Lattice Structures: A Novel Approach to Skin Temperature Management in Veterinary Orthotics for Dogs

This article explores the application of 3D printing technology in developing orthotic products for animals. By leveraging 3D printing's capabilities, a novel approach to skin temperature management that surpasses traditional foam padding has been introduced. This method offers enhanced product usability and effectiveness through customized designs tailored to individual limb shapes. The integration of digital workflows optimizes comfort and performance, demonstrating the potential of 3D printing to revolutionize skin contact products in the animal care industry.

Introduction

Prolonged skin contact with conventional materials is a frequent cause of skin irritation due to friction and environmental factors such as humidity and dirt. Foam cushions have been widely adopted as a measure against pressure-related skin injuries. However their effectiveness is often compromised by the quality of the fitting to individual patient anatomy. This limitation may result in inconsistent pressure distribution and potential discomfort.[1][2]

Recent advancements in additive manufacturing have enabled the creation of customizable structures. They exhibit unique properties that may surpass those of traditional foams. While some lattice structures have demonstrated the ability to replicate the cushioning characteristics of soft foams, others allow control mechanical properties through the local manipulation of their internal structure. This capacity to precisely engineer open lattice structure holds the potential to enhance temperature regulation and facilitate cleaning, thereby addressing common challenges associated with traditional cushioning materials.[3]

The objective of this study is to evaluate the effectiveness of 3D-printed lattice structures in managing skin temperature when used in orthotic products for animals. The study aims to determine whether lattice structures can provide superior temperature regulation while maintaining comfort by comparing lattice designs to traditional foam padding. The research focuses on how the customization capabilities of additive manufacturing can be leveraged to create orthotic products that better fit individual limb shapes, thereby improving overall product performance and animal well-being.

Materials and methods

Additive manufacturing (AM), commonly known as 3D printing, is a method for fabricating three-dimensional structures directly, layer by layer. Unlike traditional methods such as machining and injection molding, it does not require additional tooling for specific parts. This approach allows for the design of customizable geometries, enhancing flexibility in the manufacturing process. [4]

Thermoplastic polyurethane (TPU) is known for its exceptional elasticity and resilience. Its high deformability makes TPU highly efficient in absorbing energy. When engineered into lattice structures through additive manufacturing, this material offers a unique combination of flexibility and strength. The porosity of lattice structures enhances breathability, while enabling the creation of lightweight, customized components. [5][6]

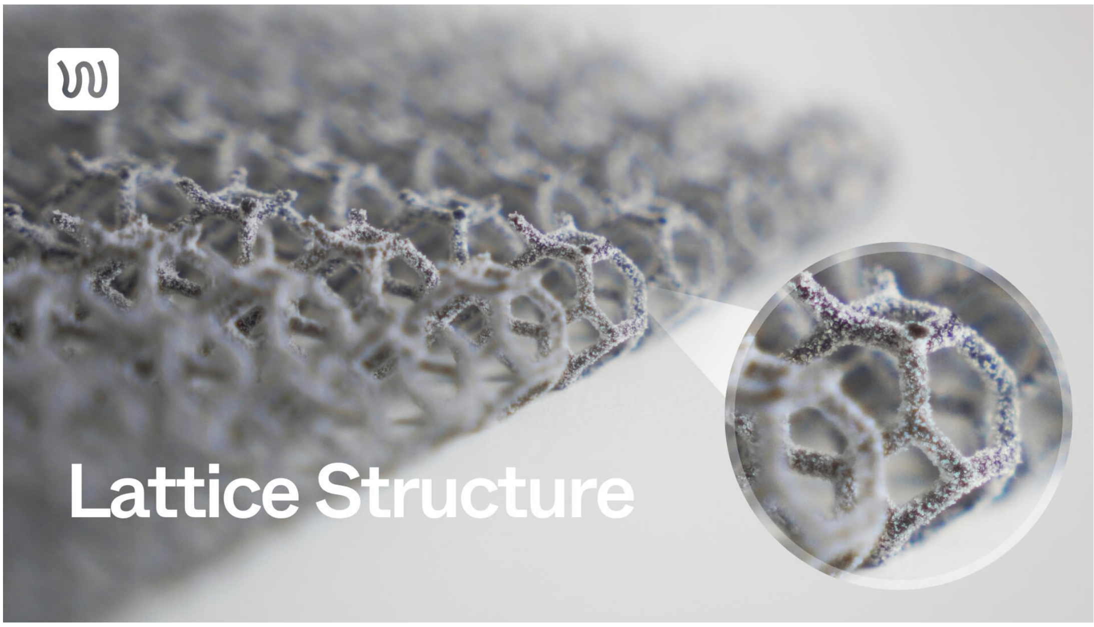


Fig. 1 3D-Printed TPU Inserts

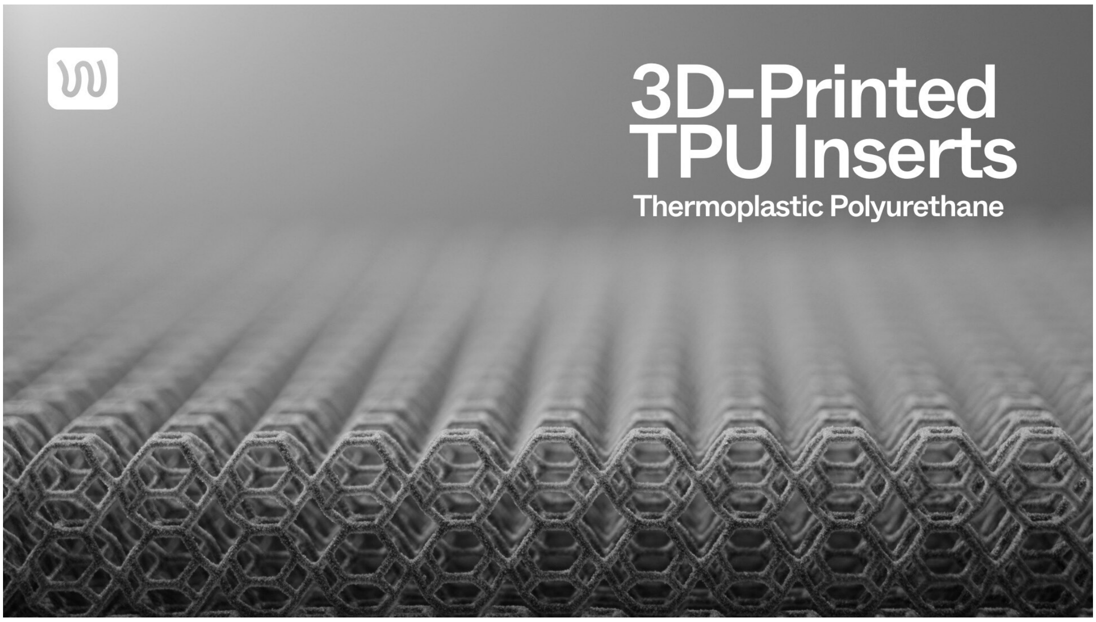


Fig. 2 Lattice structure of inserts

Fig. 3 EVA Foam

EVA (Ethylene Vinyl Acetate) foam is one of the most commonly used materials in various applications, especially in the medical field. It is a polymer material made from a combination of ethylene and vinyl acetate, known for its softness, flexibility, and resilience. EVA foam is widely utilized as padding in medical applications, such as orthotic insoles and protective cushioning, due to its excellent shock absorption properties and closed-cell structure, which also enhances its durability and ability to withstand repeated use. [7][8]

Lattice structures are complex geometric designs that can be fabricated using additive manufacturing techniques, offering enhanced performance with reduced material and weight. The efficiency of lattice structures in thermal management is attributed to their ability to enhance heat transfer rates while reducing pressure drop. [9][10]

In the context of orthotics, such as those developed by WIMBA, lattice structures offer several advantages. They are used in the design and production of orthotic devices. Their open-cell geometry improves heat dissipation, which is essential for maintaining comfort in orthotic devices. Enhanced heat transfer rates help to prevent overheating and moisture buildup, contributing to the overall comfort of the pet wearing the orthotic device. Additionally, lattice structures can be engineered to reduce pressure points, providing better weight distribution and alleviating potential discomfort during extended use.

Lab tests

Skin temperature tests

The first test conducted was a skin temperature assessment. The research subject was a 10-year-old female German Shepherd. Thermal imaging was conducted in a room with a consistent ambient temperature of 26°C. A FLIR E6-XT thermal imaging camera with 240 x 180 resolution was used for the study. The dog was positioned for the photos without making contact with its fur. For full-body photos, the camera was placed at a distance of 0.75 m ± 0.1 m from the dog. For limb photos, the distance was 0.25 m ± 0.1 m. Three photos were taken, along with two point measurements (2 cm ± 1 cm above the joint and 2 cm ± 1 cm below it) in each test situation - repeated three times, totaling six point measurements. To ensure consistency, all measurements were taken by the same person.

During thermographic imaging and acclimation period nobody was allowed to touch the dog's limbs. Before the test the dog was acclimated to room temperature for 30 minutes. The pet owner was asked to remove the harness upon entering the room. The dog fasted for 2 hours before the thermal images were taken. After the acclimation period, control thermal images were taken of the entire dog and of the limb itself.

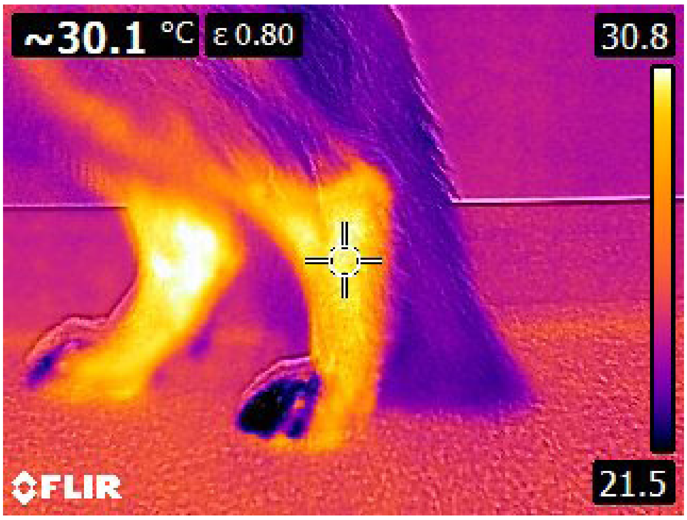


Fig. 4: Measurement of the dog's skin temperature prior to the application of the orthotics.

Table 1. Average and Standard Error of Skin Temperature Measurements at Specific Points Relative to the Joint Prior to the Application of the Orthotics

Measure Number	1	2	3	Average	Standard error
Point over the joint [°C]	27.3	29.0	27.8	28.0	0.9
Point under the joint [°C]	29.2	30.4	30.1	29.9	0.6

The orthosis was worn by the dog for a continuous duration of 2 hours, during which time running and excessive movement were prohibited, and the dog was not permitted to engage in any play activities. Thermal imaging was conducted after the completion of the 2-hour period.

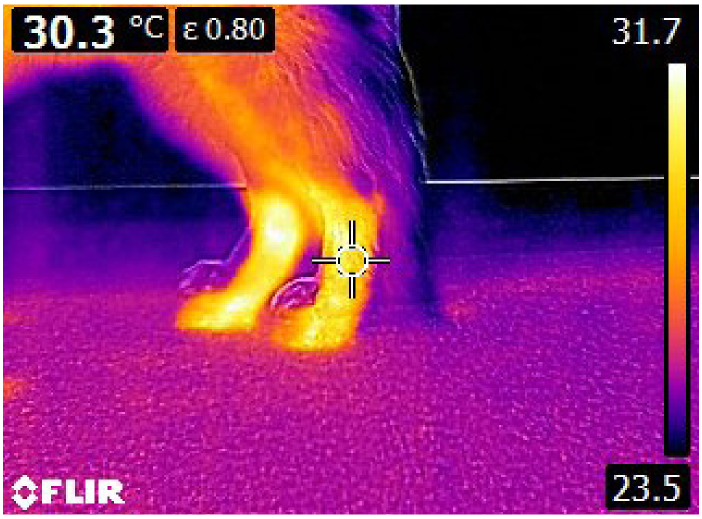


Fig. 5: Thermal imaging of the dog's skin temperature after 2 hours of wearing the orthosis featuring TPU lattice structures.

Table 2. Average and Standard Error of Skin Temperature Measurements at Specific Points Relative to the Joint After the Application of the Orthotics

Measure Number	1	2	3	Average	Standard error
Point over the joint [°C]	26.6	27.5	27.7	27.3	0.6
Point under the joint [°C]	30.3	30.4	30.9	30.5	0.3

After a break time of 2 hours, the same brace but with EVA foam padding was fitted onto the dog. The same test protocol as before was used.Both full-body images and limb images were taken after the 2-hour period.

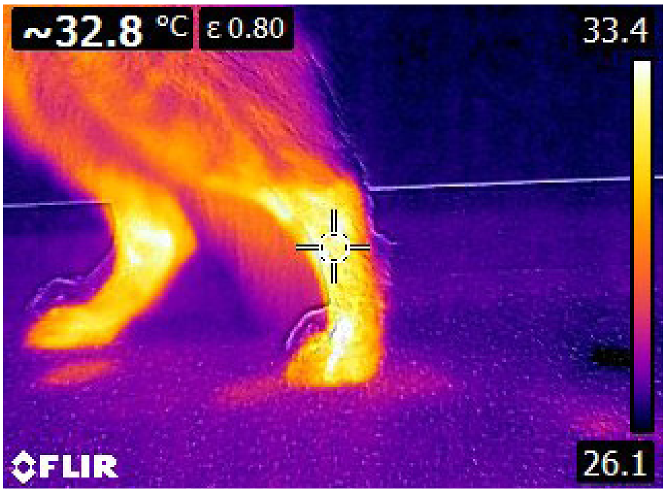


Fig. 6 Thermal imaging of the dog’s skin temperature after EVA foam padding was fitted.

Table 3. Average and Standard Error of Skin Temperature Measurements at Specific Points Relative to the Joint After the Application of EVA Foam Padding

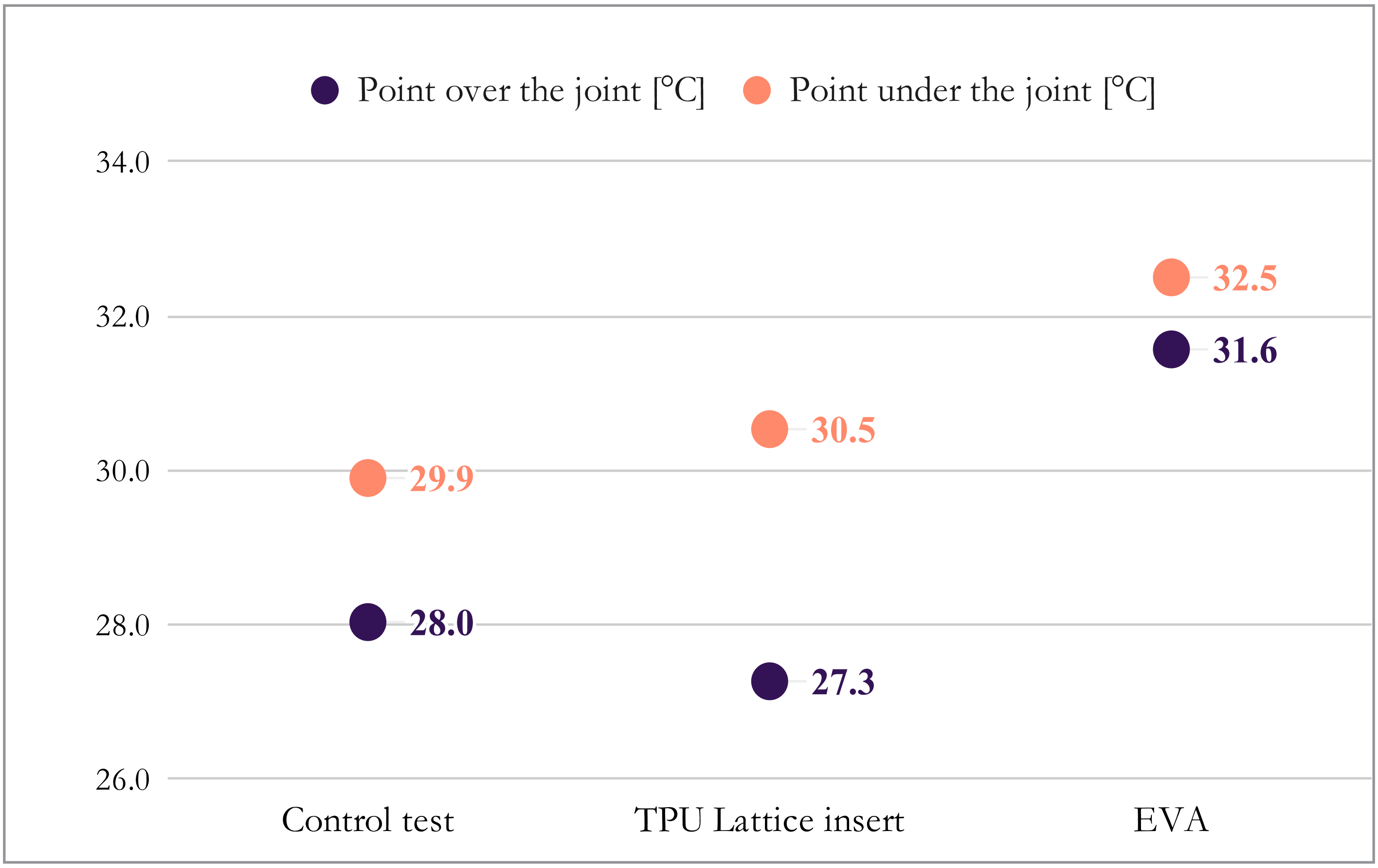
Measure Number	1	2	3	Average	Standard error
Point over the joint [°C]	32.0	30.6	32.1	31.6	0.8
Point under the joint [°C]	32.5	32.8	32.2	32.5	0.3

Last but not least immediately after removing the brace, thermal images of the brace were taken. The images below indicate that the temperature of the device was higher when EVA foam padding was used compared to the TPU lattice insert. This observation suggests that EVA foam may contribute to higher thermal retention in the brace.

Table 4. Average and Standard Error of Skin Temperature Measurements at Specific Points Relative to the Joint After the Application of EVA Foam Padding

Measure Number	Control test	TPU Lattice insert	EVA
Point over the joint [°C]	28.0	27.3	31.6
Point under the joint [°C]	29.9	30.5	32.5

Chart 1. Average temperatures taken at the two measuring points



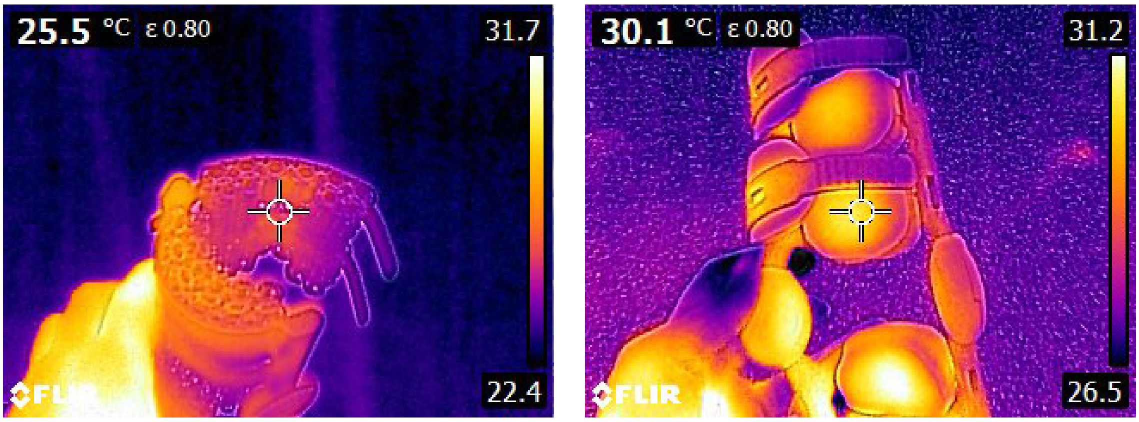
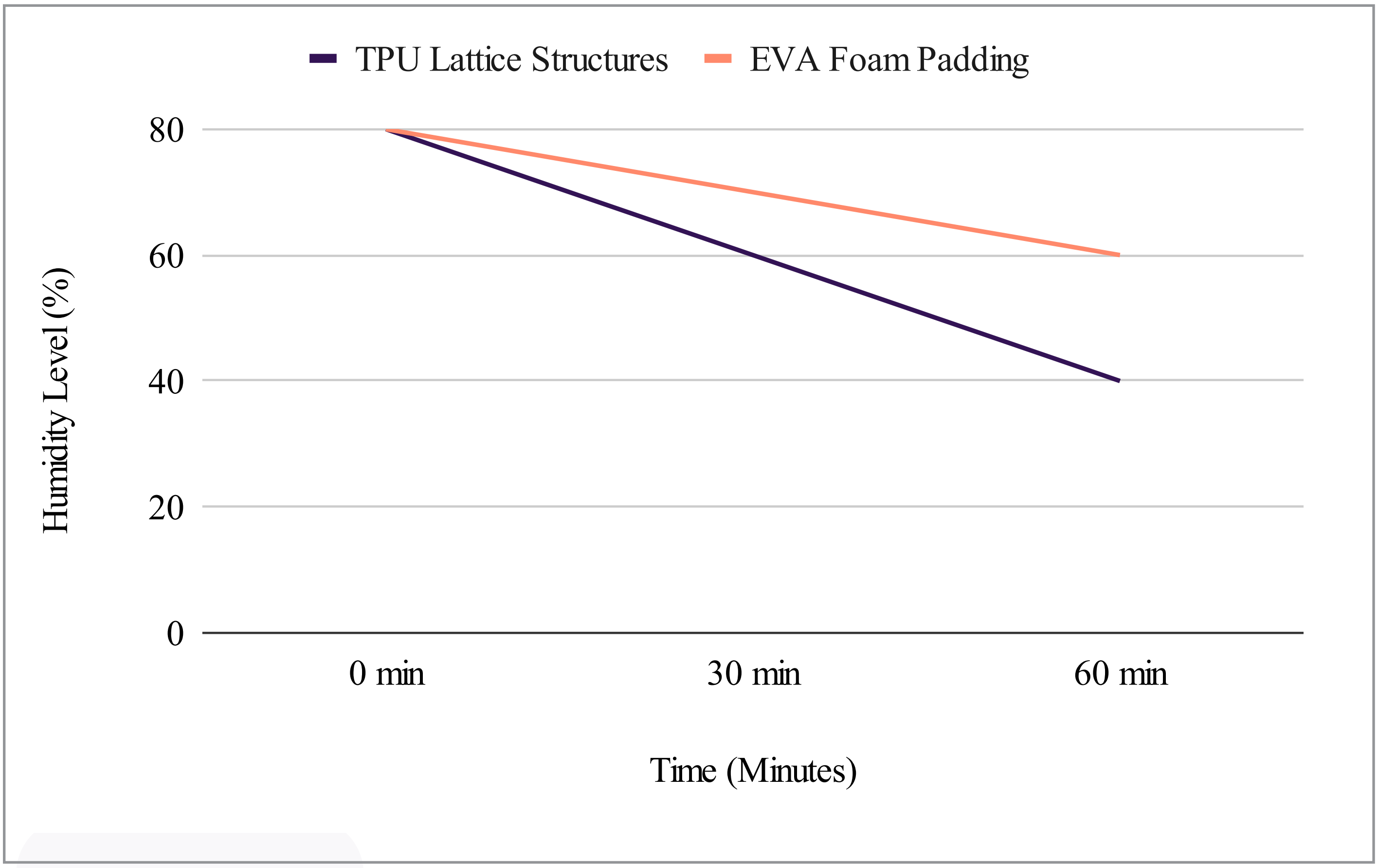


Fig. 7 Thermal images of the brace after removal: EVA foam (right) and TPU lattice insert (left)

Moisture test

In addition to the skin temperature assessment, a moisture test was conducted using a A UNI-T hygrometer to measure the moisture level on the surface of the dog's fur. The test was conducted in a room with a temperature of 26°C and air humidity of 32%. The fur of the test animal was generously sprinkled with water. A brace with TPU lattice structures and EVA foam padding was fitted to the dog. Moisture measurements were taken three times at 30-minute intervals.

Chart 2. Comparison of Humidity Reduction Over Time (Base Humidity Level 30%)



Conclusions

The study reveals that the use of TPU lattice structures in orthotic devices, compared to traditional EVA foam padding, improves thermal management and overall comfort. By creating a more open structure, 3D printed lattice structures promote better airflow, moisture evaporation and reduce the risk of skin irritation. Improved breathability contributes significantly to better skin temperature regulation. Moreover, lattice structures simplify hygiene maintenance, minimizing the accumulation of bacteria and other contaminants that can lead to skin infections.

In contrast, EVA foam, often used in standard orthotics, tends to enclose the limb and may result in higher temperatures due to its less breathable nature. EVA foam padding, commonly found in widely available plastic orthoses, typically covers the entire surface, potentially leading to even higher temperatures. Although EVA foam was applied to the lightweight and breathable orthotic structure designed by WIMBA, the temperature was still higher.

The TPU lattice structures, with their open design, proved more effective in maintaining lower temperatures by enhancing airflow and moisture evaporation. This highlights the more effective thermal management capabilities of TPU lattice structures over EVA foam, even when the foam is used in conjunction with an already ventilated orthotic design.

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Ethics Statement

Written informed consent was obtained from the owner for the participation of their animal in this study. The study involved non-invasive observations of a dog wearing a custom-made orthosis as part of its regular daily routine and the dog's well-being was prioritized throughout the study.

References

1. Lee, H., & Choi, S. (2024). Protocols and their effects for medical device-related pressure injury prevention among critically ill patients: a systematic review. BMC nursing, 23(1), 403. https://doi.org/10.1186/s12912-024-02080-y
2. Chien, W. C., & Tsai, T. F. (2024). Pressure and Skin: A Review of Disease Entities Driven or Influenced by Mechanical Pressure. American Journal of Clinical Dermatology, 25(2), 261-280. https://doi.org/10.1007/s40257-023-00833-0
3. de la Rosa, S., Mayuet, P. F., Méndez Salgueiro, J. R., & Rodríguez-Parada, L. (2021). Design of customized TPU lattice structures for additive manufacturing: influence on the functional properties in elastic products. Polymers, 13(24), 4341. https://doi.org/10.3390/polym13244341
4. Khorasani, M., MacDonald, E., Downing, D., Ghasemi, A., Leary, M., Dash, J., ... & Bateman, S. (2024). Multi Jet Fusion (MJF) of polymeric components: A review of process, properties and opportunities. Additive Manufacturing, 104331. https://doi.org/10.1016/j.addma.2024.104331
5. Beloshenko, V., Beygelzimer, Y., Chishko, V., Savchenko, B., Sova, N., Verbylo, D., ... & Vozniak, I. (2021). Mechanical properties of flexible tpu-based 3d printed lattice structures: Role of lattice cut direction and architecture. Polymers, 13(17), 2986. https://doi.org/10.3390/polym13172986
6. Ji, X., Deng, L., Zhang, J. et al. Energy Absorption Characteristics of 3D Lattice Structure Filled with Periodic Inner Core Based on 3D Printing. J. of Materi Eng and Perform 31, 6784–6794 (2022). https://doi.org/10.1007/s11665-022-06692-w
7. Chen, H., Sun, D., Gao, L., Liu, X., & Zhang, M. (2023). Mechanical Behavior of Closed-Cell Ethylene-Vinyl Acetate Foam under Compression. Polymers, 16(1), 34. https://doi.org/10.3390/polym16010034
8. Gong, W., Ma, Y. L., Fu, H., Ban, D. M., He, L., & Gang Yin, X. (2018). Study on thermal insulation performance of EVA foaming materials. Ferroelectrics, 527(1), 16-24. https://doi.org/10.1080/00150193.2018.1450044
9. Tang, Y., & Zhao, Y. F. (2014, November). Design method for lattice-skin structure fabricated by additive manufacturing. In ASME International Mechanical Engineering Congress and Exposition (Vol. 46445, p. V02BT02A030). American Society of Mechanical Engineers. https://doi.org/10.1115/IMECE2014-38645
10. Sajjad, U., Rehman, T. U., Ali, M., Park, C. W., & Yan, W. M. (2022). Manufacturing and potential applications of lattice structures in thermal systems: A comprehensive review of recent advances. International Journal of Heat and Mass Transfer, 198, 123352. https://doi.org/10.1016/j.ijheatmasstransfer.2022.123352