MRC score, <2) are likely displaying lower frequency CP movements (i.e., horizontal center-of-gravity movements) when wearing P-AFOs.

The predictive analysis has divided patients into subgroups using a proven methodology, attributing the most appropriate orthosis model to each subgroup. Considering that this prediction analysis is generally used with binary predicted parameters (healthy or ill, for instance), whereas our posture and gait parameters are linear, a subsequent statistical analysis had to be performed to ensure the validity of the predictions. This consideration proved useful in light of these results. Indeed, the fact that most of the patients had better results with one of the AFOs does not preclude that a significant difference can be found with the other model, even though poor predictive values were found (54%).

Although these findings might be of interest for rehabilitation, several points in our protocol could be improved. First, the sensory assessment should be
improved using a clinical scale24 (Semmes-Weinstein monofilaments or electrophysiologic testing, for example). Noting only the presence or absence of a deficit prevents gaining additional predictive information. Second, the deformity of the feet, which can induce pain and thereafter posture modification and/or foot rolling, can constitute an influential parameter for motor performance and should be quantified. Even if passive and active ranges of motion in the hindfoot, midfoot, and forefoot in the subjects are difficult to assess, the knowledge of these data would be interesting to make sure that motor tasks remain unaffected. Third, even though our sample size can be regarded as respectable when compared with previous studies involving CMT patients, a more accurate prediction could be made with a larger sample.

After highlighting that various models of AFOs are relevant to improve at least gait performance, our analysis focused on comparing two orthosis conceptions. Optimizing the choice between plastic and elastic models appears to require testing distal muscle capacity. The fact that the main difference between the devices concerns the presence or absence of resistance to ankle dorsal flexion movement accounts for the type of the decision-making parameter. Consequently, knowing flexor muscle strength appears relevant when choosing the appropriate model to maximally increase posture and gait gain. However, taking into account antagonist muscle strength appears useful. It seems important to keep in mind that predictive analysis results do not signify that clinical parameters are involved in controlling posture or gait parameters but can merely reflect an overall condition in these patients, which corresponds better to one or the other of the two orthosis models. Although the clinical situation, the patient's opinion, and/or the deformity of the feet could lead physicians to give priority to orthopedic shoes, our data could be used as an objective decision-making aid for prescription givers in choosing the most appropriate AFO model.

ACKNOWLEDGMENTS

We thank the Ormihl-Danet company for the ex gratia lending of their ankle-foot orthosis models, and we thank Linda Northrup for proofreading the English and Professor Dominic Pérennou for improving our awareness of predictive analysis.

REFERENCES


