Kinematic Analysis of the Lower Extremities of Subjects with Flat Feet at Different Gait Speeds

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Abstract. [Purpose] This study determined the difference between flat feet and normal feet of humans at different gait velocities using electromyography (EMG) and foot pressure analysis. [Subjects] This study was conducted on 30 adults having normal feet (N = 15) and flat feet (N = 15), all of whom were 21 to 30 years old and had no neurological history or gait problems. [Methods] A treadmill (AC5000M, SCIFIT, UK) was used to analyze kine- matic features during gait. These features were analyzed at slow, normal, and fast gait velocities. A surface electromyogram (TeleMyo 2400T, Noraxon Co., USA) and a foot pressure analyzer (FSA, Vista Medical, Canada) were used to measure muscle activity changes and foot pressure, respectively. [Results] The activities of most muscles of the flat feet, except that of the rectus femoris, were significantly different from the muscle activities of the normal feet at different gait velocities. For example, there was a significant difference in the vastus medialis and abductor hallucis muscle. Likewise, flat feet and normal feet showed significant differences in pressures on the forefoot, midfoot, and medial area of the hindfoot at different gait velocities. Finally, comparison showed there were significant differences in pressures on the 2nd–3rd metatarsal area. [Conclusion] Because muscle activation has a tendency to increase with an increase in gait velocity, we hypothesized that the lower extremity with a flat foot requires more work to move due to the lack of a medial longitudinal arch, and consequently pressure was focused on the 2nd–3rd metatarsal area during the stance phase.

Key words: Flat foot, Electromyography, Foot pressure

INTRODUCTION

Flat foot is a disease that is either congenital or acquired, having characteristics such as talus medial rotation, decreased medial arch height, and forefoot supination and abduction1). Flat foot also causes excessive movement to be pronated and shock absorption to be decreased. In general, a normal foot experiences a pressure 1.5 times body weight when in contact with the ground, whereas people with flat feet feel more fatigue because of the problem of shock absorption. Furthermore, researchers have explained the kinematic causes of flat feet. Flat foot is a dysfunction of the posterior tibial tendon, one of the important supporters of the medial arch, a dysfunction of the spring ligament2), or an injury to the plantar fascia3). It can also result from obesity increasing the load on the feet during the stance phase, causing abnormal foot movement5). Obesity also puts greater stress on the knees5).

Most previous studies have been causal analyses of flatfoot and studies of treatment effectiveness through sugery. Few studies have investigated the extent to which dynamic activities, such as gait, affect the lower extremities of flat-footed people. Gait is a natural action in daily life, and there is great diversity in individual gait patterns, especially at different gait velocities5, 6). Because the human foot has evolved for standing and upright movements, such as gait, the alignment of the foot and ankle joints plays an important role in supporting weight during gait. Thus, the human foot uniquely contacts the ground, supplying the momentum for movement via the ground reaction force and playing an important role in the weight-bearing function of subtalar movement7). Ultimately, gait is possible through interactions that link the human calcaneus, the sole of the foot, and the tips of the toes, and this is why we have conducted this study, to determine the difference between flat feet and the normal feet at different gait velocities using EMG and foot pressure analysis.

SUBJECTS AND METHODS

People with normal feet (N = 15) and people with flat feet (N = 15), all of whom have no neurological history and were between the ages of 21 and 30, participated in this study. Age, weight, and height were measured to determine the body characteristics of the subjects. Flat foot was confirmed by posture analysis (GPS400, Redbalance, Italy). As described by Clarke8), Strake’s line and Marie’s line were used to confirm flat foot. Strake’s line passes from the forefoot’s medial line to the rearfoot’s medial line, and Marie’s line passes from the center of the 3rd metatarsal bone to the center of the rearfoot. If the line of the medial sole falls out-
side Marie's line, it is confirmed as a normal foot. If the line of the medial sole falls inside Marie's line, it is confirmed as a flat foot.

All the subjects received explanation of the research and provided their consent to participation. A treadmill (AC5000M, SCIFIT, UK) was used to analyze kinematic features during gait, using a slope of 0% with gait velocities of 1.0–1.25 m/s (9). The average gait velocity of the average man at slow, normal, and fast rates are 3, 4, and 5 km/h, respectively, and those of the average woman are 2.7, 3.7, 4.7 km/h, respectively (10). Subjects walked for about one minute to determine their natural gait velocity before the experiment began. Then all subjects walked barefoot for five minutes on the treadmill, looking forward.

Muscle activity data were collected and analyzed using a wireless surface electromyograph (TeleMyo 2400T, Noraxon Co., USA). Active electrodes were used, consisting of two stainless-steel pads. The electrode diameter was 11.4 mm, and the distance between the electrodes was 20 mm. The sampling rate for the EMG signal was set at 1000 Hz, the bandwidth was set between 20–450 Hz, and the notch filter was set at 60 Hz. EMG was performed after depilating the electrode-attachment areas with a razor, removing the horny layer with sand paper, and cleansing the areas with an alcohol swab. To measure muscle activations in the lower extremities during gait, electrodes were attached to the abductor hallucis, tibialis anterior, peroneus longus, medial gastrocnemius, lateral gastrocnemius, vastus medialis, vastus lateralis, and biceps femoris muscles. The frequency range of the EMG signal was band-pass filtered between 20 and 500 Hz, and the sampling frequency was 1024 Hz. We normalized the signal of each muscle to the maximal voluntary isometric contraction (MVIC). Data on the change of foot pressure was collected using a foot pressure analyzer (FSA, Vista Medical, Canada). The pressure measurement pad is 0.88 mm thick, and it has 128 numbered resistance sensors (9×16 mm each) arranged in a 8×16 grid. We used a sampling rate of 3,072 Hz, and measurement range of 0–30 psi. The sizes of the pressure measurement mats were 230×100 mm, 250×100 mm, and 270×100 mm, and they were fitted to subjects’ insoles according to their foot size.

In this study, the foot was divided into eight areas for analysis according to foot regions: two toe regions (1st toe region and 2nd–5th toe region), three forefoot regions (1st metatarsal region, 2nd–3rd metatarsal region, and 4th–5th metatarsal region), the midfoot region, and two heel regions (medial heel region and lateral heel region) (9). The average pressure of each region was measured during the experiment. The general subject characteristics (age, height, and weight) were tested for homogeneity using the independent t test. Data were analyzed by repeated ANOVA in SPSS for Windows (Version 17.0), and the differences between groups at the different gait velocities were examined with the independent t test. Statistical significance was accepted for p values less than 0.05.

### RESULTS

The general characteristics of the subjects are shown in Table 1. Muscle activities (excepting that of the rectus femoris) of the flat-footed subjects were significantly different from those of the normal-footed subjects at all of the different gait velocities (p < 0.05), especially those of the vastus medialis and abductor hallucis muscles (p < 0.05) (Table 2). Significant differences in pressure were also detected on the forefoot, midfoot, and the medial area of the hindfoot (p < 0.05). Table 3 shows a significant difference in the 2nd–3rd metatarsal area (p < 0.05).

### DISCUSSION

Nakajima et al. (12) studied the relationship between the foot’s arch height and the shock effect on the knee. They concluded that a correlation exists between the height of the foot’s arch and the shock on the knee. Thus, we know that the adduction moment of the knee joint of flat-footed subjects is higher than the adduction moment of subjects with normal feet. This is due to higher muscle activation of the vastus medialis muscle in flat-footed people. Furthermore, muscle activation of the abductor hallucis muscle in flat-footed people decreases relative to the changes in velocity compared to people with normal feet is relatively lower according to the changes in velocity. Thus, we can conclude that, compared to subjects with normal feet, the medial longitudinal arch of flat-footed subjects does not work well as a dynamic stabilizer.

Fiolekowski et al. (13) confirmed that the abductor hallucis muscle affects the height of the navicular bone in a tibial nerve block study, and that foot pressure changed with gait velocity. We confirmed the weight of flat foot was not moved onto the toe until the terminal stance phase, and that the weight of flat footed subjects was focused on the 2:3rd metatarsal area. We also confirmed that hindfoot eversion of a flat foot is higher with increasing gait velocity, and the foot pressure of a flat foot is higher on the medial side of foot in the terminal stance phase. We suppose the load of moving the lower extremity increases with velocity and ability of medial longitudinal arch of flat foot is less than normal foot resulting in pressure being focused on 2:3rd metatarsal area in the stance phase.

### Table 1. General characteristics of each group (Mean±SE)

|                  | EG (n=15) | CC (n=15) |
|------------------|-----------|-----------|
| Number of individuals (Male / Female) | 6/9       | 7/8       |
| Age (years)      | 20.1±2.3  | 21.0±1.3  |
| Height (cm)      | 159.3±0.3 | 162.2±3.4 |
| Body Weight (kg) | 57.3±5.3  | 55.6±3.8  |
| Foot length (mm) | 261.3±7.6 | 255.3±5.3 |
| Ankle width (cm) | 7.5±0.5   | 7.3±0.3   |

EG: Experimental group; CC: Control group
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