The Isokinetic and Electromyographic Assessment of Knee Muscles Strength in the Short- and Long-Term Type 2 Diabetes

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Abstract

Background: Type 2 diabetes (T2DM) patients are subject to muscle weakness.
Objectives: The aim of the study was an assessment of electromyographic (EMG) activity of knee muscles during isometric maximal voluntary contraction in the different disease durations of T2DM.
Methods: Eighteen patients with less than 10 years and twelve patients with more than 10 years of T2DM were compared with nineteen matched healthy control subjects. EMG of flexor and extensor muscles of knee concurrently with isometric maximal peak torque of knee flexion and extension at 75 degrees of knee flexion were recorded in three groups.
Results: Isometric maximal peak torque of extension and root mean squared (RMS) of vastus lateralis and medial hamstring in the healthy control was significantly higher than both patient groups. Whenever the maximal isometric peak flexion torque was not significantly different between groups, the mean power frequency (MPF) of flexor muscles especially medial hamstrings were higher in the short-term T2DM than healthy control groups. The two factors, gender and age, had significant effect on maximal peak torque and RMS of knee muscles.
Conclusions: EMG could show the effect of T2DM, gender and age on knee muscles activity. It seems that the medial hamstring was the most sensitive muscle of knee compartment to show the effect of T2DM and difference of short and long-term T2DM in EMG study.

Keywords: Type 2 Diabetes Mellitus, Isometric Maximal Peak Torque, Electromyography, Knee

1. Background

Several studies have demonstrated that type 2 diabetes (T2DM) causes poor muscle quality and strength especially in the lower limb (1-6). Strength reduction has been associated positively with increase of neuropathy, glycated hemoglobin A1c (HbA1c) and duration of diabetes (1, 2, 4, 7). Muscular weakness in T2DM could be due to insulin resistance, intracellular lipid accumulation, mitochondria dysfunction, sarcopenia and neuromuscular impairments (8-15). The electromyographic (EMG) assessment of muscle as a sarcolemma output provides more information about the properties of motor units to control neuromuscular function (16). EMG frequency, an indicator of muscle fiber conduction velocity, and EMG amplitude, a sign of neural excitation (17).

Rare studies assessed the EMG properties of diabetic muscles (7, 18, 19). The most electrophysiological assessments in T2DM were limited to measure nerve conduction velocity (20) and compound muscle action potentials that showed reduction in nerve conduction velocity and density of fibers and motor unit in the diabetic polyneuropathy (6, 15, 16). Watanabe et al. compared the root mean squared (RMS) activity of vastus lateralis in 10% MVC for 120 seconds between healthy and T2DM by 64 multi-channel EMG. They found that the modified entropy as a sign of heterogeneity of muscle was more in T2DM than healthy subjects. The results also indicated that synchronization of motor units significantly decreased in T2DM during low level sustain contraction (19). The anterior tibialis and gastrocnemius activated later during stance phase of gait in the diabetic patients than healthy subjects. The study concluded when diabetic patients faced a new difficult situation that needed a higher muscle performance, the necessary range of motion and neuromuscular control around knee and ankle joints were insufficient (21).

Whereas exercise appears to play an important role in
controlling the diabetes, the study of muscle activity can be helpful to design a better strength exercise protocol (22). Many studies have been previously reported on the relationship between the surface EMG amplitude and muscle force. Then surface EMG is used to quantify muscle activity to improve exercise protocol design (23).

2. Objectives

To clarify the changes of muscle strength due to diabetes, the present study aims to assess the kinesiological EMG concurrently with torque of knee flexors and extensors during isometric voluntary contraction in patients with less or more than 10 years of T2DM compared to healthy subjects that were matched with patients in terms of sex, body mass index (BMI), physical activity index (PAI) and ankle brachial index (ABI). The effect of gender and age were considered in comparison too. Previously it was demonstrated that these factors affected the muscle strength (5, 24-27).

3. Methods

3.1. Subjects

Thirty T2DM patients between 25 - 70 years-old were referred by internal specialists from medicine and endocrine clinics. They did not have severe or uncontrolled cardiac disease, intermittent claudication of leg and ulcers of feet, myopathy or rheumatoid arthritis. The ABI was between 0.9 - 1.3. Patients according to the duration of diagnosed diabetes were categorized into two groups. Eighteen patients that their diabetes were diagnosed less than ten years. They were placed in the short-term T2DM group. Twelve patients with equal or more than ten years of diabetes were placed in the long-term T2DM group. The healthy control group were twenty subjects who were matched with both diabetic groups in terms of sex, BMI, ABI and PAI. The added inclusion criterion for the healthy control group was that their HbA1c was less than 6%. All participants signed the written informed consent and the protocol was approved by the medical ethics committee of the Tarbiat Modares University.

3.2. Procedure

Firstly HbA1c and fasting blood sugar (FBS) were measured from blood sampling. Then ABI were measured by Doppler ultrasound from the dominant leg in the supine position. Those who entered the study had an ABI between 0.91 - 1.3 (28). The level of physical activity was measured by scoring of PAI. The method of PAI measurement has been explained in previous papers (7). The score has been categorized into the sedentary, poor and fair physical activity groups (29). The patients did not stop the prescribed diabetic medications. The tests were done in the afternoons. The finger blood glucose and brachial pressure were measured before the test.

3.3. Isometric Recording

Isometric maximum peak torque (IMPT) [Newton meter] of knee extensors and flexors was performed with an isokinetic dynamometer (HUMAC NORM, USA). The dominant leg which determined as the preferred leg for kicking a ball was tested. All subjects were instructed about the procedure of study and performed a warm-up and training trials. The adjustment of isokinetic machine and positioning of subjects for the test were explained previously (30). They were asked to push the fixed lever arm maximally to extension and then to flexion for three times at 75 degrees of knee flexion (30), each trial was done for 3 seconds and a rest period of 30 seconds was given between consecutive contractions. The trial which had maximal value of three trials was considered as IMPT. All IMPT were divided by weight for normalization.

3.4. EMG Recording and Analysis

Surface EMG signals concurrently with the isokinetic test were recorded from the vastus lateralis, vastus medialis, long head of biceps femoris and medial hamstring muscles of dominant leg. The electrodes were positioned according to surface EMG for non-invasive assessment of muscles’ (SENIAM’s) recommendations (31). The skin was first shaved and then cleaned with an 70% alcohol solution and two recording circle Ag/AgCl sensors (Telectrode, Bio Protech Inc., Korea, Diameter of 23 mm) for each muscle placed 20 mm apart (center to center distance) on the skin. A reference electrode was attached to the ipsilateral styloid process of wrist. A bipolar multi-channel EMG amplifier (Bio-Signal Pack, Bayamed Co.www.bayamed.com) (CMMR: 120 dB, Input Impedance: 10M Ω, bandwidth 200 KHz, gain:1000) was used to register the surface EMG activity. The signals were sampled with a frequency of 2460 Hz and analogue-to-digital converted and stored with 12-bit computer. LabVIEW (version 10.0.0, National Instruments) programming software was used to perform the signal processing.

Then the sampled EMG signals were digitally band-pass filtered from 10 to 500 Hz. The method of calculation the mean power frequency (MPF) and root mean square (RMS) (µV) were explained in the previous paper (7).
recording in T2DM showed that MH was more sensitive to muscles showed significantly more value in patients. EMG was higher than both diabetic groups. The MPF of flexor muscles, especially VL and MH of healthy control group was more than both T2DM groups, the RMS of agonist or genders. However the MPF of MH muscle of short-term T2DM group was significantly more than healthy controls. The RMS of VL and MH were significantly lower than that of healthy control subjects. The MPF of both extensor muscles did not differ between groups and no covariation variable was proved, Bonferroni post hoc was used to follow up pairwise comparison. P-value less than 0.05 was considered as significantly. The SPSS software version 21 was used for analysis.

4. Results

We included 12 long-term T2DM and 18 short-term T2DM patients that were matched with 20 healthy control subjects. Demographic and blood parameters are presented in Table 1, diabetic subjects with good and moderate blood glucose control were included in this study. The three groups were matched according to sex, BMI, PAI and ABI. The long-term T2DM group was 10 years older than the healthy control group (P = 0.02), HbA1c, FBS and glucose tests of the two diabetic groups were higher than the healthy control group (P < 0.000), while the two diabetic groups were not significantly different.

Table 2 showed the extension IMPT and MPF and RMS of the VL and VM muscles. Table 3 showed the flexion IMPT and MPF and RMS of The BF and MH muscles. Both extension (EXT) and flexion (FLEX) IMPT and related RMS of women were significantly lower than men. The EXT IMPT of both diabetic groups were lower than that of healthy control group. The RMS of VL and MH were significantly lower in both diabetic groups than healthy controls. The MPF of both extensor muscles did not differ between groups or genders. However the MPF of MH muscle of short-term T2DM group was significantly more than healthy control group while only the MPF of BF muscle of both diabetic women was more than healthy women.

5. Discussion

As the isometric maximal peak torques of healthy controls was more than both T2DM groups, the RMS of agonist muscles, especially VL and MH of healthy control group was higher than both diabetic groups. The MPF of flexor muscles showed significantly more value in patients. EMG recording in T2DM showed that MH was more sensitive to effects of diabetes than other knee muscles. Because the diabetic medial hamstring, a small and single-joint muscle, had significantly lower RMS and slightly higher MPF than the healthy control group especially in the short-term T2DM.

The previous studies indicated that the main confounding factor in the strength such as age, sex, BMI and fitness should be controlled to make reliable comparison (7, 30). This study carefully controlled them. The results of the study were consistent with those of previous studies which found the T2DM had weaker muscles than matched healthy subjects in the lower limb (1, 4-7, 30). Our findings also showed that peak torque and RMS followed the same pattern of change in 100% maximal voluntary contraction. Gabriel et al. showed that the RMS in according force increases but median frequency slightly decreases at 100% MVC. They showed an increase in synchronization of motor units to be the source of these changes (32, 33). Moreover frequency-domain features are sensitive to variations in shape and peak to peak activation and synchronization of motor units (34). Then it might be suggested that the reason for lower RMS and higher MPF of weaker diabetic muscle in comparison to healthy muscle was low ability of motor units to produce synchronization around 100% MVC. It is noticeable that the behavior of mean frequency and median frequency is always similar, and they are two kinds of averages in statistics (35).

The decrease in muscle strength in T2DM is a result of muscle quality decline. It is dependent on loss of muscle fibers especially type 2 and an increase in intermuscular lipids, decrease in oxidative enzymes and secondary increase in glycolytic muscle enzymes that produced more metabolic residuals (9, 11, 36-39). Then the muscle fibers of diabetic muscle in the long term shift to type 2 because of loss of muscular capillary and oxidative enzymes (11, 40). These changes affect the quality of EMG (41).

The hamstring in comparison with quadriceps has a higher proportion of type 2 muscle fibers (42, 43). It is well known that the axon of fast motor units is thicker and has more conduction velocity (44). Therefore, it seems that higher MPF of knee flexors was associated with the existence of more fast motor units in addition to the effect of diabetes on muscle. To confirm that, the current study also showed that knee flexors had higher MPF than knee extensors although we did not analyze it. In contrast to the anticipation that MPF of women is less than that of men, the MPF of flexor muscles especially BF of short-term diabetic women was shown to be significantly more than that of men of the same group and others.

The limitations of the study included the selection of a non-specific position to test knee flexors as well as lack of measurement of neuropathy intensity in T2DM patients.
Table 1. Demographic and Blood Characters of the Three Groups and the P Value

|                          | Healthy Control (N = 20) | Short-Term T2DM (N = 18) | Long-Term T2DM (N = 12) | P Value |
|--------------------------|--------------------------|--------------------------|--------------------------|---------|
| Number of cases (women/men) | 20 (10 / 10)            | 18 (9 / 9)               | 12 (6 / 6)               |         |
| Age (years)              | 49.55 ± 10               | 52.11 ± 9.2              | 59.17 ± 7.1              | 0.02b   |
| Weight (Kg)              | 73.68 ± 7.7              | 77.61 ± 12.5             | 77.72 ± 12.4             | 0.47    |
| Height (cm)              | 167.89 ± 9.2             | 164.33 ± 8.3             | 166.09 ± 11              | 0.51    |
| BMI                      | 26.25 ± 3                | 28.71 ± 4.1              | 28.54 ± 3.6              | 0.09    |
| Duration of diabetes (years) | 4.8 ± 2                 | 15.5 ± 7                 | 19.3 ± 7                 | 0.000c  |
| Medication (insulin + drugs / drugs) (N of cases) | 1 / 17                   | 3 / 9                    | 1 / 1                    | 0.000c  |
| PAI (sedentary/poor/fair) (%) | 63.2, 26.3, 10.5         | 66.7, 27.8, 5.6          | 45.5, 54.5, 0.0          | 0.83    |
| ABI                      | 1.77 ± 0.08              | 1.22 ± 0.09              | 1.34 ± 0.14              | 0.43    |
| HbA1c (%)                | 4.7 ± 0.8                | 7.02 ± 1.5               | 7.3 ± 1.4                | 0.000c  |
| FBS (mmol/L)             | 91 ± 12.6                | 141.65 ± 36.9            | 160.91 ± 31.4            | 0.000c  |
| Blood sugar (mmol/L)     | 114.05 ± 17.7            | 167.39 ± 44.23           | 205.20 ± 84.24           | 0.000c  |

aData is mean ± SD.
bPost Hoc between health and long-term T2DM groups.
cPost Hoc between healthy control and both diabetic groups.

Table 2. The mean (lower and upper level of 95% confidence interval) of males and females in three groups of IMPT of extension and EMG variables of vastus lateralis and medialis are described. The P value of two-way ANCOVA for IMPT and RMS of muscles and two-way ANOVA for MPF of muscles between three groups, two gender and interaction effect of them are in the last three columns.

|                          | Gender | Healthy Control (N = 20) | Short-Term T2DM (N = 18) | Long-Term T2DM (N = 12) | P Value |
|--------------------------|--------|--------------------------|--------------------------|--------------------------|---------|
| IMPT of extension        | Male   | 3.01 (2.5-3.5)           | 2.4 (1.8-2.8)            | 2 (1.7-2.4)              | 0.018b  |
|                          | Female | 1.9 (1.5-2.3)            | 1.7 (1.1-2.1)            | 1.1 (1.4)                | 0.000   |
| MPF of vastus lateralis  | Male   | 60.59 (55-65)            | 64.2 (54-81)             | 68.6 (58-78)             | 0.47    |
|                          | Female | 60.2 (54-66)             | 65.6 (56-77)             | 68.1 (55-79)             | 0.97    |
| MPF of vastus medialis   | Male   | 67.2 (60-75)             | 68.3 (59-76)             | 69.4 (65-73)             | 0.69    |
|                          | Female | 73.5 (67-81)             | 76.1 (67-86)             | 66.9 (56-72)             | 0.33    |
| RMS of vastus lateralis  | Male   | 328 (280-382)            | 260.5 (196-336)          | 234.7 (146-332)          | 0.017b  |
|                          | Female | 231 (160-315)            | 142.1 (70-228)           | 85.2 (64-106)            | 0.001   |
| RMS of vastus medialis   | Male   | 196.5 (148-250)          | 184.6 (119-270)          | 149.1 (106-195)          | 0.36    |
|                          | Female | 98.6 (59-119)            | 79.1 (46-110)            | 85.1 (50-129)            | 0.81    |

aData is mean ± SD.
bPost Hoc was significant between healthy control and short-term T2DM.

Not matching the age between groups and small sample size were other limitations.

This study concluded that both short and long-term T2DM patients had lower knee IMPT extension and VL and MH RMS than healthy control group. No significant difference was seen between the two diabetic groups in strength features such as maximal torque or RMS contrast endurance features that were shown previously (30, 45). MPF of MH muscle showed significant increase in the short-term T2DM in comparison with the healthy control group. It may be worth noting that the MH muscle was the most sensitive muscle to show the effect of diabetes in the
Table 3. The mean (lower and upper level of 95% confidence interval) of males and females in three groups of IMPT of flexion and EMG variables of biceps femoris and medial hamstring are described. The P value of two-way ANOVA for IMPT and RMS of muscles and two-way ANOVA for MPF of muscles between three groups, two gender and interaction effect of them are in the last three columns.

| Gender | Healthy Control (N = 20) | Short-Term T2DM (N = 18) | Long-Term T2DM (N = 12) | P Value |
|--------|-------------------------|--------------------------|-------------------------|---------|
|        | Groups                   | Gender                   | Gender × Groups         |         |
| IMPT of flexion | Male                     | 0.98 (0.7-1.1)           | 0.79 (0.4-0.9)           | 0.84 (0.6-0.9) | 0.12 | 0.000 | 0.37 |
|        | Female                   | 0.5 (3.6)                | 0.49 (3.6)              | 0.39 (3.6) |       |       |       |
| MPF of biceps femoris | Male                     | 96.6 (92-101)           | 106.2 (93-109)          | 225.4 (170-285) | 0.000 | 0.016 | 0.003³ |
|        | Female                   | 103.1 (93-111)          | 151.4 (139-147)         | 128 (113-143) |       |       |       |
| MPF of medial hamstring | Male                     | 90.4 (77-106)           | 111.8 (83-144)          | 106.7 (92-120) | 0.03³ | 0.81 | 0.92 |
|        | Female                   | 90.3 (79-105)           | 122.6 (110-134)         | 102.6 (88-107) |       |       |       |
| RMS of biceps femoris | Male                     | 113.5 (82-142)          | 102.7 (76-110)          | 121.4 (65-196) | 0.43 | 0.001 | 0.94 |
|        | Female                   | 77 (60-93)              | 64 (33-104)             | 68.7 (57-79) |       |       |       |
| RMS of medial hamstring | Male                     | 225.4 (70-285)          | 173.7 (136-224)         | 163.2 (106-209) | 0.016³ | 0.000 | 0.78 |
|        | Female                   | 152 (102-208)           | 94.7 (52-151)           | 91.3 (55-89) |       |       |       |

³ Post Hoc was significant between healthy control and both diabetic groups.
⁴ Post Hoc was significant between healthy control and short-term T2DM. IMPT: normalized isometric maximal peak torque, RMS: root mean square, MPF: mean power frequency.

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Footnotes

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