Environ Health Prev Med (2016) 21:179–185
DOI 10.1007/s12199-016-0512-8

REGULAR ARTICLE

Relationship of toe pinch force to other muscle strength parameters in men with type 2 diabetes

Hiroaki Kataoka[1,2] · Nobuyuki Miyatake[2] · Naomi Kitayama[1] · Satoshi Murao[3] · Fumikazu Kohi[4] · Satoshi Tanaka[5]

Received: 2 November 2015 / Accepted: 23 January 2016 / Published online: 15 February 2016

Abstract
Objective The aim of this study was to explore the relations between toe pinch force and other muscle strength parameters in male patients with type 2 diabetes mellitus.
Methods A total of 40 men with type 2 diabetes (age: 53.4 ± 13.1 years, duration of diabetes: 8.5 ± 8.1 years) who needed exercise training were enrolled in this cross-sectional study. We evaluated the clinical parameters and 4 muscle strength parameters, which were toe pinch force, handgrip strength, isometric knee extension force, and isometric ankle dorsiflexion force.
Results The HbA1c, toe pinch force, handgrip strength, isometric knee extension force, and isometric ankle dorsiflexion force were 10.1 ± 2.4 %, 3.2 ± 1.2 kg, 37.3 ± 7.0 kg, 39.6 ± 11.4 kgf, and 17.0 ± 6.3 kgf, respectively. Toe pinch force was significantly correlated with handgrip strength ($r = 0.365$, $p = 0.0206$), isometric knee extension force ($r = 0.668$, $p < 0.0001$), and isometric ankle dorsiflexion force ($r = 0.514$, $p = 0.0007$). All muscle strength parameters were significantly lower in patients with diabetic polyneuropathy than in those without polyneuropathy.
Conclusion Although toe pinch force was significantly correlated with the other muscle strength parameters, the correlation was not so strong. However, evaluation of toe pinch force might be recommended for assessment of distal limb muscle strength in patients with type 2 diabetes.

Keywords Type 2 diabetes mellitus · Toe pinch force · Handgrip strength · Isometric knee extension force · Isometric ankle dorsiflexion force

✉ Hiroaki Kataoka
h.kataoka59@gmail.com

1 Rehabilitation Center, KKR Takamatsu Hospital, Tenjinmae, Takamatsu, Kagawa 760-0018, Japan

2 Department of Hygiene, Faculty of Medicine, Kagawa University, Miki, Kagawa 761-0793, Japan

3 Department of Diabetes and Endocrinology, KKR Takamatsu Hospital, Tenjinmae, Takamatsu, Kagawa 760-0018, Japan

4 Department of Internal Medicine, KKR Takamatsu Hospital, Tenjinmae, Takamatsu, Kagawa 760-0018, Japan

5 Department of Physical Therapy, Faculty of Health and Welfare, Prefectural University of Hiroshima, Mihara, Hiroshima 723-0053, Japan

Introduction

The foot is the only part of the human body that comes into contact with the ground and the toes are especially important for stabilizing the posture and for movement [1, 2]. There have been several reports that toe muscle strength decreases with aging [1, 3, 4] and is correlated with the risk of falling [2, 5, 6]. In addition, it has been reported that toe muscle strength training reduces falls [7] and increases both maximal walking speed and single-leg standing time [7, 8]. We previously evaluated the reproducibility of measuring the toe pinch force, which is one of the major methods for assessing muscle strength in the foot, and found that measurement has a high reproducibility (coefficient of variation and intraclass correlation coefficient) in healthy young Japanese men [9].

It is well known that muscle strength is closely associated with all-cause mortality [10]. In patients with type 2 diabetes mellitus, muscle strength training has a beneficial effect on insulin resistance [11]. An increase of leg strength per unit body weight was associated with improvement of metabolic syndrome in a longitudinal analysis [12].

Therefore, accurate evaluation of muscle strength could be useful for prevention and treatment of type 2 diabetes. However, evaluation of toe pinch force has not been fully discussed in type 2 diabetes and the factors influencing toe pinch force remain to be investigated in these patients.

Accordingly, this pilot cross-sectional study was performed in men with type 2 diabetes to evaluate the relationship between toe pinch force and other muscle strength parameters, such as handgrip strength, isometric knee extension force, and isometric ankle dorsiflexion force.

Methods

Subjects

A total of 40 male patients with type 2 diabetes who met the following criteria were enrolled in this cross-sectional study (Table 1). (1) They were inpatients of KKR Takamatsu Hospital (Kagawa, Japan) from May 2012 to April 2015 with type 2 diabetes, (2) they were recommended to increase physical activity and perform exercise, (3) they did not have orthopedic diseases or an exercise habits, and (4) they provided written informed consent.

The protocol of this study was approved by the Ethics Committee of KKR Takamatsu Hospital (Approval number: E92).

Clinical parameters

We collected data on height (cm), body weight (kg), duration of diabetes (years), medications, and results of blood and urine tests. Fasting blood samples were obtained for determination of fasting plasma glucose (mg/dl), HbA1c (%), total cholesterol (mg/dl), LDL-cholesterol (mg/dl), HDL-cholesterol (mg/dl), and triglyceride (mg/dl) levels using standard laboratory methods. Diagnosis of type 2 diabetes based on fasting plasma glucose and HbA1c levels was performed according to the guidelines of the Japan Diabetes Society [13].

Table 1 The clinical characteristics of the subjects ($n = 40$)

		Minimum	Maximum
Age (years)	53.4 ± 13.1	30	82
Height (cm)	169.0 ± 5.0	159.8	178.8
Weight (kg)	80.5 ± 16.8	54.9	139.0
Duration of diabetes (years)	8.5 ± 8.1	1	30
HbA1c (%)	10.1 ± 2.4	6.8	15.5
Fasting plasma glucose (mg/dl)	174.4 ± 55.6	97	323
Total cholesterol (mg/dl)	196.9 ± 36.5	126	290
LDL-cholesterol (mg/dl)	117.1 ± 27.4	37	169
HDL-cholesterol (mg/dl)	46.3 ± 9.2	31	69
Triglycerides (mg/dl)	187.4 ± 125.6	62	695
Retinopathy			
None	31		
Simple	3		
Preproliferative	5		
Proliferative	1		
Nephropathy			
Stage 1	26		
Stage 2	12		
Stage 3	1		
Stage 4	1		
Neuropathy	12		
Drug therapy			
Insulin	7		
OHA	25		
Insulin and OHA	8		

Values are presented as the mean ± standard deviation

OHA oral hypoglycemic agent

Muscle strength measurement

As was done in previous reports [9, 15–17], we measured toe pinch force, hand grip strength, isometric knee extension force, and isometric ankle dorsiflexion force to evaluate muscle strength.

Toe pinch force was measured by using a Checker-kun (Nisshin Sangyo Inc., Saitama, Japan), as described previously [9]. The subject sat on a chair with arms crossed over the chest. A pinch force dynamometer was attached to the foot of the subject between the great toe and second toe while in the sitting position with the hip and knee joints in 90° of flexion (Fig. 1). The test was performed twice each on the left and right sides, and the best results for the left and right feet were averaged.

Handgrip strength was measured with a handgrip dynamometer (T.K.K.5401; Takei Scientific Instruments Co., Ltd., Niigata, Japan), as in previous studies [14]. The subject was in the standing position with the upper limb relaxed at the side, elbow fully extended, and palm inward [15] (Fig. 2). The test was performed twice each on the left and right sides, and the best results for the left and right hands were averaged.

Isometric knee extension force and isometric ankle dorsiflexion force were measured using a μTas F-1 handheld dynamometer (Anima Corp., Tokyo, Japan), as in previous studies [16]. Isometric knee extension force was measured according to the method of Kato et al. [16]. The subject sat on a chair and was positioned so that a leg of the chair was behind the lower extremity undergoing measurement (Fig. 3). Then the chair was adjusted to a height at which both feet of the subject were just off the floor. Subjects placed their hands on the chair on each side of the body and kept the trunk perpendicular. The tester placed a large folded towel at the popliteal fossa of the subject on the side of measurement to keep both femurs parallel, and the knee joints were maintained at 90° of flexion with the lower extremities hanging perpendicularly. The handheld dynamometer and a belt were used to measure isometric knee extension force while the knee joint was at 90° of flexion. The sensor of the dynamometer was placed on the anterior surface of the leg, and fixed at the level of the upper border of the medial malleolus using Velcro. Then the leg to which the sensor had been attached was tied to the chair leg directly behind using a belt. Testing was done twice each on the left and right sides, and the best results for the left and right lower extremities were averaged.

Isometric ankle dorsiflexion force was evaluated in the supine position, with the knee extended and the ankle joint in an unrestrained neutral position (Fig. 4). The handheld dynamometer was placed against the dorsal surface of the foot near the metatarsal heads [17]. Testing was done twice each on the left and right sides, and the best results for the left and right feet were averaged.

Fig. 2 Measurement of handgrip strength

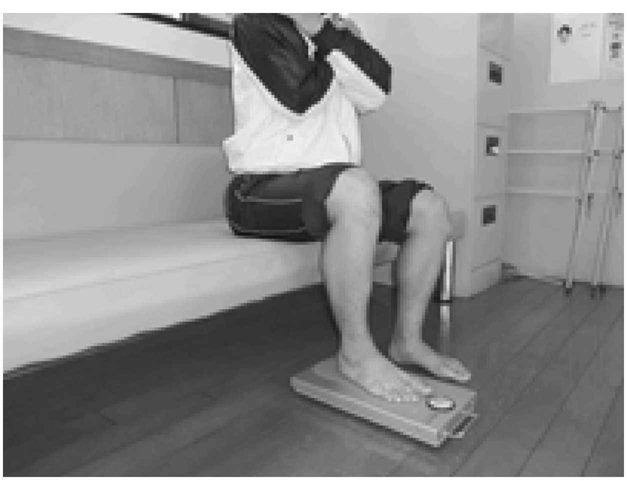

Fig. 1 Measurement of toe pinch force at KKR Takamatsu hospital (Kagawa, Japan)

Fig. 3 Measurement of isometric knee extension force

Fig. 4 Measurement of isometric ankle dorsiflexion force

Assessment of chronic complications of diabetes

The diagnosis of diabetic retinopathy and diabetic nephropathy was based on the guidelines of the Japan Diabetes Society, while diabetic polyneuropathy was diagnosed according to the Japanese criteria. Diabetic polyneuropathy was defined as being present if the patient had at least two of the following three criteria: (1) symptoms such as dysesthesia, pain, and/or loss of sensation, (2) decreased or absent Achilles tendon reflex, and (3) decreased vibratory sensation (≤10 s).

Statistical analysis

Results were expressed as the mean ± standard deviation (SD). The Mann–Whitney *U* test was used to compare two groups and $p < 0.05$ was taken to indicate statistical significance. Pearson's correlation coefficients were calculated to evaluate the relationship between continuous variables after the Shapiro–Wilk test. All analyses were performed using the JMP 12.0.1 software (SAS Institute., Cary, NC, USA).

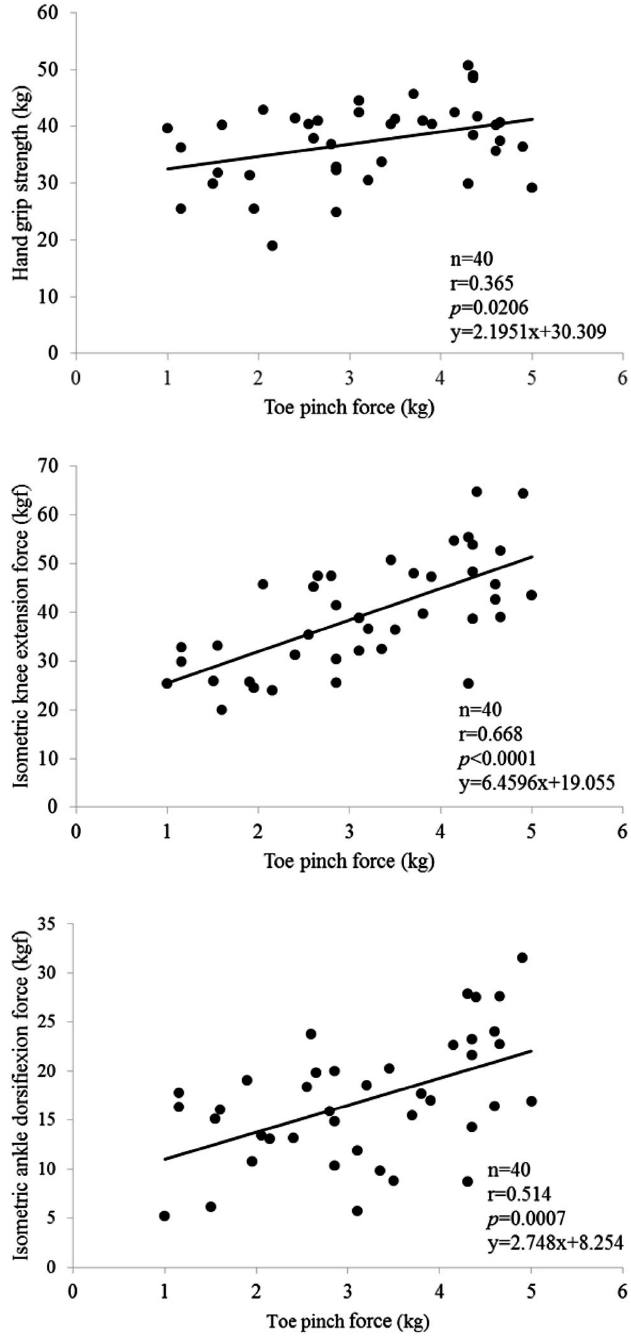

Fig. 5 Relationship between toe pinch force and other muscle parameters

Results

The clinical characteristics of the subjects are summarized in Table 1. The age, duration of diabetes, and HbA1c were 53.4 ± 13.1 years, 8.5 ± 8.1 years, and 10.1 ± 2.4 %, respectively. In addition the toe pinch force, handgrip strength, isometric knee extension force, and isometric ankle dorsiflexion force were 3.2 ± 1.2 kg, 37.3 ± 7.0 kg, 39.6 ± 11.3 kgf, and 17.0 ± 6.3 kgf, respectively (Table 2).

We evaluated the relationship between toe pinch force and age, and also the relationships between toe pinch force and other muscle strength parameters. Toe pinch force was not significantly correlated with age ($r = -0.183$, $p = 0.2579$). When we evaluated the relationship between toe pinch force and other muscle parameters, we found that toe pinch force was significantly correlated with handgrip strength ($r = 0.365$, $p = 0.0206$), isometric knee extension force ($r = 0.668$, $p < 0.0001$), and isometric ankle dorsiflexion force ($r = 0.514$, $p = 0.0007$) (Fig. 5)

Table 2 Muscle strength parameters ($n = 40$)

		Minimum	Maximum
Toe pinch force (kg)	3.2 ± 1.2	1.0	5.0
Handgrip strength (kg)	37.3 ± 7.0	19.0	50.8
Isometric knee extension force (kgf)	39.6 ± 11.4	20.1	64.9
Isometric ankle dorsiflexion force (kgf)	17.0 ± 6.3	5.2	31.6

Values are the mean ± standard deviation

Table 3 Comparison of clinical characteristic and muscle strength between patients with and without chronic diabetic complications

	Retinopathy		*p* value	Nephropathy		*p* value	Neuropathy		*p* value
	−	+		−	+		−	+	
n	31	9		26	14		28	12	
Age (years)	51.8 ± 13.7	58.7 ± 9.5	0.1122	54.3 ± 13.8	51.6 ± 12.1	0.4606	50.5 ± 12.0	60.1 ± 13.7	**0.0478**
Height (cm)	169.3 ± 5.1	167.9 ± 4.7	0.2493	168.9 ± 4.6	169.2 ± 5.8	0.9887	169.5 ± 4.8	167.9 ± 5.3	0.2197
Weight (kg)	81.4 ± 16.5	77.2 ± 18.3	0.3644	75.8 ± 9.9	89.1 ± 23.0	**0.0359**	83.6 ± 17.2	75.5 ± 15.3	0.4606
Duration of diabetes (years)	5.6 ± 5.8	18.4 ± 7.1	**0.0001**	8.1 ± 8.5	9.4 ± 7.5	0.3649	7.0 ± 7.2	12.0 ± 9.4	0.0996
HbA1c (%)	10.4 ± 2.6	9.0 ± 1.1	0.2500	9.9 ± 2.5	10.4 ± 2.2	0.3492	10.4 ± 2.7	9.4 ± 1.5	0.6366
Fasting plasma glucose (mg/dl)	173.1 ± 59.0	179.1 ± 44.4	0.7582	171.5 ± 57.7	179.8 ± 53.3	0.5705	166.5 ± 58.6	192.8 ± 45.0	0.0569
Total cholesterol (mg/dl)	203.7 ± 36.4	173.3 ± 26.7	**0.0287**	190.5 ± 34.8	208.8 ± 37.8	0.0861	204.1 ± 33.6	180.0 ± 38.8	0.0841
LDL-cholesterol (mg/dl)	120.4 ± 28.5	105.9 ± 20.8	0.1053	115.1 ± 28.5	120.9 ± 25.8	0.5514	123.5 ± 23.2	102.3 ± 31.7	**0.0289**
HDL-cholesterol (mg/dl)	47.4 ± 8.9	42.7 ± 9.6	0.1193	46.9 ± 9.0	45.3 ± 9.7	0.6191	46.5 ± 8.8	46.0 ± 1.4	0.5249
Triglyceride (mg/dl)	193.8 ± 139.6	165.1 ± 55.9	0.8206	175.7 ± 126.1	208.9 ± 126.6	0.2687	193.8 ± 138.7	172.3 ± 91.5	0.7792
Hand grip strength (kg)	37.0 ± 6.9	38.2 ± 7.7	0.5597	35.5 ± 6.9	40.6 ± 6.1	**0.0232**	38.5 ± 7.3	34.4 ± 5.6	**0.0479**
Isometric knee extension force (kgf)	40.1 ± 11.5	37.8 ± 11.4	0.6386	38.6 ± 10.3	41.4 ± 13.3	0.4109	42.9 ± 11.5	31.9 ± 6.2	**0.0048**
Isometric ankle dorsiflexion force (kgf)	17.7 ± 6.2	14.7 ± 6.4	0.3476	16.9 ± 5.7	17.2 ± 7.5	0.9661	18.6 ± 5.8	13.3 ± 6.1	**0.0324**
Toe pinch force (kg)	3.2 ± 1.1	3.1 ± 1.3	0.7336	3.1 ± 1.3	3.4 ± 1.0	0.5325	3.6 ± 1.0	2.3 ± 1.1	**0.0015**

Values are the mean ± standard deviation

Statistical analysis was done by the Mann–Whitney *U* test

Bold values indicate $p < 0.05$

In addition, we evaluated the differences of clinical parameters and muscle strength parameters between patients with and without chronic complications of diabetes (Table 3). The duration of diabetes was significantly longer in patients with diabetic retinopathy than in those without diabetic retinopathy and total cholesterol was significantly lower. Body weight was significantly higher in patients with diabetic nephropathy than in those without diabetic nephropathy. Furthermore, patients with diabetic polyneuropathy were significantly older than those without diabetic polyneuropathy and their LDL-cholesterol was significantly lower. All of the muscle strength parameters were significantly lower in patients with diabetic polyneuropathy than in those without diabetic polyneuropathy [handgrip strength (38.5 ± 7.3 vs 34.4 ± 5.6 kg, $p = 0.0479$), isometric knee extension force (42.9 ± 11.5 vs 31.9 ± 6.2 kgf, $p = 0.0048$), isometric ankle dorsiflexion force (18.6 ± 5.8 vs 13.3 ± 6.1 kgf, $p = 0.0324$), and toe pinch force (3.6 ± 1.0 vs 2.3 ± 1.1 kg, $p = 0.0015$)]. Also, handgrip strength was significantly higher in patients with diabetic nephropathy than in those without it. However, there were no significant differences of other muscle strength parameters in relation to the presence/absence of chronic diabetic complications.

Discussion

The main objective of this study was to explore the link between toe pinch force and other muscle strength parameters in men with type 2 diabetes. While we found that there were significant correlations between toe pinch force and other muscle strength parameters, evaluation of toe pinch force was thought to be evaluated.

The relationship between toe pinch force and other muscle strength parameters in type 2 diabetes has not been evaluated before. In general, different muscle strength parameters are thought to be correlated with each other. However, this cross-sectional study of male patients with type 2 diabetes showed that the correlations were not very strong. Park et al. reported that the handgrip strength of patients with type 2 diabetes was similar to that of healthy subjects [18], while Andersen et al. found that isometric knee extension force and isometric ankle dorsiflexion force were significantly lower in patients with type 2 diabetes than in healthy subjects [19]. These results may indicate that reduction of lower limb muscle strength is a fundamental feature of type 2 diabetes. This could explain why the correlation between toe pinch force and handgrip strength was weaker than those between toe pinch force and isometric knee extension force or isometric ankle dorsiflexion force. However, the correlation between toe pinch force and isometric knee extension force was still not very strong ($r = 0.668$). Although handgrip strength and isometric knee extension force are the main tests used for evaluation of muscle strength in clinical practice, our results suggest that measuring toe pinch force might provide useful information for management of type 2 diabetes.

Regarding the influence of chronic diabetic complications on muscle strength, Andersen et al. also reported that leg strength was significantly lower in patients with diabetic polyneuropathy than in those without it [18]. It is well known that diabetic polyneuropathy develops earlier than other chronic complications, such as diabetic retinopathy and diabetic nephropathy, in patients with type 2 diabetes [20], and over 50 % of these patients are reported to have signs of diabetic polyneuropathy [21], especially affecting the digits. These reports suggest that diabetic polyneuropathy could be a critical determinant of the toe pinch force. In fact, our study revealed that muscle strength parameters were significantly lower in patients with diabetic polyneuropathy than in patients without diabetic polyneuropathy, although there were significant differences of age and LDL-cholesterol between patients with and without diabetic polyneuropathy. However, handgrip strength was higher in patients with diabetic nephropathy than in those without it. The small sample size of this study may have influenced the results, and large-scale analysis stratified according to chronic diabetic complications might be needed to fully explore the effects of these complications.

In the exercise therapy for patients with type 2 diabetes mellitus, walking is often recommended because it is easy to perform in clinical practice. Although the lower levels of the toe pinch force were closely linked to falls [2, 5, 6], the toe pinch force has not been accurately evaluated and also not been focused on for preventing falls. In this pilot cross-sectional study, it is noteworthy that we firstly clarified the relationship between toe pinch force and other muscle strength parameters. Our results promise useful data for evaluating toe pinch force in patients with type 2 diabetes mellitus.

There were some limitations of this study. First, it was a cross-sectional (not longitudinal) study. Second, the small sample size might have influenced the results obtained when we explored the relationship between toe pinch force and chronic complications of diabetes, especially diabetic nephropathy. Third, we did not evaluate women with diabetes. Nevertheless, the correlations between toe pinch force and other muscle strength parameters were not so strong in this study, suggesting that measurement of toe pinch force and relevant exercises should be recommended in patients with type 2 diabetes to prevent falls. Further studies in larger populations will be required to explore these issues in more detail.

Acknowledgments This study was partly supported by a research grant from 114 Bank (Kagawa, Japan).

Compliance with ethical standards

Conflict of interest There are no conflicts of interest in relation to this study.

References

1. Endo M, Ashton-Miller JA, Alexander NB. Effects of age and gender on toe flexor muscle strength. J Gerontol A Biol Sci Med Sci. 2002;57:M392–7.
2. Menz HB, Morris ME, Lord SR. Foot and ankle characteristics associated with impaired balance and functional ability in older people. J Gerontol A Biol Sci Med Sci. 2005;60:1546–52.
3. Menz HB, Zammit GV, Munteanu SE, Scott G. Plantarflexion strength of the toes: age and gender differences and evaluation of a clinical screening test. Foot Ankle Int. 2006;27:1103–8.
4. Scott G, Menz HB, Newcombe L. Age-related differences in foot structure and function. Gait Posture. 2007;26:68–75.
5. Menz HB, Morris ME, Lord SR. Foot and ankle risk factors for falls in older people: a prospective study. J Gerontol A Biol Sci Med Sci. 2006;61:866–70.
6. Mickle KJ, Munro BJ, Lord SR, Menz HB, Steele JR. ISB clinical biomechanics award 2009: toe weakness and deformity increase the risk of falls in older people. Clin Biomech. 2009;24:787–91.
7. Murata S, Kutsuna T. Prevention of falls in the elderly disabled at home—foot grip strength exercise. J Japan Acad Home Health Care. 2004;7:67–74 **(in Japanese)**.
8. Kito N, Ihara H, Miwa M, Kouya H, Shimazawa S, Baba Y, et al. Effect of toe motion exercise to prevent falls in elderly. J Japan Phys Ther Assoc. 2001;28:313–9 **(in Japanese)**.
9. Kataoka H, Ishikawa A, Hayashino S, Yamamoto K, Miyazawa Y, Tanaka S, et al. Reproducibility of toe pinch dynamometer procedure. J Dist Environ Health Welf Res (**in press**).
10. Ruiz JR, Sui X, Lobelo F, Morrow JR Jr, Jackson AW, Sjostrom M, Blair SN. Association between muscular strength and mortality in men: prospective cohort study. BMJ. 2008;337:a439.
11. Cauza E, Hanusch-Enserer U, Strasser B, Ludvik B, Metz-Schimmerl S, Pacini G, et al. The relative benefits of endurance and strength training on the metabolic factors and muscle function of people with type 2 diabetes mellitus. Arch Phys Med Rehabil. 2005;86:1527–33.
12. Miyatake N, Miyachi M, Numata T. Increasing leg strength per body weight is associated with improvements in metabolic syndrome in Japanese men. Anti-Aging Med. 2009;6:1–4.
13. Tajima N, Noda M, Origasa H, Noto H, Yabe D, Fujita Y, et al. Evidence-based practice guideline for the treatment for diabetes in Japan 2013.Diabetol Int. 2015;6:151-87.
14. Nascimento Dda C, Tibana RA, Benik FM, Fontana KE, Ribeiro Neto F, Santana FS, et al. Sustained effect of resistance training on blood pressure and hand grip strength following a detraining period in elderly hypertensive women: a pilot study. Clin Interv Aging. 2014;9:219–25.
15. Chen CH, Ho-chang, Huang YZ, Hung TT. Hand-grip strength is a simple and effective outcome predictor in esophageal cancer following esophagectomy with reconstruction: a prospective study. J Cardiothorac Surg. 2011;6:98.
16. Katoh M. Reliability of isometric knee extension muscle strength measurements made by a hand-held dynamometer and belt: a comparison of two types of device. J Phys Ther Sci. 2015;27:851–4.
17. de Moura Campos Carvalho E Silva AP, Maqalhaes E, Bryk FF, Fukuda TY. Comparison of isometric ankle strength between females with and without patellofemoral pain syndrome. Int J Sports Phys Ther. 2014; 9: 628–34.
18. Park SW, Goodpaster BH, Strotmeyer ES, Kuller LH, Broudeau R, Kammerer C, et al. Accelerated loss of skeletal muscle strength in older adults with type 2 diabetes: the health, aging, and body composition study. Diabetes Care. 2007;30:1507–12.
19. Andersen H, Nielsen S, Mogensen CE, Jakobsen J. Muscle strength in type 2 diabetes. Diabetes. 2004;53:1543–8.
20. Andersen H. Motor dysfunction in diabetes. Diabetes Metab Res Rev. 2012;28(Suppl 1):89–92.
21. Dyck PJ, Kratz KM, Karnes JL, Litchy WJ, Klein R, Pach JM, et al. The prevalence by staged severity of various types of diabetic neuropathy, retinopathy and nephropathy in a population-based cohort: the Rochester diabetic neuropathy study. Neurology. 1993;43:817–24.