The Effect of Ankle Foot Orthosis on Energy Expenditure during Walking in Children with Spastic Diplegia due to Cerebral Palsy

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ABSTRACT

Objective: The aim of the study was to find the effect of ankle foot orthosis (AFO) on energy expenditure (EE) during walking in children with spastic diplegia (SD) due to cerebral palsy (CP).

Materials and methods: Twenty-six subjects with SD CP who could ambulate with and without the help of orthoses were selected after screening with inclusion criteria. The EE of these patients during ambulation with and without orthoses was measured using the K4b2 machine. Statistical analysis was performed with the help of Epi Info 3.5.3. t-test, chi-square test, and correlation tests were used to study the parameters of oxygen cost, oxygen pulse, heart rate, and EE.

Results: The use of AFO resulted in decreased EE in 73% of patients in the first day itself. In the sequential assessment, these patients showed further decrease in EE with AFO use. The patients who initially showed an increase of EE also showed a decrease in the rise in EE during walking in their subsequent analysis. Oxygen cost also showed a positive correlation with EE. Heart rate was not much related to use of AFO; rather, it showed an increase in the assessment done second in the same day (among walking with and without the AFO). There was no linear relation or correlation between O2 pulse and other parameters of the study.

Conclusion: The AFOs are an important intervention in the treatment of SDs. It can help decrease the EE and improve the speed of walking in most patients when prescribed along with other needful therapies like exercises, antispastic medications, etc. O2 cost showed positive correlation with EE analysis. In patients with increased EE with AFO use, the mean difference between EE with and without AFO decreases, suggesting long-term benefits that AFO could offer. A study of longer duration with more patients should be conducted to view the full benefits of AFO in children with SD CP.

Keywords: Ankle foot orthosis, Ankle foot orthosis in cerebral palsy, Cerebral palsy, Effects of ankle foot orthosis, Energy expenditure, Energy expenditure during walking, Gross Motor Function Classification System, Heart rate, K4b2, Oxygen cost, Oxygen pulse, Spastic diplegia.

INTRODUCTION

Cerebral palsy describes a group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to nonprogressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of CP are often accompanied by disturbances of sensation, perception, cognition, communication and behavior, by epilepsy, and by secondary musculoskeletal problems.

Cerebral palsy is the most prevalent physical disability originating in childhood. The most frequently reported incidence is 1 to 2.3 per 1000 live births. Perinatal hypoxia was previously considered the major cause, whereas current knowledge suggests that prenatal causes are most important.

Previous studies have reported the relative proportions of Gross Motor Function Classification System (GMFCS) levels (GMFCS I: 27.9–40.7%, GMFCS II: 12.2–18.6%, GMFCS III: 13.8–18.6%, GMFCS IV: 11.4–20.9%, and GMFCS V: 15.6–20.5%); motor types (spastic: 78.2–86.4%, dyskinetic: 1.5–6.1%, mixed: 6.5–9.1%, ataxia: 2.5–2.8%, hypotonia: 2.8–4.1%); and motor topography (hemiplegia: 15.3–40.0%, diplegia: 28.0–46.4%, and quadriplegia: 13.6–50.8%) within various CP cohorts.

Gait abnormalities in CP are often treated with physical therapy, neuroinhibitory drugs, orthosis, occupational therapy, neurosurgery, orthopedic surgery, etc. Orthotic management is a widely utilized method of treatment due to its conservative nature. The primary brain lesion in CP and the secondary alterations in the locomotor apparatus can cause an energy-inefficient gait, which can often be improved with an orthosis. These may improve function by helping to prevent deformity, support normal alignment and mechanics, and allow a more normal range of motion.
The efficacy of AFO can be studied with weightage on the EE during walking. For this purpose, various studies have been conducted, but with conflicting results. So, a study on the effect of AFO should be conducted with a quality-tested, internationally approved, and standardized unit, like Cosmed K4b² analyzer. This portable unit utilizes a breath-to-breath measurement of gas exchange, and analyzes a wide range of data during the testing. The test–retest reliability of K4b² has been demonstrated by testing studies.²²

AIMS AND OBJECTIVES
• Quantitative measurement of effectiveness of AFO on EE during walking in SD due to CP (SD CP).
• To determine the role of AFO as a conservative management option in CP.
• To find a relation between the variables of O₂ cost, O₂ pulse, EE, and heart rate in children undergoing treatment with AFO in SD due to CP.
• To determine whether the EE study can be used to predict the effectiveness of AFO use in SD CP.

MATERIALS AND METHODS
Study design: Prospective study.
Study population and study area: Patients diagnosed to have SD due to CP, who are able to walk independently without assistive devices, attending outpatient department (OPD) and indoor of National Institute for Locomotor Disabilities (NILD) during the specified period.
Sample size: Thirty subjects were included in the study (16 males); 2 of the subjects among these 30 dropped out; 2 patients’ data were excluded after start of study: One, as he underwent surgery after therapy started, and the other had heart rate above 150 beats per minute, which is outside the permissible range for interpretable data of the K4b² analyzer.

Inclusion Criteria
• Children with SD CP
• Age group: 4 to 16 years
• Subject able to walk independently without assistive devices
• Children able to obey commands

Exclusion Criteria
• Fixed or deformed equines foot
• Patient with knee contractures
• Subjects who are taken for surgery or Botulinum injections before 1 month or after the study has started.

Equipment
Cosmed K4b² spirometer (Manufacturer: Cosmed, S.R.L., Via dei Piani di Monte Savello 37, Pavona di Albano, I-00041 Italy) (Fig. 1).

Data Collection
• Oxygen cost (amount of oxygen consumed per kilogram of body weight per unit distance, mL/kg m)¹³
• Oxygen pulse (the rate of O₂ consumption divided by heart rate)¹³
• Heart rate (beats per minute, bpm)¹³
• EE per minute¹³ (rate of energy required for a given activity per minute, kcal/minute). All data were collected with the help of K4b² machine, which were obtained as direct output from the machine after analysis.

Study Technique
The patients who fulfilled the inclusion criteria were approached with the proposal of the study. The aim of the study and the procedure were explained and a written informed consent was taken from the guardian of the subjects who agreed to participate. Thorough history and physical examination were done. Before starting on AFO (Fig. 2), an evaluation of EE during walking was done with the K4b² machine (Fig. 3). The oxygen cost, oxygen pulse, heart rate and EE per minute were taken. These data were recorded as the first visit data, i.e., on the day of starting the AFO use (Fig. 4). The patients were advised to use the orthosis regularly.

Fig. 1: Pretesting calibration of K4b2 machine, using pure Oxygen
during ambulation, at least 4 hours a day, 7 days a week. Regular follow-up was done every 30 days to ensure the adequate use of orthosis, on OPD basis. The patients were reevaluated at the end of 4 months. This was recorded as the second visit data. Energy expenditure was calculated using the K4b² machine, while walking with and without AFO at the end of first 4 months of starting therapy along with orthosis. The parameters of K4b² analysis, with and without AFO, were compared to get the effect of AFO on EE during walking. While wearing Cosmed K4b², the child was instructed to (1) Sit quietly for 1 minute, (2) walk at their usual pace: Self-selected, comfortable walking speed with or without the AFO for 30 m, with a time interval of 15 minutes in between the recordings. Study parameters were recorded using the K4b² machine. Although the aim of the study is to measure the effect of AFO on EE during walking, we have also tried to assess whether any statistically significant relationship exists between the data of O₂ cost and O₂ pulse, and heart rate.

Data Analysis

Data obtained were summarized using descriptive statistics and represented graphically. Statistical analysis was performed with the help of Epi Info™ 3.5.3.

RESULTS

Totally 26 (54% males) children were assessed and data were collected. The mean age of patients were 10.53 years. They were classified into two groups. Fifteen patients belonged to the age group of 9 to 10 years, and 11 patients between 11 and 14 years.

Comparison of Parameters at the First Visit

Comparison of EE: The mean EE with AFO was lower than the mean EE without AFO ($t_{50} = 0.83; p = 0.41$).

Comparison of O₂ cost: The mean O₂ cost with AFO was lower than the mean O₂ cost without AFO ($t_{50} = 0.48; p = 0.63$).

Comparison of O₂ pulse: The mean O₂ pulse with AFO was higher than the mean O₂ pulse without AFO ($t_{50} = 0.38; p = 0.70$).

Comparison of heart rate: The mean heart rate with AFO was higher than the mean heart rate without AFO ($t_{50} = 0.73; p = 0.46$).

Comparison of Parameters at the Second Visit

Comparison of EE: Mean EE with AFO was lower than the mean EE without AFO ($t_{50} = 1.03; p = 0.31$).
Comparison of O$_2$ cost: The mean O$_2$ cost with AFO was lower than the mean O$_2$ cost without AFO ($t_{50} = 0.70; p = 0.48$).

Comparison of O$_2$ pulse: The mean O$_2$ pulse with AFO was higher than the mean O$_2$ pulse without AFO ($t_{50} = 1.01; p = 0.31$).

Comparison of heart rate: The mean heart rate with AFO was higher than the mean heart rate without AFO ($t_{50} = 0.46; p = 0.64$).

**Comparison between the Two Visits**

Comparison of EE without AFO: The mean EE at the second visit was lower than the mean EE at the first visit ($t_{50} = 0.83; p = 0.41$).

Comparison of O$_2$ cost without AFO: The mean O$_2$ cost at the second visit was lower than the mean O$_2$ cost at first visit ($t_{50} = 0.83; p = 0.41$).

Comparison of O$_2$ pulse without AFO: The mean O$_2$ pulse at the second visit was lower than the mean O$_2$ pulse at the first visit ($t_{50} = 0.83; p = 0.41$).

Comparison of heart rate without AFO: The t-test showed that the mean heart rate at the second visit was significantly higher than that of the first visit ($t_{50} = 2.89; p = 0.0057$).

Correlation between EE and O$_2$ cost: In the first and second visits, with AFO and without AFOs showed good positive correlation (All $r$ and $p$-values respectively, first visit, without AFO: 0.41, 0.0375; with AFO: 0.44, 0.0245; second visit: Without AFO: 0.47, 0.0154; with AFO: 0.58, 0.0019).

**DISCUSSION**

**Age**

In the study group, we found that 57% of children belonged to the age group of 9 to 10 years, and 43% belonged to the age group of 11 to 14 years. A possible explanation could be that with increasing age, less number of patients turn up for institutional therapy and most opt for home-based exercise programs.

**Gender**

In the study group, 54% were males. Sex ratio was 1.16:1.

The association between the gender and age of study population was not found to be statistically significant.

**Energy Expenditure**

During the first visit, the EE during walking with AFO compared with walking without AFO was found to be less in most patients (73%), $p > 0.05$. Still, 19 of 26 subjects (73%) showed a decrease in EE with use of AFO in their first visit. This signifies the importance of AFO as an important intervention in providing more energy-efficient walking in SD children.

In the second visit, 20 of the 26 subjects showed a decrease in EE while using the AFO, while 6 of them showed an increase in EE. The mean values of the decrease and increase in EE were 10 and 6% respectively. This also signifies that the use of AFO improves the energy efficiency in these patients while walking. These findings are corroborated with the findings of the study conducted by Mossberg et al$^{14}$ which indicated that the EE of ambulation at self-selected speeds in SD children was reduced by the application of conventional AFOs. The results of our studies are in keeping with observations made from the study done by Bennett et al,$^{15}$ which states that AFOs can reduce the work needed to walk for some children with CP; they do not do so for others.

When comparing walking with and without AFO in the first and second visits, the EE during both activities was decreased in the second visit. All the patients between their first and second visits were using AFOs, doing home-based exercise programs and therapies and hence, this improvement in EE could be a combined effect of these factors. This implies that the continued use of AFO along with therapy resulted in improved energy efficiency in these patients.

**O$_2$ Cost**

In the first visit, O$_2$ cost was decreased in 19 out of 26 patients while using the AFO. In the rest of 7 patients, the O$_2$ cost was increased while using AFO.

In the second visit, there was a decreased O$_2$ cost with AFO in 19 children and increased O$_2$ cost with 7 children. Comparing the O$_2$ cost without AFO in both visits, mean O$_2$ cost at the second visit was lower than mean O$_2$ cost at the first visit.

These findings corroborate the observations made by Maltais et al$^{16}$ in their study of O$_2$ cost during walking in children with spastic CP with AFO. Although the difference is not statistically significant, this correlates with the findings obtained in energy efficiency while walking with and without AFO.

**O$_2$ Pulse**

We were unable to find out a linear relation or correlation between the O$_2$ pulse and other parameters in this study.

**Heart Rate**

In the first visit, the mean heart rate while walking with AFO was higher than the mean heart rate without AFO (15 of 26). There was no statistical significance in the difference in heart rate seen with and without AFO. The mean increase in heart rate was 4 bpm in patients while using AFO.
During the second visit also, the heart rate was increased while walking with AFO. The patients who showed an increased heart rate with AFO also gave the 30-minute walk test with AFO in a lower time than without AFO, i.e., they ambulated faster with AFO. This could have resulted in an increased heart rate in them. Although there was an increase in heart rate, these patients did not show increase in EE, which implies that increase in the heart rate in these patients does not essentially lead to an increase in EE.

Most of the patients showed increased heart rate during the second assessment of the day. This was independent of walking with or without AFO. It was also independent of whether it was the first or second visit of the patient. A rest period of 15 minutes was given in between the assessments also. Even then, this trend continued to prevail.

**Comparing the Heart Rates without AFO**

The mean heart rate at the second visit was significantly higher than that of first. All children in their second visits took less time to complete the 30-minute walk test with and without the AFO, which implies that they had increased velocity of walking and hence, could have caused an increase in heart rate in the second visit. Similar findings were obtained in the study done by Bennett et al.\(^\text{15}\) in their study, where they concluded that AFO use was associated with significant increases in stride length and gait speed, but the effect on work varied within the group.

**Correlation between EE and Oxygen Cost**

The correlation between EE and oxygen cost was seen independent of AFO use, and was positive \((r > 0.4)\). This showed that whenever the EE increased, the \(O_2\) cost also showed a similar trend and vice versa \((p < 0.05)\) (Table 1)

The patients were categorized according to the decrease or increase in EE, with and without AFO. The data on graphical representation showed similar trend in both the first and the second visits (Graph 1).

In the group with increased EE with AFO use, the increase in EE showed a decline in its mean value in its second visit \((p\text{-value} 0.14)\) (Graph 2), which was a definite improvement. As explained earlier, this could be either due to AFO or other therapies in the same time, which can only be confirmed with further studies.

**CONCLUSION**

Detailed search of available literature did not reveal any similar published study in an Indian setting. To the best of our knowledge, this is the first such study. However, this is a single-center study. Spatial and gait parameters, which may have some effect on outcome, were not included in this study. Nevertheless, it can be used as a starting point.

Ankle foot orthosis is an important tool for improving the energy efficiency in walking in children with SD CP. This is evident from the results of our study which show that 73% of patients had improved energy efficiency of walking while using the AFOs. Even in some of the patients who initially showed decreased energy efficiency, there was noticeable improvement in their subsequent visit.

We also found that the parameters of \(K4b^2\), \(EE\), and \(O_2\) cost show good positive correlation. \(O_2\) pulse, however,

| Table 1: Correlation between Energy expenditure (Kcal/minute) and \(O_2\) Cost (ml/kg.m) |
|-----------------------------------------------|-----------------|------------------|
| Correlation between Energy expenditure (kcal/minute) and \(O_2\) Cost (ml/kg.m) | Pearson Correlation Coefficient \((r)\) | \(p\)-value |
| 1st Visit Without AFO | 0.41 | 0.0375* |
| 1st Visit With AFO | 0.44 | 0.0245* |
| 2nd Visit Without AFO | 0.47 | 0.0154* |
| 2nd Visit With AFO | 0.58 | 0.0019* |

*Means \(p\) value significant
did not show any reliable relationship with other parameters of the study. Even if the indication of AFO in SDs is not just improving their energy efficiency, this analysis can show the role of AFO in EE in these ambulatory patients. Each patient should be evaluated individually further to know how energy-efficient these AFOs are. Even in some of the patients who initially showed decreased energy efficiency, there was noticeable improvement in their subsequent visit.

LIMITATIONS

• Lack of published studies in English language medical literature on the use of K4b² machine for EE analysis.
• Majority of published studies are multicenter studies—often involving more than a country.
• Respiratory, gait, and spatial parameters were not included in this study which may have some effect on the outcome.
• Lack of uniformity in walking speed and gait pattern in children with SD CP, which can result in variability of data.
• Stringent atmospheric conditions are required for optimum results.

RECOMMENDATIONS OF THE STUDY

It is recommended to conduct longitudinal studies on a more number of patients for a longer duration in order to describe the exact statistics for a clearer picture for the effectiveness of AFO during walking on EE in SD children.

REFERENCES