MAXIMIZE BIOMECHANICAL BENEFITS BY USING 3D CUSHIONING GEOMETRY

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INTRODUCTION

Footwear cushioning system has been improved tremendously over the past 30 years. Leading athletic footwear companies have all introduced their own innovative cushioning technologies, such as air bags and wavy plates. The main goal of these cushioning technologies was to maximize biomechanical benefits, and therefore, reduce the risks causing acute and chronic injuries. These cushioning systems are mainly deployed in 2D plane with minimum contoured interface between foot and footwear. In footcare industry, footcare professionals tend to use customized 3D structural modules, such as heel cups, heel wedges, arch supports, and metatarsal pads to treat and prevent specific foot injuries and ailments. Some of these customized 3D structures are clinically proven to alleviate symptoms and pains in patients.

It is natural to marry the strengths from the two distinct fields and provide end users maximum protection and benefits during exercise and sports. Heel cupping was an example of applying 3D structure to relief heel pressure during soccer activities (Morag el al., 2002.) The challenge is to harmonize footwear mass production with customization. The purpose of this article was to summarize a selection of three small studies to demonstrate the effects of using 3D geometry on the foot loading and illustrate the possibility of introducing 3D cushioning system in future footwear design for mass-market.

METHODS

Ten, thirteen, and eighteen female subjects (161.2±5.6 cm; 71.0±14.5 kg; 41.1±10.3 years) participated in Study I, II and III of this project respectively. Subjects walked at their self-selected speeds for at least five times in each condition along a 20-yard walkway wearing the same type of deck shoes with flat synthetic rubber midsole/outsole. The contoured 3D geometry was achieved by modifying inner soles. Three steps in the middle of each walking trial were extracted for further analysis.

In Study I, six prototype insoles with two different heel geometries (contoured and flat) and three arch support levels (low, medium, and high) were tested. The base structure of these prototypes was identical and had a contoured heel cup and low arch support. Flat heel shape was achieved by shaving off the heel cup, while different arch support level was obtained by adding arch cookies with different thickness to the base structure.

In study II, two types of arch products were tested along with the control condition that has no arch support. Product A used a wedge shaped design that has heel thickness of 6.9 mm and arch thickness of 8.6 mm. Product B used an arc shaped design with heel thickness of 6.4 mm and arch thickness of 10.4 mm.

In study III, an insole made of dual-layer forefoot and contoured heel was tested against flat foam insole. The dual-layer forefoot was constructed by direct casting a layer of low resilient viscoelastic foam on top of resilient foam layer. Because of the slow resilience, the top layer foam took 1-5 seconds to fully recover after release of compression. Therefore, after release of compression, a 3D indentation of foot is left on the footbed before second step was exerted. The indentations could be considered as dynamic 3D conformation to foot.

Plantar pressure was collected using a Pedar in-shoe pressure system at 50 Hz. Peak pressure and maximum force in different regions were analyzed.

RESULTS

In study I, it was found that heel geometry had significant effect on heel peak pressure ($p<0.0001$), while arch support level only interact with heel structure ($p=0.0005$). When using low or medium arch support, heel pressure was reduced by up to 17.5% when using heel cups. No pressure reduction was found when high arch support was used (Table 1)

Table 1. Peak pressure (N/cm**2) comparison in the heel region.

Arch Support	Heel	LSMeans	Std Err.
Low	Flat	33.50	0.62
Low	Contoured	28.06	0.62
Medium	Flat	32.73	0.64
Medium	Contoured	27.01	0.62
High	Flat	31.13	0.62
High	Contoured	30.13	0.62

In study II, Product A had significantly lower heel maximum force and peak pressure (p=0.001 and 0.003). Product B provided more arch support indicated by 10% increase of maximum force in the medial arch region. Product B also showed significantly lower peak pressure in the center of forefoot region (p=0.0002) （Table 2）.

Table 2. Peak pressure and maximum force comparison among three tested conditions.

	Mean Peak Pressure (N/cm**2)			Mean Maximum Force (N)		
	Heel	Medial Arch	Center of Forefoot	Heel	Medial Arch	Center of Forefoot
Control	31.5	7.5	38.3	534.7	28	335.7
Product A	24.6	9.8	39.4	473.5	51.4	327.4
Product B	26.9	8.7	34.6	508.9	56.7	322.5

In Study III, the heel cupping structure along with arch support effectively reduced heel peak pressure by over 20% and increased arch support by 13.5%. Forefoot peak pressure had an average reduction of about 10%. Peak pressure reduction in the toe area was less than 5% (Figure 1.)

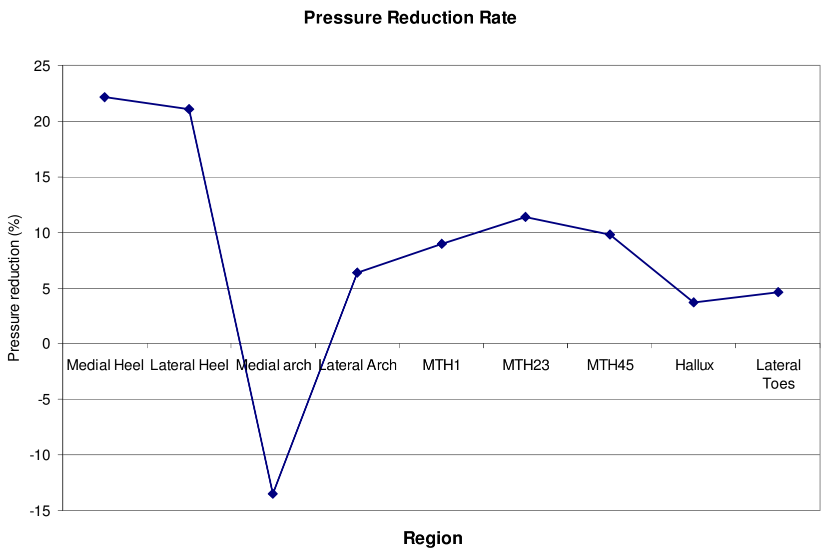

Figure 1. Pressure reduction rate in different foot regions.

DISCUSSION AND CONCLUSIONS

It was evident that biomechanical benefits can be improved by applying appropriate 3D cushioning structure across the whole foot without sacrificing mass-production feasibility. This project confirmed that heel cupping is an effective way to reduce heel pressure as demonstrated in the study by Morag et al (2002). 3D arch design can increase the arch support in the medial arch area without increase peak pressure. However, arch design is much more complicated as it may interact with heel structure and affect forefoot function as shown in Study I and II. Optimization study is needed to define the best combination of heel and arch structure for a specific activity or sport.

The limited space in the forefoot region of footwear prevents any substantial 3D geometry manipulation. A pre-molded structure is a potential option for mass-production. However, without appropriate designs, pre-molded products can also cause serious injuries in sport activities. One of the promising solutions is to use slow resilient material so that dynamic 3D geometry can be achieved during sport actions.

Even though 3D cushioning system has been used for many years in footcare industry, no systematic research is available because of practical difficulties and unlimited geometric possibilities. In order to marry 3D cushioning system with athletic or other footwear, further understanding of foot bony and soft tissue structure is necessary. Furthermore, subjective perception should also play a major role in product development process.

REFERENCES

Morag, E, Johnson, D, Amos, M (2002), The effect of heel cupping on heel pressure during soccer activities. Proceedings of VIII emed Scientific Meeting, Kananaskis, Alberta. Page 45.