

Measurement of the Muscle Power of the Toes in Female Marathon Runners Using a Toe Dynamometer

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The aim of this study was to investigate the relationship between the strength of the foot muscles that control the toes and disorders such as shin splint. In order to this, we designed and built a toe dynamometer to compare the muscle power exerted through the toes in top female marathon runners and age-matched women not involved in sports. The subjects were 12 top-level female marathon runners (Group A) and 37 student nurses who were not involved in sports (Group B). We devised a dynamometer to measure the total power exerted by the flexor muscles of the 5 toes of a single foot (total flexor power) and the combined power of the abductors of the big (1st) and little (5th) toes (abductor power). In Group A, the total flexor power was 14.3 ± 5.3 kg in the right foot and 15.4 ± 4.7 kg in the left foot. The abductor power was 1.9 ± 1.8 kg in the right foot and 2.2 ± 1.9 kg in the left foot. In Group B, total flexor power was 18.3 ± 6.7 kg in the right foot, while the abductor power was 1.9 ± 1.7 kg. The subjects from Group A with an arch index < 1.0 ($n = 8$) or > 1.0 ($n = 4$) were respectively classified as Group I and Group II. In Group I, total flexor power was 14.9 ± 5.3 kg (right) and 15.5 ± 5.2 kg (left), while the abductor power was 2.6 ± 1.9 kg (right), and 3.1 ± 1.7 kg (left). In Group II, the total flexor power was 13.2 ± 5.8 kg (right) and 15.1 ± 4.2 kg (left), while the abductor power was 0.7 ± 0.6 kg (right) and 0.3 ± 0.2 kg (left). The abductor power of toes was significantly lower in Group II than in Group I. The incidence of posteromedial shin pain was higher in Group II (75.0%) than in Group I (12.5%).

toe dynamometer

The muscle power of the toes appears to have decreased in humans due to the wearing of shoes and the consequent lack of chances to use the toes. This makes it more difficult for the toes to appropriately regulate shifts of body weight and to act as a buffer against repetitive loads on the feet. Some authors have reported that the muscle power of the foot muscles that control the toes is related to foot deformity (1-5), but there have only been a few detailed studies on toe muscle power and its importance. Among the various disorders of the toes (6-8), hallux valgus is well known, and it is also possible that a decrease in toe muscle power may cause shin splints (1). In sports such as marathon running, the repetitive load placed on the feet is clearly greater than in daily life. The objective of the present study was to use a toe dynamometer to investigate the mechanism of disorders such as shin splints by comparing the muscle power of the toes between female marathon runners and age-matched women who were not athletes.

Subjects and Methods

Subjects. The subjects were 12 top-level female marathon runners (Group A) and 37 healthy women who were not involved in sports (Group B). In Group A, the subjects were 18-24 years of age (mean; 19.9 ± 1.8 years) and weighed 38-56 kg (mean; 46.1 ± 5.5 kg). Some of them had participated in Asian championship races and their mean personal best time for 3,000 meters was 9 min and 19 sec. Their Kaup index was 14.8-21.9 (mean; 18.2 ± 1.9). In Group B, the subjects were all

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21-year-old student nurses. They had no symptoms and no history of trauma affecting the feet. They weighed 41.0–68.0 kg (mean; 52.8 ± 7.2 kg). Their Kaup index was 18.2–25.6 (mean; 21.0 ± 1.6), and obese or emaciated women were excluded.

Methods. We devised a dynamometer which could measure the total power of the flexor muscles for all 5 toes (total flexor power) and the combined power of the abductors of the big (1st) and little (5th) toes (abductor power). The toe dynamometer measured muscle power using a sensor with a built-in strain gauge and displayed it digitally via an amplifier and an analog to digital converter (Fig. 1). The positions of the sensor, belt, and stopper could be changed freely. It could measure the power of the flexor muscles in 0.1 kg-increments up to 50 kg and that of the abductor muscles in 0.1 kg increments up to 10 kg. The measurement error was within $\pm 3\%$ (8).

The subjects were placed in a supine position with the knees extended to 0 degrees and their ankle joints in a neutral position. The legs, ankle joints, and feet were firmly fixed with belts, and the heels and metatarsophalangeal joints were fixed using stoppers. Three measurements were obtained and the maximum value was used. The mean coefficient of variation in the measurement of muscle power was 7.5% for total flexor power and 13.2% for abductor power. Both right and left feet were

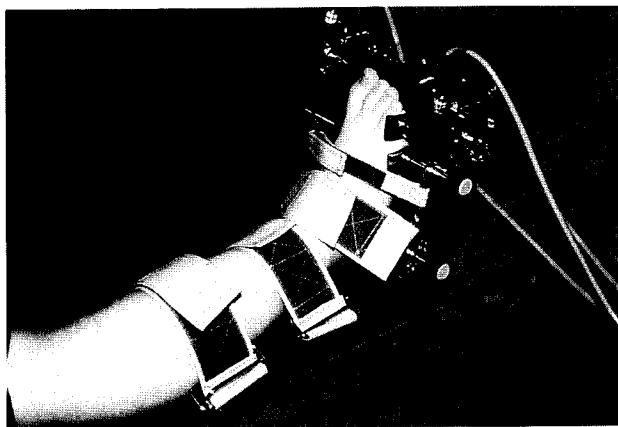


Fig. 1 Our new toe dynamometer. This dynamometer can measure the total power of the flexor muscles for all 5 toes and the combined power of the abductors of the big (1st) and little (5th) toes. The toe dynamometer measures muscle power using a sensor with a built-in strain gauge and displays it digitally via an amplifier and analog to digital converter. The positions of the sensor, belt and stopper can be changed freely.

measured in Group A, while only the right foot was measured in Group B. In both groups, footprints were also taken to calculate the arch index of Staheli *et al.* (9)

Statistical analysis was performed using the Student's *t*-test and a *P* value of less than 0.05 was considered significant.

Results

In Group A, the total flexor power was 6.6–25.4 kg (mean; 14.3 ± 5.3 kg) in the right foot and 8.1–25.0 kg (mean; 15.4 ± 4.7 kg) in the left foot. It tended to be higher in the left foot. The abductor power of great (1st) and little (5th) toes was 0–5.9 kg (mean; 1.9 ± 1.8 kg) in the right foot and 0–6.1 kg (mean; 2.2 ± 1.9 kg) in the left foot. It also tended to be higher in the left foot. In Group B, the total flexor power of the toes was 8.0–36.8 kg (mean; 18.3 ± 6.7 kg) in the right foot, while the abductor power of the toes was 0.2–5.3 kg (mean; 1.9 ± 1.7 kg).

The subjects from Group A with an arch index < 1.0 ($n = 8$) and > 1.0 ($n = 4$) were respectively classified as Group I and Group II. In Group I, the total flexor power was 14.9 ± 5.3 kg (right) and 15.5 ± 5.2 kg (left), while the abductor power of the great and little toes was 2.6 ± 1.9 kg (right), and 3.1 ± 1.7 kg (left). In Group II, the total flexor power was 13.2 ± 5.8 kg (right) and 15.1 ± 4.2 kg (left), while the abductor power was 0.7 ± 0.6 kg (right) and 0.3 ± 0.2 kg (left). The abductor power was significantly lower in Group II than in Group I. The incidence of posteromedial shin pain was higher in Group II (75.0%) than in Group I (12.5%).

Discussion

In Japan, most top-level female marathon runners are professionals and they run up to 700 km per months. Since Japan is highly ranked in world long-distance running, Japanese runners must train very hard to gain a spot of the national team. Therefore, some marathon runners develop posteromedial shin pain during training and a long time is required for them to return to their original performance level after the onset of symptoms. In fact, we were surprised to find that many runners who could not perform abduction of the great and little toes during measurement of their muscle power.

Hughes *et al.* (10) reported that the toes are in contact with the ground for about three-quarters of the walking

cycle and the clinical implication is that the toes play an important role in increasing the weight-bearing area during walking. Many previous studies have shown that both the intrinsic muscles of the foot and muscles extrinsic to the foot play a role in maintaining the foot arch (3, 11-14). However, muscle power was not measured in these studies, while deformity was investigated electrophysiologically using an electromyograph (12, 13) and a strain gauge (14). Although these studies have shown that the toe muscles go through various phases of activity to maintain the foot arch, none of them have directly measured toe muscle power. In the present study, the mean coefficient of variation was 7.5 % for the total flexor power of the toes and 13.2 % for the abductor power, so the measurements obtained using our dynamometer were considered to be reasonably reproducible and reliable. It has already been reported that the combined abductor power of the great and little toes is positively correlated with the arch index (8).

Garth *et al.* (1) classified the power of the intrinsic muscles of the foot into intrinsic positive, intrinsic negative, and extrinsic dominant categories. They emphasized the importance of the intrinsic muscles of the foot, because claw toe deformity and posteromedial shin pain tended to develop when the power of these muscles was decreased. In the present study, the total flexor power of the marathon runners (Group A) was 14.3kg in the right foot and 15.4kg in the left foot which was lower than in Group B (18.3kg). The abductor power was 1.9kg (right) and 2.2kg (left) in Group A, and this was also lower than in Group B (2.6kg). In fact, this was considered too low for marathon runners in active training, even taking into account their lower body weight. In particular, the abduction power of the toes reflects the condition of the abductor muscles of the foot, which are among the intrinsic muscles of the foot responsible for maintaining foot arch and therefore potentially related to foot deformity and pain. When Group A was separated, the combined abductor power of the great and little toes was 2.6kg (right) and 3.1kg (left) in Group I, while it was 0.6kg (right) and 0.3kg (left) in Group II. The abductor power was lower in Group II members, who showed a tendency for flat foot. In the present study, the muscle power of the toes was lower and the incidence of posteromedial shin

pain was higher in Group II. As reported by Garth *et al.* (1), a decrease in the power of the intrinsic muscles of the foot may have the potential to cause posteromedial shin pain. In our subjects, training to increase the muscle power of the toes was performed after obtaining these measurements and the incidence of posteromedial shin pain was found to decrease. The possibility seems strong that toe muscle power is related to posteromedial shin pain. Thus, measurement of the muscle power of the toes may be useful for investigation of posteromedial shin pain and various other disorders of the foot.

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