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Designing and manufacturing medical insoles with flexi material using sole scanning and SolidWorks software and force analysis using OpenSim software

Mohammad Mahdi Giahi[a, *], Mohammad Sadegh Karim Zadeh [b], Alireza Golchin [c]

[a] Department of Biomedical Engineering ,Qazvin Branch , Islamic Azad University ,Qazvin, Iran
[b] Department of Physical Education and Sport Science, Qazvin Branch, Islamic Azad University, Qazvin, Iran
[c] Department of Mechanical Engineering ,Qazvin Branch , Islamic Azad University ,Qazvin, Iran
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Abstract

This article focuses on the design and analysis of a custom medical insole developed using Solid Works software for 3D modeling and Open Sim for muscle simulation. The aim of this study is to address and improve the structural and functional weaknesses of individuals' feet by conducting a detailed analysis of foot pressure distribution and optimizing the design of personalized insoles accordingly. The process involved gathering data from 3D foot scans and pressure measurements to ensure the precise fit and effectiveness of the insoles. Results from the pressure tests demonstrate that these custom insoles significantly enhance pressure distribution across the foot and improve the performance of leg muscles during movement. Furthermore, this research highlights the potential of custom-made insoles as a valuable solution for correcting structural foot abnormalities, improving balance, and reducing pain caused by gait-related issues. The findings suggest that personalized insoles can be a highly effective therapeutic tool for addressing common foot problems and enhancing overall mobility in patients.

Keywords: Customized medical insoles, Simulation, SolidWorks, OpenSim, Foot pressure analysis, Biomechanics, Correction of foot abnormalities.

1. Introduction

Feet, as the fundamental base of the human body, play a crucial role in movement, balance, and the distribution of forces exerted on the body. Any defect or abnormality in foot structure can lead to functional impairments and chronic pain in various parts of the body. According to various studies, approximately 20-30% of the global population experiences some form of lower extremity issues, with the most common being flatfoot, ankle deviation, and plantar fasciitis [1].

Orthotic insoles are designed to correct deformities and support the natural structure of the foot. These insoles can help evenly distribute pressure and reduce stress on the joints, leading to a decrease in pain and an improvement in the overall function of the foot and related body parts. Studies have shown that the use of orthotic insoles can significantly alleviate issues such as knee pain, lower back pain, and even gait and balance problems. With recent advancements in technology, it is now possible to design and manufacture custom insoles using 3D printing and computer simulations. These technologies allow for the creation of precise insoles tailored to the specific needs of each individual. For instance, 3D printing enables the production of insoles with the appropriate structure and rigidity, based on a detailed scan of each person's foot, to optimally support and correct any weaknesses in the foot [2].

3D printing, as an innovative technology in the production of custom insoles, enables the creation of intricate and personalized designs with ease and high precision. This process involves the accurate scanning of an individual's foot and the generation of a three-dimensional model, which is then transformed into an insole. These insoles can precisely address the biomechanical needs of the individual, enhancing final performance by optimizing pressure and force distribution [2,3].

The use of computer simulations such as Open Sim also allows for a detailed analysis of muscle function and the impact of insoles on the distribution of pressure and forces exerted on the foot. These simulations can provide valuable insights into the biomechanical function of the foot and the changes resulting from the use of orthotic insoles, aiding in the optimal and more effective design of these insoles. With these tools, the function of both short and long muscles can be examined, and the exact effects of insole use on these muscles can be analyzed [2,3,4].

The aim of this study is to investigate the impact of custom insoles, designed using 3D printing, on improving the foot function of individuals with various deformities. Through the use of computer simulations, this research seeks to evaluate the precise effects of these insoles on

*Corresponding author Email address: giahimahdi@gmail.com

muscle function and force distribution. This study could be a significant step toward developing non-invasive and effective methods for improving lower extremity issues and enhancing individuals' quality of life.Early research on orthotic insoles focused primarily on the design of standard and semi-custom insoles. These insoles were generally based on general biomechanical principles and designed for the general population. For instance, a study by Chevalier et al. demonstrated that standard insoles can help reduce pain and improve foot function to some extent, but due to their lack of precise alignment with individual needs, their efficacy is not optimal [5].

With advancements in scanning and 3D printing technologies, the possibility of designing and producing fully customized insoles has emerged. A study by Telfer et al. examined the effects of 3D-printed custom insoles on plantar pressure distribution. The results of this study indicated that custom insoles can significantly reduce pressure on specific areas of the foot and provide greater comfort for the user [5].

Computer simulations play a crucial role in the analysis and optimization of orthotic insole design. One of the advanced tools in this field is the OpenSim software, which enables precise modeling of the musculoskeletal system. In a study by Delp et al. the applications of OpenSim in biomechanical analysis were explored, demonstrating that the software can accurately simulate the effects of various modifications in insole design on foot muscle performance [6].

Another study by Zhu et al. investigated the impact of custom insoles on lower limb muscle function. Using OpenSim, this study found that custom insoles can help balance muscular forces and improve motor function. Additionally, the simulations revealed that insoles can optimize the pressure exerted on both short and long muscles of the foot, potentially preventing injuries [7].

The combination of custom design with computer simulations represents an innovative and effective approach to enhancing the performance of orthotic insoles. A study examined this combination, revealing that the use of 3D printing for producing custom insoles, along with precise OpenSim simulations, can significantly improve performance and reduce pain for users [8].Furthermore, recent research has explored the long-term effects of using custom insoles on alleviating lower extremity issues. A study demonstrated that consistent use of custom insoles can help reduce pain and improve the quality of life for individuals with lower extremity problems. This research highlighted that computer simulations can provide detailed insights into biomechanical changes over time, aiding in the optimization of insole design [8].

Our primary objective is to evaluate and assess the impact of custom-designed orthotic insoles, created using 3D printing, on improving function and reducing foot abnormalities. This study employs computer simulations through the OpenSim software to analyze biomechanical changes and muscle performance before and after the use of insoles made from flexible material. The focus is particularly on addressing foot weaknesses, such as flat feet, ankle deviations, and other related issues [9].

This research introduces several significant innovations compared to previous approaches. We have utilized 3D printing with flexible material for producing the insoles, whereas many earlier studies have relied on standard or semi-custom orthotics. This research leverages 3D printing technology to produce fully customized insoles, allowing for precision in design that meets the specific needs of each individual, ultimately leading to enhanced performance and greater comfort [9].

In this study, we utilize OpenSim software to accurately simulate muscle function and analyze the effects of custom insoles, while many previous investigations have focused on empirical and field evaluations. The use of computer simulations enables a more detailed and precise examination of the insoles' effects on force distribution and muscle performance. By combining precise foot scanning with biomechanical simulations, this approach offers a comprehensive and integrated methodology. This integration allows us not only to design insoles tailored to individual needs but also to analyze their effects in a precise and predictable manner.

Unlike many studies that only consider the short-term effects of orthotic insoles, we also examine biomechanical and functional changes over time. This comprehensive approach helps to gain a better understanding of the long-term impact of custom insoles on improving foot abnormalities.

2. Method

To design custom orthotic insoles based on foot scans, we require a 3D scan of the foot in a static position. After obtaining the scan and various parameters, the desired insole is designed. The process of modeling and designing the insole can be divided into three stages. For acquiring the foot scan, we used an individual who had abnormalities in the ankle region and slight overpronation in the foot arch. In terms of anthropometric parameters, the individual's height was 167 cm and weight was 63 kg, resulting in a BMI of 22.6 based on the provided information.

2-1 Foot scan

For the design of custom orthotic insoles and precise biomechanical analysis, collecting accurate and reliable data from the foot and its functionality is crucial. In this study, a case study was selected involving an individual with ankle abnormalities and muscle imbalances, which led to an increased arch in one foot and resulted in an imbalance in the forces applied to the foot. To achieve a more accurate assessment and design a suitable model, initial data collection was conducted through a detailed scan of the foot.

For precise foot scanning, advanced 3D scanning technology was used. This device, utilizing laser and structured light technology, provides high-resolution 3D images of the foot. During the scanning process, the subject stands barefoot on the scanning platform. The feet are placed in a natural and comfortable position to accurately simulate the pressure and weight distribution. The scanner then fully scans the surface of the foot from multiple angles. The resulting 3D images provide detailed information on the dimensions, shape, and arch of the foot, pressure points, and weight distribution. This data includes an accurate pressure distribution map on various foot points, arch height, and precise measurements of foot length and width.

After collecting the scan data, various features are extracted from the 3D images. These features include pressure distribution, high-pressure points, and the geometric shape of the foot (such as arch height and ankle curvature). Using the extracted data, a 3D model of the individual's foot is created. These models serve as the foundation for designing custom orthotic insoles.

In addition to scan data, functional data related to walking and running is also collected. This data includes recording and analyzing joint movements, forces applied to the foot, and the precise timing of gait phases. For this purpose, motion capture systems and force plates are used. The subject walks and runs on the force plate, and their movements are recorded and analyzed by motion capture cameras. This data provides comprehensive information on the dynamics of movement, applied forces, and pressure distribution during various gait phases.

The collected functional data is analyzed using biomechanical analysis software such as OpenSim. These analyses include examining changes in muscle forces, pressure distribution, and movement patterns over time. After using the custom insoles, functional data is recollected and compared with the initial data. These comparisons demonstrated how the custom insoles contributed to improved performance and reduced lower limb abnormalities.

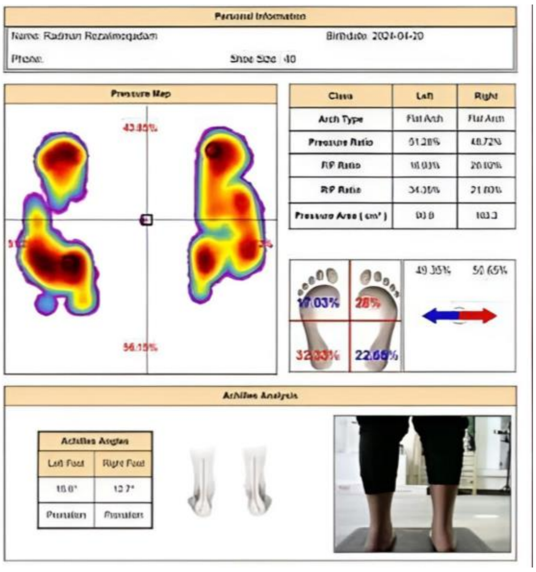

Fig 1 .The pressure distribution pattern of the foot was recorded using a pressure measurement device for an individual with a shoe size of 40. Red and yellow areas indicate high-pressure points, and an asymmetric force distribution between the left and right foot is observed. A detailed analysis of Achilles angle values, foot arch type, and the pressure ratio across different parts of the foot is also provided.

2-2 Foot sole design based on scanning in SolidWorks software

To import the initial 3D scan model into the SolidWorks environment, the 3D scan data, which includes precise information on the shape and pressure distribution of the foot, is converted into an STL file format and then imported into SolidWorks. For analysis and identifying foot weaknesses, based on the scan data and biomechanical analyses, the individual's foot weaknesses are identified. These weaknesses include areas with high pressure and structural abnormalities such as flat feet or foot arch deviations, as well as areas with uneven pressure distribution, which are accurately identified through pressure distribution maps and the 3D model of the individual's foot.

In our selected model for design, the individual has a deformity in the foot arch. For this person, the insole must have a proper arch to help compensate for the low-pressure area in the foot arch. In SolidWorks, the appropriate arch is designed according to the individual's natural foot height and curvature.

The next correction that needs to be made for this individual is the adjustment of ankle misalignment.

In the design of the insole, it is crucial to ensure that the misalignment is corrected and the ankle alignment is improved. We addressed this issue by designing specific sections of the insole in SolidWorks with varying heights and stiffness, which facilitate restoring the ankle's natural alignment.

Figures ۳,4 and 5 demonstrate the stages of design and simulation based on the foot scan data.

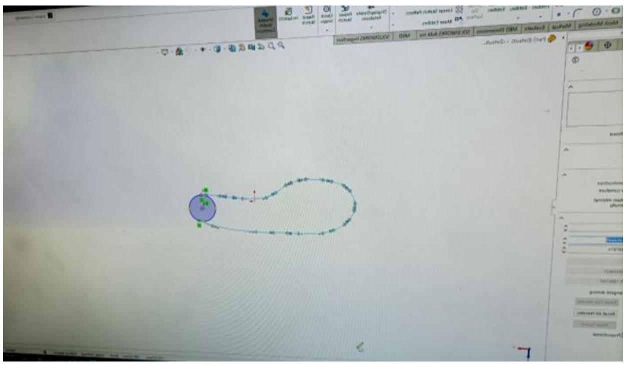

Fig .3. The first stage of design is in Salidorx, where the shape of the foot and the dimensions of the foot are entered into the Salidorx software based on the scan taken from the person.

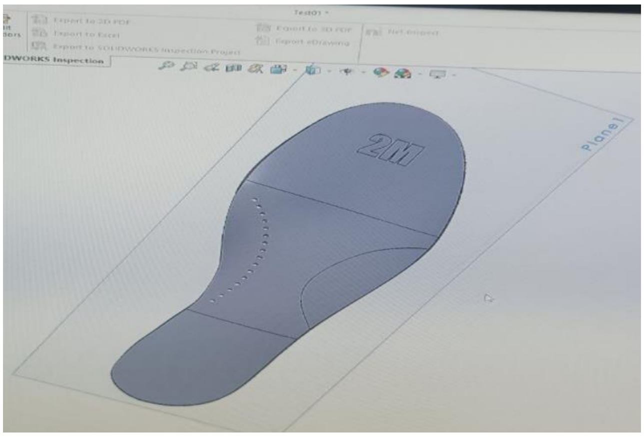

Fig.4.At this stage, the initial design is designed according to the data and the amount of thickness required based on the scan, which part has the largest thickness.

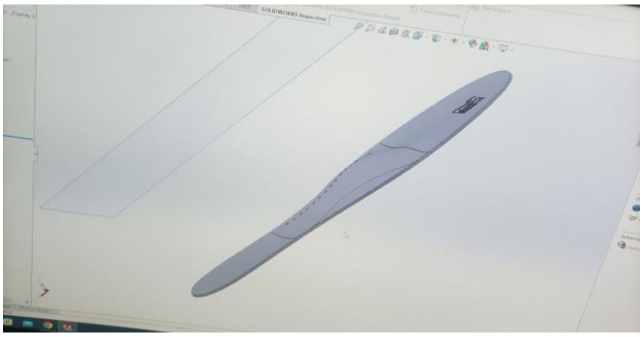

Fig.5.In the last step, according to the scan, the points that help to improve the ankle deviation disorder, the thickness is determined and the amount of arch needed to distribute the appropriate pressure throughout the foot is designed according to the person's foot. In the sole, there are spaces designed for better airflow in the shoe, which are shown with a red frame.

2.3 Analysis of data before and after the use of insoles made using OpenSim software

OpenSim biomechanical analysis software allows us to examine changes in muscle forces, pressure distribution and movement patterns over time. After using the designed insoles, performance data is collected and compared with the initial data, which shows how the designed insoles help improve performance and reduce lower limb abnormalities.

First, according to the person's BMI, we model the musculoskeletal model to simulate walking. As shown in Figure 6, first, the appropriate musculoskeletal model is modelled with the study model, and the analysis of walking and the pressures on the body in the lower part are analyzed.

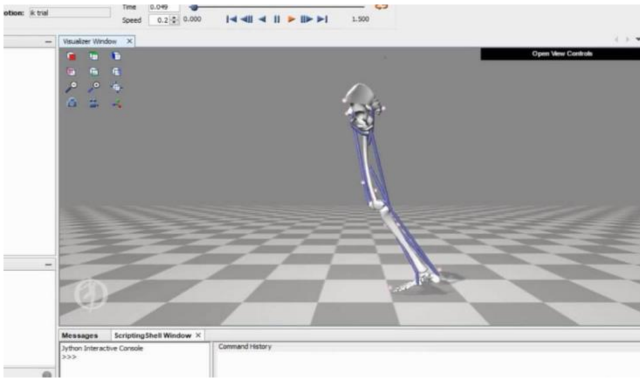

Fig.6.For simulation, we considered the person's weight to be 63 kg and her height to be 167 cm, so that modelling in the software is done based on the mentioned criteria.

To ensure the improvement of the performance and efficiency of the sole, we first implement the motion analysis by default without applying the changes made in the sole in the model based on the amount of foot arch and the amount of unevenness based on the scan on the sole of the model's foot, and then the graph related to the movement And we get the pressure on the foot.

In the following, we apply motion analysis based on the sole designed to compensate for the amount of ankle deviation and improve the amount of arch and appropriate pressure distribution in the sole of the foot, and we compare the before and after diagrams as shown in Figure.7 The amount of pressure before and after using the insole is analyzed.

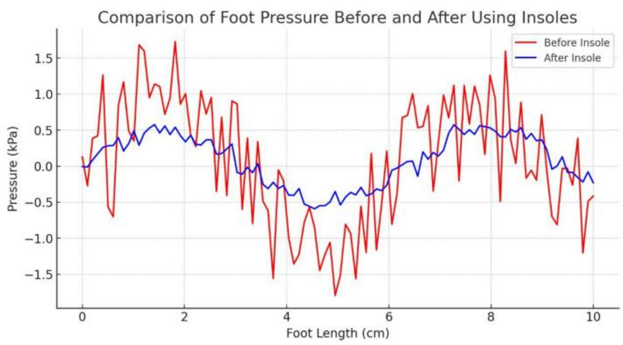

Fig.7.This graph shows the differences in foot pressure before and after using insoles. As it is known, the pressure before using the sole is uneven and high, while after using it, the pressure has become uniform and lower, and it shows the improvement of the movement condition and the uniform distribution of pressure on the sole of the foot.

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According to the analysis and acceptable feedback, we printed the desired insole using a 3D printer using white flexi material and provided the desired case. The printed sample of the insole is shown in Fig8.

To ensure the efficiency and improve the distribution of pressure on the soles of the feet, we tested the insole on a trial basis for one week. According to the opinion of the case study who used the insole for a week, the feedback was acceptable when A walk has been taken to see that the sole production process has been successful.

Fig.8.The final sample of the insole printed with flexi material, before being installed on the medical surface.

3. conclusion

In this study, a customized medical insole was designed, which helped to analyze and correct the weak points of a person's foot using Solidorex software and muscle simulation with OpenSim. The simulation results showed that the use of these insoles was able to improve inappropriate pressures in different parts of the foot and optimize performance. This research shows that the use of customized insoles based on the scan of the soles of the feet and their design and modeling in Solidorex can help improve the condition of patients with structural problems in the feet and be effective in improving their movement performance. Also, the analysis of the designed model By using Open Sim software, the possibility of error is reduced and also the best result and functionality can be obtained from the design.

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