Journal of Rehabilitation Practices and Research

Special Issue: Physical Therapy: From Acute Care to Rehabilitation and Wellness

Investigation of Impact Absorption Function of Carbon Plantar Plate for Low Arch Foot

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Article Details

Article Type: Special Issue
Received date: 12th February, 2023
Accepted date: 03rd April, 2023
Published date: 05th April, 2023

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Citation: Shimizu, S., KIDO, M., KOBASHI, K., Sasaki, K., Pei, Y., & Obinata, G., (2023). Investigation of Impact Absorption Function of Carbon Plantar Plate for Low Arch Foot. *J Rehab Pract Res, 4*(1):143. https://doi.org/10.33790/jrpr1100143

Abstract

At present, it cannot be said that the impact absorption function of the truss structure of the foot arch during static standing has been elucidated.

In this study, the spring constant and the viscous damping coefficient are calculated and examined in order to compare the shock absorption characteristics of the low-arch foot seen in flat feet and the characteristics of the normal-arch foot.

In addition, in order to supplement the spring constant and viscous damping coefficient for one case of low arch foot, we investigated using a carbon plantar plate. Six types of carbon plantar plates were compared, with heels and without heels, with 2 layers, 3 layers, and 4 layers.

As a result, the low arch foot showed a low spring constant and a high viscous damping coefficient. In the comparison of 6 types of carbon plantar plates, the one with heel showed high spring constant and viscous damping coefficient. The value closest to the normal arch was the 3-layer carbon plantar plate without heel.

It was thought that the low-arch foot had a reduced spring function that absorbs impact. The carbon plantar plate with heel cup clearly shows high values of spring constant and viscous damping coefficient, which means that hard to sink the heel.

The reason for this is presumed to be the influence of the soft tissue of the heel is likely to collapse due to the heel couter.

The carbon plantar plate used this time was not able to compensate for the impact class function of the normal arch foot, so further examination was necessary. However, this research has a small number of subjects, so it is necessary to increase the number of subjects and investigate again. As a future task, we will consider increasing the number of subjects.

Key words: Low arch foot, Normal arch foot, Spring constant, Viscous damping coefficient, Carbon plantar plate

Introduction

It is said that one of the functions of the foot arch is a shock absorbing function that absorbs the impact on the foot and knees during walking. The foot arch softens the foot during walking to absorb the impact of a load, and conversely hardens the foot to increase forward propulsion when kicking. The foot arch has a shock absorption function and a function to increase propulsion force. Truss structures and windlass mechanisms exist to assist in this function. The truss structure is a mechanism that the plantar aponeurosis is stretched and the arch sinks when the foot is loaded, distributing the load. In the windlass mechanism, when the metatarsophalangeal joint becomes dorsiflexed during kicking, the tension in the plantar fascia increases, the arch of the foot becomes higher, and the foot becomes stiffer, thereby propelling forward. Standing work causes pain in the bottom of the foot, and various diseases appear.

In this static standing posture, unlike when walking, there is no effect of the windlass mechanism or other function that increases the forward propulsion force that kicks off the floor, The function of distributing the load of the truss structure and absorbing the impact is important. However, the current situation is that the impact absorption function of the truss structure of the foot arch during static standing has not been sufficiently elucidated.

We are as a result of many years of research on the foot arch, we have proved that the shock absorption function of the low-arch foot is lower than that of the normal-arch foot. In this study, measurements were taken to compare the shock absorption characteristics of a typical low-arch foot seen in flat foot with those of a normal-arch foot, and the difference in characteristics was examined from the differences in the stiffness and viscosity. In addition, based on the results of this study, we will obtain guidelines for the design of insoles, etc., to bring the shock absorption characteristics of low-arch foot closer to those of normal-arch foot. Therefore, we focused on lightweight and strong carbon as an insole material, and examined the number of layers and trimming suitable for carbon. The reason why carbon is used is that in recent years, there are many sports goods using carbon, and it is also used for prosthetic leg sockets. Since carbon is lightweight, strong, and flexible with a repulsive force, we speculated that this flexibility could be used for shock absorption.

The purpose of this study was fully explained to the subjects, and their informed consent was obtained both verbal and in writing.

Subject

Subjects were required to have no history of special mention such as fractures or sprains in the past. The subjects were a man in his 20s with a normal arched foot, 168 cm tall and weighing 55 kg, and a man in his 40s with a low arched foot, 160 cm tall and weighing 53 kg. The target leg was the left leg. The medial longitudinal arch height ratio, which is the value obtained by dividing the height from the floor to the navicular bone by the actual foot length and multiplying by 100, was used as the criterion for low-arch foot. In our previous study, low-arch foot medial longitudinal arch height rate, and the reference value was 15.7 ± 0.7% or less for men. The standard value for the medial longitudinal arch height ratio of normal arched foot was defined as 16.5% or higher as the average value plus the standard deviation for low arched foot, and 15.7% or lower for low arched foot. The medial longitudinal arch height rate was 17.35% for men in their 20s with normal arch foot, and 11.8% for men in their 40s with low arch foot.

The contents of this study were fully explained to the subjects, and consent was obtained both verbal and in writing.

Method

As for the method, we designed a measuring instrument for accurate measurement and compared 6 types of carbon plantar plates.

A carbon plantar plate with the closest values to the spring constant and viscous damping coefficient of the normal arch foot was investigated.

Measurement method

For the measurement method, the subject was asked to sit on a chair with the hip, knee, and ankle joints flexed at 90 degrees. I told him not to use his hands. A load measuring instrument was placed at the foot to measure the height h of the arch of the foot and the load Fr when a load of 12.5 kg (mass: M [kg]) was applied to the long axis of the lower leg.

Figure 1 shows the posture of the subject during the experiment, the weighting device, and the laser measuring instrument. A laser for displacement measurement measures the distance from below, and a plate-like rod is attached vertically below the scaphoid process. The sampling frequency of the distance from the floor to the navicular bone and the measurement data of the load meter is 100 [Hz]. The spring constant k (N/mm) was measured by dividing the force f (N) by the distance d (mm) that the medial longitudinal arch changed. In addition, the time Ts [sec] obtained by subtracting the time when the load is applied from the time when the displacement of the height from the floor to the navicular bone when the load is applied above the knee enters a steady state, is the load transfer time. (viscous decay time).

This time, we calculated the viscous damping coefficient from the formula model shown in Figure 2.

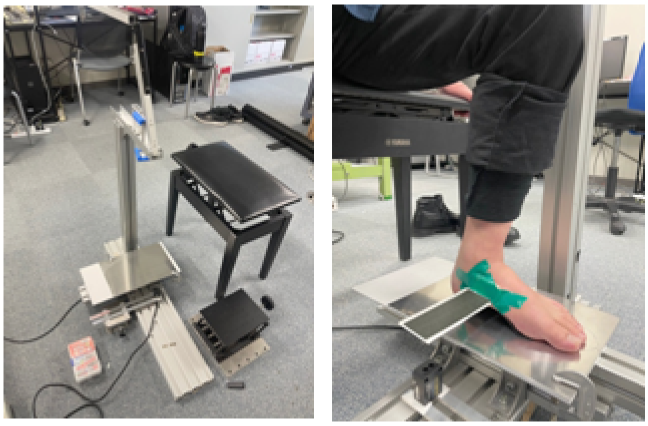

Figure.1. Measuring Device

Force : f (N)
Acceleration : a(m/s²)

$Weight\ of\ foot : m(kg)$

$Spring\ viscosity\ coefficient : d(N/v)$

$Spring\ constant : k(N/mm)$

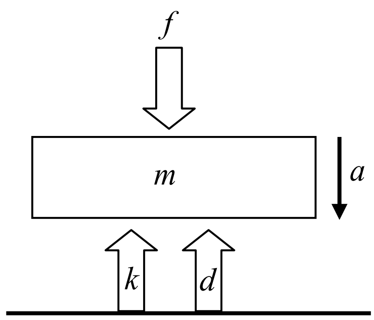

Figure 2. Model of spring constant and viscous damping coefficient

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The characteristic of this model is assumed to be linear and is expressed by the following linear least-squares differential equation.

(1) $ma + dv + kx$

Here, x is the displacement of the arch height h, and the vertical downward direction is positive as the sign. m is the equivalent mass of the lower leg, k is the spring constant, and d is the viscous damping coefficient. Also, F = mwg is the force acting on the lower leg due to the weight placed on it (the sign is positive when vertically downward; g is the gravitational acceleration). From the measured time-series data of x, the time-series data of velocity v = d/dt(x) and acceleration a = dv/dt(x) were calculated.

Substituting the time-series data xi, vi, ai, Fi of displacement, velocity, acceleration, and floor reaction force at time i into equation (1), the difference between the values on the left and right sides (equation error) can be defined as follows.

(2) $e_i = ma_i + dv_i + kx_i - f_i$

The sum of the squares of this error is given by the following equation.

(3) $e_i^2 = x(ma_i + dv_i + kx_i - f_i)$

The parameter set (m, d, k) that minimizes J can be calculated from the following linear algebraic equation.

(4)

$$J = \sum_{i=0}^{n-1} e_i^{\,2} = \sum (m^2a^2 + 2mdav + 2\text{mkax}$$

$$-2maf + d^2v^2 + 2dkvx - 2dvf + k^2v^2 - 2kxf + f^2)$$

$$\begin{bmatrix} \sum_{i=0}^{N-1} x''^2 & \sum_{i=0}^{N-1} x''x' & \sum_{i=0}^{N-1} x''x \\ \sum_{i=0}^{N-1} x''x' & \sum_{i=0}^{N-1} x^2 & \sum_{i=0}^{N-1} x'x \\ \sum_{i=0}^{N-1} x''x & \sum_{i=0}^{N-1} x'x & \sum_{i=0}^{N-1} x^2 \end{bmatrix}^{-1} \begin{bmatrix} \sum_{i=0}^{N-1} x''f \\ \sum_{i=0}^{N-1} x'f \\ \sum_{i=0}^{N-1} xf \end{bmatrix} = \begin{bmatrix} m \\ d \\ k \end{bmatrix}$$

It can be said that the set of (m, d, k) calculated by solving the differential equation (1) using m, d, and k obtained by this method captures the characteristics of the lower leg.

Carbon plantar plate

Six types of carbon plantar plates were used in this experiment: 2, 3, and 4 layers of carbon with a heel cup, and 2, 3, and 4 layers of carbon with an arch only (Fig. 3). All carbon plantar plates are made according to the shape of the foot. The carbon sheet used this time is EASYPREG A1-C245K-56 made by OSM Herbst, and the thickness is 0.3 mm per layer.

The spring constant and viscous damping coefficient were measured by the same method using 6 types of carbon plantar plates attached to one patient with a low arch foot, and the spring constant and viscous damping coefficient of a normal arched foot were compared.

With heel cup — No heel cup

Figure.3. Carbon plantar plate

Result

Compare the spring constant and viscous damping coefficient of the normal arched foot and the low arched foot. Six types of carbon plantar plates are attached to the low arch foot, and the spring constant and viscous damping coefficient are compared, and the carbon plantar plate with the value closest to the normal arch foot is selected and examined.

Comparison of normal arch foot and low arch foot

The measurement results for the normal arched foot were a spring constant of 55.5 [N/mm] and a viscous damping coefficient of 1.702 [(N•s/mm] (Table 1). The low-arch foot had a spring constant of 26.4 N/mm] and a viscous damping coefficient of 2.256 [(N•s/mm] (Table 1). A high spring constant means a hard material with little deformation, and a high viscous damping coefficient means a strong resistance to suppress vibration.

	spring constant	viscous damping coefficient
Normal arch foot	55.5N/mm	1.702N s/mm
Low arch foot	26.4N/mm	2.256N s/mm

Table.1. Comparison between normal arch foot and low arch foot

Comparison with 6 types of carbon plantar plates attached

The measurement results were a spring constant of 55.1 [N/mm] and a viscous damping coefficient of 2.454 [(N•s/mm]) for two layers of carbon plantar plates with heel cups. The three layers of carbon plantar plates with heel cups had a spring constant of 68.5 [N/mm] and a viscous damping coefficient of 2.267 [(N•s/mm].

The four layers of carbon plantar plates with heel cups had a spring constant of 188.6 [N/mm] and a viscous damping coefficient of 1.872 [(N•s/mm]. The two layers of the arch-only carbon plantar plate had a spring constant of 34.6 [N/mm] and a viscous damping coefficient of 1.930 [(N•s/mm]. The three layers of the arch-only carbon plantar plate had a spring constant of 48.9 [N/mm] and a viscous damping coefficient of 1.389 [(N•s/mm]. The four layers of the arch-only carbon plantar plate had a spring constant of 87.7 [N/mm] and a viscous damping coefficient of 1.243 [(N•s/mm]. The spring constant and viscous damping coefficient of carbon plantar plates with heel cups tended to show high values (Table 2). The closest approximation to a normal foot arch function was a 3-layer arch-only carbon plantar plate (Table 2). This is because the 3-layer arch-only carbon plantar plate was the closest to the spring constant and viscous damping coefficient of the normal arched foot. However, this research has a small number of subjects, so it is necessary to increase the number of subjects and investigate again.

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With heel cup		
	Spring constant	Viscous damping coefficient
2-layer	55.1N/mm	2.454N s/mm
3-layer	68.5N/mm	2.267N s/mm
4-layer	188.6N/mm	1.872N s/mm
No heel cup		
	Spring constant	Viscous Damping Coefficient
2-layer	34.6N/mm	1.930N s/mm
3-layer	48.9N/mm	1.389N s/mm
4-layer	87.7N/mm	1.243N s/mm

Table.2. Measurement result of carbon plantar plate

Consideration

In the comparison between the normal arched foot and the low arched foot, the spring constant of the low arched foot clearly showed a low value and the viscous damping coefficient showed a high value. In this state, it can be inferred that the foot is softer and the heel is less likely to sink compared to the normal arched foot. In other words, it seems that the foot is not suitable for absorbing impact. It is said that the foot arch has a shock absorption function due to the spring function, and the low arch foot shows a decline in the spring function, which seems to support the previous research [1,2].

As shown in Fig. 4, the foot has plantar fascia, ligaments, muscles, etc. to maintain the arch of the foot. In a normal arch, the plantar fascia and ligaments are stretched and stopped, but in a low-arch foot, the plantar fascia and ligaments are stretched, and the load reaches the limit of extension. The reason is that the low-arch foot showed a lower spring constant and a higher viscous damping coefficient than the normal-arch foot.

This is because the values were clearly different from those of the normal arch foot. Therefore, it was thought that some different tissue was stretched and exhibited a function different from that of the normal arch.

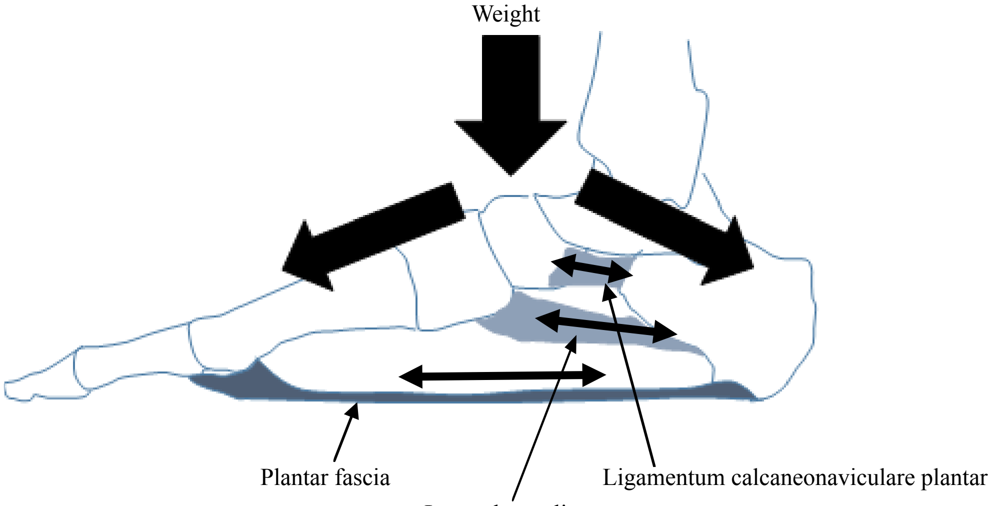

Figure 4. Plantar fascia and ligaments that support the foot

However, in this study, the mechanism has not been elucidated so far, so it is necessary to examine it in the future. From the results of this research, the carbon plantar plate with a heel cup clearly shows high spring constant and viscous damping coefficient, which means that the heel is hard and does not sink easily. The reason for this is presumed to be the influence of the soft tissue of the heel. In a previous study by Kon et al., it was reported that a general insole type design without a heel cup absorbed the most impact force. Kon et al state that the side wall of the heel cup prevents the heel soft tissue from escaping under load and transforms the heel soft tissue into hard tissue. No carbon plates were used in Kun et al.'s study. This is a paper on the results of a sole plate with a heel and a sole plate without a heel, the sole plate without a heel absorbing more impact [3,4].

Therefore, the results of this study support the previous research by Kon et al., and it was thought that the heel cup made the soft tissue of the heel harden, increasing the spring constant and the viscous damping coefficient, making it impossible to absorb impact [5,6].

As a result, a plantar plate with only an arch without a heel cup is more suitable as a plantar plate that compensates for the spring constant and the viscous damping coefficient for absorbing impact. However, since the results do not compensate for the function of a normal arched foot, it is necessary to consider making the trimming line shallower and adding materials in the future.

Conclusion

As a result of comparing the shock absorption function of one normal arched foot and one low arched foot in terms of spring constant and viscous damping coefficient, the low arched foot showed a low spring constant and a high viscous damping coefficient.

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ISSN 2581-3846

Therefore, the low-arch foot was a soft and hard-to-sink foot. Focusing on carbon to compensate for the shock absorption function of the low-arch foot were adjusted using a carbon plantar plate with a heel cup (2-layer, 3-layer, 4-layer) and carbon foot with only an arch (2-layers, 3-layers, 4-layers) , Six types of carbon plantar plate were measured the spring constant and viscous damping coefficient .

As a result, the carbon plantar plate with heel cup had high spring constant and viscous damping coefficient. The 3-layer carbon plantar plate with only the arch showed the values closest to the spring constant and viscous damping coefficient of the normal arch.

However, the values of the spring constant and viscous damping coefficient of the normal arch foot have not yet been reached, so it is necessary to consider the trimming line and materials. From this research, the spring constant and viscous damping coefficient of the carbon plantar plate with heel cup showed abnormally high values.

Therefore, it was suggested that the absence of the heel cup is suitable for compensating for the shock absorption function of the low arch.

However, this research has a small number of subjects, so it is necessary to increase the number of subjects and investigate again. As a future task, we will consider increasing the number of subjects.

This article was originally published in a special issue:
Physical Therapy: From Acute Care to Rehabilitation and Wellness
Handled by Editor(s):
Prof. Masaharu Morita
Department of Health Sciences Physical Therapy, International University of Health and Welfare, Japan.
Dr. Soma Tsujishita
Department of Physical Therapy, Kobe International University, Japan.

Competing interests: The authors declare that they have no competing interests.

References

1. Hideo Fujii, Noriaki Maezawa Japan (2004): Podiatric Manual, Ishiyaku Shuppan, 18-20.
2. Makoto Iritani, Foot-Ankle, Tsutomu Yamazaki Japan (2001): Theory and techniques of orthopedic physical therapy, *Medical View*, 36-61.
3. Shingo, S., Keisuke, K., Yanling, P., Gorou O Japan (2020): Compensation of shock absorption function of low-arch foot based on mechanical properties. *Biomechanism 25*, 139-148.
4. Mamoru, O., Akira, S., Keishi, U., Gen, Y., Takashi, T., & Kouichi, N. et al. Japan (1989): Examination of foot arch high rate measurement method in medical check. *Clinical Sports Medicine, 6*, 336-339.
5. Shingo, S., and Yoshiyuki K Japan (2009): Reliability of footprint and arch height values for flat feet. *Clinical Biomechanics, 30*, 243-248.
6. Keisuke, K., Takumi, O., Kota, H., Yosuke N Japan(2022): A study on the structure and impact absorption effect of sole braces with heel cups, *PO Journal*, vol.30, no.1, 38-43.