The Effect of Quadriceps Fatigue on Back Muscles Electromyographic Activity During Lifting In Osteoarthritis Patients

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ABSTRACT

Background: *Knee osteoarthritis (KOA) is a chronic joint disease characterized by weakness of the quadriceps and it may has an effect on lumbar region as there is a correlation exists between the counterforce of the knee and the counterforce of the lumbar region.* ***Purpose:*** *This study was conducted to investigate the effect of quadriceps muscle fatigue on back muscle myoelectric activity during lifting in KOA patients.* ***Material and methods:*** *60 subjects from both genders of convenient sample were assigned into two equal groups; Group (A) consisted of 30 patients with KOA (13 males and 17 females) with mean age (47.90± 1.77) and Group (B) consisted of 30 healthy control subjects, (15 males and 15 females) with mean age (48.40±2.39). The root mean square of EMG signal recorded from the lumbar erector spinae muscles was measured by EMG during lifting sand bag 30% of the subject body weight pre fatigue exercises, and then fatigue exercises to quadriceps muscle of the unaffected leg conducted on isokinetic system. Immediately after fatigue exercise, the root mean square of EMG signal recorded from the lumbar erector spinae muscles during lifting.* ***Results:*** *Indicated that, there were significant differences in root mean square recorded from right and left lumbar erector spinae muscles between and within both groups in favor of group (A) pre and post quadriceps fatigue exercises (P=0.0001). There was linear correlation between fatigue index and root mean square of lumbar erector spinae muscle where r value equals (+0.35).* ***Conclusion:*** *Quadriceps muscle fatigue lead to increase involvement of lumbar erector spinae muscles during lifting, and there is a correlation between fatigue level of quadriceps and lumbar muscles, as high fatigue level of quadriceps result in elevating low back load and thus increasing the risk of lumbar injury.*
Key words: *Quadriceps muscle fatigue, Electromyographic activities, Knee osteoarthritis, erector spinae muscle, lifting.*

INTRODUCTION

Osteoarthritis (OA) is a common, chronic joint disease characterized by pain, disability, and progressive loss of function. It is the most common musculoskeletal complaint worldwide and is associated with significant health and welfare costs[1]. The knee is the most frequently affected joint of the lower limb and therefore essential activities which require considerable loading of the lower extremities are directly affected[13]. Knee osteoarthritis (KOA) characterized by progressive declines in strength, flexibility and function, accompanied by increases in joint pain[7]. It has been observed that KOA is accompanied by pain in other joints, including the hip and spine, and has been linked with bone demineralization, muscle atrophy, inflexibility and loss of functional ability[12].

A correlation exists between the counterforce of the knee and the counterforce of the lumbar region. Fatigue of the quadriceps femoris muscle, may lead to increased activity of the lumbar muscles[18]. Back and leg muscles strength may be intrinsic determinants of the lifting strategy, and the ratio between back and total knee strength can differentiate and to some extent predict the lifting strategies[16]. Muscle fatigue is an exercise-induced reduction in maximal voluntary muscle force. It may arise due to peripheral changes at the level of the muscle action, or failure of central nervous system (CNS) to drive the motor neurons adequately[25]. Basically it is a protective mechanism that prevents us from exhausting metabolic reserves within muscle and limits the buildup of harmful metabolic products. It also reduces continual generation of high forces, which may cause damage to the contractile elements[4].

The risks of injury to a joint increase as the load shifts from the fatigued muscles to the joint capsule and ligaments[11]. Overload-related lumbar lesions caused by manual load lifting can be prevented by tests specifically developed to identify muscular activity patterns characteristic of a state of fatigue. Because fatigue results from the repetition of tasks and overloads, it is one of the major causes of musculoskeletal injuries of the spine[2].

Electromyography (EMG), essentially, is the measurement of action potentials. During a fatiguing muscle contraction, the EMG decreases in amplitude, frequency at which motor units fire decreases and fatigued muscles had been shown to exhibit extended latency in firing. This is caused by the fast twitch muscle fibers fatiguing more rapidly and slow twitch fibers being recruited to compensate[3,6]. The aim of this study was to prove the hypotheses that there is effect of quadriceps femoris muscle fatigue and leg dominance on the root mean square of EMG signal recorded from the right and left lumbar erector spinae muscles, during lifting in osteoarthritis patients.

SUBJECT AND METHODS

This study was approved by the Ethical Committee of the Faculty of Physical Therapy, Cairo University. Sixty subjects from both genders (28 males and 32 females) were participated in the study after signing institutionally approved consent form prior to data collection. The subjects were selected from the out clinic of Faculty Physical Therapy, Cairo University. Subjects age ranged from 40 to 55 years with mean age (48.15± 2.08) and their body mass index ranged from 25 to 29.9 Kg/m^2.

1. Inclusion Criteria

Group (A):

- Age ranged from 40-55 years, since KOA is more prevalent in this subject population[8].
- Body mass index ranged from 25-29.9 kg/m^2.
- Patients with grade 3 KOA (moderate OA): These patients with moderate multiple osteophytes, definite joint space narrowing, some sclerosis, and possible deformity of bone ends[17].

(Group B)

- All subjects were with no musculoskeletal or neuromuscular disorders.
- No history of low back or knee pain.
- No history of hip or back injury or surgery.

2. Exclusion Criteria

- Patients with history of hip and/or back injury or surgery.
- Past history of lower-limb joint replacement.
- Control participants has no history of lower limb pathology or joint disorder, injury or pain in either knee in the past year.
- History of significant problems related to any other joint of upper limb, lower limb or the spine.
- Patients with osteoprosis.
- Patients with lower limb vascular disorders.
- Diabetic patients.
- Athelets.
- Smokers.
- Patients with cardiovascular problems.

Design of the study

A pre test post test measurement study was conducted to investigate the effect of quadriceps femoris muscle fatigue on the root mean square of EMG signal recorded from the right and left lumbar erector spinae muscles, during lifting in KOA patients. Sixty participants of convenient sample were assigned into two groups: Group (A) included thirty patients (13 males and 17 females) with chronic UKOA who received fatigue exercise to sound limb. Group (B) included thirty healthy (15 males and 15 females) control subjects who received fatigue exercise to matched limb.

Instrumentation

1- Wireless Surface Kinesiological EMG (Electromyography Apparatus)

The root mean square of the right and left lumbar erector spinea were assessed by using Myomonitor Wireless EMG Systems (DE 2.3 SEMG Sensor, Delsys, Inc., USA) that had an inter-electrode distance of 1 cm. The Myomonitor is a portable EMG and physiological signal data acquisition system. The device operates in Wireless Mode: Data is transmitted to a receiving host computer for real-time viewing and storage. Myomonitor Systems are available in 8 channels and are designed to make the acquisition of signals comfortable and reliable[19].

2- Isokinetic system

Biodex system 3 pro Isokinetic dynamometer was used to perform fatigue exercises to quadriceps muscle. It provides an objective method for testing and rehabilitation for joints of the upper limb, lower limb and the trunk. Calibration of the Biodex System 3 was done by associated researcher of the lab every month by using reference weight, under the supervision of Manufacture Company[9].

3- Sand bags with 30% of body weight for the purpose of lifting.

Procedures

The root mean square of EMG signal recorded from the lumber erector spinae muscles was measured by EMG during lifting sand bag 30% of the subject body weight pre fatigue exercises, and then fatigue exercises to quadriceps muscle were conducted on the isokinetic system. Immediately after fatigue exercise, the root mean square of EMG signal was recorded from the lumbar erector spinae muscles during lifting. The electrodes were placed three cm lateral to the third lumber spinous process over the right and left erector spinae parallel to the direction of muscle fibers[26]. The reference electrode was fixed over the left anterior superior iliac spine to overcome electrical noise or artifacts. The weight of the sand bag was set at 30% of body weight, and maintained at a distance five cm from the subject[18].

1- Assessment of the maximum voluntary contraction (MVC).

The subject is prone on table, legs strapped, hands beside the body, resistance applied to thoracic area with examiner standing beside the table. The (MVC) for the lumbar erector spinea muscles was assessed, each isometric contraction maintained for 3sec separated by 3-min pauses and repeated for three times. Verbal encouragement was given by the experimenter for all normalization trials.

2- Pre fatigue amplitude of EMG signal recording during lifting

The subject stood with the legs apart at a comfortable width. The subject was instructed to lift the plastic container until the trunk and the legs are fully extended. The subject was asked to lift the plastic container at a rate at which the entire lifting movement can be performed smoothly as the EMG surface electrodes recorded the EMG signal from the right and left lumbar erector spinae muscles during lifting. Three trials were recorded. The mean of the three trials was used in the statistical analysis[5].

3- Fatigue exercises to quadriceps muscle

The isokinetic dynamometer was set at parameters of fatigue exercises with knee positioned 90◦ of flexion. The leg was exercised at the isokinetic knee extension at a speed of 120◦ deg/s. The subjects were instructed to perform maximal effort. The mean value of maximal voluntary contraction (peak torque) was obtained. Subjects seated on the dynamometer chair with stabilization straps at the trunk, abdomen and thigh to prevent inappropriate joint movements. The knee of the exercised limb positioned at 90◦ of flexion.

Local fatigue of the quadriceps femoris muscle was evaluated by measuring changes (decline) in peak torque from the beginning to the end of the fatigue protocol as the subject performed 30 consecutive maximal gravity corrected concentric contractions of the knee extensors on the isokinetic dynamometer. Initial peak torque and final peak torque are the average of the first and the last five repetitions peak torques of the fatigue protocol[23].

4- Post fatigue amplitude of EMG signal recording during lifting

Immediately after isokinetic quadriceps femoris fatigue exercises the root mean square of EMG signal during lifting was recorded as mentioned before.

Data Collection

Data was collected through EMG unit in two sheets:

1. Personal data sheet: It had age, sex, height, weight, BMI.
2. EMG sheet: It had measured the EMG activities (onset, RMS and MDF of muscle activities) of left and right lumbar erector spinae muscles.
3. Fatigue index from isokinetic biodex, it was calculated according the formula:

Fatigue index = (initial peak torque - final peak torque) / initial peak torque × 100

Statistical Analysis

1. Descriptive statistic

It was used to calculate the means and standard deviations of characteristics of the subjects; age in yrs, weight in kg , and height in cm for each group.

2. Normality test of data

Kolmogorov-smirnov test and Shapiro-Wilk test was used, that reflect the data was not normally distributed, so non parametric statistical tests in the form of (Wilcoxon matched pairs and Mann-Whitney tests) were used to analyze the data of this work.

3. Wilcoxon matched pairs test used to test the significance of difference in pre and post quadriceps fatigue measurement of root mean square of the EMG signal recorded from lumbar erctor spinae muscles within each group.
4. Mann-Whitney test to test the significance of difference in pre and post quadriceps fatigue measurement of root mean square of the EMG signal recorded from lumbar erctor spinae muscles between group A and B.
5. Spearman correlation analysis used to test correlation between quadriceps fatigue index and the root mean square of the EMG signals recorded from the right and left lumber erector spinae muscles, during lifting.
6. Level of significance was set at P > 0.05.

RESULTS

General Characteristics of the Subjects

Group (A) included thirty patients with chronic UKOA (13 males and 17 females) who received fatigue exercise to sound limb. Group (B) included thirty healthy control subjects (15 males and 15 females) who received fatigue exercise to matched limb. There was no significant difference between both groups in their age, weight and height, while there was a significant difference between both groups in their fatigue index (table 1).

Table (1): Demographic data of subjects in group (A) and (B).

Variables	Group (A)	Group (B)	t-value	P-value	Sig.
	Mean ± SD	Mean ± SD			
Age (year)	47.90± 1.77	48.40±2.39	-.751	.457	NS
Height(cm)	162.95±2.98	163.25±3.46	-.750	.458	NS
Body weight(Kg)	76.85± 2.94	77.45± 2.04	-.249	.771	NS
Fatigue index	5.31±2.27	6.97±2.78	2.52	0.01	S

P= probability, S= significance, SD= standard deviation

Root mean square of lumbar erector spinae pre and post quadriceps fatigue within Subjects

There was a significant difference in the Wilcoxon matched pairs test between pre and post fatigue values in both groups (A&B) at left and right lumbar erector spinae muscles. The P- value was 0.001, 0.0001, 0.0001, 0.0001 respectively. (table 2).

Table (2): Median, Range, Mean and ±SD, and P values of right and left lumbar erector spinae muscles root mean square pre and post quadriceps fatigue for groups (A&B).

Variable	T	Group A		Group B	
		Right muscle	Left muscle	Right muscle	Left muscle
Median	Pre	81.45	80.9	99.0	95.3
	Post	101.45	101.75	163.4	151.05
Range	Pre	181.7	175.9	123.5	151.6
	Post	277.4	333.2	546.1	295.7
Mean	Pre	95.39	97.01	103.08	103.92
	Post	117.08	128.19	181.76	159.76
±SD	pre	±48.09	±51.93	±33.4	±42.55
	post	±65.51	±84.79	±101.14	±65.87
p-value	Pre/post	0.001	0.0001	0.0001	0.0001
S	Pre/post	S	S	S	S

*SD: standard deviation, P: probability, S: significance

<u>Root mean square of lumbar erector spinae pre and post quadriceps fatigue between Groups</u>

The Mann-Whitney test results for the Right and left lumbar erector spinae muscle root mean square pre and post quadriceps fatigue between groups A and B revealed no significant difference in pre fatigue values with p-value 0.1, 0.22 respectively, while there was a significant difference in the post fatigue values with P-value 0.001,0.005 respectively (Table 3).

Table (3): Mann-Whitney test between groups A and B for right and left lumbar erector spinae muscle root mean square pre and post fatigue.

	T	Right muscle	Left muscle
Mann-Whitney U value	pre	340.0	367.5
	post	186.0	260.5
P-value	Pre	0.1	0.22
	post	0.001	0.005
S	Pre	NS	NS
	post	S	S

* P: probability, S: significance, NS: non-significant

<u>Correlation between quadriceps fatigue index and root mean square of lumbar erector spinae muscle</u>

The correlation analysis between quadriceps fatigue index and root mean square of lumbar erector spinae muscle revealed a significant correlation between fatigue index and root mean square of lumbar erector spinae muscle as reflected by spearman correlation analysis where the r value equals (+0.35) and had an associated probability value of (0.005) as shown in table (4) fig (1).

Table (4): Correlation Analysis between the quadriceps fatigue index and root mean square of lumbar erector spinae muscle.

correlation coefficient	
r-value	+0.35
P-value	0.005
S	S

*r-value: correlation coefficient, P-value: probability, S: significance

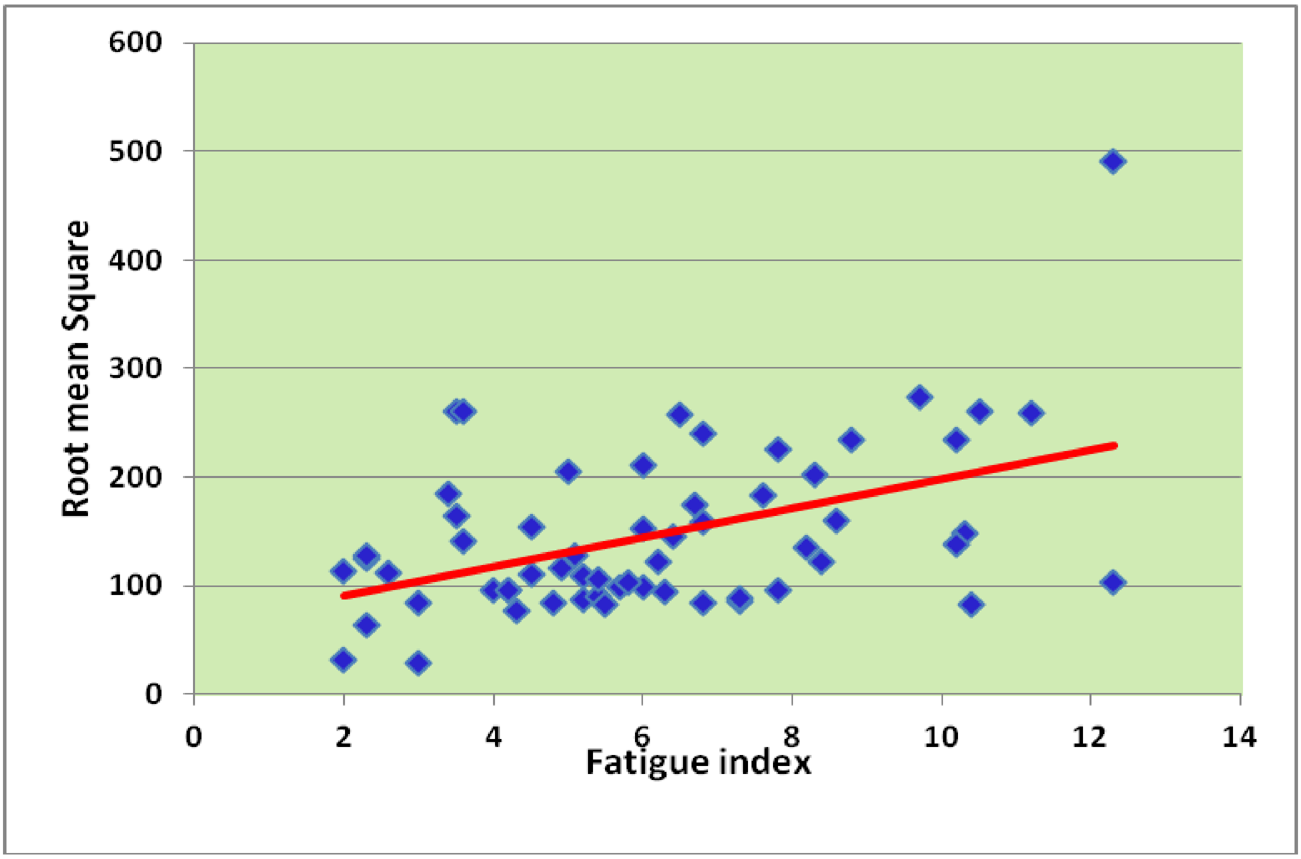

Fig. (1): Correlation between quadriceps fatigue index and root mean square of lumbar erector spinae muscle.

DISCUSSION

Lifting is a common volitional daily task required in numerous occupational activities. Both, stoop lifting and squat lifting strategies, are used. Back and leg muscle strengths are indeed the two primary limiting factors of the subject lifting capacity[30]. Muscle fatigue can cause force variations that can impair movement accuracy and result in joint injury[10]. There is an indirect relationship between lumbar paraspinal muscles and quadriceps muscle, which may exist to facilitate stability and maintain normal function during prolonged activities[15].

The results of this study revealed a significant difference between both groups in fatigue index as in favor of group A. This may be attributed to over reliance on the affected limb can result in weakness in the contra lateral limb, which can decrease the non affected extremity's ability to absorb large forces associated with functional activities[14]. These results are contradictory with the findings of Mertletti et al. (1994)[20] who found that dominance related differences in fatigue index when back muscles is electrically evoked.

The second findings of this study concerning root mean square of lumbar erector spinae muscles pre and post quadriceps fatigue within subjects, there was statistical significance difference of root mean square pre and post quadriceps fatigue in both groups. This may be attributed to the inverse correlation exists between the counterforce of the knee and the counter force of the lumbar region, as when fatigue restricts muscle activity of the quadriceps, the muscles activity of the lumbar area increases[18].

The relative strength between the back and knees might differentiate and predict the posture at the onset of a lift. It can be concluded that subjects with back strength greater than their total knee strength tended to use a back preferred lift strategy, whereas those who had total knee strength greater than their back strength used a leg-preferred lift strategy. This indicates a general tendency to involve more the joints of relatively greater muscle strength in performing a physically demanding task[16]. The advantages of squat method can be interpreted as: by dispersing vertebral load and shifting stress from the lumbar region to the leg, the compression force and intervertebral shear force are lowered, and normal forward curvature of the lumbar vertebrae restricts stress being applied to the dorsal posterior ligament[5,18].

The results of this study are consistent with Makoto et al. (2008)[18] who revealed that, quadriceps muscle fatigue elevating low back load and increasing the risk of lumbar injury, and lead to change of lifting mode toward stoop lifting. This comes in agreement with Potiven and O'Brien (1998)[22] who reported that, subjects respond to fatigue with large increases in antagonistic activity. The thoracic erector spinae and internal oblique muscles tended to respond more to stability demands, and lumbar erector spinae and external oblique muscle respond more to moment demands.

This also matches with van Dieen and his colleagues (1998)[29] who demonstrated that several changes in kinematic lifting parameters were observed during repetitive lifting. Subjects changed to a lifting posture, which resembled the stoop technique, with decreased flexion at the knee and increased trunk flexion. Also, as lifting continued, an increase in twisting of the trunk was observed. The findings are in consistence with Sprato et al. (1997)[27] who found that, the fatigue was associated with decreased knee and hip motion, and increased lumbar flexion. Also there was significant decrease in postural stability because of repetitive lifting task indicated a higher risk of injury in the presence of unexpected perturbation.

On the other hand the results of this study are contradictory with the findings of Parcero and Potiven (2001)[21] who found that muscle fatigue did not result in large systematic effects during sudden loading in the sagittal plane. The findings also disagree with van Dieen and Toussaint (1996)[28] who examined the effect of long bouts of repetitive lifting and lowering, assumed to induce fatigue, on kinematic parameters in squat and stoop lifting. A decrease in the phase lag between knee and hip extension was observed during squat lifting, but no other changes in lifting strategy were observed.

Limb asymmetry has long been identified in strength, stability and functional performance. Bilateral differences in neuromuscular control have been hypothesized to cause postural instability and predispose one side to higher risks of injury. Traditional assessment of limb dominance such as the kick ball method overemphasized the mobilizing function of the leg more than stabilizing role. Significant bilateral differences in lower extremity joint kinetics, suggest that dominant and non dominant legs had different neuromuscular control strategy to achieve a similar level of movement performance. Subjects with strong right or left sided dominance would use their limb and back muscles in an unbalanced way, therefore modifying one side with respect to the other. Back muscle on the non dominant side would be subjected to more intense use to compensate for loads and forces applied to the dominant side during daily activities[20,24].

Significant difference between dominant and non dominant side may be attributed to the continued preferential use of muscle groups on the non dominant side of the back to compensate for moments applied to the dominant side in daily life activities. It is generally accepted that exercise modifies the fiber constituency of a muscle, mostly by converting type II b into type II a fibers, a fact that would result in lesser myoelectric manifestations of muscle fatigue because type IIa fibers have greater fatigue resistance than do type IIb fibers. It was reported that, when electrically stimulated muscles on the dominant side displayed a statistically significant slower rise time of the twitch response, which suggests a higher percentage of type I fibers with respect to the non dominant side[20].

The findings of this study come in agreement with Merletti, (1994)[20] who reported that there was significant difference between right and left myoelectric back muscles activity when electrically evoked due to limb dominance. The findings of the study are also supported by Givoni et al. (2007)[11] who found significant difference between dominant and non dominant limb after quadriceps muscle fatigue.

The results of this study are contradictory with the findings of Mannion, (1997)[19] who showed no significant differences in the mean rate of median frequency of the right and left lumbar erector spinae muscles in evaluation of back muscle function by EMG power spectral analysis. This comes in agreement with Makoto et al., 2008[18] who reported, increased level of quadriceps fatigue result in more involvement of lumbar erector spinae muscles, as lumbar muscle strongly contracted to lift the object off the floor, and thus increasing the risk of lumbar injury.

Conclusion

Quadriceps muscle fatigue lead to increase involvement of lumbar erector spinae muscles during lifting, and there is a correlation between fatigue level of quadriceps and lumbar muscles, as high fatigue level of quadriceps result in elevating low back load and thus increasing the risk of lumbar injury. So, any therapeutic interventions should focus not only on muscles of affected limb but also on back muscles during rehabilitation process in patients with KOA.

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الملخص العربي

تأثير الإجهاد العضلي للعضلة الرباعية على النشاط الكهربائي لعضلات الظهر أثناء رفع الأحمال في مرضى التهاب مفصل الركبة

يعد التهاب مفصل الركبة من الأمراض المزمنة وغالبا ما يكون مصحوبا بضعف العضلة الرباعية . وله العديد من التأثيرات على الفقرات القطنية حيث أن هناك علاقة بين قوة الركبة والفقرات القطنية . ولذلك فإن هذا البحث يهدف إلى دراسة تأثير الإجهاد العضلي للعضلة الرباعية للطرف السليم على الرسم الكهربائي للأنشطة العضلية أثناء الوقوف من وضع الجلوس في المرضى الذين يعانون من التهاب مفصل الركبة في أثناء رفع حمل . **الوسائل :** أجريت هده التجربة علي 60 فردا من الجنسين تم اختيارهم بعينة مرضية وتم تقسيمهم إلي مجموعتين : مجموعة تجريبية (أ) تتكون من 30 فردا (13 ذكر و 17 أنثى) وكان متوسط أعمارهم 1.77 ± 47.90 . ومجموعة ضابطة (ب) تتكون من 30 مريض (15 ذكر و 15 أنثى) يعانون من التهاب مفصل الركبة في جانب واحد وكان متوسط أعمارهم 2.39+،48.4 . وقد تم قياس الجذر التربيعي لمتوسط التربيعات والتردد الأوسط و زمن بداية نشاط العضلات الكهربائي أثناء رفع حمل يوازي 30% من وزن الجسم . ثم تم عمل تمرينات إجهاد للعضلة الرباعية للطرف السليم في المجموعة التجريبية وللطرف المقابل في المجموعة الضابطة على جهاز الأيزوكينيتك . ثم إجراء نفس القياس أثناء رفع نفس الحمل . أثبتت المعالجات الإحصائية النتائج الآتية : وجود اختلافات ذات دلالة إحصائية في قياس الجذر التربيعي لمتوسط التربيعات في كل مجموعة وكذلك بين المجموعتين في صالح المجموعة الأولى بعد و قبل إجهاد العضلة الرباعية P= 0.0001 . كما توجد علاقة خطية بين معامل الإجهاد و قياس الجذر التربيعي لمتوسط التربيعات لعضلات الظهر حيث R= +0.35 . **الخلاصة :** إجهاد العضلة الرباعية يؤدي إلى زيادة التحميل على عضلات الظهر أثناء رفع الأحمال . وأن هناك علاقة خطية بين مستوى إجهاد العضلة الرباعية و عضلات الظهر، حيث أن زيادة معدل الإجهاد في العضلة الرباعية يؤدي إلى زيادة التحميل على عضلات الظهر مع زيادة خطورة إصابات الجزء القطني .

الكلمات الدالة : الإجهاد العضلي للعضلة الرباعية- الرسم الكهربائي للأنشطة العضلية - التهاب مفصل الركبة- رفع الأحمال .