ORIGINAL ARTICLE

Upper extremity kinematics analysis in obstetrical brachial plexus palsy


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Summary
Introduction: Several recent studies demonstrate that upper extremities kinematics analysis is in increasing use to assist clinical practice. We describe an upper limb kinematics analysis protocol that was first applied to a group of healthy children (to obtain normative data), and subsequently, to a child presenting with obstetrical brachial plexus palsy (OBPP) before and after surgical treatment.

Materials and methods: The protocol is based on two very simple tasks. Reflective markers are placed on the studied segments, and optoelectronic cameras three-dimensionally record the position of the markers during the course of movement. The data, collected by a Vicon system (Oxford Metrics Ltd., Oxford, UK), are analyzed by a dedicated software; this software provides coefficient of multiple correlation (CMC) for the comparison of different kinematics curves and motion amplitudes. A CMC above 0.95 was considered to be excellent, between 0.85 and 0.95 was good, and below 0.85 was poor. Twelve healthy children, average age 9.7 years (from 7 to 14 years), were analyzed. A 7-year-old patient presenting left OBPP was similarly analyzed, pre- and postoperatively, after a lateral rotation osteotomy of the humerus.

Results: The analysis of the 12 healthy children established a kinematics corridor for each task and each angle considered. Analysis of the pathological patient revealed kinematics anomalies during movement which went undetected at simple clinical examination. CMC analysis after treatment showed improvement of all movements around the shoulder, going from “poor” preoperatively to “excellent” postoperatively. Amplitudes analysis similarly demonstrated postoperative improvement, which increased from 28 to 67% according to the rotations considered, around the shoulder and elbow. The interest in these results should be confirmed by studies in a larger number of patients.

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Introduction

Obstetrical brachial plexus palsy (OBPP) is caused by trauma during delivery. Its incidence is one to two out of 1,000 live births. The picture encountered most often is a paralysis of the upper roots, C5-C6 (46% of cases) or C5-C6-C7 (29% of cases), most often corresponding to a post-ganglionic lesion [1]. Its spontaneous evolution tends towards recovery, but a deficit persists in 20% of cases. When recovery is incomplete, patients often present a limitation of shoulder elevation and external rotation, that sometimes necessitating surgical treatment. Clinical evaluation thus takes into account active and passive mobility as well as the possibility of performing certain movements, such as putting hand to mouth, or back, on the head or nape of the neck. Several clinical classifications, such as that of Mallet or the Toronto Test Score [2], have been proposed and validated. Nevertheless, these methods of evaluation do not take into account the kinematics of the upper limbs or the electromyographic activity of different muscle groups, in the course of daily activities.

The advent of movement analysis methods and notably gait analysis has allowed us to reconsider preoperative evaluation as well as therapeutic strategies for patients with neuro-orthopaedic problems [3]. Knowledge of numerous normal walking parameters has improved our understanding of the abnormalities encountered. The importance of treatments, and especially of surgery, was modified by a more global approach that aims to correct the muscle and bone anomalies at the same time and on different levels after careful clinical and instrumentation analysis of children walking.

The situation is different at the upper limbs, because they are not used in a repetitive and cyclical manner as during walking [4]. Compared to the lower limbs, little work has focused on analyzing upper limb kinematics, probably because the evaluation of task performance is complex [5—7]. These studies have nevertheless demonstrated the interest in such pretherapeutic movement analyses, but little research have been devoted in the evaluation of post-treatment results.

To complete the clinical analyses of patients presenting neuro-orthopaedic damage to the upper limb, we have developed a kinematics analysis protocol that quantifies movements of the upper limb during two very simple tasks.

First, we analyzed upper limb movement in a cohort of healthy subjects to obtain normative data and to study its reproducibility. Then, we investigated an OBPP patient pre- and postoperatively.

Discussion: Upper extremity kinematics analysis is increasingly utilized in current clinical practice. Although many problems occur because of the non-cyclical and non-automatic nature of movement, review of the literature and our preliminary results show that reproducibility is satisfactory. Interest in our work arises from helping develop a preoperative evaluation tool (providing a more global view of abnormalities) as well as a postoperative assessment one (for the quantification of movement gains obtained by surgery after humeral osteotomy).

Level of evidence: Level IV. Diagnostic retrospective study.

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Materials and methods

Our protocol of complete movement analysis has been described elsewhere [8]. Here, we reiterate its major principles.

Experimental protocol

To mobilize the upper limb in different directions in space, the study subjects performed two simple tasks. Each of them was seated on a chair with the hips and knees flexed at 90°, palms of the hands on the knees:

- First task: bringing an object to the mouth ("cookie test"). The subject took a barrel placed in front of him/her and brought it to his/her mouth, and returned it to its initial position. This movement mainly studied the sagittal plane.
- Second task: moving an object on a table. The subject moves the barrel from the side analyzed towards the contra-lateral side, then returned it to its initial position. This movement mainly studied the coronal and horizontal planes.

Each task was repeated three times consecutively. The two sides were analyzed successively. The level of the table, the volume, position and weight of the barrel were adapted to each subject’s anthropometric data and grip strength.

Kinematics analysis

For kinematics measurements, we used the Vicon optoelectronic system (Oxford Metrics Ltd., Oxford, UK) with a minimum of six cameras and reflective markers placed on the subject [9—13]. Each segment—trunk, arm, forearm and hand—was considered as a rigid segment.

To record upper limb kinematics, the "trunk", "arm", "forearm" and "hand" segments were marked spatially. To do so, anatomical markers were defined for each segment, starting from the anatomical points.

To limit measurement errors arising from skin movements in relation to the anatomical points [14—16], tripods markers were placed on the segments studied (Fig. 1). Fixed on a plate, they avoid relative movements between markers for the same segment.

The relative positions of the anatomical reference points (used for the kinematics calculations) and tripods (used during measurement) were defined during a preliminary static
acquisition phase where the tripod markers and markers placed on the anatomical points were present simultaneously.

An additional tripod was placed on the table to study trunk movements in relation to a fixed reference point.

The different markers positioned allowed the following movements to be studied:

- Trunk with regard to the table: flexion-extension, left and right inclination, axial rotation.
- Arm with regard to the trunk: flexion-extension, abduction-adduction, internal-external rotation.
- Forearm with regard to the arm: flexion-extension, pronation-supination.
- Hand with regard to the forearm: flexion-extension, radial and ulnar inclination.

All kinematics calculations and data analysis were performed with software developed for this purpose.

Data analysis

Movements were made at different speeds in trials from one subject to another; normalization of the curves (of 0 to 100%) was necessary for comparisons between sessions and subjects.

Different kinematics curves were compared by coefficient of multiple correlation (CMC), as described by Kadaba et al. [17]. Similarities between two curves were quantified by mathematical criteria. CMC above 0.95 were considered as excellent, between 0.85 and 0.95 as good, and below 0.85 as poor [18].

For the two tasks described and for the 10 angles measured, the software analyzed the CMC of the angle measured in relation to the average curve of the healthy subjects. Furthermore, it calculated movement amplitude and the percentage of points of the average curve of the patient included in the corridor of healthy subjects.

Healthy subjects

Twelve healthy children, with an average age of 9.7 years (from 7 to 14 years), were analyzed. A kinematics corridor, corresponding to the average curve ± one standard deviation, was established for each task and each angle considered.

Patient

The study subject was 7 years old at the time of surgical treatment. He presented sequelae of left OBPP.

His body weight at birth was 4.17 kg, his height was 51 cm, and his cranial circumference was 35 cm. He had incomplete C5-C6 OBPP. There were no signs of Horner syndrome or diaphragmatic palsy. At 1 month, he showed neither elevation nor active external rotation of the shoulder. The patient was initially treated by physiotherapy. At 7 years, he presented normal active and passive mobility of the hand, wrist, forearm and elbow. Shoulder elevation was 160° (contralateral = 180°), external active and passive shoulder rotation was −30° and 0°, respectively. A trumpet sign (absence of active external rotation) was apparent. Radiographs and scans confirmed the presence of gleno-humeral incongruence.

Because of the disability caused by the lake of shoulder external rotation, a lateral rotation osteotomy of the humerus was performed, followed by a shoulder immobilization splint for 45 days and rehabilitation. Kinematics analysis was undertaken just before surgery and at 2 years postoperatively.

Results

Normative data

Analysis of the 12 healthy subjects allowed us to obtain kinematics corridors for the 10 angles studied. The curves of the studied patient were compared to the corridors of the healthy subjects.

Kinematics data on the pathological subject

The clinical examination data did not reveal a clear limitation of arm abduction or flexion relative to the trunk. In contrast, the kinematics data obtained during the "displacement" task disclosed:

- Arm with regard to the trunk mobility:
  o On flexion-extension curves: a clear decrease in amplitude with a 23° arc of motion (average of healthy subjects = 41°) and arm hyperextension (Fig. 2).
  o On abduction-adduction curves: a similar clear decrease in amplitude with a 9.5° arc of motion (average of healthy subjects = 20°). The shape of the average curve of the pathological subject did not have the same aspect as the corridor and was flattened (Fig. 3).
  o On medial-lateral rotation curves: a curve outside the corridor (Fig. 4) with a poor CMC (0.25).
On flexion-extension curves of the elbow: displacement of the curve towards flexion (Fig. 5) with a reduced arc of motion ($22^\circ$ versus $31^\circ$ in the healthy subjects).

Kinematics of the forearm and wrist did not show significant differences in relation to the corridor of healthy subjects (Fig. 5).

After surgery, significant changes were observed:

- Average flexion-extension, abduction-adduction and internal-external curves for the arm in relation to the trunk were reintegrated in the corridors of healthy subjects with similar patterns (Figs. 6—8).
- Although it remained a little too much in flexion, the flexion-extension curve of the elbow was found to be superposable on the corridor of the healthy subjects (Fig. 9).

Pre- and postoperative CMC evaluation showed an improvement of values for all movements measured around the shoulder and elbow (Fig. 10). For arm movements in relation to the trunk, the three CMC averages went from "poor" preoperatively to "excellent" postoperatively. For elbow flexion-extension, the average CMC was improved (from 0.61 to $0.79^\circ$) postoperatively.
Discussion

Kinematics analysis of the upper limb

Gait analysis, currently analyzed in clinical practice and research, allows the evaluation of many parameters in patients presenting neuro-orthopaedic problems. Such assessments provide valuable pre- and postoperative information to clinicians.

The situation is very different at the level of the upper limb:

Figure 6  Average postoperative flexion-extension curve of the arm in relation to the trunk.

Figure 7  Average postoperative abduction-adduction curve of the arm in relation to the trunk.

Figure 8  Average postoperative medial-lateral rotation curve of the arm in relation to the trunk.

to 0.78), although it remained "poor" according to the criteria of Mackey et al. [18].

Evaluation of pre- and postoperative amplitudes similarly revealed an amelioration of values around the shoulder and elbow, which rose from 28 to 67% according to the rotations considered (Fig. 11).

Figure 9  Other postoperative kinematics curves.
The variability of movements and their non-cyclical and non-anatomical character require the preliminary definition of specific tasks whose reproducibility is more difficult to obtain.

Three-dimensional viewing is necessary for the joint motion studies.

Accessibility of the scapula to cutaneous markers is difficult, just like the radius and ulna.

Surface electromyography gives signals that are sometimes difficult to interpret, especially in children, because muscles are very close to each other at the level of the forearm.

Despite these difficulties, many studies have been published to evaluate the upper limb kinematics of healthy [4—7] and pathological subjects [8,19,20]. Various tasks performed by subjects have been described, making comparisons difficult between different studies. Nevertheless, the most frequently used is the "Cookie test" in which an object is moved to the mouth to investigate movement essentially in the sagittal plane. We chose to add a second task to mobilize segments in two other planes.

Reproducibility

Reproducibility is a major issue when performing an upper limb motion study. We have demonstrated, in a preliminary study, that reproducibility seems to be satisfactory during the same session and between sessions [8], despite the relatively limited number of study subjects. These observations concur with those of Mackey et al. [18]. A more complete study with a larger number of subjects is currently under way.

Patient evaluation

The evaluation of patients presenting neuro-orthopaedic problems remains difficult, and the reproducibility of inter-observer and inter-session scores is poor [18], making it necessary to use more sophisticated tools. For the lower limb, correlation between gait analysis and clinical evaluation is similarly poor, indicating the need for recourse to two evaluation methods [21,22].

Kinematics analysis of the upper limb should not replace clinical assessment but must be considered as a complementary examination giving information inaccessible to clinical examination. Its goal is to provide kinematics evaluation during daily activities in three dimensions, to precisely quantify and evaluate the compensations.

Lateral rotation osteotomy of the humerus improves the shoulder function of children presenting with brachial plexus palsy [23]. However, clinical classifications within this framework take into account only the active and passive mobility of the upper limb joints. The patient studied did not present active or passive shoulder limitation in the sagittal and coronal planes during clinical examination. However, kinematics evaluation revealed anomalies in these two dimensions during movement. The interpretation of these anomalies encountered must therefore make the difference between a primary anomaly, related to a muscular deficit or an architectural vice, and a secondary anomaly, linked to a compensation. Probably, in the patient studied, the preoperative anomalies in the sagittal and coronal planes were compensations since they improved after correction of the rotational anomaly. Moreover, CMC and amplitude analysis allowed objective, quantified evaluation of the postoperative improvement.
Mosqueda et al. [20] investigated upper limb kinematics in a group of patients with OBPP of the upper roots and also showed that there were kinematics anomalies in three dimensions during various tasks performed. Their study nevertheless focused only on preoperative evaluation. The objective of our work was post-humeral osteotomy assessment and the quantification of gains made by surgery.

Study limitations

For the shoulder, we evaluated only arm movements in relation to the trunk, as in other studies [4]. The two tasks described did not require abduction beyond 40°, and therefore require little motion in scapulo-thoracic joint. Nevertheless, we believe it is important to consider scapular position during tasks needing more significant shoulder amplitude [24]. Our study was performed on only one case pre- and postoperatively, and the objective of this protocol will be reached only by investigating a larger number of patients.

It appears to us that synchronous electromyographic analysis of various muscle groups of the upper limb during task performance is indispensable and complementary to kinematics study. Our protocol includes the recording of 11 muscle groups of which analysis is in progress.

Conclusion

We have developed a kinematics protocol for analysis of the upper limb to complete the clinical examination with objective, quantified data. The goal of this analysis is to provide quantified data to clinicians, making it possible to supplement their clinical evaluation and to compare the results before and after treatment. Our work has confirmed the interest in such evaluation of a child with OBPP. These preliminary observations will nevertheless have to be confirmed by studying a larger number of patients and in association with electromyographic analysis.

Conflict of interests

None.

References