Effect of walking aids and foot orthoses on energy expenditure in children with cerebral palsy: a systematic review

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Introduction
Cerebral palsy (CP) is a familiar cause of postural and movement disorders among children, which are caused by damage of immature brain. Children with CP have pathological changes of musculoskeletal system. Disorders of balance, muscle tone, and strength are considered primary impairments that are related to central nervous system damage. However, joint deformities and muscle contractures occur in response to musculoskeletal growth and primary impairments and are termed as secondary impairments. All of these impairments allow children with CP to walk with inefficient pattern [1].

Ankle–foot orthoses (AFOs) have been recommended to enhance the dynamic gait efficiency of children with CP [2]. Many authors reported the effectiveness of different types of AFOs on gait kinematics and kinetics [2,3], as well as functional performance, in children with CP [4].

Energy expenditure is the amount of oxygen consumed during physical exertion. The change in energy expenditure during activity reflects the metabolic cost of muscles, from moving the body against gravity and from accelerating and decelerating different body parts [5]. The appropriate use of walking aids improves efficiency, stability, and posture. Walking aids include canes, crutches, and walkers [6].

There is a strong relation between the degree of motor disorders and energy cost of walking [7]. Children with CP often begin their walking later than normal children [8] and walk with a higher energy cost and slower speed [9].

Independent mobility is important for participation, activity, and self-sufficiency, all of which decrease dependence on caregivers. Efficiency and safety are considered essential factors for selecting methods of mobility suited to different environmental conditions [10].

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It is essential to measure energy consumption because of its role in the evaluation of functional ability as the quantification of energy expenditure; at the same time, walking provides objective data to assist in the evaluation of children with walking disabilities as well as effectiveness of therapeutic modalities, such as walking aids, orthoses, rehabilitation programmes, and surgical treatments [11].

A previous study performed on AFO and on different types of walkers concluded that high-quality studies are still required to support evidence-based decisions concerning the use of AFOs [12]; low quality of existing evidence and the heterogeneity prevent the recommendation of one walker type over the other, and well-designed studies are needed to provide clinical recommendations [13].

Therefore, there was a need for further research to provide adequate evidence to inform clinical recommendations, with adequately powered studies and careful design to minimize bias.

The purpose of this review was to assess the quality of present research on the effect of walking aids and AFOs on energy expenditure in children with CP.

**Materials and methods**

**Literature search**

The authors underwent a training programme for online search to be able to perform the searching process in different databases. The following databases were searched to identify relevant published studies: the Cochrane Library, Scopus, PubMed, and the Web of Science. Those databases were searched by using the following keywords: energy expenditure, gait, walking aids, walkers, foot orthosis, CP, diplegia, and hemiplegia. Several search strategies were developed to accommodate the databases.

**Study selection and eligibility criteria**

Studies were included if they met the following criteria:

**Participants**

Children with different types of CP of both sex aged up to 18 years old were included. Methodology: studies that investigated the immediate or long-term effect of lower limb orthoses or any type of assisted walking aid on energy expenditure were involved. Study design: all research designs except case reports were accepted.

**Language**

Full-text papers in English were included.

**Data extraction**

Two authors (Abd El-Hakiem Abd El-Nabie and Abd El-Aziz) extracted the following items from the included articles: (a) the author and year of publication; (b) information on the population, describing numbers of included children by diagnosis, age, and sex; (c) study design; (d) methodology, including the type of intervention or assessment, technique of its application, and its duration; (e) measured outcomes as explained by their authors; and (f) results. The extracted data are grouped into two tables: Table 1 related to articles that evaluated the effect of orthosis on energy expenditure [14–23], whereas articles investigating the effect of assisted walking aids, for example, a Walk Aide foot drop stimulator, walkers, sticks, a robotic-assisted gait trainer, and a flexible derotator, on energy expenditure [24–31], were presented in Table 2.

**Assessment of methodological quality**

Methodological quality in the current systematic review was evaluated by the PEDro scale. This ten-item instrument is a valid measurement of methodological quality of clinical trials. The items are scored as present (1) or absent (0) [32]. Two reviewers (Abd El-Hakiem Abd El-Nabie and Abd El-Aziz) independently assessed the methodological quality of included studies, and discrepancies between them were resolved by consultation with the third author (Elshennawy) to reach the final decision. After each item was classified as ‘present’ or ‘absent’, the total score of each study was calculated as the sum of ‘present’ responses (Table 3). As reported by Foley et al. [33], the methodological quality was considered to be ‘excellent’ when studies scored from 9 to 10 on the PEDro scale, whereas studies scoring from 6 to 8 were considered ‘good’ quality, studies with 4 and 5 scores were graded as ‘fair’ quality, and studies with a score below 4 were classified as ‘poor’ quality.

**Level of evidence**

The level of evidence of all included studies was scored according to the modified Sackett scale (Tables 3 and 4). This five-level scale is used to determine the strength of evidence regarding the intervention (Table 4) [34].

**Results**

**Literature search**

The search strategy revealed 981 articles from previously mentioned databases, as follows: Cochrane Library (304), Scopus (70), PubMed
| References      | Design            | Participants                                                                 | Methodology                                                                 | Outcome measures | Results                                                                                                                                                                                                 |
|-----------------|-------------------|------------------------------------------------------------------------------|------------------------------------------------------------------------------|------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Bhise et al.    | Cross-sectional   | N: 41 normal children and 41 children with spastic diplegic cerebral palsy  | Exp.=diplegic children, some of them using conventional AFOs and some without conventional AFOs; PCI was measured for both at their chosen velocities over four consecutive lengths of a 12.5 m walkway | PCI              | For normal children, PCI was the same in shoes and barefoot                                                                                                                                              |
|                 |                   | Age (years): 6–18                                                            | Cont.=normal children; PCI was measured barefoot and in shoes                  | BMI              | For diplegic children, PCI was lower with AFOs than without AFO.                                                                                                                                        |
|                 |                   | Sex: not identified                                                          | PCI was calculated from walking speed and heart rate for each child            |                  | PCI for spastic diplegic children with and without AFOs is higher than PCI for normal children ($P<0.05$)                                                                                           |
| Kerkum et al.   | Pre-post          | N: 15 children with spastic cerebral palsy                                   | Exp.=Each child wore a hinged VAFO with adjustable stiffness (rigid, stiff, and hinged) for 3 months, and the intended outcome were assessed before and after the treatment period while walking with the optimized VAFO and walking with shoes only to individually select the optimal stiffness | Walking energy cost | A significant 9% decrease in net EC ($P=0.077$) was found for walking with the optimized VAFO compared to shoes only                                                                                      |
|                 | experimental study|                                                                              |                                                                              |                  |                                                                                                                                                                                                       |
|                 |                   | Age (years): 6–14                                                            | Cont.=no control group                                                        | Daily walking activity | Daily activity remained unchanged                                                                                                           |
|                 |                   | Sex: 11 male and 4 female                                                     | Kiue angle and ankle power (gait biomechanics were assessed by 3D-gait analysis) | Knee flexion instance was reduced by 2.48 ($P=0.006$) |                                                                                                                                                                                                       |
| Kerkum et al.   | Pre-post          | N: 15 children with spastic cerebral palsy                                   | Exp.=Each child wore each configuration of VAFO stiffness for 4 weeks. Outcomes were assessed at baseline (with shoes only), then assessed after each configuration of VAFO was work | Kinetic and kinematic parameters of lower limb | Speed was significantly lower while walking with VAFOs ($P=0.016$)                                                                             |
|                 | experimental study|                                                                              |                                                                              |                  |                                                                                                                                                                                                       |
|                 |                   | Age (years): 6–14                                                            | Cont.=no control group                                                        | Walking energy cost | All VAFOs decreased the knee flexion angle at contralateral toe-off, midstance, and timing of KEpk ($P=0.025$)                                                                                       |
|                 |                   | Sex: 11 male and 4 female                                                     |                                                                              |                  | Ankle power generation and work were preserved only by the spring-like VAFOs                                                                                                                          |
|                 |                   |                                                                              |                                                                              |                  | All VAFOs decreased the net energy cost compared with shoes-only, but no differences were found between VAFOs                                                                                          |
| Uckun et al.    | Cross-sectional   | N: 48 children with cerebral palsy                                           | Exp.=Children lower extremity orthoses and were grouped according to type of orthosis they used. The energy expenditure was assessed during the wearing of the following orthoses: solid PAFO, articulated PAFO, GRAFO, plastic and metallic KAFO and metallic AFO | Energy expenditure | It was found that plastic orthoses ensured energy efficiency during walking, and this effect was most significant in patients using solid PAFOs ($P=0.008$)                                           |
|                 |                   | Age (years): 9–13                                                            | Cont.=no control group                                                        |                  |                                                                                                                                                                                                       |
|                 |                   | Sex: 27 male and 21 female                                                   |                                                                              |                  |                                                                                                                                                                                                       |
| Brehm et al.    | Retrospective     | N: 172 children with cerebral palsy (hemipleg, diplegia and quadriplegia)   | Exp.=children were using a SAFOs or PLS orthoses, and the intended outcomes were measured at 2 sessions with 10 min rest in between first one during | Oxygen consumption | The following was found with AFO use: Speed was increased by 9% ($P<0.001$)                                                                                                                           |
|                 |                   |                                                                              |                                                                              |                  |                                                                                                                                                                                                       |

(Continued)
Table 1 (Continued)

| References   | Design          | Participants                          | Methodology                                                                 | Outcome measures                      | Results                                                                 |
|--------------|-----------------|---------------------------------------|----------------------------------------------------------------------------|----------------------------------------|------------------------------------------------------------------------|
| Balaban et al. [19] | Cross-sectional within group | N: 11 children with hemiplegic cerebral palsy. | Exp.=Children wore an HAFO on the involved side for at least 2 months; each HAFO was custom made by the same orthotist for the individual child prior to participation in this study. Gait parameters and energy expenditure were assessed barefoot for baseline gait assessment and while wearing the HAFO for each child | Kinematic and kinetic gait parameters by motion analysis | Walking speed NN-cost was reduced by 6% (P=0.007) NN-cost pct was reduced by 9% (P=0.022) The Gait Index was unchanged (P=0.607) Subgroup analysis showed the following: Significant improvement in NN-cost pct only for quadriplegics (20%, P=0.004), whereas it remained unchanged for hemiplegic and diplegic children Knee flexion angle in stance phase and in terminal swing were significantly improved (P=0.013 and 0.022, respectively) |
| Age (years): 4–18 | Sex: 103 male and 69 female | Cont.=no control group | | | |
| Age (years): 7.18 +1.1 | Sex: 7 male and 4 female | | | | Walking stride length and single were improved during the wearing of AFO compared with barefoot walking |

Buckon et al. [4] | Cross-sectional within group | N: 16 children with diplegic cerebral palsy | Exp.=children participation in the study lasted 1 year and involved four visits: a baseline assessment after 3 months of no AFO wear, and an assessment at the end of each AFO 3-month wearing period. Each AFO configuration (HAFO, PLS and SAFO) was worn daily for 6–12 h and removed at night for 3 months | Kinematic and kinetic gait parameters, assessed with a six-camera Vicon 370 system (Oxford Metrics Ltd, Oxford, UK). | Improved ankle kinematics in stance-increased step/stride length while the cadence was decreased Decreased energy cost of walking |
| Age (years): 4 years 4 months to 11 years 6 months | Sex: 10 male and 6 female | Cont.=no control group | | | |

| Age (years): 4 | Sex: 10 male and 6 female | | | | Improved walking jumping, and running skills coordination of upper extremities; and fine motor speed/dexterity There was no change in the quality of gross motor skill performance or mobility independence There were no significant differences in the following | (Continued) |
| References | Design | Participants | Methodology | Outcome measures | Results |
|------------|--------|--------------|-------------|------------------|---------|
| Smiley et al. [20] | Cross-sectional within group | N: 14 children with diplegic cerebral palsy | Exp.=children wearing solid, articulated and PLS AFOs that were fabricated and fit prior to gait analysis without training period and shoes alone. A baseline assessment was conducted before wearing an orthosis and during wearing different types of AFOs. Assessment was conducted in a single day | Gait kinematics and temporospatiaparameters by motion analysis with 6 3D cameras | Stride length, cadence, velocity and energy efficiency index |
| | | | Age (years)= 6.9–16 | Cont.=no control group | Brace preference |
| | | | Sex : 8 male and 6 female | | Articulated AFO was preferred by eight children |
| Buckon et al. [21] | Cross-sectional within group | N: 30 children with spastic hemiplegic cerebral palsy | Exp.=children who were participated in the study were using AFO or indicated for using AFO. Each child was randomly to one of three sequences of AFO use: HAFO, SAFO, PLS; SAFO, PLS, HAFO; and PLS, HAFO, SAFO. Each AFO configuration (HAFO, PL and SAFO) was worn daily for 6–12 h and removed at night for 3 months. Assessments were performed barefoot or with shoes on and at the end of each 3-month period | Ankle range of motion by goniometer | Articulated AFO was preferred by six children |
| | | | Age (years): 4–18 | Cont.=no control group | |
| | | | Sex: 21 male and 9 female | | Six diplegic children preferred posterior leaf spring |
| | | | | | No one of the children preferred solid AFO |
| | | | | | PLS and HAFO improved passive ankle dorsiflexion and normalized rocker function of ankle. HAFO was the most effective in controlling knee hyperextension instance, while PLS was the most effective in promoting knee extension in stance |
| Maltais et al. [22] | Cross-sectional within group | N: 10 children with diplegic cerebral palsy | Exp.=children were using hinged AFO participated in the study and the measured outcomes were measured during sitting and with AFO on and off during steady state treadmill walking at three speeds: 3 km/h | Metabolic and cardiopulmonary responses oxygen cost of walking (cardiovascular and ventilatory costs of walking) | During the wearing of AFO |
| | | | Age (years)=9.0±6 2.1 SD | Cont.=no control group | Gross motor skills=GMFM |
| | | | Sex=8 male and 2 female | | Net oxygen uptake was (P=0.05) reduced by 8.9% at 3km/h and by 5.9% at 90% of FWS |
| | | | | | Net pulmonary ventilation was (P=0.05) lower by 10.3% but only at 3 km/h |
| | | | | | Net HR and respiratory exchange ratio did not affect at any speed |
| | | | | | PCI was lowered with AFO compared without orthoses |
| Mossberg et al. [23] | Cross-sectional within group | N: 18 children with diplegic cerebral palsy | Exp.=children wearing bilateral conventional ankle-foot orthoses and energy expenditure was measured without | PCI | |

(Continued)
Thirty-six duplicated articles out of 981 were found when the results from all databases were combined and screened for duplicate. The reviewers screened titles and abstracts of the remaining 945 articles independently, and the result of this screening was 53 included articles. Fifty-three articles were filtered on the basis of full-text; 34 were excluded because they were outside the scope, because the children’s diagnosis was not CP or outcome of interest was absent, or, in one case, the full-text paper was not available, as shown in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow chart (Fig. 1). The remaining 19 studies formed the basis for the current systematic review.

Characteristics of the studies
There was some variability among included studies regarding characteristics of participants (diagnosis and age), study design, methodology, outcome measures, and assessment methods.

Characteristics of participants
The children, who ranged from 3 to 18 years of age, were diagnosed with diplegic, hemiplegic, quadriplegic, and triplegic CP of different levels of severity. Both sexes were represented (261 boys and 173 girls). Two studies, namely, those of El-Shamy et al. [24] and Bhise et al. [14], did not identify sex distributions of their subjects.

Study designs
The included articles had a variety of study designs. There were 12 studies with cross-sectional design [4,14,17,19–23,27,28,30,31], two pre–post experimental studies [15,16], one RCT [24], one clinical trial [25], one case-series study [29], and two retrospective studies [2,18], as shown in Tables 1 and 2.

Methods
All studies in the current systematic review examined the effect of different types of lower limb orthoses (different configurations of AFO [4,14–16,18–23], plastic and metallic knee-AFO [17] or the effect of assisted walking aids (anterior and posterior walkers [27,28,30,31], walking sticks [29], robotic-assisted gait training [25], flexible derotator [26] and Walk Aide foot drop stimulator [24]) on energy expenditure in children with CP. All included studies can be classified into the following types: (a) studies that investigated the immediate effect of lower limb orthoses [14,17,18,20,22,23] or assisted walking aids [28,30,31] on energy expenditure, in which energy expenditure was assessed during the wearing of orthotic devices or during the usage of assisted
| References          | Design       | Participants                                      | Methods                                                                 | Outcome measures                                                                 | Results                                                                                                                                                                                                 |
|---------------------|--------------|--------------------------------------------------|-------------------------------------------------------------------------|----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| El-Shamy et al. [24]| RCT          | N: 34 children with hemiplegic cerebral palsy    | Exp.=received functional electrical stimulation by using the Walk Aide foot drop stimulator in addition to traditional exercise programme, 3 days/week for 3 months | GSTPs                                                                            | -The gait parameters improved after treatment in the study group more than control group as the following: Stride length, cadence, speed, cycle time, and stance phase percentage were 0.74 m, 119 steps/min, 0.75 m/s, 0.65 s, 55.9% and 0.5 m, 125 steps/min, 0.6 m/s, 0.49 s, 50.4%, respectively. |
| Peri et al. [25]    | Clinical trial | N: 7 4 children with diplegic cerebral palsy and 3 normal children | Exp.=received robot-assisted gait training (training with the paediatric version of Lokomat) and traditional physical therapy programme | Energy expenditure per minute                                                   | The trend of the energy expenditure per minute was increased while the trend of the energy expenditure per step was decreased accordingly to the control group After treatment, 6 min walk test showed an increased in the walked distance from 199.5 (226.7–223.2 m (191.8 m) |
| Marcucci et al. [26]| Retrospective | N: 30 (22 diplegic children, three right-sided hemiplegic children, four tetraparetic children and one triplegic child) | Exp.=used flexible derotator that consists of two straps attached to an abdominal belt and two thigh bands and the straps are placed in a spiral position in order to prevent poor posture for 6 h/day for 1 year | Bone parameters (deg.)                                                          | In the flexible derotator group after the treatment procedure The right femoral anteversion and right and left external tibial torsion were improved ($P<0.05$) Gait speed and distance were significantly increased ($P<0.05$) EEI was significantly decreased ($P<0.05$) There were no differences between the initial and final examinations in the control group |
| Konop et al. [27]   | Cross-sectional study | N: 10 children with diplegic cerebral palsy | Exp.=children used posterior walker and upper extremity kinetics were evaluated after 30 days, same evaluation process repeated on anterior walker. Resting HR was calculated before gait analysis while walking HR was measured after gait analysis to determine EE | GTSPs (walking speed, cadence, step length, and stride length) | Medial JRF in the wrist, the inferior and superior JRFs in the shoulder and the posterior JRF in the elbow were strongly correlate during the use of anterior walker |

(Continued)
| References  | Design          | Participants                                      | Methods                                                                 | Outcome measures                                      | Results                                                                 |
|------------|-----------------|---------------------------------------------------|-------------------------------------------------------------------------|-------------------------------------------------------|------------------------------------------------------------------------|
| Strifling et al. [28] | Cross-sectional | N: 10 children with diplegic cerebral palsy | Exp.=the children were evaluated at 2 separated visits; at visit 1, children used posterior walker, while at visit 2, children used anterior walker | Upper limbs kinetics (joint reaction forces JRF and moments JRM | EEIHR was higher with the use of anterior walker                      |
|            |                 | Age (years): 5–18 Cont.=no control group          |                                                                         |                                                       | Several kinetic variables correlated well with temporal and stride parameters, as well as the EEIHR |
| Toms et al. [29]       | Case series     | N: 8 children with cerebral palsy                | Exp.=The researchers designed prototypes of a walking stick and a tripod called Multi positional Paediatric Walking Aids for the children. The study was divided into four periods AABA, Prototypes were used during period (B) four used sticks and four used tripods and each child had been assessed at the beginning of the study and every 4 weeks. Children tested using either multi positional walking aids (period B) or conventional walking aids (period A) | GTSPs: (walking speed, cadence, step length, and stride length) | There was no difference in energy expenditure, walking speed or stride length between the two walker types |
|            |                 | Age: 4–11 Cont.=no control                        |                                                                         |                                                       | With the posterior walker use, there was a reduction in anterior torso tilt and the shoulder extension and elbow flexion were increased |
| Park et al. [30]       | Cross-sectional within group | N: 10 diplegic cerebral palsy children | Exp.=children using anterior and posterior walker. Ambulation with anterior and posterior walker use was practised for 1 month before evaluation so that children were familiarized with both walkers. Children tested two times, one time with each walker, in random order | Temporospatial variables and kinematic values in sagittal plane measured by motion analysis system | No differences were found between both types of walkers in walking velocity and cadence |
|            |                 | Age (years): 7–12 Cont.=no control group          |                                                                         |                                                       |                                                                       |
|            |                 | Sex: 2 male and 6 female                         |                                                                         |                                                       |                                                                       |
|            |                 | Sex: 7 female and 3 male                         |                                                                         |                                                       |                                                                       |
|            |                 | Sex: 6 male and 4 female                         |                                                                         |                                                       |                                                                       |

(Continued)
walking aids and (b) studies that examined the long-term or cumulative effect of orthoses [4,15,16,19,21] or assisted walking aids [24–26,29] on energy expenditure, in which lower limb orthosis or assisted walking aids were applied for a specific duration (weeks or months). In these studies, energy expenditure was evaluated before and after treatment.

Types of outcome measured
Although energy expenditure was the outcome of interest in the present systematic review, there were other measured outcomes in the included studies, for example, kinematic and kinetic gait parameters [4,16,18–21,23,24,26–28,30,31]; gross motor skills [4,21,22,29]; metabolic and cardiopulmonary responses [22]; upper limb speed, dexterity, and kinematics [9,28]; joint angles, power, daily walking activity, and range of motion [15,21]; bone parameters [26]; joint reaction force and moments [27]; BMI and perceived exertion [14]; brace preference [20]; performance on the 6-min walking test [25]; and hand/forearm position [29].

Measurement of energy expenditure
Energy expenditure can be measured with different methods. In the present systematic review, all studies were accepted regardless of the method of measuring energy expenditure. Methods of measuring energy expenditure in the included studies were as follows: the energy expenditure index method [17,18,20,26,28] or the Physiological Cost Index method [4,14,23], in which energy expenditure was measured by subtracting the maximum heart rate from the resting heart rate and divided by speed of walking; an open-circuit indirect calorimeter [19,24] or portable breath gas analysis system [15,16,18,22,30,31] which assess energy expenditure by measuring the amount of oxygen consumption; the dilution model [4,21]; and a SenseWear Armband (Table 5) [25]. Table 5 shows methods of measuring energy expenditure in the included studies.

Level of methodological quality
The score of each study on the PEDro scale is presented in Table 3. The mean score of the 19 studies was 3.736. One study was given a score of 6 [24], one study obtained a score of 5 [23], nine studies had a score of four [15–17,21,26–28,30,31], and the remaining eight studies scored 3 [4,14,18–20,22,25,29]. One of the included studies represented ‘good’ quality [24], 10 studies were ‘fair’ quality [15–17,21,23,26–28,30,31], and eight studies were ‘poor’ quality [4,14,18–20,22,25,29]. The criteria of a blinded therapist (criterion five) and intention-to-
Table 3  Level of evidence and methodological quality

| References                        | Random allocation of subjects | Concealed allocation | Similarity at baseline | Blinded subjects | Blinded therapists | Blinded assessors | More than 85% follow-up | Intention-to-treat analysis | Between-group statistical analysis | Point and variability estimates | Total score on PEDro scale | Level of evidence according to modified Sackett |
|-----------------------------------|-------------------------------|----------------------|-------------------------|------------------|--------------------|------------------|------------------------|-------------------------------|---------------------------------|-------------------------------|-------------------------------|---------------------------------|
| Maltais et al. [22]               | No                            | No                   | No                      | No               | No                 | No               | Yes                    | No                            | Yes                             | Yes                           | 3                              | 2                               |
| Park et al. [30]                  | Yes                           | No                   | No                      | No               | No                 | Yes              | No                     | No                            | Yes                             | Yes                           | 4                              | 2                               |
| Marcucci et al. [26]              | No                            | No                   | Yes                     | No               | No                 | Yes              | No                     | Yes                           | Yes                             | Yes                           | 4                              | 3                               |
| Mattsson and Andersson [31]       | No                            | No                   | Yes                     | No               | No                 | No               | Yes                    | No                            | Yes                             | Yes                           | 4                              | 2                               |
| Peri et al. [25]                  | No                            | No                   | No                      | No               | No                 | Yes              | No                     | Yes                           | Yes                             | Yes                           | 3                              | 2                               |
| Smiley et al. [20]                | Yes                           | No                   | No                      | No               | No                 | No               | Yes                    | No                            | Yes                             | Yes                           | 3                              | 2                               |
| Mossberg et al. [23]              | Yes                           | No                   | Yes                     | No               | No                 | No               | Yes                    | No                            | Yes                             | Yes                           | 5                              | 2                               |
| El-Shamy et al. [24]              | Yes                           | Yes                  | Yes                     | No               | No                 | Yes              | No                     | Yes                           | Yes                             | Yes                           | 6                              | 1                               |
| Kerkum et al. [15]                | No                            | No                   | No                      | Yes              | No                 | No               | Yes                    | No                            | Yes                             | Yes                           | 4                              | 4                               |
| Balaban et al. [19]               | No                            | No                   | No                      | No               | No                 | No               | Yes                    | No                            | Yes                             | Yes                           | 3                              | 2                               |
| Buckon et al. [21]                | Yes                           | No                   | No                      | No               | No                 | Yes              | No                     | Yes                           | Yes                             | Yes                           | 4                              | 2                               |
| Buckon et al. [4]                 | Yes                           | No                   | No                      | No               | No                 | No               | Yes                    | Yes                           | Yes                             | Yes                           | 3                              | 2                               |
| Uckun et al. [17]                 | No                            | No                   | Yes                     | No               | No                 | No               | Yes                    | No                            | Yes                             | Yes                           | 4                              | 2                               |
| Bhise et al. [14]                 | No                            | No                   | No                      | No               | No                 | No               | Yes                    | No                            | Yes                             | Yes                           | 3                              | 2                               |
| Strifling et al. [28]             | No                            | No                   | Yes                     | No               | No                 | No               | Yes                    | No                            | Yes                             | Yes                           | 4                              | 2                               |
| Brehm et al. [18]                 | No                            | No                   | No                      | No               | No                 | No               | Yes                    | No                            | Yes                             | Yes                           | 3                              | 3                               |
| Konop et al. [27]                 | No                            | No                   | Yes                     | No               | No                 | No               | Yes                    | No                            | Yes                             | Yes                           | 4                              | 2                               |
| Kerkum et al. [16]                | No                            | No                   | Yes                     | No               | No                 | No               | Yes                    | No                            | Yes                             | Yes                           | 4                              | 4                               |
| Toms et al. [29]                  | No                            | No                   | No                      | No               | No                 | No               | Yes                    | No                            | Yes                             | Yes                           | 3                              | 4                               |
treat analysis (criterion eight) were not met by all included studies. On the contrary, the criteria of between-group statistical analysis (criterion nine) and estimation of point and variability measures (criterion 10) were satisfied by all included studies.

**Level of evidence**

According to the modified Sackett scale, one study [24] was ranked on level one, 13 studies were on level two [4,14,17,19–23,25,27,28,30,31], two studies were on level three [18,26], and three studies were on level four [15,16,29].

**Discussion**

Our search in literature revealed moderate-quality to low-quality evidence on the effect of assisted walking aids and foot orthoses on energy expenditure in children with CP. The current systematic review
Energy expenditure among children with CP is very important as children with CP consume more energy during ambulation and they have lower physical activity levels and lower energy requirements than do typically developing children [35].

Different mechanisms have been suggested to clarify the advantage of foot orthoses for children with CP; one of them is the improvement of energy expenditure after using foot orthoses. Because the use of foot orthoses results in normal ankle motion during stance phase, this might lead to increased stability, with decreases in mechanical power and reduction in O2 cost of walking [36].

Another explanation mentioned when using other assisted walking aids like walkers revealed that posterior walker gives children with CP more stability as it decreases flexion angles of trunk, hips, and knees and gives more upright posture for them [37].

This review analyzed 19 studies; most of them were a cross-sectional design. This design enables researchers to estimate the prevalence of increased energy expenditure in children with CP and gave the best opportunities to know the different treatment modalities used to improve it. Studies with cross-sectional design provide a ‘snapshot’ of characteristics and outcomes associated with it, at a specific time [35]. Results of all included studies in this systematic review were consistent and agreed that foot orthoses and other assisted walking aids may improve energy expenditure in children with CP.

This review found moderate-quality to low-quality evidence supporting the use of foot orthoses and other assisted walking aids for children with CP; it also highlighted the variation in use of assisted walking aids and foot orthoses (types, duration, and technique of application), outcomes, and follow-up in the

| Table 5 Methods of measuring energy expenditure in the included studies |
|-----------------|------------------------------------------------------------------|
| References      | Measurement of energy expenditure                                 |
| Maltais et al. [22] | Oxygen cost of walking                                           |
| Park et al. [30]  | Oxygen cost measured by KBI-C (portable oxygen)                  |
| Marcucci et al. [26] | Energy Expenditure Index method: heart rate beats/m/average speed |
| Mattsson and Andersson [31] | Oxygen cost of walking measured by an argon dilution method described by Linnarsson et al. [1989] |
| Peri et al. [25]      | Energy expenditure per minute                                    |
| Smiley et al. [20]   | Energy expenditure index method                                  |
| Mossberg et al. [23] | Physiological Cost Index (the resting heart rate was subtracted from the ambulation heart rate and the difference divided by the walking speed) |
| El-Shamy et al. [24] | Energy expenditure measured with a breath-by-breath method using an open-circuit indirect calorimeter |
| Kerkum et al. [15]   | Oxygen uptake measured by a portable breath gas analysis system  |
| Balaban et al. [19]  | Oxygen consumption measured by an open-circuit indirect calorimeter |
| Buckon et al. [21]   | Sensor Medics 2900 metabolic cart using dilution model           |
| Buckon et al. [4]    | Sensor Medics 2900 metabolic cart using dilution model           |
| Uckun et al. [17]    | Energy expenditure index method                                  |
| Bhise et al. [14]    | Physiological Cost Index (calculated from maximum HR, resting HR, and Speed) |
| Strifling et al. [28] | Energy expenditure index method                                   |
| Brehm et al. [18]    | Oxygen consumption measured by breath-by-breath gas analysis     |
| Konop et al. [27]    | Energy expenditure index method                                  |
| Kerkum et al. [16]   | Oxygen uptake measured by a portable breath gas analysis system  |
| Toms et al. [29]     | Physiological Cost Index                                         |

Figueiredo et al. [12] performed a descriptive review of literature about the effect of AFOs on gait in children with CP. They reported that studies with high-quality methods are still desired to support evidence-based decisions on the use of AFOs for those children. As, studies included flaws such as; lack of randomization procedures, lack of parity among groups and no masking of subjects, therapists, and examiners, except for one blinding was mentioned for examiners [12]. Consequently, there has been little progress in the quality of evidence since the last published review on orthoses. Instead of, we found that it is important to address other assisted walking aids used by children with CP to clarify its effect on energy expenditure because they were not addressed in any other systematic reviews. It should be borne in mind that ambulation with assisted walking aids is incorporated into daily life, so energy conservation is a major issue when choosing walking aids [30].

aimed to collect this evidence by using systematic methods for search and evaluating best available studies on the benefit of assisted walking aids and foot orthoses for children with CP, based on clinically relevant outcomes including different methods of measuring energy expenditure, kinematic and kinetic gait parameters, and functional motor skills.
included studies. This clinical heterogeneity (characteristic of participants, absence of allocation concealment and blinding, small sample sizes, and wide variability) restricted the comparison between results of these studies and made meta-analysis inapplicable.

According to this results of PEDro scale, we had only two studies with moderate methodological quality and 17 studies with low quality. This might be owing to the absence of blindness in studies, which may be affected by the type of intervention used.

Conclusion
Results of the current review revealed moderate-quality to low-quality evidence, and they were consistent and agreed that foot orthoses and assisted walking aids can improve energy expenditure in children with CP.

Recommendation
Well-designed and high-quality studies on the effect of foot orthoses and assisted walking aids on energy expenditure in children with CP are still needed to provide strong evidence.

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Conflicts of interest
There are no conflicts of interest.

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