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Mechanical work and energy consumption in children with cerebral palsy after single-event multilevel surgery

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ABSTRACT

Multilevel surgery is commonly performed to improve walking in children with cerebral palsy (CP). Classical gait analysis (kinetics, kinematics) demonstrated positive outcomes after this intervention, however it doesn't give global indication about gait's features. The assessment of energy cost and mechanical work of locomotion can provide an overall description of walking functionality. Therefore, we propose to describe the effects of multilevel surgery in children with CP, considering energetics, mechanical work, kinetic and kinematic of walking. We measured external, internal, total work, energy cost, recovery, efficiency, kinetic and kinematic of walking in 10 children with CP (4 girls, 6 boys; 13 years ± 2) before and 1 year after multilevel surgery. Kinetic and kinematic results are partially comparable to previous findings, energy cost of walking is significantly reduced ($p < 0.05$); external, internal, total work, recovery, efficiency are not significantly different ($p = 0.129$; $p = 0.147$; $p = 0.795$; $p = 0.119$; $p = 0.21$). The improvement of the walking's energy consumption is not accompanied by a corresponding improvement of mechanical work. Therefore it is conceivable that the improvement of walking economy depend on a reduced effort of the muscle to maintain the posture, rather then to an improvement of the mechanism of energy recovery typical of human locomotion.

1. Introduction

Children with cerebral palsy (CP) are characterized by many heterogeneous disorders that unavoidably influence the functions related to everyday activities. Walking is one of the most compromised functions in CP, therefore this condition affects participation and quality of life of this population. Nowadays single-event multilevel surgery (SEMS) is commonly performed to improve walking in children with CP [1–5]. The successful outcomes of this procedure have been demonstrated by several studies. For instance, it has been shown that it can improve the capability to achieve sagittal plane balance [5]; that the kinematic and kinetic of walking become more similar to the one of the healthy population, and therefore more advantageous [1]; the speed and the stride length can change significantly [1]; without improvement of the GMFM-66 [5].

In the last years, gait analysis has become a very common tool for the assessment of several clinical populations, and for the correct managing of the treatment. Indeed the information obtained by this evaluation procedure is considered necessary for planning the surgical interventions and it represents a good instrument to verify the treatment's effectiveness [1–8].

Classical gait analysis focuses on the body segments, joint angles, muscular moments and powers during the gait cycle. Although this method provides detailed information about the walking's mechanic, it does not provide directly evidences of treatment effectiveness in the everyday life. The measure of energy cost (C) and mechanical work (W) of locomotion can be useful since they consist of global index of walking's functionality [9].

Many studies demonstrated that C tends to be larger in CP than in normal developing children [10–17]. One of the explanations of

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this low economy of walking, consist in an increased mechanical work in the CP population [17], likely due to an exaggerated vertical displacement of the body centre of mass (COM_b).

The evaluation of C has become quite common in clinical assessment of walking, for many types of pathologies [6–9]. Whereas, W is not a common evaluation parameter in clinical environment, maybe because requires more complicated computational procedures. The evaluation of W, might allow to understand whether the modification of the gait, due to SEMS, have actually a significant impact on the pendulum like mechanism of energy recovery, typical of human walking. An improvement of walking's pendulum mechanism, would mean a reduction of the total work of the muscles to enable the body's advance, and of the energy waste, and hence it should be reflected in reduction of C. This method could provide some new information about the efficacy of SEMS to improve walking's functionality.

The present study aims to describe the energy consumption and the mechanical work of locomotion, combined with kinetics and kinematics, in CP children, before and one year after SEMS.

2. Material and methods

The study was conducted in accordance with the 1964 Declaration of Helsinki. The ethical committee of the Clinique gave his approval to the aims, protocols and methods of the study. The children and their families were informed about the procedures and the relative risks about the assessment and surgical procedures, in clinical routine practice. This is a prospective study. Ten children with diplegic, hemiplegic and tetraplegic CP who had undergone a SEMS (4 girls, 6 boys; age: 13 years ± 2; height: 149.3 cm ± 8.8; weight: 39.4 kg ± 9.8) participated to this study (GMFCS between I and III). The patients were enrolled in the study between 2005 and 2010, and they processed to SEMS between 2005 and 2009. The anthropometrical and identifying data are reported in Table 1.

All children were processed to a clinical examination and gait analysis, before and after SEMS (5.5 ± 3.11 months before SEMS, and 12.4 ± 1.6 months after).

2.1. Clinical assessments

The clinical scale used for the walking evaluation was a translated Gillette Scale in French [18].

2.2. Gait analysis

2.2.1. Kinematic data

Gait was assessed using a 3D Gait Analysis motion system, which included synchronous kinematic, kinetic, mechanic and metabolic measurements. The patient was walking on a treadmill at spontaneous speed. Six CCD infrared cameras (Elite system V5, BTS; Milan, Italy) at 100 Hz, were used to collect the kinematic data, recording the coordinates in the 3 spatial planes of 19 reflective markers positioned on specific anatomical landmarks (according to the Davis' protocol [19]. From kinematic data, the angular displacements of pelvis, hip, knee and ankle were calculated in the 3 planes.

Spatiotemporal parameters were assessed using the 3D position data of foot (cadence, step length, and percentage of stance phase duration). The same speed was maintained in the first and in the second assessment.

2.2.2. Mechanical data

Total positive mechanical work (W_{tot}) performed by the muscles was calculated by the sum of external work (W_{ext}) (performed to move the body centre of mass (COM_b)), and internal work (W_{int}) (performed to move the body segments relative to the COM_b).

W_{ext} was computed by the measurement of the ground reaction force in the three directions, by means of four strain gauges located under each the four corners of the treadmill [20,21]. From the ground reaction forces, by an integration of the COM_b's acceleration, it was possible to calculate the COM_b's speed (V), then kinetic energy in the three directions was calculated (forward: $E_{kf} = m \times V_f^2 \times 2^{-1}$; vertical: $E_{kv} = m \times V_v^2 \times 2^{-1}$; lateral: $E_{kl} = m \times V_l^2 \times 2^{-1}$; where m = mass). By a second integration of E_{kv} it was possible to calculate the vertical displacement (S_v) of COM_b, and then gravitational potential energy ($E_p = m \times g \times S_v$). The energy necessary to move COM_b in the three directions (W_{ekf}; W_{ekv}; W_{ekl}) was calculated by the sum of the increments of each curve E_{kv}, E_{kl} and E_v (E_v calculated by the sum of E_{kf} and E_p). Total W_{ext} performed by the muscles was calculated by adding E_{kf}, E_{kv}, E_p curves, to obtain the total mechanical energy curve. Then by adding the increments of the total mechanical energy curve it was possible to calculate the total mechanical energy necessary to move COM_b.

W_{int} was calculated by the kinematic, according to the method of Willems [22]. The body was divided in 7 rigid segments: head–arm–trunk (H.A.T.), thighs, shanks, and feet. For each segment rotational and translational energy were calculated. Then the internal mechanical energy/time curve of thigh, shank and foot of each lower limb, were summed up together to take into account the transfer effect. Then the internal mechanical energy of H.A.T. and limbs were summed up. Percentage recovery was calculate by the following equation: $100\,[(W_{ekf} + W_{ekv} + W_{ext})/(W_{ekf} + W_{ekv})$, as proposed by Cavagna [20].

2.2.3. Kinetic data

By the four strain gauges it was possible to recorder the ground reactions forces [20] and deduced the force under each foot [23]. By

Table 1
Age, anthropometric and clinical data of the subjects before and after surgery.

Subject	Sex	Age			Height (m)		Weight (Kg)		GMFCS	Involvement	Gait Pattern
		yy	mo	Total months	Pre	Post	Pre	Post			
1	f	14	9	177	1.63	1.63	63	61	1	Bilateral	Jump
2	m	15	3	183	1.61	1.65	45	50	3	Bilateral	Crouch
3	m	16	5	197	1.53	1.61	38	38	2	Unilateral	Jump
4	f	11	1	133	1.44	1.46	41	45	2	Unilateral	Jump
5	f	12	11	155	1.52	1.57	38	53	2	Bilateral	Jump
6	f	14	1	169	1.45	1.45	35	37	1	Unilateral	Jump
7	m	13	1	157	1.49	1.58	34	40	1	Unilateral	Jump
8	m	13	7	163	1.40	1.50	33	38	1	Unilateral	Crouch
9	m	9	3	111	1.37	1.43	29	32	2	Bilateral	Jump
10	m	16	8	200	1.72	178	58	63	2	Bilateral	Crouch
Average		13.30	4.90	164.50	1.52	1.57	41.28	45.65			
St. Dev.		2.21	3.67	27.57	0.11	0.11	10.97	10.56			