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Comparison between visual and three-dimensional gait analysis in patients with spastic diplegic cerebral palsy

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Abstract

Fifty patients with spastic diplegic cerebral palsy were included in this retrospective study which compared visual assessment of gait to three-dimensional (3D) gait analysis. Inter-observer variability was evaluated as well. Inclusion criteria comprehended independent ambulation (i.e. without assistive devices or orthoses). All subjects went through 3D gait analysis at the Gait Analysis Laboratory of the AACD Hospital. Four observers, viewing videotaped gait cycles, evaluated 10 specific points of interest of the cycle: hip flexion at terminal stance; knee flexion at initial contact; knee extension at terminal stance; knee flexion at initial swing; ankle dorsiflexion at initial contact; pelvic obliquity at mid stance; hip adduction at loading response; pelvic rotation; hip rotation at mid stance and foot progression angle, in relation to the lower limb, at mid stance. Their evaluation was then compared to the 3D kinematics data. A statistical analysis of the results was performed using kappa and McNemar's test in order to determine inter-observer and visual/3D analysis agreement. Results showed that inter-observer agreement was high but on the other hand, only two points of the gait cycle (knee flexion at initial contact and pelvic obliquity) were shown to have been similarly evaluated visually and with the 3D analysis. In conclusion, this study indicates that only knee flexion at initial contact and pelvic obliquity appear to be reliably evaluated on a visual basis alone. Visual observation is therefore inadequate for the evaluation of the other eight selected points of the gait cycle which require some form of quantitative assessment.

Keywords: Cerebral palsy; Spastic diplegia; Gait analysis; Gait laboratory; Visual gait assessment

1. Introduction

Cerebral palsy (CP) results from a static injury to the developing brain [1]. This type of injury to the central nervous system commonly results in abnormal motor control with associated delay in the onset of walking and on an abnormal gait pattern [2].

Gait analysis is the systematic measurement, description and assessment of quantities that characterize human locomotion [3,4]. These techniques have been proposed for use in the management of children with walking disabilities in order to provide detailed data on the components of gait and add information during decision making processes [5].

The modern gait laboratory relies on four interdependent disciplines: visual observation (the observer's capacity to assess body movements, in two planes, during fast, repetitive gait cycles), quantitative measurement (kinematic parameters of gait, time–distance measurements and joint angles), biomechanical analysis (forces and their effects in gait) and electromyography (EMG). Gait analysis or gait assessment is comprised of the combination of all these methods [6].

Before the development of three-dimensional (3D) gait analysis systems, the evaluation of the patient with CP was

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based on physical examination, selected radiographs and visual gait evaluation [7].

Analysis of the gait cycle is possible for all joint levels (foot, ankle, knee, hip and pelvis) with the use of kinematic plots for motion in all three planes of body movement: coronal, sagittal and transverse. Familiarity with gait plots for the major joint levels in the three planes of motion provides the framework for understanding normal walking. A deviation from these plots is therefore relatively easy to visualize and understand [3].

Visual observation relies on the observer being able to assess body movement in two planes (sagittal and coronal), assess step length and step time as well as movements occurring at the pelvis, hip, knee and ankle–foot during the gait cycle [8].

Utilization of a diagnostic matrix that includes quantitative gait analysis will play a central role in the incorporation of an evidence-based-medicine paradigm for clinical decision making to optimize the walking ability of children with CP [9].

The purpose of this study was to test inter-observer reliability in observational gait analysis (OGA), determine its correlation to a method of quantitative gait analysis (QGA), and to identify existent correlations between the studied parameters, all this in a population of patients with spastic diplegic CP. Our final objective was to transpose the overall results to our clinical practice after determining which aspects of the gait cycle could be evaluated reliably through visual assessment and which gait points of interest really require a quantitative method for their appraisal.

2. Methods

In this retrospective study, 50 patients with spastic diplegic CP, older than 8 years, evaluated in the Gait Analysis Laboratory of the AACD Hospital between May and October 2004, were reviewed. Independent gait without orthoses or assistive devices, corresponding to levels I and II of the Gross Motor Function Classification System (GMFCS), were considered inclusion criteria [10].

Video recordings were performed in the gait laboratory using sagittal and coronal cameras. Patients strolled down a walkway and were recorded in real-time split-screen video along with close-ups of their feet.

The 3D kinematics data were collected using a Vicon 370 six-camera system (Oxford Metrics, Oxford, UK). All data were analyzed using the models implemented in the Vicon Clinical Manager; employing the Helen Hayes marker set with an estimation of joint centers based on Davis' anthropometric model [11].

Each case was reviewed by four physical therapists, each with previous clinical experience in CP plus an additional 2 month training period in normal gait and gait analysis which was provided to them before evaluations got started. The initial review process included videotape analysis with the convenience of slow motion and freeze-frame replay. Each rater was blinded to the conclusions of the others.

Ten specific points of interest of the gait cycle were observed: hip flexion at terminal stance (with the onset of the mid stance phase the hip progressively extends and the thigh reaches neutral alignment at 38% of the gait cycle and then assumes a posteriorly aligned posture with peak hip extension, of about 10°, occurring as the other foot touches the ground); knee flexion at initial contact (knee is flexed about 5° at initial contact); knee extension at terminal stance (minimum stance phase flexion of the knee averaging 3° is reached about midway in terminal stance, or at 40% of the gait cycle); knee flexion at initial swing (60° is the maximum knee flexion angle reached at initial swing); ankle dorsiflexion at initial contact (the initial contact occurs in a neutral position or on a slight plantar flexion of about 3–5°); pelvic obliquity at mid stance (neutral pelvic position is reached about midway through mid stance); hip adduction at loading response (peak hip adduction of about 5° occurs at loading response); pelvic rotation (a small arch of motion is expected at the pelvis on the transverse plane with about 10° of posterior and anterior rotation); hip rotation at mid stance (peak internal rotation of about 5° occurs at the end of the loading response and just before the onset of the mid stance phase of the cycle) and foot progression angles at the mid stance phase [4].

Observers then independently filled out a record of evaluation (Appendix A). Each of the 10 studied events could be evaluated as normal, decreased or increased and only a single answer was considered for each topic. The same points of interest of the gait cycle analyzed in the video were studied with kinematics data. At least six gait cycles per side were collected and the mean values of each patient was selected. In order to make the comparison between OGA (subjective) and QGA (objective) possible, the degree values obtained using the RES4® program (Gillette Children's Hospital – Motion Lab) were classified according to normal walking database. All values between ±1 standard deviation (S.D.) from the mean, according to the RES4® program, were considered normal. Those values 1S.D. above from the mean were defined as increased and those 1S.D. below the mean were defined as decreased.

Comparisons between observers and between visual and 3D analysis were assessed by evaluating observer scores for each child. The grading of the kappa was carried out according to Landis and Koch [12] (Table 1). The disagreements shown above and below the agreement diagonal were also assessed by McNemar's test [13]. Differences were considered significant when the value of p was less than 0.05.

Finally, statistical analysis was done to verify the inter-observer variability and, for each of the several studied gait points of interest, to determine the reliability of a visual gait analysis when compared to kinematics data.

Table 1
Agreement categorization for Kappa values

Kappa value	Strength of agreement
<0.00	Poor
0.00–0.20	Slight
0.21–0.40	Fair
0.41–0.60	Moderate
0.61–0.80	Substantial
0.81–1.00	Almost perfect

Interpretation: Landis and Koch [12].

3. Results

3.1. Inter-observer agreement

Inter-rater kappa scores are shown in Table 2. Agreement was fair for hip adduction at loading response ($k = 0.39$–0.25), knee position at initial swing ($k = 0.32$–0.31) and for hip extension at terminal stance ($k = 0.36$–0.38). The knee position at initial contact ($k = 0.29$–0.54) and the hip rotation at mid stance ($k = 0.45$–0.40) showed fair to moderate agreement. Kappa statistics showed agreement that was moderate for knee position at terminal stance ($k = 0.44$–0.56), foot progression angle at mid stance ($k = 0.59$–0.46), position of the pelvis on transverse plane ($k = 0.53$) and pelvic obliquity ($k = 0.58$). Agreement for ankle dorsiflexion at initial contact ($k = 0.88$–0.74) was substantial to almost perfect. Among all gait cycle points selected the largest index in diagonal agreement was ankle dorsiflexion at initial contact (98.04–34.12%) and the smallest index was knee flexion at initial swing (52.94–55.77%).

3.2. Observational gait analysis versus quantitative gait analysis

Agreement for ankle dorsiflexion at initial contact ($k = 0.01$–0.10) and for hip adduction at loading response ($k = 0.15$–0.12) was slight. Agreement for hip rotation at mid stance was slight to fair ($k = 0.13$–0.36). Kappa statistics showed agreement that was fair for hip extension at terminal stance ($k = 0.31$–0.24), knee position at initial swing ($k = 0.35$–0.21), pelvic rotation ($k = 0.22$) and knee position at terminal stance ($k = 0.35$–0.33). Hip rotation at mid stance showed slight to moderate agreement ($k = 0.13$–0.49). Agreement for pelvic obliquity was moderate ($k = 0.51$) and for knee position at initial contact was moderate to substantial ($k = 0.65$–0.47). Among all gait cycle points studied, largest index in diagonal agreement was knees flexion at initial contact (96.08–88.24%) and the smallest index was ankle dorsiflexion at initial contact (33.33–35.29%) (Table 3).

4. Discussion

Gait analysis has been a very useful tool in the assessment of children with CP. It is used both to guide and evaluate treatment [14,15]. With time, the medical approach to gait

Table 2
Agreement data among observers obtained by Kappa and McNemar tests

Question	Kappa test			McNemar test		
	Side	k	p	Diagonal agreement (%)	X^2	p
1. Hip extension at terminal stance	R	0.36	0.01	66.00	4.76	0.05
	L	0.38	0.001	70.60	5.40	0.05
2. Knee flexion at initial contact	R	0.54	0.001	88.24	6.00	0.02
	L	0.29	0.01	82.25	2.78	NS
3. Knee extension at terminal stance	R	0.44	0.001	70.59	0.60	NS
	L	0.56	0.001	76.47	0.33	NS
4. Knee flexion at initial swing	R	0.32	0.001	55.77	3.52	0.05
	L	0.31	0.001	52.94	6.00	0.02
5. Ankle dorsiflexion at initial contact	R	0.88	0.001	98.04	1.00	NS
	L	0.74	0.001	94.12	3.00	NS
6. Pelvic obliquity		0.58	0.01	78.43	0.09	NS
7. Hip adduction at loading response	R	0.39	0.001	66.67	1.47	NS
	L	0.25	0.01	60.78	5.00	0.05
8. Pelvic rotation		0.53	0.001	74.51	0.69	NS
9. Hip rotation at mid stance	R	0.45	0.001	72.55	0.29	NS
	L	0.40	0.01	70.59	3.27	NS
10. Foot progression angle at mid stance (related to the lower limb)	R	0.59	0.001	76.00	1.33	NS
	L	0.46	0.001	74.51	0.08	NS

R, right side; L, left side; NS, non-significant.

Table 3
Agreement data between visual and computerized gait analysis obtained by Kappa and McNemar tests

Question	Kappa test			McNemar test		
	Side	*k*	*p*	Diagonal agreement (%)	X^2	*p*
1. Hip extension at terminal stance	R	0.31	0.01	66.67	4.76	0.05
	L	0.24	0.01	60.78	7.20	0.001
2. Knee flexion at initial contact	R	0.65	0.01	96.08	2.00	NS
	L	0.47	0.001	88.24	0.00	NS
3. Knee extension at terminal stance	R	0.35	0.01	68.63	1.00	NS
	L	0.33	0.001	68.63	9.00	0.001
4. Knee flexion at initial swing	R	0.35	0.001	56.86	8.91	0.01
	L	0.21	NS	50.98	1.00	NS
5. Ankle dorsiflexion at initial contact	R	0.01	NS	33.33	1.88	NS
	L	0.10	NS	35.29	2.45	NS
6. Pelvic obliquty		0.51	0.01	76.47	1.33	NS
7. Hip adduction at loading response	R	0.15	NS	43.14	0.03	NS
	L	0.12	NS	35.29	3.67	NS
8. Pelvic rotation		0.22	0.05	52.94	2.67	NS
9. Hip rotation at mid stance	R	0.13	0.05	43.14	1.69	NS
	L	0.36	NS	43.14	0.03	NS
10. Foot progression angle at mid stance (related to the lower limb)	R	0.13	0.01	52.94	10.67	0.001
	L	0.49	0.001	74.51	3.77	NS

R, right side; L, left side; NS, non-significant.

analysis became less empiric, more rational and based on the physiopathology of the disease. As a result, the decision making process concerning children with CP has changed a lot during the past 10 years [16]. Although some instrumented gait analysis systems have been shown to give reliable and valid measurements, they are costly and may be impractical for most clinicians to use as an everyday assessment tool [17].

Observational gait analysis can be greatly facilitated by the use of color videotape with slow motion and computer-controlled freeze-frame resources [14]. This type of gait analysis can still be reasonably reliable and consistent with the observers' specific training on normal gait parameter values [18].

However, accurate assessment of treatment cannot be achieved with videotape alone [14]. Visual analysis does not emphasize quantitative data [6] and it has only low to moderate inter-observer accordance levels, even among experienced ones [18,19]. Mild disruptions, as important for the gait cycle as they may be, cannot be visualized often, even by trained observers. These very same disruptions can, on the other hand, be easily detected by kinematic analysis [14].

All this correlates with the data demonstrated in our present study. In spite of the fact that six items (pelvic rotation, foot progression angle, pelvic obliquity, knee extension at terminal stance, right knee flexion at initial contact and ankle dorsiflexion at initial contact) presented moderate to almost perfect categorical inter-observer agreement, only three items (left foot progression angle, pelvic obliquity and knee flexion at initial contact) presented moderate to substantial categorical agreement values when we compared visual to 3D analysis. High inter-observer agreement levels can be explained by the fact that all observers had taken the exact same visual analysis training course, had academic backgrounds which were very alike and also a similar professional experience.

According to Read et al. [20], coronal plane observations are possibly the most difficult to interpret during viewing. However, DeLuca et al. [7], when analyzing the differences concerning surgical decisions for patients with CP which were based either on visual or on 3D gait analysis, found that transverse plane visualization was also very limited and troublesome. Therefore, there is no consensus in the literature on which plane is harder to be visually analyzed. In this study, by observational analysis, the lowest inter-observer agreement was found for the assessment of knee flexion at initial swing in the sagittal plane (55.77–52.94%, $k = 0.31$ and 0.32).

Ankle dorsiflexion at initial contact was the event that presented the highest inter-observer agreement index. However, it was also the point of interest which obtained the lowest OGA/QGA agreement index, which comes in accordance to DeLuca's study [7], where there were dramatic changes in surgical recommendations for gastrocnemius lengthening after the computerized gait analysis was performed. The reason of this is based mainly on the fact that foot position at initial contact does not depend on the ankle alone, but on the entire lower limb positions as a whole. Therefore, increased knee flexion in the beginning of the gait cycle can produce a forefoot floor contact even when the ankle presents an appropriate dorsiflexion. Another possible explanation for this poor OGA/QGA agreement is that, for the visual analysis, the position of the foot is considered in relation to the floor and not in relation to the tibia.

The slight agreement between methods regarding hip adduction in loading response can be explained by the fact that some patients in this study presented crouch gait. Knee flexion in conjunction with the internal rotation of the hip can generate a visual appearance of hip adduction [7].

OGA/QGA agreement for hip extension in terminal stance was fair, the exact position of the hip is usually difficult to visualize probably because pelvic and associated hip position during standing and gait is a result of a complex relationship between trunk and lower extremity positions [7].

Pelvic asymmetry in the transverse plane (i.e. one side rotated forward), can give the impression of ipsilateral internal hip rotation even though the hip may actually be neutrally rotated in relation to the pelvis, which can explain the differences found between visual and computer analysis of hip rotation at mid stance [7].

Transverse plane rotations, specifically internal femoral rotations, make it very hard to assess the sagittal plane of motion of the knee [7]. This is probably the largest cause for the ‘‘fair’’ agreement index found in this present study for knee extension at terminal stance and knee flexion at initial swing.

The rotation of the hip, femur, tibia and talus influences foot progression angles, which actually represents the sum of the four previously mentioned components [21]. Previous studies demonstrated that evaluations based exclusively on visual analysis of the foot progression angle could lead to inappropriate decisions, due to the difficulty of evaluating these segments in an isolated fashion [7].

Visual assessment of pelvic rotation is very limited once visual observation is limited to evaluating body movements in only two planes (sagittal and coronal). Kinematic analysis supplies larger specificity when analyzing those rotational deviations which occur in the transverse plane [22].

According to McNemar’s test [13], most items were not significant. That means there was not a tendency from the observer to underestimate or overestimate appraised items, the same happened when visual analysis was compared to computer assessment.

We could observe through this study that visual gait analysis, in spite of being quite frequently used in clinical practice, cannot be considered, individually, as a totally reliable method. As demonstrated by our study, six out of the 10 analyzed variables (ankle dorsiflexion at initial contact, right knee flexion at initial contact, knee extension at terminal stance, pelvic obliquity, foot angle progression related to the lower limb at mid stance and pelvic rotation), presented moderate to almost perfect kappa scores between observers, but within these six variables, only one, pelvic obliquity, also bore one of the highest OGA/QGA agreement indexes.

At present, it is unlikely that most Brazilian centers will be able to afford expensive computer-based systems and so 3D analysis becomes for us inaccessible at least on a large scale. Previous studies already proved that a small increase of reliability of visual analysis can be obtained when it is performed through frame by frame video observation and in association with a properly performed physical examination and EMG. However, this approach does not change the importance and need for a quantitative measurement as the one allowed by a computerized assessment.

The objective of the present study consisted on comparing visual and 3D gait analysis in patients with spastic diplegic CP. We noted that, among 10 studied items, only two (pelvic obliquity and knee flexion at initial contact) can be reliably evaluated on a visual basis alone, and that for all the other eight items a quantitative method of assessment is required even if inter-observer agreement occurs. In conclusion: the majority of visual observations are not reliable; there is strong disagreement between OGA and GGA for most parameters and when visual observers agree on something it does not necessarily mean they are getting it right, in most cases it just means they are probably simply making the same mistake.

Future researches carried out with a larger number of observers may better judge visual gait analysis sensibility and may also better define complementary techniques or examinations which can in fact increase its reliability.

Appendix A

Sagital Plane

1. Hip at terminal stance:

R	( ) normal extension	( ) decreased extension	( ) increased extension
L	( ) normal extension	( ) decreased extension	( ) increased extension

2. Knee at initial contact:

R	( ) normal flexion	( ) increased flexion	( ) increased extension
L	( ) normal flexion	( ) increased flexion	( ) increased extension

3. Knee at terminal stance:

R	( ) normal extension	( ) increased flexion	( ) hyper extension
L	( ) normal extension	( ) increased flexion	( ) hyper extension

4. Knee at initial swing:

R	( ) normal flexion	( ) decreased flexion	( ) increased flexion
L	( ) normal flexion	( ) decreased flexion	( ) increased flexion

5. Ankle at initial contact:

R	( ) normal dorsiflexion	( ) decreased dorsiflexion	( ) increased dorsiflexion
L	( ) normal dorsiflexion	( ) decreased dorsiflexion	( ) increased dorsiflexion

Coronal plane

6. Pelvic obliquity:

( ) symmetrical ( ) left hemipelvis drop ( ) right hemipelvis drop

7. Hip at loading response:

R	( ) normal adduction	( ) increased adduction	( ) decreased adduction
L	( ) normal adduction	( ) increased adduction	( ) decreased adduction

Transverse plane

8. Pelvic rotation:

( ) symmetrical ( ) right hemipelvis rotated forward ( ) left hemipelvis rotated foward

9. Hip rotation at mid stance:

R	( ) neutral rotation	( ) internal rotation	( ) external rotation
L	( ) neutral rotation	( ) internal rotation	( ) external rotation

10. Foot rotation angle at mid stance (related to the lower limb):

R	( ) neutral rotation	( ) internal rotation	( ) external rotation
L	( ) neutral rotation	( ) internal rotation	( ) external rotation

* Define "Normal" from QGA as all values between 1 Standard Deviation (SD) from the mean, "Increased" as >1SD from the mean and "Decreased" as <1SD from the mean.

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