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Electromyographic analysis of rectus femoris activity during seated to standing position and walking in water and on dry land in healthy children and children with cerebral palsy

L.C. Oliveira [a,*], T.O. Trócoli [b], M.S. Kanashiro [a], D. Braga [a], F.N. Cyrillo [c]

[a] Associação de Assistência à Criança Deficiente (AACD), São Paulo, Brazil
[b] Instituto de Assistência Médica ao Servidor Público Estadual (IAMSPE), São Paulo, Brazil
[c] Universidade Cidade de São Paulo (UNICID), São Paulo, Brazil

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ABSTRACT

Purpose: To analyze rectus femoris activity during seated to standing position and walking in water and on dry land comparing a group of children with the spastic diparesis type of cerebral palsy (CP) and a group of children without neurological disorders. *Methods:* This study included a group of nine children with CP and a control group of 11 children. The study compared the electromyographic activity of the rectus femoris during seated to standing position and walking, in water and on land. *Results:* A greater activation of the rectus femoris was observed in the group of children with CP compared with the control group when moving from a seated position to a standing position in water ($p = 0.0039$) and while walking on land ($p = 0.0014$) or in the pool ($p = 0.007$). *Conclusion:* This study demonstrated the activation of the rectus femoris while walking or standing up from a seated position in water was greater in the group of children with CP. Further studies should be performed to better understand the extent of muscular activation during body immersion in individuals with neurological disorders.

1. Introduction

Cerebral palsy (CP) is the umbrella name for a group of developmental disorders that affects movement and posture. CP results from nonprogressive abnormalities during the development of the fetal or infant brain and results in limited functional activities. The resulting motor phenotypes are frequently accompanied by sensory, cognitive, communication, perception, and behavioral disorders (Rosenbaum et al., 2007; Ferreira and De Paula, 2006; Schwartzman, 2004).

In recent years, the incidence of CP in developed countries has been between 1.5 and 2.5 per 1000 live births. Interestingly, the incidence of CP in developing countries is 7 per 1000 live births (Mancini et al., 2002; Cândido, 2004; Leite and Prado, 2004).

The sequelae of CP are variable, and their functional consequences are diverse; therefore, it is difficult to classify children with CP based on the clinical profile of their motor activities (Rosenbaum et al., 2007). According to the Committee for the Definition of Cerebral Palsy, various components must be considered when classifying CP, including motor abnormalities (the nature and typology of the motor disorders); functional abilities, which are classified using objective scales; associated deficiencies; anatomical and neuroimaging findings; and the cause and timing of symptom manifestation (Rosenbaum et al., 2007).

The Gross Motor Function Classification System (GMFCS) was created with the Committee for the Definition of Cerebral Palsy components in mind to classify the levels of gross motor function in children with CP. The GMFCS levels range from I to V, with V indicating the most severe impairment (Hanna et al., 2008; Palisano et al., 2000). Pediatric patients are divided into the following age groups: 0–2 years of age, 2–4 years of age, 4–6 years of age, 6–12 years of age, and 12–18 years of age (Palisano et al., 2000; Pfeifer et al., 2009). The GMFCS scale evaluates various motor activities, including sitting, moving, running, jumping, and walking (Hanna et al., 2008). The levels of gross motor function are distinguished based on the degree of functional limitation, the dependence on a walking aid, and the use of a wheelchair (Palisano et al., 2000).

Children with CP display various changes in their walking gait, including decreased speed, changes in patterns of movement, decreased ability to appropriately plan a sequence of movements, reduced muscular activity and strength, and reduced recruitment of motor units (Damiano et al., 2006; Krogt et al., 2007).

* Corresponding author at: 531 Diana St, apt 21, 05019-000 Sao Paulo, Brazil.
E-mail address: layscardoso@hotmail.com (L.C. Oliveira).

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In children with the spastic diparesis type of CP, typical walking disorders may be divided into four groups: genu recurvatum, jump knee, stiff knee, and crouch knee. These disorders alter the biomechanics of the movements involved in walking and affect the activation of the muscular groups of the lower limbs (Rodda et al., 2004).

One method of evaluating muscular activity during walking is through electromyography (EMG). EMG is an experimental technique that is used to detect, record, and analyze myoelectric signals. The EMG signal represents the sum of the nearly simultaneous firing of a set of motor units. Therefore, EMG can be used to capture neuromuscular activation during postural tasks, functional movements, work conditions, and treatment/training programs (Konrad, 2005; Iyer et al., 2001). Importantly, both invasive and superficial electrodes can be used to capture the muscular electrical activity (Konrad, 2005).

Surface EMG is a noninvasive technique that measures the electrical activity that results from the contraction and relaxation of surface muscles (Quach, 2007). The main advantages of surface electrodes are the disposability of the materials and the ease of handling the electrodes (Konrad, 2005).

There is a significant difference in the muscular activity during movements performed on dry land versus movements performed in water. Deeper immersion results in a reduced load on the muscles due to physical principles, such as buoyancy, which decrease the weight that has to be supported by the lower limbs. For example, studies have shown that the weight load of an individual who is immersed up to his xiphoid process decreases by 75% (Barela, 2005). However, the drag force provides resistance to movement, which increases the activation of specific muscles that are responsible for controlling the gait (Barela, 2005; Mazuquin et al., 2009).

Many studies have examined human movements in water, and the gait of adults is one of the most studied movements. There have been few objective EMG analyses of the gait of children with CP in water, and studies are needed to clarify muscle behavior during movement in water compared with movement on the ground.

The purpose of the present study was to analyze rectus femoris activity during seated to standing position and walking in water and on dry land comparing healthy children and those with cerebral palsy.

2. Methods

2.1. Case series

This cross-sectional experimental study was performed in the Division of Aquatic Physical Therapy at the Association for the Care of Disabled Children (Associação de Assistência à Criança Deficiente – AACD) of Sao Paulo. The study was approved by the Ethics and Research Committee of Association for the Care of Disabled Children of Sao Paulo under protocol number 018/2010.

The study sample consisted of 11 children without neurological pathologies and nine patients with a diagnosis of spastic diparesis who were classified as level II on the GMFCS, with crouch knee gait pattern and were undergoing treatment at the AACD. All of the children were between five and ten years of age and were familiarized with aquatic environment. The children's legal guardians were informed of the study objectives and signed an informed consent form.

Exclusion criteria included participants who were not familiarized with water environment, clinical instability, and/or uncooperativeness.

2.2. Materials

A four-channel Miotec® surface EMG with precoated Kendall 200® Ag/AgCl circular electrodes was used to measure muscle recruitment. The electrodes were isolated from the liquid medium using a Bioclusive dressing. The EMG was 140 mm wide, 136 mm long, and 40 mm tall, and it weighed 800 g. We used a Miotool 400 USB model EMG with 14-bit resolution, noise <2 LSB, a one-pole high-pass Butterworth filter, and a two-pole low-pass Butterworth filter at 500 Hz. The Miograph® program was used to acquire and analyze the signal.

2.3. Procedure

All eligible participants in both groups were shaved (when necessary) where surface electrodes were to be placed, and the skin was sterilized with 70% alcohol. The children were placed in a seated position, and the electrodes were placed on the rectus femoris of the right leg to give more freedom of movement when walking in the pool, specifically placed halfway between the top edge of the patella and the anterior superior iliac spine following the recommendations of SENIAM. Four layers of Bioclusive dressing were applied to isolate the electrodes from the liquid medium.

After the electrodes were placed, the patient performed three maximal voluntary isometric contractions (MVICs) that each lasted 5 s, and there was a 2-min interval between each repetition, to calibrate the system before starting the analysis of the movements. After each MVIC, the electrical activity in this muscle was evaluated while the children stood up from a seated position. They were also asked to walk a distance of 3 m to evaluate the activity of the rectus femoris muscle during walking.

All of these activities were analyzed with the participants on dry land and aquatic environment, and it was standardized level of immersion in xiphoid process. So we did not consider anthropometric data such as hight and weight. Each trial was repeated three times, and the water temperature ranged from 32 °C to 33 °C.

2.4. Statistical analysis

The Mann–Whitney U test was used to compare the control group and the group of children with CP, and the Wilcoxon signed-rank test was used to compare the data from the ground and water immersion trials. GraphPad Prism® version 4 software was used to perform the statistical tests. The significance level was set at $p = 0.05$ for all of the comparisons.

3. Results

The study sample consisted in a control group of 11 children without neurological disorders and a group of nine patients with the spastic diparesis type of Cerebral Palsy classified as level II of GMFCS. Both groups had children with ages ranged from 5 to 10 years (Table 1).

All participants were familiarized with water environments, as they were patients in the rehabilitation center, specifically in the Division of Aquatic Physical Therapy, and the control group was also adapted, as they were used to perform recreational activities in pools.

The rectus femoris activation when standing up from a seated position on dry land had no statistical difference between groups ($p = 0.06$) (Fig. 1).

The rectus femoris activation when standing up from a seated position in water was greater in the group of children with CP compared with the control group ($p = 0.003$) (Fig. 2).

The rectus femoris activation in the control group for the same activity (i.e., standing up from a seated position) was lower in water than on land ($p = 0.01$) (Fig. 3).

The rectus femoris activation in CP group when standing up from a chair, comparing the activity on dry ground and in water,

Table 1
Control group and CP group age distribution, range and median.

	Healthy children	CP children
Age (years)	5	5
	5	5
	5	5
	5	5
	6	5
	6	6
	6	6
	6	7
	7	8
	8	
	8	
SD	1.08	1.03
Range	6.09	5.77
Median	6	5

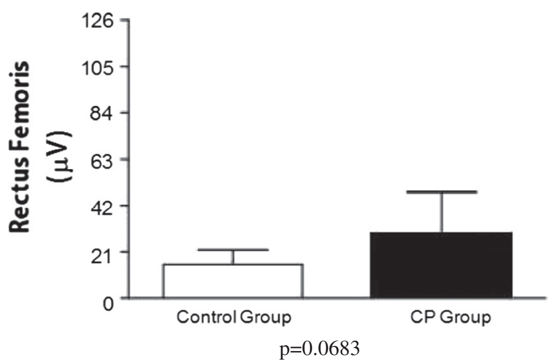


Fig. 1. A comparison of the rectus femoris muscle activity while standing up from a seated position on dry ground between the control group and the CP group.

had no statistical difference between children of the same group ($p = 0.91$) (Fig. 4).

The activity of the rectus femoris while walking on dry land was greater in the group of children with CP compared with the control group ($p = 0.001$) (Fig. 5).

The activation of the rectus femoris while walking in water was also greater in the group of children with CP compared with the control group ($p = 0.007$) (Fig. 6).

The rectus femoris activation for the control group when comparing walking on dry ground and in water had no statistical difference ($p = 0.24$) (Fig. 7).

The rectus femoris activation for the CP group when comparing walking on dry ground and in water had no statistical difference ($p = 0.57$) (Fig. 8).

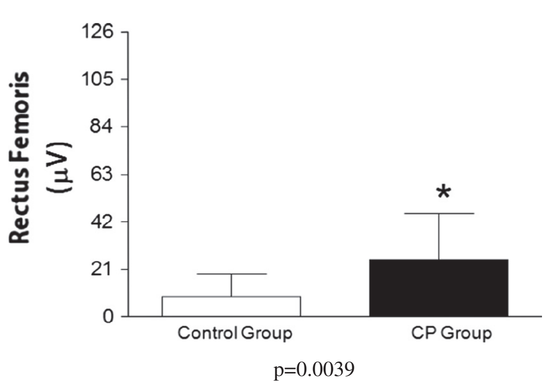


Fig. 2. A comparison of the rectus femoris muscle activity while standing up from a seated position in water between the control group and CP group.

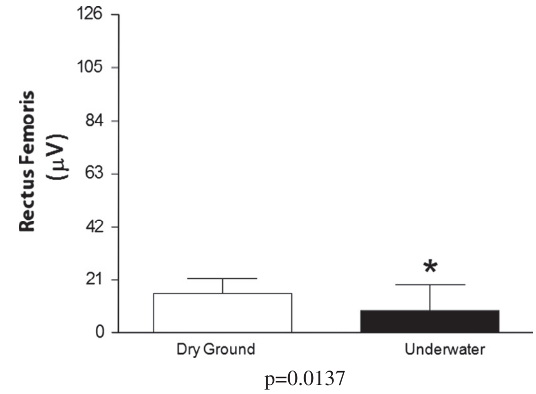


Fig. 3. A comparison of the rectus femoris muscle activity in the control group when standing up from a seated position on land and in water.

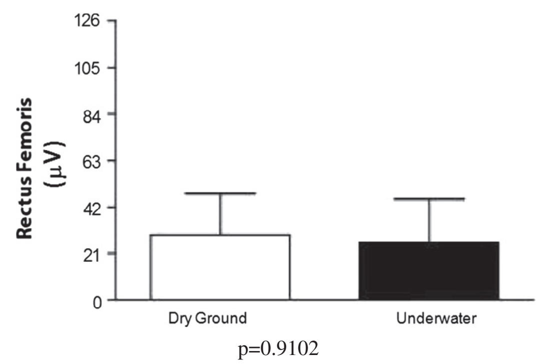


Fig. 4. A comparison of the rectus femoris muscle activity in the CP group while standing up from a seated position on land and in water.

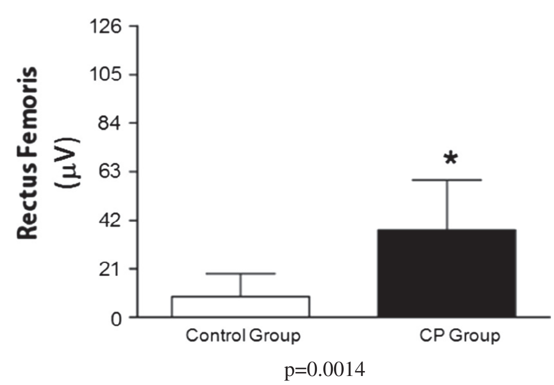
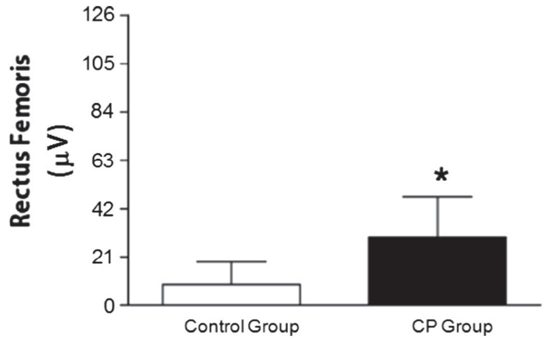


Fig. 5. A comparison of the rectus femoris muscle activity while walking on dry land between de control group and CP group.

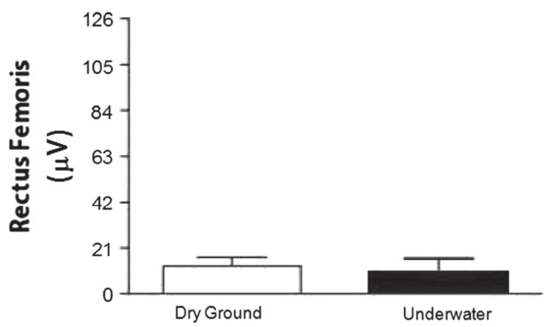
4. Discussion

In the present study, we observed that the group of children with CP had a greater activation of the rectus femoris when walking on dry land compared with the control group. We hypothesized that this difference may have been caused by the "crouch knee" gait pattern, which is characteristic of the spastic diparesis type of CP and involves greater flexion of the knees during the support phase and an increase in the knee extensor moment. Greater flexion of the knees and increased knee extensor movement leads to a



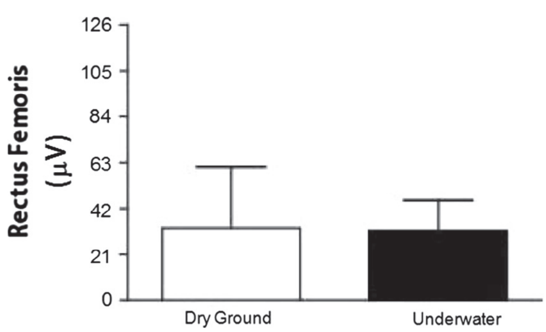
p=0.007

Fig. 6. A comparison of the rectus femoris muscle activity while walking in water between the control group and CP group.



p=0.2402

Fig. 7. A comparison of the rectus femoris muscle activity in the control group while walking on land and in water.



p=0.5703

Fig. 8. A comparison of the rectus femoris muscle activity in the CP group while walking on land and in water.

greater activity of the rectus femoris while attempting to extend the knee (Temelli and Akalan, 2009), which explains the increase in the activity of the rectus femoris while walking on dry land.

The children with CP also exhibited greater activity of the rectus femoris muscle while walking in the liquid medium compared with the control group ($p = 0.007$). This result was contrary to the expectation that less activation would be observed due to the physical principles involved. We believe that the changes caused by CP make it harder for affected children to overcome the resistance of the water, which acts as a barrier to movement by generating molecular friction. In regards to gait, individuals who have a greater difficulty moving exhibit an inconsistent speed of movement and muscle and joint compensation. In addition, when water flows into the low-pressure area between the legs, there is a tendency for individuals with CP to be dragged backwards. Therefore, a greater force is needed to overcome the resistance, and the movements and resulting muscular activation are also greater.

The present results differ from studies in the literature, but the most current data for EMG analysis in an aquatic environment describe populations that are different from the one in this study. According to a review by Mazuquin et al. (2009), there has not been any standardization in the studies that address gait in water using EMG, and different studies have yielded different results.

This study also analyzed the transfer from a seated position to a standing position. The group of children with CP exhibited greater rectus femoris activation when performing this activity in the pool compared with the control group ($p = 0.0039$). The same pattern of activation was observed on dry land (i.e., the group with CP had a greater activation); however, the difference was not statistically significant.

Few comparable studies have been performed, which makes it difficult to compare our results to previously published data. We can hypothesize, however, that the observed increase in the activity of the rectus femoris muscle in CP patients was due to the difficulty of performing activities in unstable situations, such as being immersed in water. Unstable conditions place greater demands on the musculature of children with CP compared with children with no underlying pathology.

We did not assess the rectus femoris at rest because at first it was not the purpose to evaluate the spasticity of the muscle in the group with CP. However, we have observed an increased activity of the rectus femoris muscle in CP patients during activities inside the pool, probably because of the difficulty in balance in unstable conditions.

A study with children with CP that analyzed agonist and antagonist activity (co-contraction ratio) of ankle dorsiflexors and plantiflexors, discuss that excessive antagonist co-activation contributed to weakness in spastic muscle, by reducing the net force produced through reciprocal inhibition of spastic muscle (Poon and Hui-Chan, 2008).

We suggest evaluating spastic muscle at rest as well as agonist and antagonist activity on further studies, to better understand the muscular behavior in rest, in activity conditions and in different environments.

There was less activity in the rectus femoris of the control group while standing up from a seated position in the pool compared with the same movement on the ground ($p = 0.0137$). This result may be explained by buoyancy in the water, which exerts a force in the same direction as the task being performed. Indeed, buoyancy reduces the body weight, facilitates movement, and requires fewer demands of the musculature.

Aquatic physical therapy uses the physical principles of water to facilitate and/or make movement harder, depending on the specific therapeutic objectives. The EMG analysis of the activities of certain key muscles while performing activities in a pool helps to improve the design of physical therapy to achieve specific objectives. In addition, the EMG analysis permits the visualization of the effects of physical principles on the activities that the patients are asked to perform.

Walking in water is clearly different than walking on land due to the specific physical principles of the medium involved. For example, horizontal displacement is slower in water, which is primarily due to the greater density of the liquid medium. Furthermore, body weight is reduced in water due to buoyancy. These factors may result in a lower propulsive force, the maintenance of an upright posture, and less neuromuscular activation when walking in water (Silva and Kruel, 2008).

Further studies of muscle activity during aquatic therapy are necessary, especially in children with neurological disorders that cause changes in muscular activation, coordination, and strength patterns. Similar to the results of the present study, other neurological disorders may lead to muscular responses in a liquid medium that are different than the expected results.

In this study, children with CP displayed greater activation of the rectus femoris muscle while walking and while standing up from a seated position in water compared with the controls. This result likely occurred because the changes in biomechanics and postural control caused by CP make it more difficult for affected children to overcome the resistance generated by the liquid medium, particularly the viscosity and the turbulence. Because of the scarcity of data and the importance of understanding muscular activation behavior, further studies are necessary to improve aquatic therapy.

Conflict of interest

The authors declare that they have no conflict of interest.

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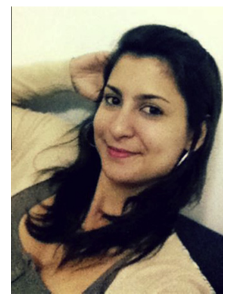
L.C. Oliveira Physiotherapist specialized in Neuropediatrics by the Universidade Federal de São Carlos (Ufscar – SP), working as physiotherapist at the Division of Aquatic Therapy of AACD Rehabilitation Center in Sao Paulo.



Dr. T.O. Trócoli Physical Therapist, master degree in Health Sciences, working with neurological rehabilitation at Hospital do Servidor Público Estadual of Sao Paulo (Brazil).

Dr. M.S. Kanashiro Aquatic Physical Therapist at AACD, specialized in neurological area at Federal University of Sao Paulo (Brazil).

Dr. D. Braga Aquatic Physical Therapist at AACD, hydrotherapy specialist in rehabilitation of neuromuscular diseases at UNIFESP, master degree in Health Sciences at UNIFESP (Brazil).

Dr. F.N. Cyrillo Prof. Master of physical therapy department of Sao Camilo and UNICID Universities (Sao Paulo). Clinical director and owner of fisiologic institute of health solutions (Brazil).