CHAPTER IV

RESULTS

In this study, we measured three variables i.e. maximal plantar flexion strength, tendon displacement, and tendon moment arm length. These three measured variables were then used to calculate the tendon force and tendon stiffness.

1. Participant characteristics

Sixteen healthy participants were recruited to the study. Two participants were excluded because they did not complete the eccentric training protocol. Therefore, fourteen participants' data were included in the statistical analyses.

The participants' demographics details were presented in Table 1. Fourteen participants consist of 3 men and 11 women participated in this study. The mean (± S.D.) age, height, and body mass of the participants were 22.3 ± 2.7 years, 164.0 ± 7.6 cm, and 55.5 ± 9.0 kg, respectively. In addition, body mass did not significantly change after 6 weeks of training (pre: 55.5 ± 9.0 kg; post: 55.6 ± 9.3 kg) ($p > 0.05$).

Table 1 The participants' demographic data (n=14)

Characteristics	Mean ± SD	Range
Age (years)	22.3 ± 2.7	19-28
Height (cm)	164.0 ± 7.6	152-180
Body mass (kg)	55.5 ± 9.0	42-72

2. Baseline

Fourteen participants' data were included in statistical analyses. For the baseline measurements, no statistically significant differences were existed between the two conditions: EL and CL. All baseline variables were presented in Table 2.

Table 2 The baseline characteristics of measured variables and calculated variables of eccentric leg condition and control leg condition (Values presented as mean ± standard error of mean).

Variables	Eccentric	Control
Measured variables		
MVC (Nm)	34.9 ± 2.9	35.4 ± 3.5
TD(mm)		
25%MVC	2.4 ± 0.3	2.9 ± 0.4
50%MVC	4.2 ± 0.4	4.5 ± 0.5
75%MVC	5.8 ± 0.4	6.2 ± 0.4
100%MVC	7.1 ± 0.4	7.4 ± 0.5
TM (mm)	43.9 ± 1.0	44.9 ± 1.0
Calculated variables		
TF (N)	787.7 ± 51.1	784.1 ± 69.4
TS (Nmm^{-1})	180.7 ± 32.9	179.1 ± 23.6

MVC=maximal voluntary isometric contraction in plantar flexor muscles, TD=tendon displacement, TM=tendon moment arm length, TF=tendon force and TS=tendon stiffness.

Measured variables: MVC, tendon displacement, and tendon moment arm length

After training, the torque produced by the plantar flexor muscles during an isometric MVC increased by 20.1 ± 2.4 Nm (pre: 34.9 ± 2.9 Nm; post: 55.0 ± 4.1 Nm) for EL and increased by 12.1 ± 2.0 Nm (pre: 35.4 ± 3.5 Nm; post: 47.5 ± 3.5 Nm) for CL (Table 3 and 4). There were significant differences between pre- and post-training of the torque in both legs ($p=0.001$) (Table 3). In addition, when compared the changes after training between EL and CL, there was a significant difference in plantar flexion force ($p=0.022$) (Table 4).

For the tendon displacement using ultrasound imaging, after 6 weeks of eccentric training, tendon displacements in all levels of MVC decreased significantly ($p<0.05$) (Table 3). However, when compared to the changes after training between EL and CL, there were no significant difference in tendon displacement at most levels of MVC ($p>0.05$) except at highest force level (100% MVC). At that level, tendon displacement was significantly lower in the EL condition compared with the CL condition ($p=0.048$) (Table 4).

To determine the Achilles tendon moment arm length, MRI was applied for all participants before and after eccentric exercise for 6 weeks. No significant difference in the tendon moment arm was found in both conditions either when compared pre- and post-training (pre: 43.9 ± 1.0 mm; post: 43.7 ± 1.0 mm; $p > 0.05$ for EL, and pre: 44.9 ± 1.0 mm; post: 44.4 ± 0.9 mm; $p > 0.05$ for CL; Table 3) or when compared the changes in pre- and post-training values (EL: 0.1 ± 0.9 mm; CL: 0.5 ± 0.9 mm; $p=0.636$; Table 4).

Calculated variables: calculated maximal tendon force and tendon stiffness

The calculated maximal tendon force (see methods for the formula) was significantly increased in both legs after training. For EL, the tendon force increased by 454.6 ± 51.0 N (pre: 787.7 ± 51.1 N; post: 1242.2 ± 69.1 N) and for CL, it increased by 261.4 ± 48.5 N (pre: 784.1 ± 69.4 N; post: 1045.5 ± 67.1 N (Table 3 and Table 4). Comparison between pre- and post- training for the maximal tendon force, there were significant differences in both legs ($p<0.01$) (Table 3). In addition, when the changes after training between EL and CL compared, there was a significant difference in tendon force ($p=0.009$) (Table 4).

To determine the tendon stiffness, the relationship between tendon force and tendon displacement were plotted and the slope ($\Delta F/\Delta mm$) at the final 10% of the force range was used to represent the tendon stiffness (Fig.7). Achilles tendon displacement at baseline increased curvilinearly from 2.4 ± 0.3 mm at 25% MVC to 7.1 ± 0.4 mm at 100% MVC for EL and from 2.9 ± 0.4 mm at 25% MVC to 7.4 ± 0.5 mm at 100% MVC for CL. After training, Achilles tendon displacement was maintained an increase in a curvilinear fashion from 1.7 ± 0.1 mm at 25% MVC to 5.1 ± 0.3 mm at 100% MVC for EL, and from 1.9 ± 0.1 mm at 25% MVC to 5.8 ± 0.2 mm at 100% MVC. However, the curve shifted to the left indicating an increase in the tendon stiffness since the tendon force increased after training whereas tendon displacement at all levels of MVC were reduced ($p< 0.01$; Fig.9). The tendon stiffness also significantly increased by 198.5 ± 58.1 Nmm^{-1} (pre: 180.7 ± 32.9 Nmm^{-1}; post: 379.2 ± 41.5 Nmm^{-1}) for EL and for CL, tendon stiffness was increased by 53.1 ± 43.7 Nmm^{-1} (pre: 179.1 ± 23.6 Nmm^{-1}; post: 232.5 ± 25.8 Nmm^{-1}) (Table 3,

Table 4, and Fig.9).   However, tendon stiffness increased significantly only in EL (p=0.041). In addition, when compared with the changes and percent increase in the tendon stiffness after training between EL and CL, there was a significant difference (EL 198.5 ± 58.1 Nmm^{-1},109.74% compared to the CL 53.1 ± 43.7 Nmm^{-1}, 29.83%; p=0.048) (Fig.9).

Table 3 Comparison of measured and calculated variables between pre- and post-training in eccentric leg condition and control leg condition (Values presented as mean ± standard error of mean).

Variables	Eccentric				Control			
	Pre	Post	p-value	T+ value	Pre	Post	p-value	T+ value
Measured								
MVC (Nm)	34.9 ± 2.9	55.0 ± 4.1	0.001*	105	35.4 ± 3.5	47.5 ± 3.5	0.001*	104
TD (mm)								
25%MVC	2.4 ± 0.3	1.7 ± 0.1	0.009*	90	2.9 ± 0.4	1.9 ± 0.1	0.046*	84
50%MVC	4.2 ± 0.4	2.6 ± 0.2	0.022*	90	4.5 ± 0.5	3.1 ± 0.2	0.019*	89
75%MVC	5.8 ± 0.4	4.0 ± 0.3	0.011*	93	6.2 ± 0.4	4.5 ± 0.2	0.005*	97
100%MVC	7.1 ± 0.4	5.1 ± 0.3	0.005*	97	7.4 ± 0.5	5.8 ± 0.2	0.006*	96
TM (mm)	43.9 ± 1.0	43.7 ± 1.1	0.893	58.5	44.9 ± 1.0	44.4 ± 0.9	0.636	62
Calculated								
TF (N)	787.7 ± 51.1	1242.2 ± 69.1	0.001*	105	784.1 ± 69.4	1045.5 ± 67.1	0.001*	104
TS (Nmm^{-1})	180.7± 32.9	379.2 ± 41.5	0.008*	95	179.1 ± 23.6	232.5 ± 25.8	0.221	72

* Significant difference (p < 0.05) found between pre- and post-training in eccentric leg condition and control leg condition. MVC=maximal voluntary isometric

contraction in plantar flexor muscles, TD=tendon displacement, TM=tendon moment

arm length, TF=tendon force and TS=tendon stiffness.

Table 4 Comparison the changes in pre- and post-training values of measured
variables and calculated variable between eccentric leg condition and control leg
condition (Values presented as mean ± standard error of mean).

Variables	Mean changes			
	Eccentric	Control	p - value	T+ value
Measured variables				
MVC (Nm)	20.1± 2.4	12.1± 2.0	0.022*	100
TD(mm)				
25%MVC	0.7 ± 0.3	1.0 ± 0.4	0.167	59
50%MVC	1.4 ± 0.6	1.1 ± 0.4	0.975	61
75%MVC	1.8 ± 0.5	1.7 ± 0.5	0.064	49.5
100%MVC	2.0 ± 0.5	1.6 ± 0.5	0.048*	33
TM (mm)	0.1 ± 0.9	0.5 ± 0.9	0.284	45
Calculated variables				
TF (N)	454.6 ± 51.0	261.4 ± 48.5	0.009*	99
TS (Nmm^{-1})	198.5 ± 58.1	53.1 ± 43.7	0.019*	80

* Significant difference ($p < 0.05$) found between eccentric leg condition

and control leg condition. MVC=maximal voluntary isometric contraction in plantar

flexor muscles, TD=tendon displacement, TM=tendon moment arm length,
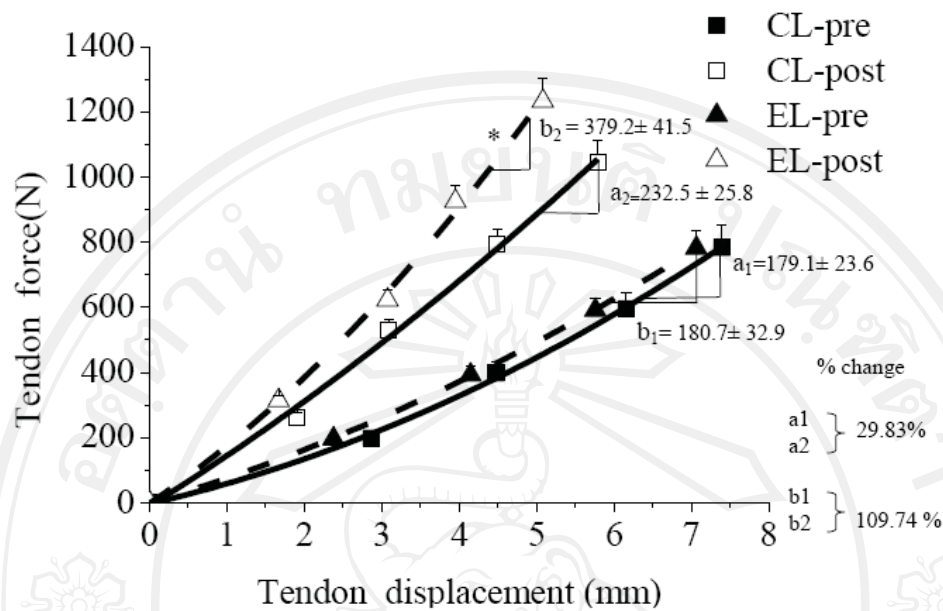
TF=tendon force and TS=tendon stiffness.

Figure 9 Tendon force-displacement relationship of eccentric exercise leg and control leg. The tendon stiffness was calculated from the slope of tendon force-displacement relationship after quadratic fitted. Data are mean ± SEM.

* Significantly ($p<0.05$) increased in tendon stiffness after training. CL= control leg condition, EL= eccentric leg condition, a_1= CL-pre, a_2= CL-post, b_1= EL-pre, b_2= EL-post.