Effect of Different Parameters of High Voltage Pulsed Current on the Torque Output of Rectus Abdominis Muscles in Women Having Diastasis Recti after Vaginal Delivery

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ABSTRACT

Objective: *This study was designed to determine to what extent different frequencies and electrode placements of high voltage pulsed current (HVPC) could affect the torque of the rectus abdominis (RA) muscles in women having diastasis recti after vaginal delivery.* ***Study design:*** *Forty eight multiparous women (2 to 3 times) with diastasis recti (i.e. more than 23mm between the two recti) after six weeks of vaginal delivery were participated in this study from EL-Sahel Teaching Hospital. The women were randomly assigned into four groups equal in numbers; group (1) and (2) received the same frequency of 100Hz and group (3) and (4) received 20Hz, whereas, electrode placements were the same in group (1) and (3) at the origin and insertion of the RA muscles and to their motor points in group (2) and (4). HVPC was administered three times per week with maximum tolerable intensity for 30 minutes each session in the four groups according to their frequencies and electrode placements. The maximal isokinetic torque of the RA as well as intra-recti distance were evaluated before and after two months of HVPC training.* ***Results:*** *The output torque of the RA muscles increased significantly after two months of HVPC training in all groups. But, there is no significant differences among the two pulse frequencies (20 and 100Hz) that selected in terms of increasing muscle torque in spite of tendency towards the high pulse frequency (100Hz). Regarding the placement configuration, no significant differences were observed suggesting that the two electrode placement sites appear to be preferable for maximizing RA muscle torque, with increasing the tendency toward the origin and insertion electrode placement. The intra-recti distance showed a statistically non significant difference in the four groups after two months of HVPC training.*
Conclusion: *High pulse frequency at 100Hz as well as placing the electrodes at the origin and insertion of the RA muscles are pronounced in increasing the RA torque in women having diastasis recti after vaginal delivery, which should be considered when interpreting electrical stimulation (ES) studies and further studies are recommended.*
Key words: *High voltage pulsed current, pulse frequency, rectus abdominis, diastasis recti, electrode placement, vaginal delivery, muscle torque.*

INTRODUCTION

Rectus abdominis (RA) is the major flexor muscles of the torso compared with other muscles in the abdominal wall which play an important role in spine stability. During pregnancy, the abdominal muscles are under the effect of mechanical load which generated by the growing foetus and hormonal changes that affect the ground substances which act as the adhesive substance between the muscle fibers[12] that may lead to widening of the linea alba, termed diastasis of RA[9]. Diastasis recti occurs commonly in pregnancy and its incidence rates of more than 67%[19,29] if the separation between upper and lower portion of them exceed 23mm and it is greater in multigravidae than primigravidae[29], that takes 2 - 4 months after delivery to return to the pre-pregnant state when there is a good planned postnatal program[19,25]. All the abdominal muscles have an insertion in the median plane of the linea alba so, the presence of the diastasis recti indicates a number of changes affecting the integrity of the abdominal wall[9]. Because of the absence of stable insertion for all abdominal muscles, which influence the inter-relationship between attachment and muscle fiber direction. So that, these changes in the angle of insertion of the abdominal muscles may influence the muscle's line of action[12] and subsequently their functional capabilities that resulted in decreased their ability to stabilize the pelvis. Such inadequacies could lead to muscle imbalance, inefficiency in the movement, changes in the posture and the development of low back pain[7].

So that, if the RA diastasis less than two fingers (20mm) in widths, abdominal exercises may progress rapidly. Whereas, if the gap is greater, trunk flexion, rotation and side flexion should be delayed until the size of the gap has been reduced as these movements may increase the gapping because of the shearing forces. Static abdominal exercise as well as pelvic tilting exercises and ES may be performed safely for such women[19,25,29].

ES has provided a variety of benefits in the area of rehabilitation. The clinical interest in the use of ES techniques as means for improving the strength capability of normally innervated muscle has led to numerous studies[10,15]. Some investigators have evaluated training programs, while others have focused on the relationship between voluntary and electrically stimulated muscular contraction intensities[17,20,30]. When using ES for augmentation of muscle strength the criteria describing ES intensity, frequency and electrode placement have varied widely. The mechanism for muscle strengthening using an electrically induced muscle contraction is the same as that of a voluntary muscle contraction by substantially increasing the muscle functional load and is only dependent on the load at the tendon, measured as torque. To produce overload, the muscle must exceed the minimum electrically evoked torque production threshold, at which the contraction produces measurable and meaningful tension in the muscle[5].

Accordingly Walmsley et al.,[30] believed that in order for a current to be successful in ES, it must generate tensions beyond that produced by a maximum voluntary contraction to maximally recruited all muscle fibers to full tetany.

It was reported in the literature that ES increased isometric muscle strength in healthy subjects[10,16,24]. A common problem in drawing comparisons among these studies is the variety of ES current formats and application techniques. The ES techniques for quadriceps femoris muscle described in the published literature have been using various stimulation frequencies including the following: 20[15], 50[30], 80[24] and 100Hz[10]. A side form variations in the ES current frequency, several different waveforms, pulse durations application techniques and subject types were examined in these studies.[4] But up-to-date no studies have been used to examine the optimal frequency for augmenting the isokinetic muscle torque of the RA muscles after vaginal delivery.

Pulse frequency is considered as an important characteristic when using ES to determine the strength of contraction and the rate of force fatigue.[26] The selection of a specific electrical stimulation current frequency generally has been a subjective decision on the part of the investigators, aiming at achieving the greatest muscular contraction intensity through the recruitment of motor units with minimal subject discomfort[8,14].

The question then arises as to magnitude of contractile force that can be elicited by an ES. HVPC has been used for pain reduction, ulcer healing, edema reduction, increasing joint mobility, prevention of disuse atrophy and augmentation of muscle strength. The short pulse duration of this current allows a high intensity stimulus with less discomfort[2,5,26].

During electrically stimulated muscular contractions (ESMC), the same frequency of the stimulation is delivered to all activated motor unit, the contractions are relatively synchronous[14]. Motor unit firing frequency, controlled indirectly by the ES frequency, which is a major contributor to muscle tension. ESMC are thought to be characterized by reversal of the normal motor unit recruitment pattern and selectively activating the type II muscle fibers, which are more readily fatigued than type I muscle fibers. If the reversal of normal motor unit recruitment order occurs during ESMC and if maximal tetanus of type II muscle fibers is desired, then ES current frequency may be an important factor. Because the clinician can deliver only one ES current frequency at a time per electrodes, the advantage of one frequency, in terms of subject tolerance and high intensity muscular contraction is of practical importance in making treatment decisions[5].

Electrode placements have generally included various areas for stimulating the quadriceps femoris muscle[3,6,10,11]. But the exact configuration details of these electrode placements are not known for RA muscles. So, when comparing and interpreting ES studies, major questions arise as to whether electrode placement and frequency can affect the muscle torque produced and subsequently, the results of a rehabilitation program.

Direct comparisons of electrode placements using similar electrical stimulus conditions, application techniques and test protocols have not been reported in the literatures. Practical, not all ES frequency and electrode placement sites are accessible in all women. Knowledge of placement site effectiveness in different situations is required to help clinicians to determine optimal selection.

The purpose of this study was designed to determine to what extent different frequencies and electrode placements of HVPC could affect the RA torque in women having diastasis recti after vaginal delivery.

SUBJECTS, MATERIALS AND METHODS

Subjects

Forty eight multiparous women (2 to 3 times) with diastasis recti were recruited from El-Sahel Teaching Hospital after six weeks of vaginal delivery and their age ranged from 20 - 28 years old, body mass index (BMI) not exceed $29 Kg/m^2$ and they were educated (Middle level of education) housewives.

All women were free from any musculoskeletal disorders, no previous abdominal operation and experienced normal vaginal delivery without any post partum complications and had diastasis recti in which the separation between the two recti was more than 23mm[29]. Women who missed three sessions and/or participated at any exercise training program were excluded from the study.

Women were assigned randomly to 1 of 4 equal groups in which HVPC was administered. The stimulation frequency (Frequency factor) and site (Location factor) were assigned as follows: group (1) received frequency 100Hz to the origin and insertion of both RA muscles, group (2) received frequency 100Hz to the motor points of both RA muscles, group (3) received frequency 20Hz to the origin and insertion of both RA muscles and group (4) received frequency 20Hz to the motor points of both RA muscles. Thus the frequency had two levels (100 and 20Hz) and there were two levels for electrode placements over the origin and insertion of the RA muscle and over its motor point. Informed consent form was signed from each woman before starting this study.

Instrumentations

1- Dynamax II high voltage pulsed current stimulator (U.S. Medical Crop.) with monophasic twin-peak pulse waveform was used in this study. The intensity of the stimulator up to 500 volts and pulse frequency option on the stimulator ranges from 1 to 140 pulse/sec. It includes two output leads at one polarity in conjunction with a single opposite polarity.
2- Biodex system was used for determining isokinetic torque of the RA muscles.
3- Dial calipers was used for measuring inter-recti distance.

Procedures

[I] Evaluative procedures

(a) Measurement of the intra-recti distance

The therapist palpated the medial edge of the recti muscle borders and placed the dial calipers perpendicular to the recti borders just above the umbilicus by 5cm while the woman was in crock lying position, then asked the woman to raise her head until the scapulae lifted the plinth at this point reading was taken for the distance between two rect. Three trails were taken for each assessment and the mean was recorded. The distance between two recti should exceed 23mm to confirm diastasis recti before starting the suggested program and reevaluated after the end of the HVPC training (2months).

(b) Peak isokinetic torque of the RA muscles

All women were fully acquainted with details of the procedures which were under taken through a demonstration session. Biodex was used to measure the isokinetic torque of the RA muscles at a constant speed of 30° / second and was calibrated prior to each test session. Each woman was in back lying position with both knees flexed 90° on the edge of the machine bench and fixed in this test position by belt placed just below the anterior superior iliac spines and another two belts were fixed the chest of each woman with the bench dynamometer. This test position was reliable for yielding maximal abdominal torque[13]. Torque was measured throughout 40° of forward flexion of the trunk. Three trails were made and the mean was recorded. Ten minutes rest was allowed in between each trail. During test, the woman watched the pointer of the torque dynamometer and was encouraged verbally to exceed their previous highest torque value. For each woman, peak isokinetic torque of the RA muscles was evaluated pre and post training with HVPC (2 months).

[II] High voltage pulsed current (HVPC) procedures

Quadripolar technique with six standard carbon rubber electrodes, consisting of four negative electrodes (cathode) and two dispersive electrodes (anode) were used to stimulate both RA muscles. After soaking the electrode pads in tap water, one cathode electrode was placed over the origin of each muscle (just above the pubic crest) and the other cathode electrode placed over the insertion of the same muscle (just below cartilage of 6, 7 and 8 ribs) and the anode electrode was placed laterally on the abdominal wall between the two cathodes for group (1) and (3). In group (2) and (4) one cathode was placed over the motor point of each RA muscles, above and lateral to the umbilicus by 5cm and the other cathode placed below and lateral to the umbilicus by 5cm, the anode electrode was placed laterally on the abdominal wall between the two cathodes. Pulse frequency (20 or 100Hz) depending on the group assignment. HVPC was administrated for 30 minutes each time, three times a week for two months at post partum period. At each training session the intensity of HVPC was adjusted to the current that could be maximally tolerated by each woman as the ability to tolerate high levels of electrically induced contraction has been widely suggested as a requisite for electrically mediated muscle strengthening[1]. All women were instructed to maintain their normal daily activities and to make daily three sets of 8 repetitions of static abdominal contraction, posterior pelvic tilt and curl up exercises throughout the study period.

[III] Data analysis

For the purpose of statistical analysis descriptive statistics including mean and standard deviation (S.D.) of the peak isokinetic torque of the RA muscles were used. Paired t-test was performed to further distinguish between the effect of frequency and location on the peak isokinetic torque of the RA muscles pre and post HVPC training in each group. ANOVA test was used to determine any significant differences between all groups. The level of significance for all tests used set at ($P<0.05$).

RESULTS

The physical characteristics of the four groups were presented in table (1). In which age, BMI, parity and intra-recti distance showed a statistically non significant differences ($P>0.05$) between the four groups before starting the study.

Table (1): Physical characteristics of the four groups.

Groups	Age (years)	BMI (Kg/m^2)	Parity (No.)		Intra-recti distance (mm)
	Mean ± S.D.	Mean ± S.D.	2 times	3 times	Mean ± S.D.
Group (1)	23.76±2.52	27.16±2.51	5	7	47.78±8.89
Group (2)	22.91±2.39	27.33±1.96	8	4	39.98±7.56
Group (3)	23.08±2.67	27.08±1.72	7	5	42.45±9.39
Group (4)	22.75±2.30	27.50±2.02	6	6	44.72±8.67

The maximal isokinetic torque of the RA muscles increased by 46%, 44%, 42% and 39% respectively in group (1), (2), (3) and (4) respectively after two months of HVPC training. These increase were statistically significant ($P<0.05$) between before and after two months of HVPC training in all groups, table (2).

Table (2): Peak isokinetic torque of the RA muscles in all groups.

Groups	Mean RA isokinetic muscles torque (N.m)			t value	Level of significance
	Pre training	Post training	% of change		
Group (1)	71.43±8.48	104.33±15.76	46.05%	4.13	0.021
Group (2)	70.67±11.52	101.91±17.02	44.20%	2.52	0.045
Group (3)	70.08±11.19	99.58±18.17	42.09%	2.47	0.048
Group (4)	73.54±7.56	102.76±10.40	39.73%	3.87	0.038

There were no statistically significant differences [(t=0.209, P<0.83 & t=0.945, P<0.365) and (t=0.314, P<0.760 & t= 0.421, P<0.683)] respectively among the high pulse frequencies (100Hz) between group (1) & (2) as well as low pulse frequency (20Hz) between group (3) & (4) respectively before and after HVPC training respectively, in spite of tendency toward high pulse frequency (100Hz). Regarding to the electrode placement configuration, no significant differences [(t=0.382, P<0.710 & t=0.755, P<0.460) and (t=0.699, P<0.499 & t=0.127, P<0.901)] respectively among the electrode placement at the origin and insertion between group (2) & (4) as well as electrode placement at the motor point between group (1) & (3) respectively before and after training respectively, in spite of tendency toward origin and insertion electrode placement for increasing the torque of the RA muscles, Figure (1).

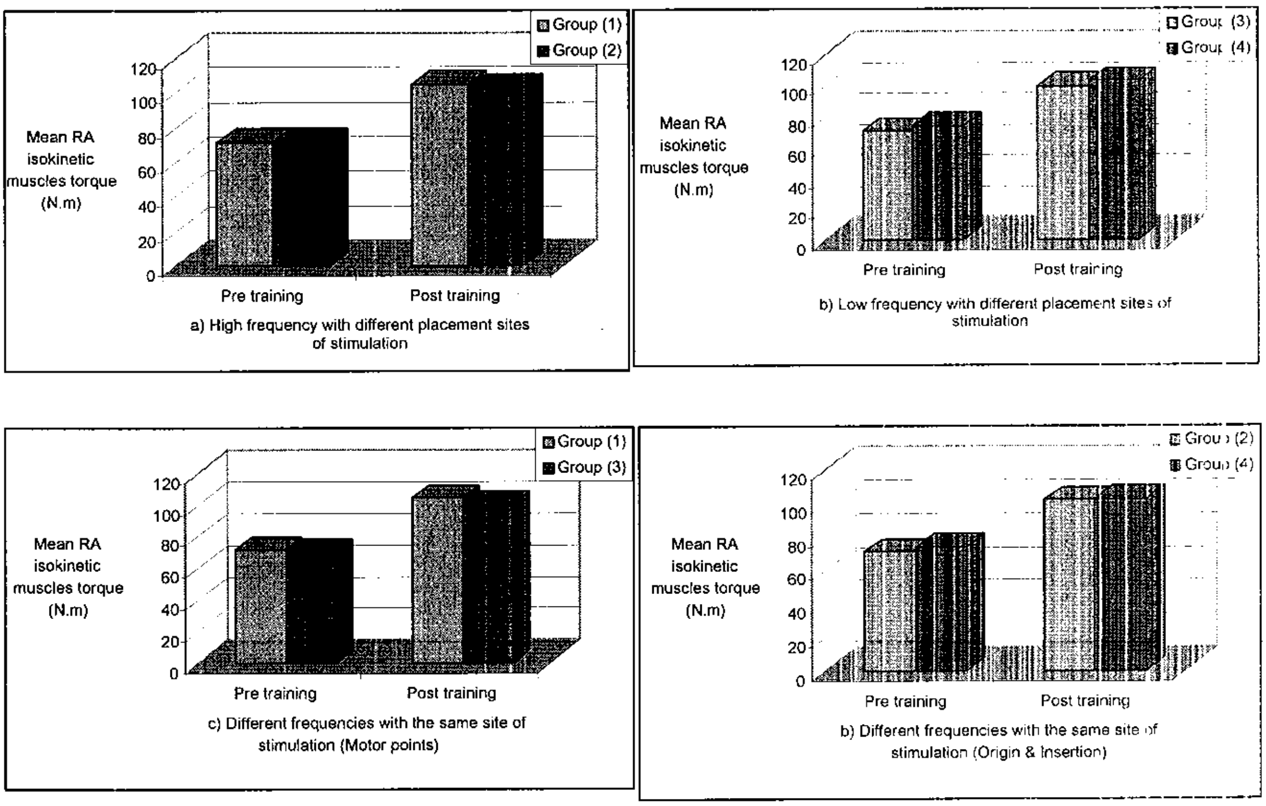

Fig. (1): Comparison of the mean values of the RA muscles isokinetic torque between before and after two months of HVPC stimulation in the four groups.

In addition, ANOVA test revealed that there was a statistically non significant difference of RA isokinetic torque between the four groups at pre and post HVPC training as shown in table (3).

Table (3): ANOVA among the four groups for the RA muscles isokinetic torque at pre and post HVPC.

Variation		Sum squares	Mean squares	F-test	P value
Pre HVPC training	Between Within Total	707.22 83.92 791.149	78.581 41.960	1.873	0.396
Post HVPC training	Between Within Total	2894.41 292.50 3186.91	321.602 146.250	2.199	0.352

The intra-recti distance above the umbilicus decreased by 15.84%, 11.88%, 11.16% and 6.64% respectively in group (1), (2), (3) and (4) respectively after two months of HVPC training, which showed a statistically non significant (P>0.05) between before and after HVPC training in the four groups. In addition, comparison between the four groups after the end of HVPC stimulation revealed a statistically non significant difference (F=1.357 & P<0.28).

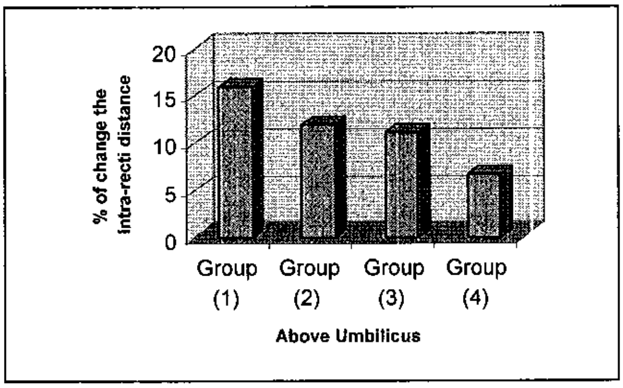

Fig. (2): Percentage of changes the intra-recti distance after two months of HVPC stimulation in the four groups.

DISCUSSION

In the present study, HVPC would augment torque of RA muscles in women after vaginal delivery. While did not support that stimulus frequency and electrode location would play an important role in determining the extent to which HVPC influenced the torque of RA muscles.

It would appear that the two pulse frequencies (20 and 100Hz) that were included in the design of this study produced a significant increase (P<0.05) in the torque of the RA muscles. But no statistical significant differences were found between them in spite of the tendency toward a high pulse frequency (100Hz).

None of the previous studies had used the same technique of training for such women. So these results can not be related to prior studies. Whereas, Moher et al.,[24] who found that HVPC was capable of producing contractile forces ranged from (17 to 85%) of maximal voluntary isokinetic contraction (MVIC) with no significant differences between the three pulse frequencies (50, 80 and 120Hz) in their effectiveness. Also there was a consistency in results with Balogun et al.,[2] using frequency (20, 45 and 80Hz) which attributed their results to the narrow range of pulse frequencies in their study.

In contrast Kramer[15] used different type of electrical stimulation and reported that (50 and 100Hz) were effective than 20Hz in terms of the torque produced by quadriceps muscle. The disagreement between the finding of the present study and Kramer's may be attributed to the use of different stimulus parameters (waveform and pulse duration). The waveform was asymmetrical bidirectional and the pulse duration was one millisecond. The used HVPC have very short pulse duration, which allow deeper penetration with high intensity with comfort (twin peak, monophasic current), thus direct stimulation of the deep muscles and nerves could be very effective[2]. Also, the lower torque values of the superimposed contractions at 20Hz at Kramer[15] study may be attributed to the skin sensory discomfort associated with 20Hz frequency, which is not the same situation with HVPC in the present study.

Because the available studies have used a variety of ES units, current formats, application techniques and subjects types (healthy athletes[4,28] and non athletes[26,28]), the relationship between different frequencies and strength gain in these studies (torque) is difficult to determine precisely or compared with the finding of the present study. Pulse frequency affects the tension developed in the normal muscle thus various muscles may have varied responses to stimulations[22]. Also, the strength gained directly correlated with the training contraction intensities and the ability of the individuals to tolerate strong and longer contraction[10]. The greater torque value at the 20 and 100Hz frequencies may be attributed to both frequencies being closer to or exceeding, the tetanus frequency of the activated motor units. Although a wide range of frequencies has been reported for continuous isometric contractions[15], researchers generally agree that increasing the stimulation frequency beyond tetanus frequency does not alter the force output of the muscle because maximal tetanus already has been achieved[14].

In the present study, there was significant increase in muscle torque after the application of HVPC for two months which ranged from 39.73 to 45.59%. Group (1) increased by 46.05%, group (2) increased by 44.20%, group (3) increased by 42.09% and group (4) increased by 39.73% of the MVIC.

Numerous studies had demonstrated strength gain in normal innervated muscle ranged from (22 to 88%)[2,6,16,18,20,23] that consistent with the present results.

Strength gained that obtained in the present study may be due to the fact that ES targets and trains type II muscle fiber more effectively than does active exercise[2]. Delitto and his colleage[5] stated that ES induced a change in muscle composition from type II to type I fibers and concluded that during stimulation the percentage of type I muscle fibers increased from mean of 4.6% to 41%. The externally applied current through the tissue takes the path of least resistance and recruits the lower resistance (large diameter) fibers than the higher resistance (small diameter) fibers[1]. Also, the afferent input from cutaneous stimulation results in inhibitory input to type I alpha motor neuron and excitatory input to type II alpha motor neuron at the same level of the spinal cord[8].

The results of this study suggested that while HVPC is capable of producing significant increase of the contractile force of the RA muscles, it was apparently that it is not capable of producing contractile forces in the excess of 100% of the MVIC as in the study of Hartsell and Kramer[11].

No significant differences were observed between the origin and insertion and motor point electrode placements, suggesting that selection preference between the two electrode placements may be made at the discretion of the clinician/woman. An electrode configuration similar to the two electrode placements used in the present study has not been supported by any previous studies. But, the recommendations for stimulating normally innervated muscles effectively and painless the active electrode must be applied over the muscle motor point. Thus less current intensity will be needed to achieve maximum muscle contraction than if the muscle belly is stimulated at other places[21].

But in the present study HVPC stimulation at the origin and insertion of the muscle was more effective in increasing the torque output of the RA muscles than the application to their motor points which could be attributed to the severely prolonged overstretch of their muscle fibers by the pregnant uterus anteriorly and laterally specially at the mid point of the RA muscles (motor points) at the end of second and third trimesters of pregnancy which declines the numbers of the motor unites as well as affects the sensitivity of these motor points to propagate action potential along the muscle fibers during activity after delivery as mentioned by Gilleard and Brown[9].

In the present study, there was a small percentage of decrease in the intra-recti distance after two months of HVPC stimulation ranged from 6 to 15% which was statistically non significant in the four groups and also between them. But, the pronounce decrease was noted in group (1) which received HVPC stimulation at high frequency (100Hz) and stimulated at the origin and insertion of RA muscles. These results did not correlated or contradicted by any previous studies. So, the noted decrease in the intra-recti distance in the four groups could be explained via the significant increase in the torque of the RA muscles which proved in this study.

Conclusion

HVPC produced statistically significant increase in the torque of the RA muscles after two months training for all groups. But no statistical significant differences among the two pulse frequencies (20 and 100Hz) that selected in terms of muscle strength gained in spite of tendency towards the pulse frequency 100Hz. Regarding the placement configuration, no significant differences were observed suggesting that either the origin and insertion or motor point electrode placement appear to be preferable for maximizing ES induced torques, although increasing the tendency toward the origin and insertion electrode placement which should be considered when interpreting ES studies and other studies for a prolonged period are recommended to determine the exact effect of ES on the diastasis recti.

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الملخص العربي

تأثير المعايير المختلفة للتيار المتذبذب عالي الجهد على عزم عضلتي البطن الطوليتان لسيدات عندهن تباعد بين عضلتي البطن الطوليتان بعد الولادة الطبيعية

هدف الدراسة : تهدف هذه الدراسة إلى معرفة مدى تأثير النبضات المختلفة وكذلك أماكن التنبيه (وضع الالكترودات) للتيار المتذبذب عالي الجهد على عزم عضلتي البطن الطوليتان لسيدات لديها تباعد (دياستازز) بين عضلتي البطن الطوليتان بعد الولادة الطبيعية . **تصميم الدراسة** : أجريت هذه الدراسة على٤٨ سيدة متكررة الولادة (٢ – ٣ مرات) لديها تباعد (دياستازز) بين عضلتي البطن الطوليتان (أكثر من ٢٣مم بين العضلتين) من مستشفى الساحل التعليمي بعد ستة أسابيع من الولادة الطبيعية . وتم تقسيمهن إلى أربع مجموعات متساوية عشوائيا : مجموعة (١) و (٢) أخذت نفس التردد العالي(١٠٠ هرتز) ولكن مكان التنبيه (وضع الالكترودات) في المجموعة (١) كان عند منشأ واندراج العضلة أما المجموعة (٢) فكان عند مكان نقل الإشارات الكهربية . أما المجموعة (٣) و (٤) فأخذن نفس التردد المنخفض(٢٠ هرتز) وكان مكان التنبيه في المجموعة (٣) مثل (١) والمجموعة (٤) مثل (٢) . وكانت جلسة التنبيه الكهربي باستخدام التيار المتذبذب عالي الجهد لمدة ٣٠ دقيقة , ٣ مرات في الأسبوع لمدة شهرين وقد تم قياس عزم عضلتي البطن الطوليتان و مقدار التباعد بين عضلتى البطن الطوليتان قبل وبعد الانتهاء من برنامج التنبيه الكهربي (شهرين) .

النتائج: وقد أظهرت النتائج زيادة ذات دلالة إحصائية في عزم عضلتي البطن الطوليتان في المجموعات الأربعة . ولم تظهر أي فروق جوهرية بالنسبة لتردد النبضات وكذلك مكان التنبيه فيما بين المجموعات . وقد كانت الزيادة بنسبة كبيرة في عزم عضلتي البطن الطوليتان ملحوظ في المجموعة (١) والتي أعطيت تردد عالي النبضات (١٠٠ هرتز) وكذلك التي تم تنبيهها كهربيا عند مكان منشأ واندراج العضلة . أيضا أظهرت النتائج نقصا غير فعال فى مقدار التباعد بين عضلتى البطن الطوليتان فى المجموعات الأربعة فيما بين قبل و بعد شهرين من التنبيه الكهربي.

الخلاصة : مما سبق نستنتج أن التيار المتذبذب عالي الجهد يمكنه زيادة عزم عضلتي البطن الطوليتان ويقلل من مقدار التباعد (ديستازز) بين عضلتي البطن الطوليتان وبخاصة عند استخدامه بتردد ١٠٠ هرتز وإذا تم التنبيه عند منشأ واندراج العضلة وهو ما يجب مراعاته عند استخدام التنبيه الكهربي لسيدات لديها تباعد (دياستازز) بين عضلتي البطن الطوليتان بعد الولادة الطبيعية . أيضا يجب تكرار هذه الدراسة على عينه كبيرة و زمن أطول وذلك لقياس تأثيره الفعلي على مقدار التباعد (الدياستازز) بين عضلتي البطن الطوليتان بعد الولادة .

الكلمات الدالة: التيار المتذبذب عالي الجهد ، عزم العضلة ، الولادة الطبيعية ، دياستازز، وضع الالكترودات، عضلتى البطن الطوليتان، تردد النبضة .