

Biomechanical effects of high-heeled shoes on the ankle load

Biomehanički utjecaj cipela s visokom potpeticom na opterećenje gležnja

Znanstveni rad / Scientific Paper

Ružica Marošević¹, Tanja Jurčević Lulić^{1,*}, Jasna Leder Horina² i Martina Lovrenić-Jugović³

¹University of Zagreb Faculty of Mechanical Engineering and Naval Architecture, Department of Engineering Mechanics, Ivana Lučića 5, 10000 Zagreb, Croatia

²University of Zagreb Faculty of Transport and Traffic Sciences, Vukelićeva 4, 10000 Zagreb, Croatia

³University of Zagreb Faculty of Metallurgy, Aleja narodnih heroja 3, 44000 Sisak, Croatia

*Correspondence: tjurcev@fsb.hr

Abstract

Women who wear high heels often have problems with leg and spine pain. The aim of the study was to determine the impact of high-heeled footwear on the load on the ankle and foot. Pressure measurements were carried out in a static standing position for barefoot and footwear with different heel heights (0.5 cm, 2.5 cm, 6.5 cm, 9 cm, 10 cm) and shapes (narrow heel and block heel). Using a simple biomechanical model of the foot, the forces in the ankle were calculated. The highest forces in the ankle occur with narrow, medium-height heels. With narrow heels (medium-height and high), the highest pressures also occur in the front part, where the center of pressure is located. From obtained results, it can be concluded that high-heeled shoes with narrow heel support could pose a high risk on foot and ankle joint.

Keywords: biomechanics; high-heeled shoes; pressure; ankle load

Sažetak

Žene koje nose obuću s visokim potpeticama često imaju problema s bolovima u nogama i kralježnici. Cilj istraživanja bio je utvrditi utjecaj obuće s visokom potpeticom na opterećenje gležnja i stopala. Mjerenje pritiska stopala i podloge provedeno je u statičkom stojećem položaju bez obuće, za obuću s različitim visinama potpetice (0,5 cm, 2,5 cm, 6,5 cm, 9 cm, 10 cm) i oblicima potpetice (uska potpetica i "blok" potpetica). Pomoću jednostavnog biomehaničkog modela stopala, izračunate su sile u gležnju. Najveće sile u gležnju javljaju se kod uskih potpetica srednje visine. Kod uskih potpetica (srednje visoke i visoke), najveći pritisci se javljaju u prednjem dijelu stopala, gdje se nalazi centar pritiska. Iz dobivenih rezultata može se zaključiti da cipele s visokom potpeticom s uskom potporom za petu mogu predstavljati veliki rizik za stopalo i skočni zglob.

Ključne riječi: biomehanika; cipele s visokom potpeticom; pritisak; opterećenje gležnja

1. Introduction

Studies of the biomechanical effects of high-heeled shoes on women while standing and walking have shown that they often complain of pain in their legs and spine [1]. Wearing high-heeled shoes affects the musculoskeletal system, changing ankle-foot geometry, function and the force transmission in soft tissues and bones, and interfering in load distribution of the foot [2, 3].

The plantar fascia is a tissue that connects heel bone to the toes base. It has different biomechanical functions in walking and standing. It supports the arch of the foot, absorbs shock when walking, balances weight bearing distribution on foot and prevents the foot from injury [4]. Wearing high-heeled shoes affects the morphology of the arch, more of the weight is transferred to the forefoot and the plantar contact area of the midfoot is reduced, which leads to increased force on the plantar fascia.

However, there are also different opinions about the effect of high-heeled shoes on plantar fascia stress and strain. In these studies, it is stated that plantar fascia strain can be reduced by heel of shoes raising which helps in body weight redistribution throughout the foot surface [3, 4]. Also, it was believed that the angle discrepancy between the hindfoot and metatarsus decreased under high-heeled shoes, which allowed more movement of the forefoot in the plantar-flexion position and reduced the fascia tension [3, 4].

Some research has indicated that the relationship between heel height and pain is not linear. According to research [1], a heel height of 7.5 cm is the threshold where overall body pain becomes significant.

High-heeled shoes have the capability to alter the strain and stress of ligamentous structures between the foot and ankle, which may result in ankle instability [6]. Excessive load on the ankle implies risks of ankle injury. The aim of this paper is to investigate the influence of high-heeled

shoes on the load on the ankle and on the position of the body's center of pressure.

2. Methods and subjects

The study was conducted on one female subject, i.e. as a case study. The subject was 24 years old, 179 cm tall, mass 58 kg, and had no musculoskeletal diseases. To measure pressure and determine the projection of the body's center of gravity, the MobileMat platform from Tekscan was used (dimensions 63,6 x 55,9 x 4,2 cm). The subject was measured barefoot and while wearing shoes with different heel heights (2.5 cm, 5 cm, 6.5 cm, 9 cm, 10 cm), where the shoes with 5 cm and 9 cm heel heights have a "block" heel (Table 1).

Figure 1. shows a simplified 2D biomechanical model of the foot in the sagittal plane, where F_{gr} represents the measured ground reaction force, F_{at} is the force in the Achilles tendon, F is the force in the ankle, α and γ are angles, and a and b are the arms of the ground reaction force and the force in the Achilles tendon with respect to the ankle joint. Using the equations of static equilibrium, by including the measured ground reaction force and arms a and b , it is possible to calculate the force in the joint.

Table 1. Footwear used for measuring

No 1: heel height 0,5 cm	
No 2: heel height 2,5 cm	
No 3: heel height 6,5 cm	
No 4: heel height 9 cm	
No 5: heel height 10 cm	

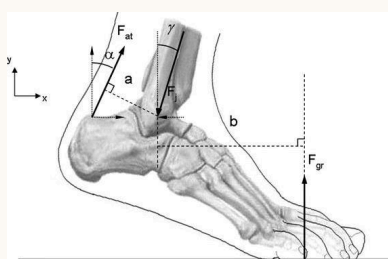


Figure 1. 2D biomechanical model of the foot

Figure 2. shows an X-ray of the foot in a high-heeled shoe, from which it can be seen that the angle γ is approximately equal to 0 and can be ignored.



Figure 2. X-ray of a foot in a high-heeled shoe [7]

Measurements were performed in a static standing position. Markers were placed on the platform so that the subject always stood in the same place, i.e. so that the results for shoes with different heel heights would be comparable.

3. Results

Based on the measured ground reaction forces and the values of a and b (Figure 1.) for the barefoot subject and for different types of footwear, using the static equilibrium equations, the magnitudes of the forces in the ankle were determined (Table 2).

Table 2. Calculated ankle forces in [N] and as a percentage of body weight

Barefoot	Footwear				
	no.1	no. 2	no. 3	no. 4.	no. 5.
803,0 N	696,4N	645,1N	862,9N	761,5N	762.1N
1.38 %	1,20 %	1.12 %	1,49 %	1,31 %	1,31 %

Figures 3. – 7. show pressure distribution and figures 8. - 13. show location of the center of pressure. Balance is achieved if the projection of the center of mass coincides with the center of pressure. While center of pressure and center of mass can serve as similar measures of postural control, they represent slightly different portions of the balance system [1]. The location of the center of pressure can generally be thought of as the cause, while displacement of the center of mass is the effect. For example, if the center of mass is located too far on the back side (posterior), the center of pressure will move back to the center of mass which will cause the center of mass to move in the front side (anterior) direction [8].

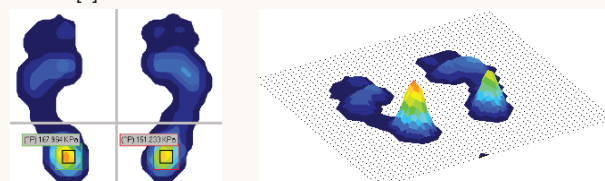


Figure 3. Pressure distribution - barefoot subject

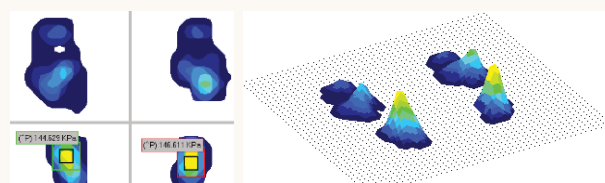


Figure 4. Pressure distribution – footwear no. 1

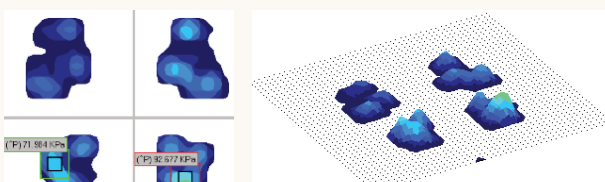


Figure 5. Pressure distribution – footwear no. 2

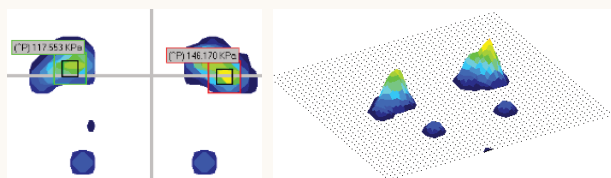


Figure 6. Pressure distribution – footwear no. 3

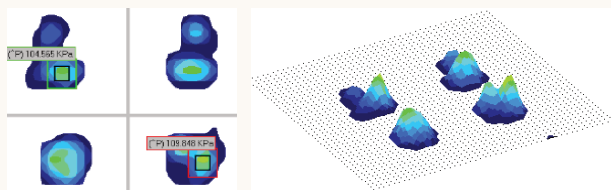


Figure 7. Pressure distribution – footwear no. 4

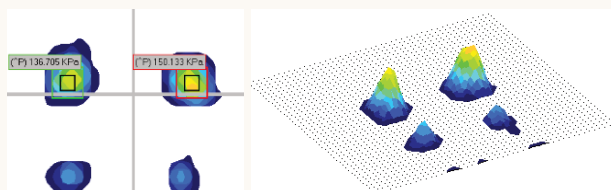


Figure 8. Pressure distribution – footwear no. 5

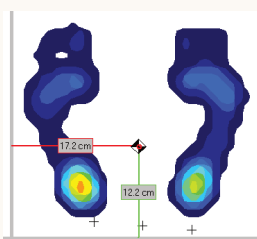


Figure 9. Centre of pressure – barefoot subject

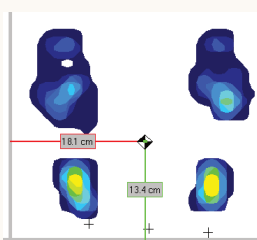


Figure 10. Centre of pressure – footwear no. 1

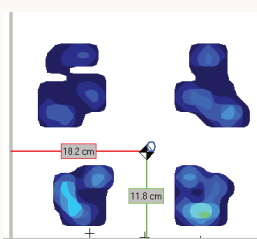


Figure 11. Centre of pressure – footwear no. 2

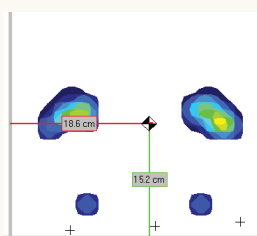


Figure 12. Centre of pressure – footwear no. 3

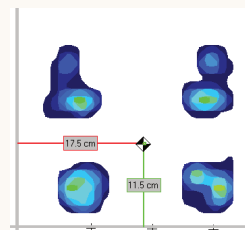


Figure 13. Centre of pressure – footwear no. 4

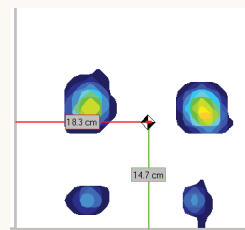


Figure 14. Centre of pressure – footwear no. 5

Coordinates of center of pressure are shown in Table 3.

Table 3: Coordinates of center of pressures

	Footwear					
	Barefoot	no.1	no. 2	no. 3	no. 4.	no. 5.
x cm	17.2	18.1	18.2	18.6	17.5	18.3
y cm	12.2	13.4	11.8	15.2	11.5	14.7

4. Discussion and Conclusion

Using a simplified biomechanical foot model, the ankle forces were calculated when wearing different footwear with different heel heights. The results showed that the highest ankle load is when wearing footwear no. 3, i.e. shoes with a narrow heel of medium height (6.5 cm). The lowest ankle load occurs in shoes with a low block heel (2.5 cm). The results showed that in the barefoot subject and in footwear no. 1 (0.5 cm), the pressure is higher on the back of the foot; in footwear with a block heel height of 2.5 cm and 9 cm, the pressure distribution is equal on the front and back of the foot. For footwear with a narrow heel height of 6.5 and 10 cm, the pressure is higher on the forefoot, also in this case the projection of the center of mass and center of pressure shifted the most towards the front of the foot. In footwear no. 2 and no. 4, the shift of the center of mass coordinate is the smallest.

From obtained results could be concluded that high-heeled shoes with narrow heel support could have a high risk on plantar pain and fasciitis development. A bigger part of weight-bearing is transferring to the forefoot, the foot arch morphology and geometry are changed, and plantar contact area of the middle part of foot is reduced which leading to increased force on the plantar fascia.

Subjects who wear high heeled shoes every day, tend to apply adaptive strategy to alter their center of mass in relation to the center of pressure. Adaptive strategies include various processes, from postural adjustments, such as rotations of the trunk and pelvis, to changes in muscle structure, which represent an increasing departure from the natural or neutral position of the body.

The findings of the study can help shoe designers to create stylish, nice and comfortable shoes.

The conducted research has many simplifications and limitations. The biomechanical model is very simplified, the duration of wearing shoes was not taken into account and the research was conducted only for one person. Future research should be conducted on a statistically significant sample of subjects, it is also necessary to measure walking, not just static position, i.e. standing, and the biomechanical model of the foot should be numerical to enable finite element analysis. Also, for pressure measuring, it is necessary to have shoes of the same shape, made of the same material, only with different heel heights.

References

- [1] Almadhaani H.M.A., Goonetilleke R.S., Wijeweera A. et al.: Transient pain and discomfort when wearing high-heeled shoes, *Scientific Reports* 14 (2024) 9291
 - [2] Wan F.K.W., Yick K.-L., Yu W.W.M.: Effects of Heel Height and High-Heel Experience on Foot Stability during Quiet Standing, *Gait Posture* 68 (2019) 252-257
 - [3] Wang M., Li S., Teo E.-C., Fekete G., Gu Y.: The Influence of Heel Height on Strain Variation of Plantar Fascia During High Heel Shoes Walking-Combined Musculoskeletal Modeling and Finite Element Analysis, *Frontiers in Bioengineering and Biotechnology* 20 (2021) 9, 791238
 - [4] Stecco C., Corradin M., Macchi V., Morra A., Porzionato A., Biz C. et al.: Plantar Fascia Anatomy and its Relationship with Achilles Tendon and Paratenon, *Journal of Anatomy* 223 (2013) 6, 665-676
 - [5] Kogler G. F., Veer F. B., Verhulst S. J., Solomonidis S. E., Paul J. P.: The Effect of Heel Elevation on Strain within the Plantar Aponeurosis: In Vitro Study, *Foot & Ankle International* 22 (2001) 5, 433-439
 - [6] Yu J, Wong DW, Zhang H, Luo ZP, Zhang M.: The influence of high-heeled shoes on strain and tension force of the anterior talofibular ligament and plantar fascia during balanced standing and walking, *Medical Engineering & Physics* 38 (2016) 10, 1152-1156
 - [7] <https://imgur.com/x-ray-of-foot-high-heel-shoe-Emq7N8K>, Accessed: 2024-11-24
 - [8] Richmond S.B., Fling B.W., Lee H., Peterson D.S.: The assessment of center of mass and center of pressure during quiet stance: Current applications and future directions, *Journal of Biomechanics* 123 (2021) 110485
-