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Impact of the Anterior-Posterior Slope Types of the Scapulae on the Pressure Distribution of the Plantar Surface of the Foot

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Abstract

Purpose : This study was conducted among 195 adults in their 20s. To analyze the impact of the slope types of the scapulae on the plantar surface of the foot, the average pressure (AP), the maximum pressure (MP), the average of local distribution values, and the average movement of the center of pressure (COP) of the different slope types of the scapulae were compared.

Method : The anterior-posterior slopes of the scapulae were measured by comparing the slopes of the left and right sides of the scapulae based on the differences in the height and the slope of the coracoid process and the angulus inferior scapulae. Those whose left side of the scapulae had an anterior slope were categorized as type 1, and those whose right side of the scapulae had an anterior slope, as type 2. The average plantar pressure, the center of plantar pressure, the maximum plantar pressure, and local distribution values were analyzed using a plantar pressure analyzer of the FSA.

Result : In terms of the AP of the left and right feet, there was no statistically significant difference both in types 1 and 2 on the left and right feet. The comparison results of the MP and the average of local distribution values of the two slope types of the scapulae showed that there was no statistically significant difference on the X-axis both in types 1 and 2 on the left and right feet, but that there was a large statistically significant difference on the Y-axis both in types 1 and 2. That is, the MP of the right foot of the left anterior slope type was located more on the hindfoot than that of the right anterior slope type, and the MP of the left foot of the left anterior slope type was located more on the hindfoot than that of right anterior slope type.

Conclusion : This study can be used as fundamental data to predict differences in the location and size of the COP and changes in plantar pressure distribution depending on the slope types of the scapulae, and control the distribution for therapeutic purposes.

Key Words : plantar surface, slope type, scapulae, pressure distribution

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Ⅰ. INTRODUCTION

Posture is the arrangement of body parts and can be maintained against gravity when body parts are in a state of balance. Posture is also defined as a composite of the positions of all the joints of the body at any given moment, and it can be changed depending on their arrangement, the actions of certain muscles or the amount of weight on each joint, affecting the musculoskeletal system (Moon, 2011). Thus, the posture of each joint has an impact on the posture of another joint. Correct posture is the position in which minimum stress is applied to each joint, requiring minimum muscle activity (Davis et al., 1998; Magee, 2014b).

The ability to control posture and balance, that is to say, the ability to maintain the center of gravity (COG) within the base of support (BOS) includes the integration of the pressure on the visual, vestibular and sensory systems of the body, and the output of the motor control system which is balanced muscular contraction (Cardoso, 2008). When the BOS changes, these systems should detect such changes, and the motor system should adapt to the new demand from the posture, maintaining the balance of the body (Naderi et al., 2013). Correct or good posture is the state of muscular and skeletal balance which protects the supporting structures of the body, and in the posture each part of the body is properly aligned with others while standing, sitting or lying down. Poor posture, however, is the state of imbalance which increases strain on the supporting structures due to a faulty relationship of the various parts of the body (Moon, 2001).

Imbalance between the left and right sides of the body is mainly attributable to scoliosis. Scoliosis can be caused by muscular and skeletal imbalance, metabolic disorder or genetic predispositions, and among them, muscular and skeletal imbalance is known as the main cause (Rosenberg, 2011). In other words, musculoskeletal disorders affect the balance of the legs, arms, and spine of the body, and make the body unable to maintain the ideal alignment of body parts. Under such conditions, the body has to use excessive energy to overcome gravity and maintain an upright posture, which results in imbalance between the left and right, front and back, and high and low, and thus lesions in these parts. This allows for the inference that the muscular and skeletal systems of the body are connected as a whole, that distal joints can control proximal joints, and vice versa, and that legs and arms can control spine and vice versa (Moon, 2011; Moon, 2001).

The spine can be considered as a sail in a boat. This sail is based on the pelvis, stretched upward to the head, and unfolded to the left and right sides of the body at the height of the shoulders. The spine acts as a sail yard, supporting the shoulders. To connect the sail to the pelvis, ligaments and muscles support every part of the spine, acting as a rope, and these supportive muscles are closely associated with the shoulder girdle (Kapandji, 2008). The shoulder girdle is also known as the shoulder joint, and multiple joints allow the shoulders to move, but some authors have classified the joints of the shoulder girdle in different ways (Marieb & Hoehn, 2016). For instance, Cailliet(2004) added the sternocostal and costovertebral joints to the five joints of the classification of Kapendgji (2008) in broad consideration of the relations between the shoulder girdle and the spine. Thus, symptoms in the shoulders are not considered just as problems in the shoulders, but they can be associated with problems in the spine (Archer & Nelson, 2013).

Meanwhile, the foot can be subdivided into three parts that is composed of a series of bones and at least one or more joints. The hindfoot is composed of the talus (ankle bone), the calcaneus (heel bone), and the subtalar joint. The midfoot is composed of the rest tarsal bones, and the articulatio tarsi transversa, and the distal intertarsal joints formed by the tarsal bones. The forefoot is composed of the metatarsal bones, the phalange, the tarsometatarsal joints formed by the bones, and all the distal joints above the joints. The functions of the foot include maintaining a stable standing

posture with the minimum muscular strength, flexibly adapting to rough surfaces, dispersing and absorbing shocks and moving the body center forward(Amis et al., 2010; Magee, 2014b). For these reasons, changes in the pressure distribution on the plantar surface of the foot affect not only the ability to control the balance between ankle joints but also knee and hip joints, and ultimately the balance of the entire body (Moon, 2001). Symptoms in the foot are associated with spinal deformities in any shape or form, and scoliosis, a kind of spinal deformity, is also known to be associated with the foot.

From these results, it can be inferred that changes in the slope shape of the shoulder girdle affect the shape of the spine, which in turn changes the pressure on the foot. It was also found that the mobilization of foot joints can cause changes in the shoulder girdle (Hyung, 2008).

Thus, it was assumed in this study that the pressure on the left and right areas of the foot surface can differ depending on the slope shapes of the shoulder girdle, and the area on which the maximum plantar pressure is put, and the level of the plantar pressure can differ depending on the slope shapes of the shoulder girdle. It was also assumed that the center of pressure on the left and right feet and the level of the plantar pressure can differ depending on the slope shapes of the shoulder girdle. Based on these assumptions, this study aimed to provide data that can be used to predict and control the distribution of plantar pressure depending on the slope shapes of the shoulder girdle.

Ⅱ. METHODS

1. Subjects and Duration

The 195 subjects who voluntarily agreed to the declaration of Helsinki were participated in this study.

Those who had any health issues such as tumors, surgery, neurological deficits, spondylitis, arthritis, fractures or dislocations were excluded from this study, but those who had treatment for functional disorders of muscles, joints, ligaments and disks for over 3 weeks were included.

2. Measurement Methods

1) Measurement Tools and Methods

(1) Measurement of the anterior-posterior slopes of the scapulae

The anterior-posterior slopes of the scapulae were measured by comparing the slopes of the left and right sides of the scapulae based on the differences in the height and the slope of the coracoid process and the angulus inferior scapulae.

The anterior-posterior slopes of the left and right sides were relatively compared, and the side that was tilted forward more was viewed as the anterior slope of the scapulae, and the side that was relatively less tilted backward was viewed as the exterior slope of the scapulae. In this study, those whose left side of the scapulae had an anterior slope were categorized as type 1, and those whose right side of the scapulae had an anterior slope, as type 2.

(2) Measurement tools and methods for plantar pressure

The average plantar pressure, the center of plantar pressure, the maximum plantar pressure, and the average of local distribution values were analyzed using a plantar pressure analyzer of the FSA (Force Sensitive Applications, VERG. Inc, Canada). The plantar pressure of the foot of participants were measured as follows.

A. The foot length of participants was measured using a measuring tape, and they wore a pad of the right foot size.

B. They marched in place for about 10 times, and spread their legs to the width of their hip. They stood with their heels on the base line, and their eyes were fixed downward (15 degrees).

C. While they were in a static posture, changes in their plantar pressure were recorded for about 20 seconds as vid-

eo data using the FSA program.

D. After that, participants took a rest for a minute and their plantar pressure was measured again.

The procedure above was repeated three times in total to measure the plantar pressure of the right foot, and the same procedure was used to measure that of the left foot. In the 20-second video, the screen at 10 seconds was used as the result values in this study.

On the plantar pressure map, the average pressure (AP), the maximum pressure (MP), the distribution of plantar pressure, and the center of pressure (COP) were analyzed. Here, changes in the location of the fore and hind parts of the foot were viewed as changes on the Y-axis. The values were divided into 16 equal parts, and their properties and changes were measured. Changes in the location of the inner and outer parts of the foot were viewed as change on the X-axis. The values were divided into 8 equal parts, and their properties and changes were measured.

2) Data Analysis

This study aimed to analyze the impact of the anterior slope types of the scapulae on the size and location of plantar pressure. The general characteristics of participants were statistically analyzed by calculating average and standard deviation as technical statistics. The independent samples t-test was conducted to measure the difference in the AP and the MP of the left and right feet depending on the anterior slope types of the scapulae, and to confirm their statistical significance. To analyze differences in the location of the MP and the COP depending on the anterior slope types of the scapulae, the map of the plantar surface of the foot was divided into fore and hind sections, and inner and outer sections.

To analyze differences in the location of the MP and the COP on the fore and hind parts of the foot, the values were divided into 16 equal parts, and the independent samples t-test was conducted to analyze statistical significance in differences in the average distribution values of the left and right feet. To analyze differences in the location of the MP and the COP on the inner and outer parts of the foot, the values were divided into 8 equal parts, and the independent samples t-test was conducted to analyze statistical significance in differences in the average distribution values of the left and right feet. The data were statistically analyzed using SPSSWIN(ver. 10.0), and the level of statistical significance was a = .05.

Ⅲ. RESULTS

1. General Characteristics of Subjects

The average age of participants was 21.45±2.61 years; the average height, 165.80±7.65 cm; the average weight, 58.35±9.93 kg; and the average plantar pressure, 2.69(Table 1).

2. Impact of the Slope Types of the Scapulae on Plantar Pressure Comparison of the Average Pressure (AP) of the Plantar Surface of the Foot

The average plantar pressure (AP) of participants was 2.69±0.44. Depending on the anterior slope types of the scapulae, the average plantar pressure of the left anterior slope type was 2.71±0.45, and that of the right anterior slope type was 2.65±0.44. The left anterior slope type showed the higher average plantar pressure, but there was no statistically significant difference between the two types (p=0.66).

Table 1. General characteristics of subjects

	Left anterior slope (N=134)	Right anterior slope (N=61)	Total (N=195)	*p*
Age (yrs)	21.35±2.53	21.67±2.79	21.45±2.61	0.66
Height (cm)	166.02±7.70	165.32±7.59	165.80±7.65	0.82
Weight (Kg)	58.58±10.57	57.84±8.42	58.35±9.93	0.12
Average plantar pressure	2.71±0.45	2.65±0.44	2.69±0.44	0.66

Mean±Deviation

The plantar pressures of the left and right feet were also compared, and the right average plantar pressure in total was 2.71±0.44. The right average plantar pressure of the left anterior slope type was 2.72±0.45, and that of the right anterior slope type was 2.7±0.43. The left anterior slope type showed the higher right average plantar pressure, but there was no statistically significant difference between the two types (p=0.5).

The left average plantar pressure in total was 2.67±0.5. The left average plantar pressure of the left anterior slope type was 2.7±0.54, and that of the right anterior slope type was 2.60±0.5. The difference in the left average plantar pressure of the two types was wider than that in the right average plantar pressure of the two types, but there was no statistically significant difference between the two types (p=0.23)(Table 2).

Table 2. Comparison of average plantar pressures

	Left anterior slope (N=134)	Right anterior slope (N=61)	Total (N=195)	*p*
RAP	2.72±0.45	2.7±0.43	2.71±0.44	0.50
LAP	2.7±0.54	2.60±0.5	2.67±0.5	0.23
AP	2.71±0.45	2.65±0.44	2.69±0.44	0.66

RAP: Right average plantar pressur
LAP: Left average plantar pressure
AP: Average plantar pressure

3. Comparison of the Maximum Plantar Pressure (MP) and the Average of Local Distribution Values between the Anterior Slope Types of the Scapulae

The maximum plantar pressure (MP) and the average of the local distribution values of the right plantar pressure were compared. The average of the left anterior slope type (type 1) was 13.93±2.44, and that of the right anterior slope type (type 2) was 13.05±3.42. This indicated that the pressure on the hindfoot of type 1 was higher than that of type 2, and the statistical significance was very high (p=.00). The average of the two types was 13.79±0.58.

In terms of the left plantar pressure, the average of type 1 was 13.86±2.62, and that of type 2 was 13.11±3.28. The statistical significance analyzed using the t-test was high (p=.01), and the average of the two types was M±SD=13.63±2.85. This indicated that the MP of the left foot of type 1 was located more on the hindfoot compared with that of type 2.

The results of the comparison between the MP and the average of local distribution values of the left and right feet showed that the AP of types 1 and 2 was M±SD=

13.90±1.99 M±SD=13.08±2.81 respectively. The average of the two types in total was M±SD=13.64±2.30, and there was statistical significance between the two types (p=.00)(Table 3). There was no statistically significant difference in the plantar surface areas (X-axis) of the left and right feet(Table 4).

Table 3. Comparison of the MP and the average of local distribution values of the left and right feet on Y-axis between the slope types of the scapulae (unit: bw/cm²)

	Left anterior slope (N=134)	Right anterior slope (N=61)	Total (N=195)	*p*
RMP_Y	13.93±2.44	13.05±0.42	13.79±0.48	0.00**
LMP_Y	13.86±2.62	13.11±3.28	13.63±2.85	0.00**
MP_Y	13.90±1.99	13.08±2.81	13.64±2.30	0.00**

Table 4. Comparison of the plantar pressures and the average of local distribution values of the left and right feet on X-axis between the slope types of the scapulae (unit: bw/cm²)

	Left anterior slope (N=134)	Right anterior slope (N=61)	Total (N=195)	*p*
RMP_X	3.52±4.34	3.43±1.09	3.49±0.94	0.23
LMP_X	3.91±0.91	3.66±1.08	3.83±0.97	0.05
MP_X	3.72±0.65	3.55±0.83	3.66±0.71	0.19

4. Comparison of the Average of Local Distribution Values of the Center of Pressure Area (COP) between the Slope Types of the Scapulae

The distribution averages of the center of pressure areas (COP) were compared, and there was no statistical significance on the X-axis of the left foot. However, there was statistical significance on the X-axis of the right foot. The COP average of the right foot of type 1 was 3.82±0.44, and that of type 2 was 3.73±0.55. The average of the two types in total was 3.79±0.48, and the results of the t-test showed statistical significance (p=.01). In other words, the COP of type 1 was mainly located on the inner part of the right foot, and that of type 2, on the outer part of the right foot(Table 5). There was no statistical significance on the Y-axis(Table 6).

Table 5. Comparison of the average of local COP values on the X-axis between the slope types of the scapulae (unit: bw/cm²)

	Left anterior slope (N=134)	Right anterior slope (N=61)	Total (N=195)	*p*
RCOP_X	3.82±0.44	3.73±0.55	3.79±0.48	0.01**
LCOP_X	4.07±0.51	4.04±0.54	4.06±0.52	0.72
COP_X	3.94±0.38	3.89±0.45	3.92±0.40	0.84

OP; Right center of pressure area
LCOP; Left center of pressure area
COP; Center of pressure area

Table 6. Comparison of the average of local COP values on the Y-axis between the slope types of the scapulae

(unit: bw/cm²)

	Left anterior slope (N=134) Average±Deviation	Right anterior slope (N=61) Average±Deviation	Total (N=195) Average±Deviation	*p*
RCOP_Y	10.79±1.23	10.60±1.45	10.73±1.30	0.71
LCOP_Y	10.89±1.09	10.43±1.53	10.75±1.26	0.18
COP_Y	10.84±0.99	10.52±1.26	10.74±1.09	0.16

COP; Center of pressure area

Ⅳ. DISCUSSION

In general, when people are standing, their weight passes through their mortise and is distributed on the plantar surface of the foot, and 60 % of the weight is distributed on the hindfoot (Neumann et al., 2017). The results of this study also indicated that the plantar pressure of most of the participants was mainly located on the hindfoot. However, this study started from the assumption that changes in posture would affect the distribution of left and right plantar pressure despite the fact that the plantar pressure of both the left and right feet is located on the hindfoot, and focused on the impact of changes in the slope of the scapulae on the plantar pressure.

Out of 195 participants, 134 people were categorized as the left anterior slope type (type 1), and 61 people as the right anterior slope type (type 2), indicating the left anterior slope type was more dominant than type 2. The average plantar pressure of all the participants was 2.71±0.45, and that of the left anterior slope type (type 1) was 2.71±0.45, and that of type 2, 2.65±0.44. The average of type 1 was higher than that of type 2, but there was no statistical significance between the two types. The maximum plantar pressure and the average of local distribution values were compared, and on the right foot, the average of type 1 was 13.93±2.44, indicating the plantar pressure of type 1 on the hindfoot was higher than that of type 2.

According to gait kinematics (Neumann et al., 2017), the sagittal movement of each shoulder joint accompanies the same sagittal movement at the hip joint of opposite side. That is, when the shoulder joint on left/right side flexes, the right/left hip joint flexes as well. When the hip joint on one side moves to extension, the shoulder joint on the other side also moves to extension. Based on this principle, it can be inferred that when a person puts the heel on one side on the ground, its plantar pressure is located on the hindfoot, and the shoulder joint on the other side moves to flexion. In this study, the flexion of the shoulder joint on one side was recognized as the anterior slope of the scapulae, and it was found that the plantar pressure of the foot on the other side was located on the hindfoot, which coincided with the principle discussed above.

In an earlier study on the location of the center of pressure in the posture of reaching out a hand to an object in front of the body (Ham, 2004), when a person reached out a hand, the shoulder joint of the hand moved to flexion, and the shoulder joint on the other side moved to extension. This made the foot on the other side move in the opposite direction of the direction of reaching out the hand, and thus the plantar pressure of the foot on the other side was located on the hindfoot. These results supported the results of this study.

In addition, the maximum plantar pressure of the left foot was 13.86±2.62 in the left anterior slope type, and 13.11±3.28 in the right anterior slope type. This indicated that the plantar pressure of the left foot of the left anterior

slope type was also located on the hindfoot as the results of the right foot showed above. This result was contrary to the assumptions in this study that the plantar pressure of the left anterior slope type would be located on the hind part of the right foot, and that the plantar pressure of the right anterior slope type would be located on the hind part of the left foot.

The average center of pressure (COP) of the right foot on the X-axis was 3.82±0.44 in the left anterior slope type, and 3.73±0.55 in the right anterior slope type, indicating that the COP of the right anterior slope type was located relatively more on the outer part of the foot than the left anterior slope type. When the body moved to the right side, the right foot slightly moved to supination, and the COP of the foot moved to the right side (Kobayashi et al., 2006).

These results supported the results of this study that the COP of the right foot of the right anterior slope type was located more on the outer part of the foot than the COP of the left anterior slope type. However, the changes in the COP of the left foot on the X-axis showed no statistical significance ($p=0.72$).

The impact of the shape of the scapulae on plantar pressure was discussed above. Most of the participants were the left anterior slope type of the scapulae, and thus their plantar pressure level was high on the hind part of the right foot.

Since this study was conducted among those of a certain age and occupational groups, it is difficult to generalize the results. In addition, using the FSA program, it was unable to test both the left and right feet together at the same time, and thus it probable that slight errors occurred. It was also impossible to control the psychological state and the daily life of participants. However, the results of this study can be used as fundamental data to predict changes in plantar pressure distribution depending on the slope types of the scapulae, and control the distribution for therapeutic purposes.

Ⅴ. CONCLUSION

This study was conducted among 195 males and females in their 20s. To analyze the impact of the slope types of the scapulae on the plantar surface of the foot, the average pressure (AP), the maximum pressure (MP), the average of local values, and the average movement of the center of pressure (COP) of the different slope types of the scapulae were compared, and their statistical significance was measured. The results of this study are as follows.

In terms of the AP of the left and right feet, there was no statistical significance both in types 1 and 2 on the left and right feet. The comparison results of the MP and the average of local distribution values of the two slope types of the scapulae showed that there was no statistically significant difference on the X-axis (plantar surface area) both in types 1 and 2 on the left and right feet, but that the statistical significance on the Y-axis (plantar surface length) was very high both in types 1 and 2. That is, the MP of the right foot of the left anterior slope type was located more on the hindfoot than that of the left foot, and the MP of the left foot of the right anterior slope type was located more on the hindfoot.

The averages of the local COP values of the slope types of the scapulae were compared. There was no statistical significance in the COP on the X-axis (plantar pressure area) on the left foot, but the statistical significance in the COP on X-axis on the right foot was very high. The COP of the right foot of the left anterior slope type was located more on the outer side than that of the right anterior slope type.

The results of this study can be used as fundamental data to predict differences in the location and size of the COP and changes in plantar pressure distribution depending on the slope types of the scapulae, and control the distribution for therapeutic purposes.

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