

복직근의 기능적 전기자극이 경직형 뇌성마비 아동의 호흡 능력에 미치는 효과

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박 래 준

Effects of Functional Electrical Stimulation of Rectus Abdominis on Respiratory Capabilities in Children with Spastic Cerebral Palsy

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〈초록〉

본 연구는 복직근의 기능적 전기자극이 경직형 뇌성마비 아동의 1회 호흡용적과 폐활량 등의 호흡능력과 복직근의 근육활동에 미치는 영향을 알아보기 위해서 대구 시내 ○○특수학교에 재학 중인 14세 이상 16세 미만의 경직형 사지 뇌성마비 아동 6명(남자 3, 여자 3)을 대상으로 하여 복직근에 1회 20분, 주 3회씩 총 6주간 기능적 전기자극을 적용하였다.

기능적 전기자극의 적용 6주 전과, 직전에 두 번의 사전 검사와 적용 후 사후 검사를 실시하였다. MP30(Biopack, USA)을 이용하여 폐활량과 예측치 폐활량 백분율, 1회 호흡용적을 검사하였으며 Table면전극 근전도(Noraxon,

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USA)를 이용하여 복직근의 근육 활동량을 측정하였다. 분석결과는 다음과 같다.

1. 복직근의 기능적 전기자극 적용 6주 전과 직전의 폐활량은 유의한 차이가 없었으나, 적용 후의 폐활량은 적용 전에 비해 유의한 증가를 나타내었다($p < 0.05$).
2. 복직근의 기능적 전기자극 적용 6주 전과 직전의 예측치 폐활량 백분율은 유의한 차이가 없었으나, 적용 후의 예측치 폐활량 백분율은 적용 전에 비해 유의한 증가를 나타내었다($p < 0.05$).
3. 복직근의 기능적 전기자극 적용 6주 전과 직전의 1회 호흡용적은 유의한 차이가 없었으나, 적용 후의 1회 호흡용적은 적용 전에 비해 유의한 증가를 나타내었다($p < 0.05$).
4. 복직근의 기능적 전기자극 적용 6주 전과 직전의 복직근의 활동 값은 유의한 차이가 없었으나, 적용 후의 복직근의 활동 값은 적용 전에 비해 유의한 증가를 나타내었다($p < 0.05$).

이상의 결과를 종합해 볼 때 6주간의 복직근의 기능적 전기자극이 경직형 뇌성마비 아동에 있어서 복직근의 근력을 강화시킴으로써 폐활량과 1회 호흡 용적 등의 호흡능력을 향상시킴을 확인할 수 있었다.

핵심어: 기능적 전기자극, 폐활량, 뇌성마비

I . Introduction

Cerebral palsy is defined as a clinical syndrome that indicates developmental disability of mobility or that of posture by non-progressive defects or lesions occurring in the maturing process of the brain(Mutch et al., 1992).

Spasticity in cerebral palsy is the most common type of movement disorder, which makes up about 80% all case of cerebral palsy. It is defined as an excessive and improper involuntary muscular activity resulting from the increase of velocity dependency of stretch reflex related to upper moter neuron paralysis. Generally, spastic cerebral palsy is reported to accompany increase of muscle tone, clonus, and spasm(Blair & Stanley, 1997 : Cheney & Palmer, 1997).

Children with spastic cerebral palsy show direct problems of breathing function by disability of neromotion that restricts and suppresses the development of active and coordinative antigravity activity. Also, abnormal muscular activity provides

lower vital capacity than that of normal children, because of reversed breathing resulting from non-simultaneous movement of the thorax and abdomen muscles, irregular breathing cycle, co-contraction of agonist and antagonist during breathing, declined expiration control and shallow inspiration by restricting anatomic development that is needed for well-coordinated abdominal respiration and thoracic respiration(Dworkin, 1996). The reason that an amount of inspiration and pre-expiration are much less than in normal children is a weakness or palsy of expiratory muscle. Another reason is that expiration muscle is interfered with by inspiration muscle involuntarily. When speaking, spastic cerebral palsy patients breathe fast inspiration and cannot do slow, gradual expiration. Attenuation of inspiration and expiration functions by dysfunction of breathing muscles restrains functions of cough, secretion, phonation, etc and increases the infection risk of the breathing airway(Zupan et al., 1997). The breathing pattern of children with

cerebral palsy presents frequent discontinuation of utterance in unnecessary parts because of small amount of expiration irregular breathing, or panting. That is the reason why irregular breathing patterns interrupt regulation of breathing speed and breathing length(Tecklin, 1999).

Some common methods to improve the breathing function of children with cerebral palsy are cephalic control, posture training to relax muscular tone, breathing training while resting, training to breathe inspiration fast, training to keep constant time of respiration and phonation, etc. The purpose of breathing training is to strengthen the strength of breathing muscles with common apparatus, to increase coordination power and improve vital lung capacity by acquiring a stable breathing cycle and a proper amount of expiration through the guiding right movement of the lungs and abdomen and weakening irregular muscular tone(Dworkin, 1996). Also, a method which use therapists' hands was presented to improve the asynchronous breathing patterns of the children with spastic cerebral palsy and to strengthen the strength of expiration muscle. That is, unlike normal breathing patterns, children with spastic cerebral palsy show asynchronous breathing to contract the pectoral muscles and relax the abdominal muscle. Thus, to prevent these, in the early stage of expiration, therapists interfere pectoral contraction with both hands and at the same time establish normal breathing patterns by facilitating contraction of the abdominal muscle.

Functional Electrical Stimulation(FES) is a useful apparatus to activate paralyzed muscle resulting from upper moter neuron disease such as hemiplegia, cerebral palsy, spinal cord injury, etc(Wilder et al., 2002). The purpose of FES, which contracts muscles by stimulating motor neuron with electric excitation, is used to strengthen weakened muscles, to decrease spasticity, to enhance the scope of joint mobility,

or to control motor regulation(McCarthy et al., 2002). Recently, FES has been comprehensively used to control of the cardiovascular system, regulation of urinary and cystitis function, and breathing assistance along with the purposes of gate, standing, locomotion, etc(Bryant, 1995). After phrenic nerve stimulation (PNS) by Glenn in 1964 was applied for paralyzed breathing muscles, mechanical ventilation (MV) as a representative supporting apparatus of breathing, has been used for palsy of breathing muscle, especially for breathing assistance of phrenic palsy patients(Kandare et al., 2002). For a case with a serious injury higher than C3, PNS is used. However, PNS and MV have some limitations to their functions and to patients' quality of life resulting from these applications. Therefore, FES of abdominal muscles by surface electrode with inserting electric stimulation is effective to ventilatory support of spinal cord injury patients, who do not have neurologic injury and who have breathing ability(Soril et al., 1998 : Stanic., 2000).

Considering the above facts, this study examines FES to strengthen rectus abdominis that are used for expiration of the ones with spastic cerebral palsy. Posture regulation and kinesiotherapy to improve the expiration capacity of cerebral palsy patients requires professional personnel and has tremendous limitation because it requires long-term training to achieve an exercise effect when it is applied in actual clinical trials. It is a meaningful treatment method to strengthen rectus abdominis by using portable FES to increase the breathing capabilities of children with cerebral palsy. Therefore, this study examines how FES affects breathing capabilities such as Tidal Volume and Vital Capacity after it intensifies the rectus abdominis.

II. Methods

1. Research Subjects

Subjects are recruited from the children with spastic cerebral palsy in this study, who are 14 to 16 years old students of a special school in Daegu. Selection criteria is as follows.

- i) children who do not have breathing treatment.
- ii) children who can understand and follow

what researchers instruct.

iii) children who agree to participate in this research.

iv) children who can sit independently and receive the breathing evaluation in a sitting position.

General characteristics of the subjects are as follows(Table 1). *l*

<Table1> General characteristics of the subjects

	Average	Standard error of measurement
Gender male 3		
female 3		
total 6		
AGE(year)	15.83	1.17
Height(cm)	160.33	3.56
Weight(kg)	49.50	4.99
*GMFM(%)	73.33	6.32

***GMFM : Gross Motor Function Measure**

Subjects of this research are children with spastic cerebral palsy and consist of three males and three females. Among categories of Gross Motor Function Measure (GMFM), sitting is 73.33%. The average age of subjects is 15.83 years, the average height is 160.33cm , and the average weight is 49.50kg.

This test was performed from August 23, 2004 to September 28, 2004.

2) Application of FES

Before the test, the proper breathing methods were explained to test subjects. Test subjects lay on a treatment mattress and attached a surface electrode of neuromuscular simulation system of model 6800s, made in the United States, to their abdominal muscle. Each electrode was attached just below part of cortical margins and a pubic part close to midline(Kandare et al., 2002). At this time, a pillow was put under the knees of test subjects, which makes hip and knee joints slightly bent to eliminate the tension of rectus abdominis. Frequency of FES of 35 Hz, and stimulation intensity of 25-90mA were gradually increased. It was applied for twenty minutes for a test and three times a week for six weeks.

2. Procedure

1) Procedure

After the selection of six children with spastic cerebral palsy and who fit the subject criteria of this research, FES was performed on the rectus abdominis . Previous tests were taken, FES was applied for six weeks and then post-tests were executed. Test items are GMFM, Tidal volume, vital capacity and electromyogram of rectus abdominis.

3. Measurement Apparatus and Test Method

1) Gross Motor Function Measure

To evaluate whether there is a possibility to test the breathing capacities of subjects in a sitting position, GMFM devised by Russell and Rosenbaum was used. GMFM mainly calibrates the motor capability of children with dysergia such as cerebral palsy (Rosenbaum et al, 1990 : Russell et al, 1989). Since this research needs the stable sitting posture while measuring breathing capacities, among five areas, only the sitting area was calculated. Each item was evaluated after voluntary movements of subjects were observed according to researchers' instructions or demonstration of what test subjects must perform.

2) Measure of Muscle Activity

To investigate the muscular performance of rectus abdominis, both before and after the test, electromyography produced by NORAXON of the U.S. was used. A surface electrode was attached to the rectus abdominis to calculate muscular performance. To reduce measure errors, the surface electrode was a dual electrode with electrode introducer that was fixed every one-centimeter.

After the electromyogram signal recorded by the surface electrode attached to rectus abdominis enters the receiver, passing the preamplifier within surface electrode and input materials to computer from the A/D converter, it was transferred to NORAXON myoresearch system and the final muscular performance was acquired.

The test was performed while subjects lay straight. The level of stability was calculated three times after tension of hip and knee joints was eliminated by slightly bending them. With the same method, rectus abdominis action during maximum expiration was evaluated three times. After skin attached to the electrode was cleaned by

alcohol to decrease skin resistance, the active electrode was put two centimeters away from midline and one centimeter above umbilicus paralleled with the direction of a muscular fiber (Ng et al., 2002 : Andersson et al., 1998).

3) Measure of Tidal Volume and Vital Capacity

To measure breathing capacities for tidal volume and vital capacity before and after testing, MP 30 devised Biopack in U.S. was used. MP 30 is a machine that changes various analog signals (ECG, EMG, EOG, EGG, SKT, GSR, RSP, PPG) within organisms into a digital signal and inputs data to a computer to analyze them. To calculate exact vital capacity, enough information and demonstration were given test subjects to help their understanding. Tests were performed more than three times. When tested, children were seated to keep coxal articulation and knee joints at 90 degree each.

4. Analysis of Data

1) Data Processing

(1) Data Processing of Muscle Activity.

The signal of muscle activity collected by the surface electrode of electromyogram primarily was sent to a receiver passing a preamplifier within the surface electrode. Collected data was inputted to a computer passing through A/D converter. Values of muscle activity were calculated for 10 seconds. Sampling Frequency of electromyogram was 1024 Hz and data processing was performed by Noraxon Myoresearch Program.

(2) Data Processing of Measure of breathing Capacity for and Vital Capacity

With MP 30, maximum inspiration after three breathings in a stable situation, maximum expiration after three breathings and three breathings in a stable situation were measured as one cycle three times. Sections were set up in a

cycle to present reproducibility and compatibility. Acquired Tidal Volume and vital capacity before the test and after the test were compared.

2) Statistical Processing

To examine how functional electric stimulation to abdominal muscles affects breathing capability such as muscle activity of rectus abdominis and breathing capacity for once, and vital capacity of spastic cerebral palsy patients, SPSS Version 12.0 for Windows was used. Measured values were mean of three measurements of a subject. Just before the test, and after the test, averages and Standard error of measurement were calculated.

By using a nonparametric method, Wilcoxon's matched pairs test, values before and after the test were compared. For the test of significance degree, α is 0.05.

III. Research Results

Muscle activity values of rectus abdominis, average and stand deviation of Tidal Volume and vital capacity before the application of FES to abdominal muscles and after six weeks of application are as follows (Table 2).

<Table 2> Changes of Muscle activity values of rectus abdominis, Tidal Volume and vital capacity before and after the test

(Average \pm Standard error of measurement)

	Pre-Test	Post-Test
Vital Capacity (l)	2.60 \pm 0.48	3.00 \pm 0.47
Tidal Volume(l)	0.32 \pm 0.07	0.34 \pm 0.06
Muscle activity (%rest) Left	117.49 \pm 9.56	150.49 \pm 18.00
Right	121.12 \pm 13.29	149.75 \pm 25.76

1. Comparison of Activity Volume of Rectus Abdominis

Results of the mean of muscle activity of rectus abdominis before and after the application of FES show that means of muscle activity of rectus abdominis after the application of FES were

150.49 \pm 19.00% rest of the left side and 149.75 \pm 25.76%rest of the right side, which means there was a significant increase compared to the means of muscle activity of rectus abdominis before the application of FES, 117.49 \pm 9.56%rest of the left side, and 121.12 \pm 13.29%rest of the right side($p < 0.05$)(Table 3).

<Table 3> Changes of Activity Volume of Rectus Abdominis(RA)

(%rest)

	RA	Average	Standard error of measurement	p
Pre-Test	Left	117.49	9.56	
	Right	121.12	13.29	
Post-Test	Left	150.49	18.00	.046
	Right	149.75	25.76	.028

2. Comparison of breathing Capacity

1) Comparison of Tidal Volume

Tidal volume for a test after the application of

FES to abdominal muscles was 0.34 ± 0.06 l, which means a significant increase compared to one before the application, 0.32 ± 0.07 l ($p < 0.05$) (Table 4).

<Table 4> Changes of Tidal Volume

(l)

	Average	Standard error of measurement	p
Pre-Test	0.32	0.07	
Post-Test	0.34	0.06	.028

2) Comparison of Vital Capacity

Vital capacity after application of FES to abdominal muscles was 3.00 ± 0.47 l, which

means there was a significant increase compared to the one before the application, 2.60 ± 0.48 l ($p < 0.05$) (Table 5).

<Table 5> Changes of Vital Capacity

(l)

	Average	Standard error of measurement	p
Pre-Test	2.60	0.48	
Post-Test	3.00	0.47	.046

IV. Discussion

Special interest has to be given to evaluate the breathing of children with cerebral palsy, related to the mobility of the thorax during breathing cycles. A normal six month-old infant has a 90-degree angle between costa and spine. According to regulation development of head and trunk and standing posture, a 90-degree relationship was changed. Because of the gravity of axial musculature and strength in antigravity, costa becomes slanted toward the lower part of backward from forward. Due to the slanting, in both pump-handle action and bucket-handle action, the diameter of costa is expanded. By this ability to change inhalation volume, the muscles of costa and abdominis are operated fixed in the exterior part of costa. This fixation facilitates the

contraction of the diaphragm by the increase of lung volume. Typically, children with cerebral palsy have a lower level of stiffness in proximal. In the standing position that requires difficult muscle activities, the active balance of flexor and extensor muscles of trunks of children with cerebral palsy decrease. Therefore, movement of lung walls of them during the breathing period is different from that of normal children as follows:

First, the downward slant of costa cannot be fully developed because of the minimization of the dynamic advantage of pump-handle action and bucket-handle action during breathing.

Second, since there is no necessary muscle tone to fix the exterior part of costa, fiber of diaphragm, and especially, sternum fiber, they have a paradoxical function. These descend processes of xiphoid process and manubrium during breathing.

Lack of thorax expansion related to descent of thoracic vertebra results in shallow breathing (Tecklin, 1999). Because of insufficient breathing supply, phonation becomes short and intensity becomes also low. Weakened breathing muscles of children with cerebral palsy cannot increase lung capacity up to the maximum volume and cannot contract it up to minimum residual volume. If the lung cannot be extended enough for a long time, lung texus becomes shortened and stiffened. Not only do muscles become fibrosis and decrease compliance of lung, but also compliance of pulmonary is decreased because within pulmonary, microatelectasis is spread. These limitations of the function of lung and abdomen decrease the functional residual volume of lung and vital capacity (Bjure & Berg, 1970 : Blumberg, 1955 : Hardy, 1964).

The general treatment to improve the breathing function of patients with cerebral palsy has been kinesiotherapy (Hulme et al., 1989 : Teckin, 1999). As with other treatments to improve the breathing function of children with serious cerebral palsy, Leopando et al (1999) asked children with serious cerebral palsy to wear Soft Boston Orthosis (SBO) which is used to stabilize scoliosis, improve the balance of sitting posture and regulate the head and measured Tidal Volume and vital capacity for evaluation of breathing capability. However, this test statistically did not present any significant results.

Previous studies were reviewed that used FES on the abdominal muscles to improve breathing capability. Kandare et al (2002) reported that Tidal Volume and total volume of lung ventilation were increased in tests of FES to abdominal muscles with patients with spinal cord injury who cannot breath voluntarily after they provided rectus abdominis and radiant muscles with frequency of 45 Hz, 60-100mA of stimulus intensity and 25 μ s of pulse amplitude.

Kandare et al (2002) reported that in tests of

FES to abdominal muscles with patients with spinal cord injury who cannot breath voluntarily after they provided rectus abdominis and radiant muscles with frequency of 45 Hz, 60-100mA of stimulus intensity and 25 μ s of pulse amplitude, Tidal Volume and total volume of lung ventilation were increased. In this test, the receptive Tidal Volume was kept for maximum three minutes of FES. Exner and Baer (2000) reported that in tests of FES to abdominal muscles with patients of spinal cord injury in higher level than C4 and patients of cephalic trauma and vascular injury, FES to abdominal muscles increased lung ventilation artificially. Taylor et al (2002) reported that FES to abdominal muscles of quadriplegia patients of C3, 4 level increased the maximum expiration capacity. Zupan et al (1997) reported that they provided FES to abdominal muscle to quadriplegia patients during the early stage of expiration as well as breathing muscle training. As a result, application of FES to abdominal muscle during the early stage of expiration was more effective than when only breathing training was performed. Linder (1993) reported that FES to abdominal muscle of quadriplegia patients increased maximum expiration pressure up to 80% compared to the period of voluntary cough. Lanbein et al (2001) reported that FES to abdominal muscle of spinal cored injury patients of C5-T7 level increased strenghted vital capacity up to 23%, strengthened expiration volume up to 16% and the rate of maximum expiration volume up to 22%.

Electrical stimulation to abdominal muscles increases pressure of the abdomen by contracting abdominal muscles and pushing abdominal walls to inside whose action moves diaphragm to thoracic cavity. As a result, translocation of the diaphragm increases pleura pressure, decreases pulmonary volume and increases expiration (DeTroyer & Deisser, 1981). Also, it is reported that applying electric stimulation to the rectus

abdominis of healthy children significantly decreased translocation of cephalic side of diaphragm and back and front diameter of costa (DeTroyer & Estenne, 1988 ; Mier et al, 1985).

On the basis of the previous study results, this study was designed with the anticipation that when FES is applied to rectus abdominis of children with spastic cerebral palsy, expiration capability will be increased because the maximum expiration muscle, muscular strength of rectus abdominis is intensified. The reasons that the inspiration volume and that of pre-expiration of children with spastic cerebral palsy are much less than in normal children are that there is a weakness of expiratory muscle, or the dysfunction of it. Whereas previous studies reported only the increased vital capacity by FES to abdominal muscle and its effects on the respiratory capability such as strengthened expiration volume, this study measured the change of performance status of rectus abdominis during expiration as well as the breathing capability. Values of performance status of rectus abdominis were calculated after measured raw data primarily received a smoothing process with rectification and RMS 20ms and secondly took a band pass filtering process in a section of 10Hz-200Hz to eliminate the noise of measured values (Bender et al., 2003 ; Soderberg & Knutson, 2000). Acquired performance status of muscle activity by these processes was normalized. Normalization of performance status of muscle activity indicates a percentage of performance status of muscle activity during task performance to reference value. Generally, maximum voluntary isometric contraction value of muscles (MVIC) is used as a standard value but it is actually a sub-maximum voluntary isometric contraction value (SMVIC), which is 20%-40% less than MVIC without special training of tested subjects (Humens & Hutten, 2004). As a substitute method, for reference value of children with cerebral palsy with

neurological malfunction, values of performance status of involuntary muscle activity or values in stability can be used (Soderberg & Knutson, 2000).

Therefore, in this study, in a condition where test subjects lay straight and bent coxal articulation and knee joints to eliminate the tension of rectus abdominis, values of performance status of muscle activity were measured three times. From these, the total area of performance status of muscle activity was calculated and the mean of this was used as reference value. During maximum expiration, performance values of status of muscle activity were measured three times. From these, the total area of performance status of muscle activity and its mean were calculated. By using normalization value (% rest) that is presented as percentage to reference values, the activity of rectus abdominis before application of FES and six weeks after its application were compared. The results of this study indicate that both vital capacity and breathing volume for a test after the application of FES to rectus abdominis were significantly increased. 9.45% of vital capacity after application of FES, and 7.63% of breathing volume for a test were increased. The reason that vital capacity and increase of breathing volume for a test after application of FES is lower than the research results of Linder (1993) and Lanbein et al (2001) is why there is a difference between breathing capability of test subjects. Whereas the previous studies measured strengthened vital capacity and expiration volume of subjects who do not have voluntary breathing capabilities, this study measured voluntary vital capacity and Tidal Volume of subjects who have voluntary breathing capabilities but lower vital capacity than normal children. Also, this research witnessed significant increase of activity of rectus abdominis after the application of FES.

Since the number of subjects is restricted, this study has a limitation to normalize its results. Also, since the application of FES is limited to only

rectus abdominis, the results of this research cannot fully indicate an increase of breathing capability that results from the operation of various factors. In this research, activity values of rectus abdominis of patients' lying posture only were measured. But for a more extensive clinical application, I suggest that the relationship between activity values of rectus abdominis and respiration volume resulted from more active postures such as sitting, walking, running, etc must be studied.

VI. Conclusion

To examine how applying FES to rectus abdominis affects breathing capabilities such as Tidal Volume and vital capacity of patients with spastic cerebral palsy, and how it effects muscle activity of rectus abdominis, subjects are recruited from six patients of spastic cerebral palsy (three males and three females), who are 14 to 16 years old students of a special school in Daegu. FES to rectus abdominis was provided for 20 minutes for a test and three times a week for six weeks. The results before application of FES and after that were each measured. Vital capacity and Tidal Volume were tested by MP 39(Biopack,USA) and muscle activity of rectus abdominis was measured by surface electrode electromyogram (Noraxon, USA). The test results are as follows: Values of muscle activity of rectus abdominis after the application of FES to it present significant increase compared to the pre-application of FES.

From the above results, applying FES to rectus abdominis for six weeks strengthened muscle strength of the rectus abdominis of patients with spastic cerebral palsy and as a result, improves breathing capabilities such as vital capacity and Tidal Volume of subjects. Because FES is applied to a direct surface electrode to rectus abdominis and contracts rectus abdominis, it improves

respiration capabilities efficiently. For the application of FES, professional personnel are not needed and nursing children can use it conveniently. Also, because this apparatus is portable and patients can live normal lives with FES, it can be regarded as a safe and convenient treatment to improve the breathing capability of children with cerebral palsy.

<References>

- Andersson, E. A., Ma, Z. & Thorstensson, A. Relative EMG levels in training exercises for abdominal and hip flexor muscles. *Scand J Rehab Med*, 30, 175-183, 1998.
- Benda, W., McGibbon, N. H. & Grant, K. L. Improvements in muscle symmetry in children with cerebral palsy after equine-assisted therapy(hippotherapy). *The Journal of Alternativer and Complementary Medicine*, 9, 817-825, 2003.
- Blair, E. & Stanley, F. J. Issues in the classification and epidemiology of cerebral palsy. *Mental Retardation and Developmental Disabilities*, 3, 184-193, 1997.
- Bjure, J. & Berg, K. Dynamic and static lung volumes of school children with cerebral palsy. *Acta Pediatr Scand*, 203, 35-39, 1970.
- Blumberg, M. L. Respiration and Speech in the cerebral palsied child. *Am J Dis Child.*, 89, 48-53, 1955.
- Bryant, S. Functional electrical stimulation : Can it help you walk? *Accent on Living*, 1, 34-35, 1995.
- Cheney, P.D., & Palmer, F. B. Overview : Cerebral palsy. *Mental Retardation and Deveropmental Disabilities*, 3, 109-111, 1997.
- DeTroyer, A., & Deisser, P. The effees of intermittent positive pressure breathing on patients with respiratory muscle weakness. *Am Rev Respir Dis*, 124, 132-137, 1981.

- DeTroyer, A., & Estenne, M. Functional anatomy of the respiratory muscles. *Clinics in Chest Medicine*, 9, 175-193, 1998.
- Dworkin, J. P. *Motor speech disorders a treatment guide*. : U.S.A. Mosby. 1996.
- Exner, G., & Baer, C. A. Functional electrical stimulation in paralyzed respiratory muscles. *International Neuromodulation Society*, 3, 211-217, 2000.
- Hardy, J. C. Lung function of athetoid and spastic quadriplegic children. *Dev Med Child Neurol*, 6, 378-388, 1964.
- Hume, H. J., & Hutten, V. Effects of electrode dislocation on electromyographic activity and relative rest time : effectiveness of compensation by a normalization procedure, *Medical & Biological Engineering & Computing*, 42, 502-508, 2004.
- Hulme, J. B., Bain, B., Hardin, M., McKinnon, A., & Waldron, B. C. The influence of adaptive seating device on vocalization. *Journal of Communication Disorder*, 22, 137-145, 1989.
- Kandare, F., Exner, G., Jeraj, J., Aliverti, A., Dellaca, R., Stanic, U. Pedotti, A., & Jaeger R. Breathing induced by abdominal muscle stimulation in individuals without spontaneous ventilation. *International Neuromodulation Society*, 5(3), 180-185, 2002.
- Langbein, W. E., Maloney, C., Kandare, F., Stanic, U., Nemchasky, B., & Jaeger, R. J. Pulmonary function testing in spinal cord injury : Effects of abdominal muscle stimulation. *Journal of Rehabilitation Research and Development*, 38(5), 591-597, 2001.
- Leopando, M. T., Moussavi, Z., Holbrow, J., Chernick, V., Pasterkamp, H., & Rempel, G. Effect of a Soft Boston Orthosis on pulmonary mechanics in severe cerebral palsy. *Pediatric Pulmonology*, 28, 53-58, 1999.
- Linder, S. H. Functional electrical stimulation to enhance cough in quadriplegia. *Chest*, 103, 166-169, 1993.
- McCarthy, J. J., Finson, R., Smith, B. T., Liggins, A. B., Malcahey, M. J., & Betz, R. R. cerebral palsy : Results of surgical release augmented with electrical stimulation. *Neuromodulation*, 5(2), 113-119, 2002.
- Mier, A., Brophy, C., & Estenne, M. Action of abdominal muscles on rib cage in humans. *J Appl Physiol*, 58, 1438, 1985.
- Mutch, L., Alberman, E., Hagberg, B., et al. Cerebral palsy epidemiology : Where are we now and where are we going?. *Dev. Med Child Neurol*, 34, 547-555, 1992.
- Ng, J. F. K., Richardson, C. A., Parnianpour, M., & Kippers, V. EMG activity of trunk muscles and torque output during isometric axial rotation exertion : a comparison between back pain patients and matched controls. *Journal of Orthopaedic Research*, 20, 112-121, 2002.
- Rosenbaum, P. L., Russell, D. J., Cadman, D. T., Gowland, C., Jarvis, S., & Hardy, S. Issues in measuring change in motor function in children with cerebral palsy : a special communication. *Phys Ther*, 70, 125-131, 1990.
- Russell, D. J., Rosenbaum, P. L., Cadman, D. T., Gowland, C., Hardy, S., & Jarvis, S. The gross motor function measure : a means to evaluate the effects of physical therapy. *Dev Med Child Neurol*, 31, 341-352, 1989.
- Soderberg, G., & Knutson, L. M. A guide for use and interpretation of kinesiologic electromyographic data. *Physical Therapy*, 80, 485-498, 2000.
- Sorli, J., Kandare, F., Jaeger, R. J., & Stanic, U. Ventilatory assistance using electrical stimulation of abdominal muscles. *IEEE Trans Rehab Eng*, 4, 1-6, 1996.
- Stanic, U., Kandare, F., Jaeger, R. J., & Sorli, J. Functional electrical stimulation of abdominal muscles to augment tidal volume in spinal cord injury. *IEEE Trans Rehab Eng*, 8, 30-34, 2000.
- Taylor, P. N., Tromans, A. M., Harris, K. R., & Swain, I. D. Electrical stimulation of

abdominal muscles for control of blood pressure and augmentation of cough in a C3/4 level tetraplegic. *Spinal Cord*, 40, 34-35, 2002.

Tecklin, J. S. *Pediatric physical therapy*, 3, Philadelphia : Lippincott Williams & Wilkins.(1999)

Wilder, R. P., Wind, T. C., Jones, E. V., Crider, B. E., & Edlich, R. F. Functional electrical stimulation for a dropped foot. *J Long Term Eff Med Implants*, 12(3), 149-159, 2002.

Zupan, A., Savrin, R., Erjarec, T., Kralj, A., Karcnik, T., Skorjanc, T. Benko, H., & Obreza, P. C. Effects of respiratory muscle training and electrical stimulation of abdominal muscles on respiratory capabilities in tetraplegic patients. *Spinal Cord*, 35, 540-545, 1997.