

## Effects of a foot muscle exercise program on foot muscle strength and sensation in patients with diabetic peripheral neuropathy: A randomized controlled trial

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### Abstract

Diabetes mellitus (DM) is the most common metabolic disease and is a growing health problem in all countries. Foot complications, including foot muscle weakness and impaired foot sensation, are a common problem in patients with diabetic peripheral neuropathy (DPN). The current study aimed to investigate the effects of a foot muscle exercise program featuring towel-curl exercises on foot muscle strength in patients with DPN. A randomized controlled trial was conducted on diabetic patients, aged 40–65 years, who were randomly allocated into either a foot exercise group (FEG, n = 12) or control group (CG, n = 12). Participants in CG were advised to undergo foot care according to the diabetics care handbook without foot muscle exercise. FEG received the diabetics care handbook and a foot muscle exercise program administered three days per week for eight weeks. Toe grip strength was tested by a digital toe grip dynamometer, and foot sensation was measured using a 10-g monofilament before and after the experiment. Results showed that a foot muscle exercise program increased toe grip strength on both feet of FEG when compared with baseline and CG ( $P < 0.05$ ). However, there was no significant difference in foot sensation. This result suggests that a foot muscle exercise program involving towel-curl exercises may provide beneficial effects in promoting foot muscle strength in patients with DPN.

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**Keywords:** Diabetes mellitus (DM), foot muscle exercise, foot sensation, toe grip strength

### Introduction

**D**iabetes mellitus (DM) is the most common metabolic disease and a growing health problem in all countries, irrespective of the level of development. The prevalence of DM in the Thai population has increased from 7.0% in 2004 to 9.7% in 2014.<sup>1</sup> The prevalence of diabetes has also increased along with its complications that results in increased morbidity, mortality, and health care costs due to specific treatment requirements for people with DM.<sup>2</sup>

Foot complications are a common problem in patients with diabetic peripheral neuropathy (DPN); it was estimated that 15–25% of DPN patients develop diabetic foot ulcers in their lifetime. Furthermore, changes to foot health associated with DPN include

weakness and atrophy in the foot muscles, which leads to an imbalance between the flexor and extensor muscles and results in changes of gait and further complications in the foot.<sup>3,4,5,6</sup> Therefore, it is important to further research interventions aimed at restoring sensory function and muscular strength of feet.

Toe-flexion exercises or towel-curl exercises are a form of isometric exercise — sensory-motor training that activates the muscles of the foot, such as the flexor digitorum longus, in an effort to strengthen them. Previous reports found that four weeks of foot muscle training with towel-curl exercises could improve dynamic balance in healthy subjects<sup>7</sup> and increase foot muscle strength in the elderly.<sup>8</sup> However, it is unclear on the effect of towel-curl exercise on muscle strength and sensation in patients with DPN. Therefore, the current study aimed to investigate the effects of a foot muscle exercise program involving towel-curl exercises on foot muscle strength and foot sensation in patients with DPN.

### Materials and Methods

#### Sample size

The sample size was calculated using the following parameters: a mean difference of toe flexor muscle strength from a previous study<sup>8</sup> ( $\mu_1 - \mu_2$ ), 1.98 kg; a pooled variance estimate ( $\sigma^2$ ) for calculating the

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sample size, 2.21 kg<sup>2</sup>; a significant level ( $Z_{\sigma}$ ), 1.96; and a power of test at 80% ( $Z_{\beta}$ ), 0.84. The number of participants was calculated using the following formula:<sup>9</sup>  $n/\text{group} = [2\sigma^2 (Z_{\sigma} + Z_{\beta})^2] / (\mu_1 - \mu_2)^2 = [2(2.21) (1.96 + 0.84)^2] / (1.98)^2 = 9$ .

The final adjusted sample size/group, allowing for a dropout rate (d) of 20%, was calculated as follow:<sup>10</sup>  $n_{\text{adj}} = n / (1-d) = 9 / (1-0.20) = 12$ .

**Participants**

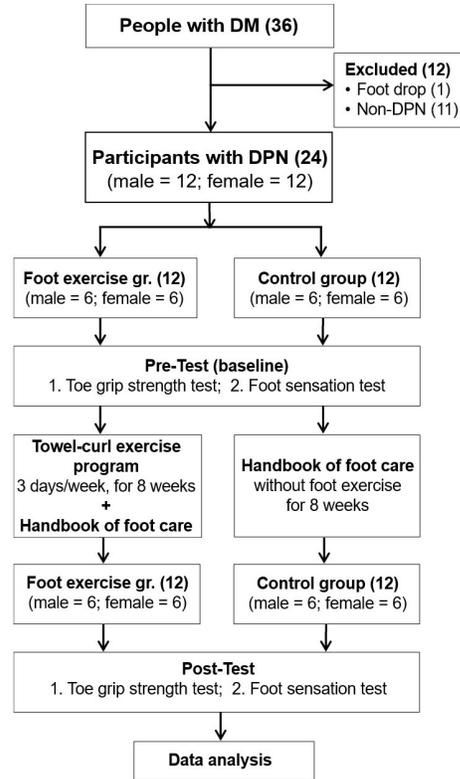
This research was a randomized controlled trial. Twenty-four participants (12 male and 12 female) with DPN, aged 40–65 years, were randomly assigned to the foot exercise group (FEG, n = 12) or control group (CG, n = 12) using stratified randomization of sex by computer (Figure 1). All participants were diabetic patients, who had exhibited foot-related symptoms of DPN and whose Thai version score of the Michigan neuropathy screening instrument (MNSI) was more than 2 points. MNSI is commonly used to assess DPN. It was indicated that MNSI Thai version presented acceptable reliability and validity to DPN screening in Thai people.<sup>11</sup> The present study excluded participants who had a history of lower extremity fractures, leg and foot ulcerations, lower extremity amputations and abnormalities in the structure of the legs and feet (such as severe foot deformities), limited toe flexion, as well as patients receiving vasodilators drugs or drugs and vitamins to treat nerve degeneration, such as vitamin B1, vitamin B6 and vitamin B12. Written informed consent was obtained from participants. This study was approved by the Ethics Committee for Human Research, Khon Kaen University (HE612349).

**Experimental procedure**

Both FEG and CG participants were advised to undergo foot care according to the diabetics care handbook in Kusuman Hospital, Sakon Nakhon, Thailand. Participants in the FEG completed a foot muscle exercise program. Following the previous study,<sup>8</sup> the towel-curl exercise started in the sitting position with a backrest, with two feet on the towel with toes flexion (Figure 2). The patients held the pose with two feet for 5 seconds for each contraction and underwent a cycle of 20 sets, five sets with a minute of rest between each set, once per day, three days per week, for eight weeks. During the first 4 week of training, they used a towel with a 2 mm thickness towel. After that, they change to use a 4 mm thickness towel for the final four weeks as resistance training progressed. Toe flexor muscle strength or toe grip strength (TGS) and foot sensation were measured before and after the intervention.

**Outcome measurement**

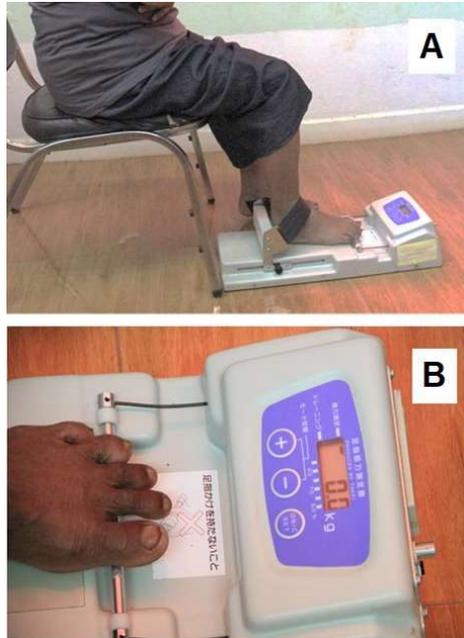
**Foot muscle strength test** Toe flexor muscle strength or toe grip strength (TGS) was used to represent the foot muscle strength and was tested by a T.K.K. 3362 toe-grip dynamometer (Takei Scientific



**Figure 1** Participants and protocol flow chart. Number of participants are in parentheses. DM, diabetes mellitus; DPN, diabetic peripheral neuropathy; gr., group.



**Figure 2** A towel-curl exercise. The sitting position with a backrest (A), with two feet on the towel with toes flexion (B).



**Figure 3** Foot muscle strength test. The sitting position without a backrest (A), and put a foot on a toe grip dynamometer (B).

Instruments, Niigata, Japan), which is portable and very reliable.<sup>12</sup> The measurement process was based on the previous study.<sup>13</sup> In brief, subjects sat on a chair without tilting or touching the flap, keeping both hip and knee joints in a 90-degree flexion and ankle joints in the normal position (Figure 3). The test was performed with the subjects barefoot, and three rounds of the test were performed for the left and right feet; muscle contraction time for each measurement was 3 seconds.<sup>9</sup> The best value of TGS (kg) and TGS normalized with body weight (TUG/Wt) were analyzed.

**Foot sensation test** Foot sensation was measured using a monofilament, a 10-g (size 5.07) Semmes-Weinstein, according to the previous study.<sup>14</sup> In brief, the subject was instructed to close their eyes, and the monofilament was randomly applied to ten areas on

**Table 1** Participant characteristics.

Characteristics	Foot exercise group (n = 12)	Control group (n = 12)
Sex (male/female)	6/6	6/6
Age (year)	57.00 ± 7.60	58.50 ± 4.58
Weight (kg)	55.75 ± 8.41	59.58 ± 7.55
Height (cm)	157.58 ± 7.50	159.33 ± 5.55
Body mass index (kg/m <sup>2</sup> )	22.47 ± 3.13	23.52 ± 3.17
Diabetic duration (year)	9.83 ± 6.28	8.75 ± 3.74

Results are expressed as mean ± SD.

each foot, with the examination repeated three times for each area. Subjects were asked about the sensation on their feet while being tested. After three rounds of examination, if the subject answered incorrectly ≥ 2 times, that area of foot was recorded as positive.

**Inter-rater reliability** Prior to data collection, the researcher conducted intra-rater reliability test with TGS test and foot sensation test in 10 patients with DPN, age between 40-65 years, from Kusuman Hospital, Sakon Nakhon, Thailand.

### Statistical analysis

Descriptive statistics (mean and standard deviation) was applied to describe baseline demographics. Intraclass correlation co-efficiency, ICC (3,1) was used to analyze the reliability of the measurement of toe grip strength and foot sensation of participants. The normal distribution of variables was assessed with the Shapiro-Wilk test. An independent sample *t*-test was used for comparison of age, weight, height, body mass index, diabetic duration, TUG, TUG/Wt, and foot sensation between the two groups. A simple paired *t*-test was used for comparison of TUG, TUG/Wt, and foot sensation within group. Statistical analysis was performed with SPSS version 17.0, with *P* values less than 0.05 as statistically significant.

### Results

This study found all variables normally distributed. The intra-rater reliability of TGS test and foot sensation test in DPN patients were within an acceptable range (ICCs > 0.9, *P* < 0.001). There was no statistically significant difference between FEG

**Table 2** Toe grip strength, toe grip strength/weight and foot sensation for both foot exercise group and control group.

Outcomes	Foot exercise group (n = 12)		Control group (n = 12)	
	Baseline	Post-test	Baseline	Post-test
TGS (kg)				
Rt foot	7.85 ± 2.50	10.59 ± 4.74*†	8.88 ± 2.34	8.27 ± 2.88
Lt foot	8.39 ± 3.24	10.76 ± 3.47*†	7.96 ± 1.53	8.53 ± 2.41
TGS/Wt				
Rt foot	0.14 ± 0.05	0.19 ± 0.08*†	0.15 ± 0.05	0.14 ± 0.06
Lt foot	0.15 ± 0.06	0.19 ± 0.07*†	0.14 ± 0.03	0.14 ± 0.04
Foot sensation				
Numbness; SWMT (points)				
Rt foot	5.42 ± 2.11	4.83 ± 1.95	4.83 ± 2.29	4.62 ± 2.39
Lt foot	5.00 ± 1.81	4.67 ± 1.72	4.92 ± 2.07	4.75 ± 2.05

Results are expressed as mean ± SD. \*Statistically different from baseline (*P* < 0.05), †Statistically different between groups (*P* < 0.05). Lt, left; Rt, right; TGS, toe grip strength; Wt, weight.

and CG for age, weight, height and body mass index, as shown in Table 1. The TGS and TUG/Wt in the FEG participants showed significant improvement when comparing post-test and the baseline values of the right and left feet ( $P < 0.05$ ) and when compared with CG ( $P < 0.05$ ). According to the monofilament testing to determine foot sensation, neither FEG nor CG showed significant improvement of foot sensation after 8 weeks of experiment, as shown in Table 2. In addition, there were no statistically significant differences between the two groups for baseline values of all variables.

## Discussion

The present study is the first report to show that a foot muscle exercise program involving towel-curl exercise, administered three times per week for eight weeks, resulted in improved toe flexor muscle strength in patients with DPN. However, no significant improvement was found in recovery of foot sensation.

Diabetic neuropathy is associated with high blood glucose levels, resulting in vascular injury, vascular disease, and peripheral nerve damage, which causes general muscle weakness, atrophy and impaired sensation.<sup>15-17</sup> Currently, foot care and foot exercise are the recommended non-pharmacological treatment for the prevention and treatment of foot complications in DPN.<sup>2</sup> The towel-curl exercise is a basic exercise method widely used to directly flex the toe muscle. The result of this study was consistent with the Donpunha et al. study,<sup>8</sup> which found that the four weeks of the towel-curl exercise training program could increase the strength of toe flexor muscles in older adults. The previous study suggested that the towel-curl exercise could increase the balance and movement of healthy participants aged 20–25 years.<sup>7</sup> Moreover, it was shown that foot exercise immediately improved the dynamic balance of subjects with excessively pronated feet.<sup>18</sup> However, the mechanism of such a foot muscle exercise program improving foot muscle strength is not clear. It was suggested, though, that strength training could cause physiological changes to skeletal muscle, an effect of short-term training which leads to increased strength that is proportionately greater than the increase in muscle size as a result of neuro adaptation. The muscle size improved in the first six to eight weeks of training. In addition, there was a result of increased neural activation or some change in the fiber arrangement or connective tissue content. The phase starts at a point in which scientific studies usually end — at about 12 weeks when healthy subjects are starting to tire of the repeated training and testing. After that, if participants continue training, there is likely a slow but steady increase in both size and strength of the exercised muscles. The stimulus for these changes remains unclear, but it almost certainly involves high forces in the muscle,

probably to induce some form of damage that promotes division of satellite cells and their incorporation into existing muscle fibers.<sup>19</sup>

The results of this study showed that a foot muscle exercise program involving towel-curl exercise — administered three times per week for eight weeks — could not improve foot sensation in patients with DPN, which was inconsistent with a previous study which demonstrated that a foot exercise program using a mini-trampoline could decrease feelings of foot numbness.<sup>20</sup> Moreover, it was reported that plantar foot-surface stimulation could improve the proprioceptive sensation and postural movements needed to maintain proper postures.<sup>21</sup> Sensory-motor training delivers proprioceptive sensory signals to the sensory cortex area of the brain and affects even the motor area to improve the asymmetric muscle tone of the foot and draw correct new movements, thereby improving the motor sensation and postural disturbance needed to help maintain the balance and stability of the body.<sup>21,22</sup>

This study has a limitation, as it was difficult to account for the unregulated activities of the participants that could possibly affect foot muscle strength. Nevertheless, our data demonstrated this foot strength program's safety and easy deployment of the towel-curl exercise.

## Conclusion

In conclusion, an eight-week towel-curl exercise foot muscle exercise program was effective in improving TGS, but it may not be appropriate for improving foot sensation in patients with DPN. This program may be useful for preventing foot muscle atrophy and weakness, and promoting foot muscle strength in diabetic patients. Further studies are needed to study the foot exercise program in combination with other interventions that address both foot muscle strength and sensation.

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## Conflict of Interest

The authors had no conflict of interest.

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