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Review

# Kinematic upper limb evaluation of children and adolescents with cerebral palsy: a systematic review of the literature

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**Abstract.** [Purpose] The aim of the present study was to perform a review of the literature on objective measures of upper limb movements in children and adolescents with cerebral palsy and describe the methods used to investigate upper limb kinematics in this population. [Materials and Methods] An extensive database search was performed using the keywords kinematics, upper limb, and cerebral palsy. A total of 146 papers were identified, but only five met the inclusion criteria. [Results] No consensus was found regarding the data collection, processing, and analysis procedures or reporting of the results. [Conclusion] Standardization of the protocol for 3D upper limb movement analysis will provide the foundation for comparable, reproducible results and eventually facilitate the planning of treatment interventions.

**Key words:** Upper limbs, Kinematics, Cerebral palsy

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## INTRODUCTION

Cerebral palsy (CP) comprises a group of movement and posture disorders resulting from nonprogressive, permanent damage to the immature brain[1)]. Motor impairment is the main manifestation of CP, with consequent effects on the biomechanics of the body[2)]. Children with CP exhibit impaired muscle coordination, difficulties in the organization of sensory information, and functional limitations[3)]. Approximately half of all children with CP have upper limb dysfunction[4)], which includes weakness, associated mirror movements, decreased velocity, overactive reflexes, muscle contractures, altered biomechanics, disuse, sensory impairment, and hypertonia[5, 6)]. These upper limb impairments lead to difficulties in reaching, grasping, and manipulating objects. Deficiencies in one or more of these basic functions hinder the performance of activities of daily living and therefore exert a negative impact on independence and quality of life[7)].

Adequate treatment planning is imperative and requires extensive knowledge of all upper limb dysfunctions. A clinical assessment combined with objective, quantitative upper limb measures can provide the necessary insights[7)]. However, most measures are subjective and use a straightforward scoring system. The main disadvantage of qualitative outcome measures is that they provide a subjective description of upper limb performance based on the opinion of the rater, who visually scores the range and quality of movement during the execution of tasks. Moreover, some outcome assessments have been criticized for not being sensitive enough to detect clinically meaningful changes in upper limb function following an intervention[8)]. In a recent study, Santos et al. reported that no consensus has been reached on the most appropriate scale or on which scale has greater clinical applicability in this population[9)]. Thus, quantitative measures are needed to provide a more detailed, objective description of upper limb movement patterns. Such measures can provide an objective description of upper limb performance

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**Table 1.** PEDro scale scores of each study

| | References | Item | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Eligibility | 1- Randomized allocation | 2- Confidential allocation | 3- Similar prognosis | 4- Blinded subjects | 5- Blinded therapists | 6- Blinded evaluators | 7- Key results | 8- Intention to treat analysis | 9- Comparison between groups | 10- Precision and variability | Score |
| 1 | Schneiberg et al.[14] | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 8/10 |
| 2 | Hung Ya-Ching et al.[15] | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 5/10 |
| 3 | Elliott et al.[16] | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 5/10 |
| 4 | Elliott et al.[17] | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 5/10 |
| 5 | Fitoussi et al.[18] | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 5/10 |

based on technical measurements and calculations (e.g., joint angles, movement duration, and velocity). Three-dimensional (3D) movement analysis is a powerful tool for quantitative assessment of movement in all degrees of freedom[7]. A number of authors have recommended the use of kinematics for objective, quantitative analysis of upper limb movements in children with CP[10].

Motion analysis is considered the gold standard for evaluating lower limb function during gait in individuals with CP[11]. Upper limb motion analysis is more technically challenging due to the noncyclical nature of upper limb use and the complexity of shoulder joint motion[12]. In addition to joint kinematics, spatiotemporal variables, such as duration, velocity, smoothness, and trajectory of movement, can provide important quantitative information on the quality of upper limb motion[13].

The aim of the present study was to perform a review of the literature on objective upper limb movement measures for children and adolescents with CP with a focus on describing methods for the assessment of kinematics, spatiotemporal variables, and/or angular joint movements. Methodological reflections are included in this report to promote standardization of a protocol for 3D analysis of upper limb movements in children and adolescents with CP.

## MATERIALS AND METHODS

A systematic review of the literature was performed with searches in the Virtual Health Library network and the Medline, PEDro, Lilacs, SciELO and PubMed databases using combinations of the following key words: upper limb, three-dimensional analysis, kinematics, and cerebral palsy. The articles retrieved were evaluated by two blinded researchers using the following inclusion criteria: 1) type of study, controlled clinical trial; 2) outcome, 3D or kinematic evaluation of the upper limbs of children/adolescents with CP; and 3) publication between 2010 and 2015.

The selected articles were evaluated, scored, and qualified using the Physiotherapy Evidence Database (PEDro) scale, which has 11 items. Item 1 is not scored, whereas the other 10 items receive a score of either 0 or 1. Thus, the final score ranges from 0 to 10 points. The purpose of this scale is to evaluate the methodological quality (Table 2) of randomized controlled clinical trials, giving priority to internal validity (whether the results published in the study have sufficient information) as well as clinical and statistical relevance, so that interpretation of the findings is clear and other researchers can reproduce the study. All divergences regarding classification of the studies analyzed based on the PEDro scale were discussed and evaluated by two blinded raters until a consensus was reached on the score of each study.

## RESULTS

The initial database search yielded a total of 146 articles. However, 141 did not meet the inclusion criteria. Thus, five articles addressing 3D analysis of the upper limbs of children and adolescents with cerebral palsy (Fig. 1) were considered methodologically adequate (minimum of three points on the PEDro scale) and were included in the present systematic review (Table 1).

All studies selected were controlled clinical trials and employed one or more upper limb evaluation methods. The methods and results of the 3D analysis were analyzed in the present review. The following information was extracted from each study: authors and year of publication, sample size, sample characteristics, methods employed, and outcomes (Table 2).

**Table 2.** Characteristics of the studies included in review

| Article | Nº of subjects | Sample characteristics | Intervention | Kinematic processing | Kinematic analysis |
|---|---|---|---|---|---|
| 1 | 12 | Children 6–11 years<br>Cerebral palsy (hemiplegic, diplegic, quadriplegic) | EG: 6 – without trunk restraint<br>CG: 6 – with trunk restraint | System: Positional data (x, y, z) recorded with an Optotrak 3020 (100 Hz; Northern Digital, Waterloo, ON, Canada) for 5 to 8 seconds.<br>Markers: Fingertip, thumb, first metacarpal head, radial styloid, mid-forearm, lateral epicondyle, ipsilateral and contralateral acromions, sternum, and lateral iliac spine.<br>Trials: 7 to 13 trials (bad trials discarded). | Kinematics analysis: Trajectories and angles. Arm and trunk trajectories and elbow angle.<br>Movement strategies: Grasping an object.<br>Results: Smoother arm trajectories and greater elbow extension were observed at the post-intervention assessment in most children, but deterioration in elbow extension for reaches was observed at follow-up. Trunk displacement was reduced at the post- intervention assessment and at follow-up. |
| 2 | 20 | Children 4–10 years<br>Cerebral palsy (hemiplegic) | EG: 10 – bimanual treatment<br>CG: 10 – unimanual treatment | System: 3-D kinematic analysis with eight infrared cameras; all markers digitized at a rate of 120 Hz with a low pass filter (6 Hz) using VICON software.<br>Markers: Reflective markers placed at mid-point of both wrists. Trials: 7 to 10 trials. | Kinematic analysis: Time. Bimanual coordination using normalized movement overlap time and goal synchronization.<br>Movement strategies: Experimental setup with a loop handle<br>Results: Significantly greater reduction in goal synchronization time in the experimental group. |
| 3 | 16 | Children 8–14 years<br>Cerebral palsy (hemiplegic and quadriplegic) | EG: 8 – Lycra® arm splint usage for three months<br>CG: 8 – no intervention | System: Seven-camera Vicon 370 motion analysis system (Oxford Metrics, Oxford, UK) operating at 50 Hz.<br>Markers: 3D position of markers throughout movement trials analyzed using customized model developed with Vicon Body Builder® software (Oxford Metrics, Oxford, UK).<br>Trials: Three successful trials of each task analyzed. | Kinematics analysis: Time and jerk. Movement jerkiness of the distal segment of the upper limb. The 3D movement substructures of the wrist joint center (WJC) were calculated from 3D positional data using a custom "Jerk Analysis" computer software (LabVIEW, National Instruments Corporation, Austin, TX, USA).<br>Movement strategies: Reach forwards, reach forwards to an elevated position, reach sideways to an elevated position, and hand to mouth and down.<br>Results: Significant improvements in the experimental group regarding movement time, normalized jerk, and jerk index in the primary and secondary movements. |
| 4 | 16 | Children 8–15 years<br>Cerebral palsy (hypertonic) | EG: 8 - Lycra arm splint usage combined with goal directed training for three months<br>CG: 8 - no intervention | System: Seven-camera Vicon 370 motion analysis system (Oxford Metrics, Oxford, UK).<br>Markers: Reflective markers placed on upper limb and trunk; 3D position of markers throughout movement trials analyzed using a customized model developed with the Vicon BodyBuilder® software (Oxford Metrics, Oxford, UK).<br>Trials: Three successful trials of each task analyzed. | Kinematics analysis: Angle-range of motion. The movement trials were analyzed using a customized model developed with the Vicon BodyBuilder software (Oxford Metrics, Oxford, UK). The data were filtered using a Woltring spline with a mean standard square error (MSSE) of 20.<br>Movement strategies: Reach forward to an elevated position, reach sideways to an elevated position, supination/ pronation, and hand to mouth.<br>Results: Significant improvements from baseline angles. |
| 5 | 8 | Children 8–15 years<br>Cerebral palsy (hypertonic) | EG1: 4 - botulinum toxin injection<br>EG2: 4- muscle lengthening Surgery | System: VICON optoelectronic system with six cameras.<br>Markers: Rigid supports provided with three markers (tripods) used to measure trunk, arm, forearm, and hand motions.<br>Trials: Four successful trials of each segment. | Kinematics analysis: Angle-range of motion (ROM) and mean angles for the trunk/table, arm/trunk, forearm/arm, and hand/forearm. Recommendations from the International Society of Biomechanics.<br>Movement strategies: Hand to mouth and moving a cup on a table.<br>Results: Significant ROM and mean angle changes between the pre- and post-therapeutic conditions (homolateral analysis). |

EG: experimental group; CG: control group

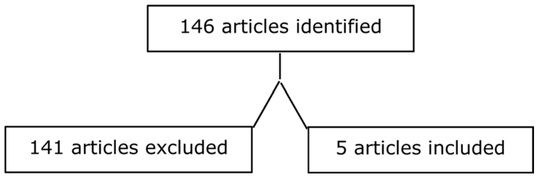


**Fig. 1.** Flowchart of studies included in the review

# DISCUSSION

Current clinical methods of upper limb evaluation are performed in terms of function, motor control, sensory impairment, dexterity, tone, and degree of fixed versus dynamic deformity as well as both passive and active range of motion. In higher functioning children, the quality of upper limb movement during functional tasks is determined using available clinical scales[19].

Kinematic analysis of upper limb function is considered "a strategy level assessment." A large number of kinematic variables are used to reflect the characteristics of the reaching motion. By quantifying specific kinematic variables, key components can be identified and the influence of motor impairment on the reaching motion can be carefully analyzed. Consequently, specific kinematic parameters with large effect sizes can provide therapists with a sensitive way to measure the effectiveness of treatment and analyze the influence of different levels of motor dysfunction on upper arm control during activities that require various degrees of accuracy. A better understanding of this information can offer insights for the evaluation of treatment and the progression of a wide variety of motor disorders, such as those that occur with CP[20].

The samples in the studies analyzed in the present systematic review were predominantly made up of children with spastic hemiparetic cerebral palsy, which confirms an observation made by Body[21]. Children with hemiparesis have limitations regarding the use of the affected upper limb and two-hand coordination, which exerts a negative impact on activities of daily living and participation at school, in the community, and in family life. Mean age (eight years) was also a common factor in the studies analyzed.

As the present review was restricted to clinical trials, all studies had two groups: an experimental group subjected to a particular intervention and a control group that did not undergo the intervention. Analyzing the kinematic variables, it is clear that there is no consensus on the data collection, processing, and analysis procedures or the reporting of the results. The VICON optoelectronic motion analysis system (Oxford Metrics, Oxford, UK) was used in four of the five studies, but the number of cameras employed differed. The Optotrak 3020 (100 Hz; Northern Digital, Waterloo, ON, Canada) was employed in the other study. Differences among the studies also occurred with regard to placement of the makers (five segments were included, the trunk, scapula, humerus, forearm, and hand, and four joints were considered, the scapulathoracic (scapula), humerothoracic (shoulder), elbow, and wrist joints, and the number of trials.

In the present review, a variety of mechanical models, numbers of segments, joint degrees of freedom, and marker configurations were encountered, with no consensus on a standardized assessment pattern. Only the study conducted by Fitoussi et al. [18] used the recommendations on the International Society of Biomechanics (ISB) regarding the definition of joint coordinate systems and rotation sequences[22]. This observation was also described in a study by Ellen Jaspers in 2011, who reported that most studies on upper limb (UP) kinematics in typically developing children and children with CP have not yet incorporated the ISB guidelines. Moreover, there is no general consensus on which tasks should be assessed[23].

In the following section on kinematic analysis, characteristics are presented for the different tasks, including spatiotemporal characteristics, joint kinematics (joint angles), trajectories of movement, and jerk analysis as well as contextual influences of interventions. The differences in spatiotemporal characteristics between the experimental group and control group during "reach to touch" and "reach to grasp" were studied in articles by Hung Ya-Ching el al.[15] and Elliot et al[16]. Both authors reported a significantly greater reduction in time in the experimental group.

Schneiberg et al.[14] compared the differences between pre-intervention and post-intervention assessments for three-dimensional arm and trunk trajectories and elbow angles and overall trend analysis; the effect size for time period indicated smoother arm trajectories and greater elbow extension at the post-intervention assessment in most children. The other articles analyzed used kinematic evaluation focused on angular data of different joint segments and also found satisfactory results with the treatment protocol offered.

In the studies analyzed, the evaluation of kinematics was effective for a discussion of the findings, but we believe that the methodogical differences between the studies likely inconsistent results and therefore, exert an impact on the clinical interpretation. We suggest, based on the present review, that authors of future clinical trials should try to use standardized patterns. Standardization of the protocol for 3D upper limb movement analysis will provide the foundation for comparable, reproducible results and eventually facilitate the planning of treatment interventions for children and adolescents with cerebral palsy.

Several clinical trials involving children and adolescents with cerebral plays have benefitted from the use of objective measurements of upper limb movements, with spatiotemporal and angular parameters used in the majority of them. However, there is a lack of consensus regarding the biomechanical model and which tasks to analyze. The findings of the present systematic review underscore the need for standardization of 3D upper limb movement analysis.

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