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Characteristics of surface electromyogram signals after Pemberton pelvic osteotomy combined with femoral osteotomy in children with unilateral developmental dysplasia of the hip

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Abstract

This study aimed to assess the surface electromyogram (sEMG) signal characteristics of the muscle around the hip joint after Pemberton osteotomy in children with unilateral developmental dysplasia of the hip (DDH).

A total of 21 children with unilateral DDH who had received Pemberton osteotomy were selected as the DDH group, and 21 healthy children of the same age were selected as the control group. The children in both groups were tested using sEMG, the Root mean square (RMS) values of the tensor fascia lata, rectus femurs, and medial head of the hamstring and gluteus maximum on both sides in standing and walking status were recorded. The value on the affected side in the DDH group was compared with the value on the healthy side himself and the value in the control group.

The mean postoperative follow-up in the DDH group was 27.76±24.30 months. The RMS value of the affected gluteus maximum muscle in the DDH group was significantly larger while standing ($P < 0.05$), the RMS value of bilateral tensor fascia lata muscle was significantly larger while walking ($P < 0.05$), and the RMS value of the affected hamstring muscle medial head was significantly less in the DDH group compared with the control group ($P < 0.05$).

An asymmetry and compensatory increase in the sEMG activity of the muscles around the hip joint when standing and walking was noted in children with unilateral DDH who underwent Pemberton osteotomy combined with a femoral osteotomy. The rehabilitation training of the muscles around the hip joint after unilateral DDH should be strengthened.

Abbreviations: COM-COP = center of mass-center of pressure, DDH = developmental dysplasia of the hip, RMS = Root mean square, SEMG = surface electromyogram.

Keywords: developmental dysplasia of hip joint, femoral osteotomy, Pemberton osteotomy, surface electromyography

1. Introduction

Developmental dysplasia of hip (DDH) is a common orthopedic disease in children. It is also a common disabling factor in children. Early diagnosis and intervention of DDH are crucial. Surgical treatment is needed for children with delayed diagnosis and ineffective conservative treatment. For patients above toddler age, pelvic osteotomy and shortage surgery of the femur are options to treat DDH.[1] Pemberton osteotomy has been reported for more than 50 years as one of the classic radical procedures; its safety and effectiveness have been widely verified. However, some patients with DDH have been reported to have increased joint loading and asymmetrical gait after Pemberton osteotomy.[2,3] Therefore checking the status of muscles around the hip after Pemberton osteotomy is crucial.

sEMG is a safe and noninvasive technique that can quantitatively and qualitatively evaluate neuromuscular functional status.[4] Opar, observing sEMG activity during activities among 28 athletes, suggested hamstring strain injury prevention and

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rehabilitation considering altered neural function following hamstring strain injury.[5] Inspire by this study, the present study was conducted to use the sEMG test for comparing the sEMG signal of the muscle around the hip joint in the control group and the DDH group who underwent Pemberton osteotomy combined with femoral osteotomy, observe the characteristics of muscle activity during daily activities, evaluate the patients from the perspective of microscopic EMG activity, and provide a valuable reference for the formulation of rehabilitation programs.

2. Materials and methods

2.1. General information

Children diagnosed with DDH treated at Hunan Province People's Hospital pediatric orthopedic department between June 2014 to and September 2017 were enrolled in this study. The inclusion criteria were as follows: (1) operation age: 3–8 years old; (2) In children with unilateral DDH, having normal development of the contralateral hip joint; (3) Dysplasia of the hip joint without other causes; (4) acetabular index 35°–60°; (5) Pemberton pelvic osteotomy and femoral shortening osteotomy performed; (6) no metabolic diseases; (7) complete follow-up data such as imaging and sEMG tests; and(8) no history of other surgeries in the lower extremities except the aforementioned ones. The exclusion criteria were as follows: (1) DDH cases treated with other osteotomies; (2) patients with bilateral DDH patients; (3) nerve injury during the surgery; (4) diagnosed with other types of hip dislocation such as teratologic and spastic dislocation of hip.

A total of 21 patients, 18 female and 3 male with an average age of 58.76 ± 18.63 months, were selected as the DDH group. The operation age was 3–8 years, and the mean follow-up duration was 27.76 ± 24.30 months. We choose 21 healthy children similar to those patients in terms of sex, age, height, and weight as the control group (Table 1).

2.2. Evaluation methods and indicators

Children underwent lower limb sEMG tests 12 and 24 months after the surgery, while children in the control group were tested at the same time. The last follow up results were analyzed. Written consent was obtained from the parents or legal guardians of the children.

The test was performed in the sEMG room using the FlexComp sEMG test system (Thought Technology, Canada). The test electrode was a disposable triodes dry electrode, with an outer diameter of 5.6 cm and an electrode diameter of 1.0 cm. The distance between the recording electrode and the reference electrode center was 2 cm. Both lower extremities of patients were fully exposed and wiped with 75% medical alcohol to sufficiently degrease the topical skin. The electrodes were placed in fullest part of the bilateral tensor fascia lata muscle, rectus femoris muscle, and medial head of hamstring muscle (internal) and gluteus maximus, parallel to the direction of the long axis of muscle fibers. sEMG signals were collected while standing and walking.

Table 1.

Comparison of general data between children in the DDH and control groups.

	DDH group	Control group	*p*
Age of last sEMG test (month)	86.24 ± 24.63	87.00 ± 23.50	0.92
Weight (kg)	25.06 ± 8.98	25.56 ± 6.62	0.839
Height (cm)	122.06 ± 13.69	124.75 ± 11.53	0.495
BMI	16.26 ± 2.33	16.17 ± 2.03	0.90

The results showed no significant difference between both groups ($P > 0.05$).

Standing requirement: The patients were required to stand independently, relax the whole body, keep the body straight, stand parallel to the shoulder width, and maintain stability for 30 seconds. The most stable 10 seconds signal data were taken for analysis.

Walking requirement: The patients should walk freely for 2 minutes on an 8 meters long footpath. The signal processing software Bioneuro Infiniti system of the instrument was used to perform root mean square (RMS) processing on the collected sEMG, and the average RMS of the measured muscle was statistically analyzed.

2.3. Statistical analysis

All data were expressed as x ± s. SPSS 21.0 statistical software was used for statistical analysis. The RMS of the affected and healthy sides in the DDH group were compared. Among these, the value of tensor fascia lata and hamstrings (inner) in the standing position, and the bilateral rectus femoris during walking coincided with the normal distribution, and the paired samples *t*-test was used. The remaining values did NOT coincided with normal distribution, and the Wilcoxon rank-sum test was used. Compared with the control group, the measured data of DDH group did not coincide with normal distribution, and the Mann–Whitney U test was used. A P value < 0.05 indicated statistical difference.

3. Results

Compared with the unaffected side, the gluteus maximum RMS value on the affected side was larger in the DDH group while standing, and the difference was statistically significant ($P < 0.05$). However, no statistically significant difference was found in the remaining parts ($P > 0.05$). Compared with the control group, the RMS value of the bilateral tensor fascia lata muscle in the DDH group was larger, and the RMS value of the affected hamstring muscle (internal) was less while walking, with statistically significant difference($P < 0.05$). Compared with the unaffected side, the hamstring (internal) RMS values on the affected side was less while walking, and the difference was statistically significant ($P < 0.05$) (Tables 2 and 3).

4. Discussion

For relatively older children with DDH, Pemberton osteotomy combined with femoral shortening osteotomy is more advantageous in terms of postoperative complication reduction and functional recovery, and the postoperative outcome satisfaction is higher.[6] Our previous research found that the mid-term clinic outcome of Pemberton osteotomy in treating spastic dyspasia of the hip yielded good results.[7] Through a detailed evaluation of the condition, we used this combination procedure for children who fit the indications.

sEMG is an important part of gait analysis. Also, RMS is the most reliable time-domain electromyography parameter used to describe the average variation characteristics of myoelectric over a specific period; it can indirectly reflect the size of the muscle force.[8,9] Under normal circumstances the upright posture can be maintained only depending on the stability of the joint capsule and ligaments, without the contraction of muscles, due to the stable characteristics of the hip joint when standing. The electromyographic activities of the same muscles on both sides should be symmetrical. However, our research found that in a static standing position, the electromyography activity of the gluteus in patients with DDH showed asymmetry, with larger lateral gluteus RMS values. Combined with the result of Xu,[10] we speculated that asymmetric weight-bearing of the lower limbs might be related to the posture control of the pelvis. Children tend to stand with weight-bearing legs,

Table 2.

Differences in RMS values between standing DDH and control groups and between unaffected and affected sides in the DDH group (unit: μV).

		DDH group		P1		
	Control group	Affected	Unaffected	Affected	Unaffected	P2
Tensor fascia lata	2.3 ± 1.23	2.75 ± 1.27	3.05 ± 2.46	0.096	0.246	0.57
Shares of rectus muscle	1.5 ± 0.64	2.63 ± 2.53	3.06 ± 4.20	0.351	0.466	0.434
Hamstring (internal)	7.4 ± 7.22	8.98 ± 11.48	9.89 ± 11.61	0.475	0.347	0.456
Gluteus maximus	1.8 ± 0.84	1.89 ± 0.89	1.68 ± 1.28	0.683	0.113	0.031※

P1 is the comparison between the DDH and the control groups. P2 is the comparison between the affected and the unaffected sides in the DDH group. The results showed a significant difference between the affected and the unaffected sides in the gluteus maximus in the DDH group.(P <0.05)(marked by ※).

Table 3.

Comparison of RMS values between the DDH and control groups and between unaffected and affected sides in the DDH group during walking (Unit: μV).

		DDH group		P1		
	Control group	Affected	Unaffected	Affected	Unaffected	P2
Tensor fascia lata	21.81 ± 9.06	39.98 ± 28.17	36.18 ± 21.46	0.000※	0.000※	0.59
Shares of rectus muscle	17.09 ± 6.75	21.21 ± 10.53	23.26 ± 13.28	0.101	0.054	0.24
Hamstring (internal)	27.41 ± 10.82	20.29 ± 8.65	26.90 ± 11.53	0.011※	0.865	0.000※
Gluteus maximus	9.83 ± 2.98	10.00 ± 6.20	8.81 ± 4.20	0.314	0.269	0.509

P1 is the comparison between the DDH and control groups. P2 is the comparison between the affected and the unaffected sides in the DDH group. The results showed a significant difference between the affected and the unaffected sides in the hamstring (internal) in the DDH group (P <0.05). A significant difference was found between the affected side and the control group in the tensor fascia lata and hamstring (internal) (P < 0.05). A significant difference was found between the unaffected side and the control group in the tensor fascia lata (P < 0.05). (All significant differences are marked by ※).

resulting in uneven weight-bearing of both lower limbs and the bilateral muscle strength is unbalanced. As one of the main extensors of the pelvis, the gluteus maximus on the affected side produces increased static contraction and a compensatory increase in myoelectric activity to maintain the stability of the pelvis.

In a normal gait cycle, the main muscles that control the hip joint in the support phase are the extensor and abductor muscles, and the flexor muscles in the swing phase. Among these, the abductor muscles play the main role in stabilizing the pelvis, whose EMG activity increases with the pelvis forward.[11] As a powerful hip flexor muscle, the rectus femurs muscle activated from the early swing phase to the end of the early swing phase, causing the lower limb to advance. As both hip flexor and abductor muscles, the tensor fascia lata activated during the initial foot landing in the early support phase, increases in the middle and continues until the end of the support phase, preventing the contra lateral pelvic drop caused by a weight falling between the lower extremities and maintaining pelvic stability. The hamstrings and gluteus maximum, the important hip extensors, are activated only during the transition between the support phase and the swing phase, ensuring that the foot is precisely on the support surface in preparation for entering the support phase, in which the rectus femoris and hamstrings are in an antagonist-synergistic relationship. During normal walking, the hip extends without the help of the gluteus maximum. Hip joint loading depends, in part, on muscle-induced joint reaction forces (JRFs) and, therefore, is influenced by hip muscle moment arm lengths (MALs) and lines of action (LoAs).[12] In this study, the sEMG activity data of the aforementioned muscles in multiple gait cycles were averaged and statistically analyzed instead of a detailed study on a single gait cycle.

Studies have shown that the anatomy of the DDH alters muscle MALs, LoAs and their contribution to JRFs while walking. Song et al performed gait analysis on untreated female patients with DDH aged 16–39 years and healthy women. The results showed that compared with healthy hips, the abductor muscles in patients with untreated DDH had smaller abduction MALs and more medially-directed LoAs. Abduction-adduction and rotation MALs also differed for major hip flexors such as rectus femoris and iliacus. The altered MALs in DDH corresponded to higher hip abductor forces, medial JRFs, and resultant JRFs. DDH anatomy not only affected hip muscle force generation in the primary plane of function, but also their out-of-plane mechanics, which collectively elevated JRFs. Overall, hip muscle MALs and their contributions to JRFs were significantly altered by DDH bony anatomy.[12]

This study showed that the RMS value of bilateral tensor fascia lata in DDH group was higher than that in the control group. Also the RMS value of the medial head of the hamstring muscle on the affected side was lower than that on the healthy side and in the control group. To a certain extent, it showed that the demand for the hip flexor muscle in the DDH group increased, the demand for the hip extensor muscle decreased, and the compensation function of the hip flexor muscle on the healthy side increased. In the DDH group, the RMS value on the affected side of the tensor fascia lata was significantly larger, which might be related to the shortening of the affected side of the femur and the shortening of the torque of the tensor fascia lata caused by the femoral shortening and derotation osteotomy. In the case of completing the same work, the muscle needs to provide greater muscle strength. Therefore, the sEMG activity increased significantly and the RMS value was significantly larger. The reasons for the increase in the RMS value on the healthy side of the tensor fasciae latae were speculated as follows: The affected tensor fascia lata lost its fulcrum support and could not produce good muscle contraction, because of the dislocation of the hip joint beforethe contra-lateralsurgery. The muscle contraction maintains the stability of the pelvis. On the one hand, the myoelectric activity of the contralateral tensor fascia lata still increased to maintain the stability of the pelvis after the surgery. Therefore, the muscle fiber itself was larger than that in normal children. On the other hand, the sEMG activity of the contralateral tensor fascia lata increased and the RMS value was significantly larger to maintain the stability of the pelvis. The RMS value of medial head of the hamstring muscle was significantly less, which might be related to asymmetric gait and hip joint load inequality caused by osteotomy. Song[13]

reconstructed the 3-dimensional pelvis and femur anatomy of each patient with DDH and control, and found that the anatomic deformity of hip dysplasia increased the acetabular margin load while walking. Xu[10] analyzed the plantar pressure of eighteen 4-year-old children with unilateral DDH who underwent Pemberton osteotomy. They found that the absolute time of the support phase of the affected limb was less than that of the healthy limb and the control group, children moved the center of gravity from the affected side to the healthy side more quickly, suggesting that the load of the affected lower limb was reduced. Combined with the research results of Xu,[10] we speculated that when the children in this study entered the support phase from the swing phase, the strength of the affected side to inhibit the forward trend of the pelvis and trunk was weakened, the body stability decreased, and the control accuracy and stability of the hip flexion and abduction of the affected side are decreased. Hence the aforementioned sEMG activity changes appeared.

Lee et al[14] studied bilateral asymmetry of gait balance control in children with unilateral hip dysplasia after Pemberton surgery, and found that children treated with unilateral DDH showed impaired and bilateral different balance control strategies. The center of mass-center of pressure (COM-COP) control changed while walking. This was similar to our results.

The present study contradicted the findings of Changet al, whose postoperative gait analysis of 11 children with unilateral DDH undergoing early Pemberton osteotomy showed that the children exhibited an asymmetrical gait. The investigators concluded that the children with DDH might have reduced demand on the hip flexors and abductors and the knee extensors on the affected side, but the compensatory effect of the hip extensors, ankle plantar flexors, and knee flexors increased on the healthy side, which was possibly related to the osteotomy.[3]

This study had certain limitations. A long follow-up period was lacking and the patient sample was not big enough. Also the sEMG results before and after the surgery were not compared in this study, Futher, patients to set up subgroups according to age were not enough. A comprehensive assessment of multiple activity modalities using sEMG with a long-term follow-up in children with DDH after Pemberton osteotomy will be the direction of our further study.

5. Conclusions

To sum up, Pemberton was the best choice for 3- to 8-year-old children with unilateral DDH. After osteotomy, the symmetry of the myoelectric activity of the muscles around the bilateral hip joint was good, but still, abnormalities existed, mainly manifested as the asymmetry of the myoelectric activity of the bilateral gluteus maximum when standing, the compensatory increase in the myoelectric activity of the affected gluteus maximum; the asymmetry of the myoelectric activity of the medial head of the bilateral hamstring muscle when walking, the decrease in the myoelectric activity of the medial head of the affected hamstring muscle, and the increase in the myoelectric activity of the bilateral tensor fascia lata. These abnormalities should arouse the attention of pediatric orthopedics and rehabilitation doctors, and provide targeted guidance on hip muscle strength training for children with DDH, so as to help children with a higher quality of life.

Author contributions

FL and YW contribute equally to this study, they share co-first author, FL and YW wrote and revised the manuscript. ZS, DTA, and XL performed data acquisition, JW and SX conceived and coordinated the study, KF, MZ, and HQ did the follow-up with the patients. All authors reviewed the results and approved the final version of the manuscript.

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