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Effects of a six-week endurance weight training program on bioelectrical activity of muscles and functional tests in patients with type 2 diabetes mellitus

ABSTRACT

Background. Type 2 diabetes mellitus (T2DM) is a common metabolic disease associated with pathophysiological changes in the neuromuscular system. The present study aimed to investigate the effects of a 6-week endurance training program on muscle strength, electrophysiological parameters, and functional activities in T2DM patients.

Methods. The study period was divided into 6 weeks without training and 6 weeks with training. Twelve T2DM patients participated in this study. During the training period, the same T2DM patients went through an endurance training program. The assessment process included measurement of muscle strength, surface electromyography (SEMG) recording, and functional tests. Twelve healthy individuals were evaluated to compare their data with the T2DM patients.

Results. The results showed that the muscle strength and the amplitudes of the SEMG signals of T2DM patients were lower than those of the healthy subjects. The bioelectric activity of T2DM patients increased after six weeks of the endurance training program. The functional tests showed significant improvement after the endurance training program in T2DM patients, while no significant difference was observed between the T2DM and healthy subjects.

Conclusions. The short-term endurance-training program for lower limb muscles increased muscle strength and SEMG amplitudes of the knee extensor and flexor muscles and improved functional tests in T2DM patients, which may be attributed to neural adaptation after the endurance-training program. (Clin Diabetol 2021; 10; 3: 245–251)

Key words: type 2 diabetes mellitus, endurance training, muscle strength, electromyography, functional tests

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Introduction

Type two diabetes mellitus (T2DM) is a common metabolic disorder, characterized by hyperglycemia due to insulin resistance. T2DM may interfere with the functioning and metabolism of muscles [1]. Hyperglycemia caused by T2DM results in changes in the muscle fiber composition, reduced capillary density, mitochondria dysfunction, and impaired fat metabolism in the muscular tissue [2]. Reduced muscle strength and muscle quality in T2DM may have detrimental effects on mobility, physical activities, and quality of life [1].

Decreased force-generating ability in T2DM can arise from the impairment of the nervous system and/or intrinsic muscular dysfunctions [3]. Central drives to alpha motoneurons characterize the muscle activation pattern. In addition, the number and type of the activated motor units are decisive factors in muscles force production [4]. Surface electromyography (SEMG), as a noninvasive procedure, is an important tool for recording muscular activity. This method provides an estimation of the activity of the neuromuscular system [5].

Numerous exercise training programs may enhance the performance of the neuromuscular system and increase the force-generation capacity in type 2 diabetic patients [3, 6, 7]. Previous studies have proposed different training programs for T2DM, which vary in type, duration, and severity of exercises. The adaptations observed after a training program can depend on its duration. Long-term training programs provide structural adaptations, while short-term training programs are mainly related to neural adaptations [8]. Several studies have demonstrated the effects of 8 to 16 weeks of training on the metabolic properties and muscle strength in T2DM. Botton *et al.* showed that a 12-week strength training program increased knee extensor and quadriceps muscle thickness in T2DM [6]. Bazzucchi *et al*. [7] stated that resultant torques and neuromuscular properties of knee extensor muscles in T2DM were improved after 16 weeks of combined strength and endurance training. However, the pattern of adaptation after a short-term training program in T2DM patients with neuromuscular impairments is not well documented.

We propose that T2DM patients with neuromuscular impairment may represent a different pattern of adaptation after training programs. The majority of previous studies have focused on metabolic properties and muscle strength after long-term training programs in T2DM. Hence, we aimed to clarify the effects of a short-term training program on bioelectric activity of the muscles, their force-generating capacity, and functional mobility in T2DM patients.

Methods

The study was conducted based on a self-controlled design in two separate periods. The first period included a six-week period without training, considered as the control period to eliminate the effects of time. At the second period, participants went through a 6-week training program, characterized as a training period. This means that at first each participant contributed as a control, followed by contributing as an experimental at the second period. The evaluations were performed in three stages, i.e., before the period without any training, before the training period, and after the training period. Moreover, the group of healthy subjects was assessed only once to act as reference data for comparison with the T2DM patients.

Participants

The T2DM group included 12 patients (6 male and 6 female, average age: 51.75 ± 4.97, average height: 166.33 ± 8.37, average weight: 77.67 ± 7.51, average BMI: 28.63 ± 2.42), while the healthy group included 12 subjects (6 male and 6 female, average age: 49.33 ± 6.56, average height: 168.33 ± 10.76, average weight: 73.08 ± 11.90, average BMI: 26.65 ± 2.23). All participants were informed about the procedures of the study, and they signed a consent form prior to participation. The study was approved by the Ethical Committee of Tarbiat Modares University.

The T2DM was diagnosed for all patients by an endocrinologist. All patients had been suffering from T2DM for 5 to 10 years. They had no history of insulin dependence and just took one or two oral glucose-lowering medications [9] with no modification during study period. The glycosylated hemoglobin (HbA1C) values ranged from 7.0 to 9.0% and fasting plasma glucose concentrations were between 150 to 200 mg per deciliter. The subjects had no history of retinopathy, nephropathy and neuropathy, thyroid and blood pressure diseases and foot ulcer according to endocrinologist examinations. The Michigan Neuropathy Screening test score was less than 6. None of the participants had a history of neurologic, orthopedic, cardiopulmonary, or rheumatologic diseases, or a history of surgery in the lower limbs. There was no history of middle ear diseases in any of the subjects. The ophthalmoscopy examinations showed that no participants had visual disorders. No regular exercise and physical activity had been performed by the participants during the last two years. The participants who were unwilling or unable to continue with the training program and the testing procedure were excluded from the study. Presence of autonomic neuropathy symptoms during training or testing would result in the exclusion of the subjects from the study as well.

Training program

The knee extensor and flexor muscles were trained. Prior to training, the one-repetition maximum (1RM) of knee flexion and extension was determined for all participants. The training program was implemented in three sets according to Reverse Pyramid Exercises protocol. The first set included high load (65% 1RM) and low repetition (25 repetitions), the second set included 60% 1RM and 30 repetition, and the last set included low loads (55% 1RM) and high repetitions (35 repetitions). Between each set of exercises, the participants had 120 seconds of rest. The difficulty of the exercises was set between 12 and 15 in Borg Scale.

Heartrate was monitored during the training program using a heartrate monitor (Beurer PM 70). The target heartrate according to the Borg Scale and the American Diabetes Association was set at 65–70% of the maximal heartrate. The maximum heartrate was calculated as 220 minus the age of the individual. The warm-up and cool-down phases included 5 minutes of cycling with zero load and three repetitions of stretching exercises for hamstring, quadriceps, cuff, and pretibial muscles. Every training sessions lasted nearly 45–50 minutes. All participants were training 3 days per weeks for 6 weeks. The training program was done under the supervision of an exercise specialist. The blood glucose level has been measured before, in the middle and immediately after the training sessions to determine the probability of hypoglycemia in all participants.

Strength assessment

To assess muscle strength, the one repetition maximum (1RM) was used. The 1RM is the maximal amount of resistance which can be moved through a full range of motion. In the present study, the 1RM of knee flexion and extension was assessed at all three evaluation sets with hamstring curled and knee extensor machines.

Electromyography assessment

The bioelectric activity of vastus medialis, vastus lateralis, biceps femoris, and medial hamstring muscles were recorded using SEMG. The SEMG signals were recorded by a 16-channel wireless SEMG device (Fanavaran Technology Company, Iran, 2015). The location of electrode attachment was shaved and cleaned by alcohol. To record the signals of each muscle, a pair of Ag-AgCl electrodes (Skintact F-301 Pediatric Electrode) with a center to center distance of 20 mm were attached to the muscles. The electrodes were placed according to SENIAM recommendation [5]. The ground electrode was placed at the styloid process of the ulna in the non-dominant hand.

The recording was done at 0°, 45°, and 90° flexion during maximal isometric contraction. The knee flexion was done at prone position with a hamstring curl machine, while the knee extension was done at the sitting position with a knee extensor machine. The contraction of the muscles was hold for 10 second, and repeated 3 times. After each repetition, 120 seconds of rest were considered to prevent fatigue.

In order to analyze the collected data, the LabVIEW software application (v14.0, National Instruments, Austin, TX, USA) was used. The sampling frequency of raw SEMG signals was 2000 Hz, and the high and low pass filters were set on 20 and 500 Hz, respectively. The root mean square (RMS) values of the SEMG signals of the knee flexor and extensor muscles during isometric contraction were calculated, and the average of three repetitions was considered as the SEMG amplitude. If the differences of RMSs during each session of contraction were more than 10% of max RMS, the test was repeated again. The RMS values were normalized to isometric MVC values at 0 degree flexion.

Functional tests

Two functional tests were used to assess the functional status of patients at three testing sessions. The 6 min walk test (6-MWT) is a functional test that measures the distance covered in 6 minutes without running. A difference of more than 20 meters was considered as a significant change [10]. The Time Up and Go Test (TUG) is a mobility test that measures the time it takes for the subject to get up from a chair, walk three meters forward, turn around, walk back, and sit on the chair [11].

Data analysis

The data collected in the study were analyzed using SPSS software application (V15.0, IBM Corporation, Armonk, NY, USA). The significance level was considered as $P < 0.05$. To analyze the variance of the three testing sessions, the repeated measures ANOVA was used. The Least Significant Difference (LSD) test was used to determine the difference between the sessions. Moreover, independent t-test was used to compare the T2DM patients and the healthy group.

Results

The Kolmogorov-Smirnov test indicated the normal distribution of the data. The results showed that the RMS of knee flexor and extensor muscles in T2DM was significantly lower than those of the healthy individuals (Tables 1–4).

The results of 1RM assessment and functional tests are presented in Table 3. The LSD analysis showed the 1RM of knee extensor and flexor muscles and functional tests at the third stage of assessment was significantly different from the first and second stages of assessment (Tables 5, 6).

The results showed that the 1RM of knee extensor and knee flexor in healthy subjects was higher than that of the T2DM subjects. After six weeks of training, the 1RM of knee extensor increased to 41.5% and that of the knee flexor increased to 31.4%. The 6MW and TUG test in T2DM patients and healthy subjects showed no significant differences with healthy subjects. The six weeks (non-training) of the control period led to no significant differences; however, after six weeks of training, the 6MW test increased (10.9%) and the TUG decreased (8.8%) in the T2DM subjects.

Table 1. The mean values of RMS of knee flexor muscles

Variable	ROM (degree)	D1 (M ± SD)	D2 (M ± SD)	D3 (M ± SD)	H (M ± SD)
RMS MH	90	100 ± 0	98.17 ± 18.89	104.61 ± 16.27	100 ± 0
	45	105.89 ± 13.37	109.28 ± 14.43	117.90 ± 14.58	141.82 ± 28.16
	0	124.53 ± 14.85	118.23 ± 17.07	134 ± 21.4	167.78 ± 31.78
RMS BF	90	100 ± 0	102.67 ± 9.36	108.13 ± 13.61	100 ± 0
	45	89.29 ± 15.99	90.53 ± 14.11	94.63 ± 13.15	95.18 ± 6.64
	0	84.82 ± 12.95	80.62 ± 13	87.41 ± 12.55	90.36 ± 7.28

BF — biceps femoris; D1 — T2DM participant first stage assessment; D2 — T2DM participant second stage assessment; D3 — T2DM participant third stage assessment; H — healthy participant assessment; M ± SD — mean ± standards deviation; MH — medial hamstring; RMS — root mean square; ROM — range of motion

Table 2. The comparison of RMS of knee flexor muscles between three assessment stages and healthy subjects

Variable	ROM (degree)	ANOVA	LSD			t-test		
			D1–D2	D1–D3	D2–D3	D1 – H	D2 – H	D3 – H
MH	90	0.33	—	—	—	NaN	0.74	0.34
	45	< 0.01*	—	Sig*	Sig*	< 0.01*	< 0.01*	0.01*
	0	< 0.01*	—	Sig*	Sig*	< 0.01*	< 0.01*	< 0.01*
BF	90	0.07	—	—	—	NaN	0.34	0.06
	45	0.18	—	—	—	0.44	0.71	0.73
	0	0.04*	—	—	Sig*	0.25	0.08	0.80

BF — biceps femoris; D1 — T2DM participant first stage assessment; D2 — T2DM participant second stage assessment; D3 — T2DM participant third stage assessment; H — healthy participant assessment; LSD — least significant difference; MH — medial hamstring; NaN — not a number; RMS — root mean square; ROM — range of motion; Sig — significant

Table 3. The mean values of RMS of knee extensor muscles

Variable	ROM (degree)	D1 (M ± SD)	D2 (M ± SD)	D3 (M ± SD)	H (M ± SD)
RMS VMO	90	149.26 ± 27.11	149.80 ± 32.71	157.03 ± 30.32	226.28 ± 45.82
	45	129.34 ± 29.91	133.10 ± 23.35	145.38 ± 29.78	204.39 ± 27.07
	0	100 ± 0	101.08 ± 9.25	107.39 ± 10.23	100 ± 0
RMS VL	90	164.75 ± 23.25	166.49 ± 22.15	183.02 ± 29.30	239.37 ± 35.85
	45	135.66 ± 19.60	142.40 ± 23.12	156 ± 24.58	213.56 ± 41.21
	0	100 ± 0	106.70 ± 6.76	117.22 ± 10.89	100 ± 0

D1 — T2DM participant first stage assessment; D2 — T2DM participant second stage assessment; D3 — T2DM participant third stage assessment; H — healthy participant assessment; M ± SD — mean ± standards deviation; RMS — root mean square; ROM — range of motion; VL — vastus lateralis; VMO — vastus medialis oblique

Discussion

The results of the present study showed that the muscle strength and RMS of knee extensor and flexor muscles in healthy individuals were significantly higher than those of the T2DM patients. The six-week endurance training program increased the muscle strength and the RMS of knee extensor and flexor muscles in T2DM patients. The functional tests assessment showed that there were no significant differences between T2DM and healthy subjects.

Numerous studies have reported that the muscle strength of diabetic patients decreased as a result of the complications of the disease compared to healthy subjects [12–15]. Similarly, the present study indicated that 1RM and bioelectrical activation of knee flexor and extensor muscles in T2DM were lower than those of the healthy subjects prior to the appearance of neuropathological symptoms. Hatef *et al.* [15] showed that the maximal peak torques and RMS of knee extensor and flexor muscles in healthy individuals were higher than those of the T2DM patients, which was attributed to the duration of the disease and the appearance of neuropathological symptoms [15]. A linear relationship was observed between the increase in RMS and isometric

Table 4. The comparison of RMS of knee extensor muscles between three assessment stages and healthy subjects

Variable	ROM (degree)	ANOVA	LSD			T–test		
			D1–D2	D1–D3	D2–D3	D1–H	D2–H	D3–H
VMO	90	0.20	—	—	—	< 0.01*	< 0.01*	< 0.01*
	45	0.03*	—	Sig*	—	< 0.01*	< 0.01*	< 0.01*
	0	0.01*	—	Sig*	Sig*	NaN	0.69	0.04*
VL	90	< 0.01*	—	Sig*	Sig*	< 0.01*	< 0.01*	< 0.01*
	45	< 0.01*	—	Sig*	Sig*	< 0.01*	< 0.01*	< 0.01*
	0	< 0.01*	Sig*	Sig*	Sig*	NaN	< 0.01*	< 0.01*

D1 — T2DM participant first stage assessment; D2 — T2DM participant second stage assessment; D3 — T2DM participant third stage assessment; H — healthy participant assessment; LSD — least significant difference; NaN — not a number; RMS — root mean square; ROM — range of motion; Sig — significant; VL — vastus lateralis; VMO — vastus medialis oblique

Table 5. The mean values of knee extensor and flexor strength and functional tests

Variable	D1 (M ± SD)	D2 (M ± SD)	D3 (M ± SD)	H (M ± SD)
TUG	6.33 ± 0.88	6.28 ± 0.85	5.73 ± 0.68	6.03 ± 0.75
6MW	514.17 ± 64.66	519.75 ± 65.69	576.42 ± 61.89	55.9 ± 83.23
1RM EXT	27.33 ± 9.06	29 ± 9.29	40.75 ± 12.17	51.5 ± 12.66
1RM FLX	15.58 ± 7.22	18.33 ± 7.58	24.08 ± 11.18	28.25 ± 13.71

1RM — one-repetition maximum; 6MW — six mean walk test; D1 — T2DM participant first stage assessment; D2 — T2DM participant second stage assessment; D3 — T2DM participant third stage assessment; Ext — extensor; Flex — flexor; H — healthy participant assessment; TUG — time up and go test

Table 6. The comparison of knee extensor and flexor strength and functional test between three assessment stages and healthy subjects

Variable	ANOVA	LSD			t–test		
		D1–D2	D1–D3	D2–D3	D1 – H	D2 – H	D3 – H
TUG	< 0.01*	—	Sig*	Sig*	0.50	0.21	0.20
6MW	< 0.01*	—	Sig*	Sig*	0.15	0.20	0.57
1RM EXT	< 0.01*	—	Sig*	Sig*	< 0.01*	< 0.01*	0.20
1RM FLX	< 0.01*	—	Sig*	Sig*	0.01*	0.03*	0.42

1RM — one-repetition maximum; 6MW — six mean walk test; D1 — T2DM participant first stage assessment; D2 — T2DM participant second stage assessment; D3 — T2DM participant third stage assessment; Ext — extensor; Flex — flexor; H — healthy participant assessment; LSD — least significant difference; TUG — time up and go test

muscle strength [16]. The complications of T2DM lead to neuromuscular dysfunction, resulting in decreased force-generating ability in relation to the decreased bioelectric activity of muscles in T2DM patients [17].

Hatef *et al.* [15] studied the neuromuscular properties of muscles after a fatigue protocol [15], while the present study assessed the effects of a short-term training program on neuromuscular properties of knee flexor and extensor muscles. The results showed that muscle force and the amplitude of the bioelectrical activity of knee extensor and flexor muscles increased after six weeks of endurance training. A similar study indicated that the muscle strength and efficiency of the neuromuscular system increased at the early stages of strength training without obvious changes in the amplitude of SEMG signals [18]. Increased force generation at the early stages of training can indicate that the role of neural adaptation is greater than that of the structural adaptation of muscles. Neural adaptations include some changes in the coordination of muscles and learning movements in the neuromuscular system, improving the neuromuscular activity of the muscles during force generation [8].

The diabetes-related international organizations recommend multiple exercise training programs in T2DM patients as non-pharmacological therapeutic strategy. Numerous exercises training including endurance, strength and combined training programs with different intensity and duration have brought beneficial effects about biochemical and physical properties in

T2DM [19]. The strength training programs compared to endurance training are introduced more recently in T2DM patients which improves muscle strength and motor functions [20]. But the exact effects of various type, intensity and duration of strength training has not been elucidated yet in T2DM patients. A review study evaluated the effects of resistance training on T2DM patients. The results showed that resistance training increased the muscle strength of T2DM patients in the lower limb muscles more than the upper limb muscles [21]. In addition, Herriott *et al.* [22] and Egger *et al.* [23] indicated that resistance training increased muscle strength in T2DM patients. The type, intensity and duration of training in the above-mentioned studies are variable. The duration of the training varied between 8 and 16 weeks and the training protocols involved the whole body training with high loads and were not specific to particular muscles. Long term and high intensity strength training programs may induce high blood pressure and muscle injuries in T2DM patients [24, 25]. In contrast to previous studies, we found that a short-term endurance weight training program for knee flexor and extensor muscles could affect muscle strength and the neuromuscular properties of the muscles. The relationship between muscle strength and RMS indicated that the bioelectric activity of knee flexor and extensor muscles increased in parallel with 1RM enhancement after a short-term training program, which could be attributed to the neural adaptation of the training [26].

Improving functional activity in T2DM patients is one of the most important goals of therapeutic exercise [27]. In addition to impaired muscle strength in T2DM patients, the T2DM patients are exposed to decreased functional capacity, physical disability, and impaired functional mobility [3]. Decreased functional capacity of movement can be affected by impaired intrinsic properties of muscles, including decreased muscle mass, impaired metabolism, and dysfunction of mitochondria [28]. Moreover, diabetic peripheral neuropathy may affect the functional ability of movement [29].

The TUG and 6MW tests are used to measure functional activities [30]. The results from the present study showed improvement of functional tests after the training program, which means that the distance increased in the 6MW test and the time duration decreased in the TUG test. Hulens *et al.* [31] demonstrated that individuals with higher strength in the quadriceps muscle had higher scores in the 6MW test. We proposed that exercise training to strengthen the knee extensor muscles could improve walking ability in T2DM patients. In the present study, the training program was designed for knee extensor and flexor muscles; hence, the improvement in the 6MW test can be attributed to increased knee flexor and extensor strength in T2DM patients. Similarly, following a 12-week strength and endurance training program, Allet *et al.* [32] reported improvement in walking speed, balance, muscle strength, joint mobility, and functional tests in T2DM patients. Another study by Ijzerman *et al.* [13] showed that the 6MW test performance in T2DM patients with and without DPN was significantly lower than healthy individuals; however, the TUG test was only significant between the T2DM patients with neuropathy and healthy individuals. Nonetheless, their results are controversial since the healthy individuals and T2DM patients were not completely matched in terms of height, weight, and BMI. Also, the functional tests are affected by age, height, BMI, sex, muscle strength and endurance, and weight [33].

Mueller *et al.* [34] reported that weight-bearing and non-weight-bearing exercises led to improvement in the 6MW test; however, the effects of weight-bearing exercises were greater. A recent review study by Hwang *et al.* showed that all types of training, including endurance, resistance, balance, and combined training had beneficial effects on the 6MW and TUG tests in type 2 diabetic patients [35]. The results of the present study show that the short-term endurance weight training for knee extensor and flexor muscles can lead to increased muscle strength and increased capacity for functional activities in T2DM patients, which may result in an independent lifestyle.

Conclusion

The T2DM patients have reduced muscle force-generating ability and functional activity compared to healthy subjects. Consequently, a short-term endurance training program for T2DM patients increases muscle strength and muscle bioelectric activity, while it can improve functional tests, which may be related to neural adaptation at the early stages of training.

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Conflicts of interest

The authors declare no conflict of interest regarding publication of this manuscript.

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