

Smart 3D-Printed Insoles for Plantar Fasciitis: A Digital Workflow and Biomechanical Approach

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Abstract: *Plantar fasciitis is a primary contributor to plantar heel pain, which severely impacts daily mobility, posture, and overall quality of life. Current clinical guidelines emphasize a multimodal rehabilitation strategy where foot orthoses serve as an effective adjunct rather than an isolated treatment. Conventional custom foot orthoses often involve labor-intensive plaster casting, vacuum forming, or thermoforming steps that complicate modifications. This project demonstrates an advanced, digitized workflow utilizing 3D scanning, computer-aided design (CAD), and additive manufacturing to fabricate patient-specific, flexible thermoplastic polyurethane (TPU) insoles. By capturing individual plantar geometry and integrating pressure-mapping evaluations, the proposed method provides precise medial arch support, heel cushioning, and systematic load redistribution. This paper outlines the anatomical background, mechanical principles, detailed digital fabrication methodology, clinical implications, and future directions for 3D-printed orthotic management.*

Keywords: Plantar fasciitis, 3D printing, Additive manufacturing, Foot orthoses, Plantar pressure, Biomechanics, CAD modelling

1. Introduction

The human foot acts as a sophisticated weight-bearing structure responsible for shock absorption, balance, structural support, and propulsion during standing and walking. The plantar fascia; a dense band of connective tissue spanning from the calcaneal tuberosity to the toes plays a fundamental role in supporting the medial longitudinal arch and transferring loads during the gait cycle. Repetitive microtrauma, altered foot biomechanics, reduced ankle dorsiflexion, and prolonged standing often result in inflammation, localized degeneration, and chronic pain, clinically recognized as plantar fasciitis.

Management of plantar heel pain is inherently multimodal, combining patient education, activity modification, targeted stretching, manual therapy, taping, and customized footwear or foot orthoses. Contemporary clinical practice guidelines caution against using orthoses as standalone, short-term solutions; instead, they highlight their efficacy as component parts of a broader rehabilitation framework.

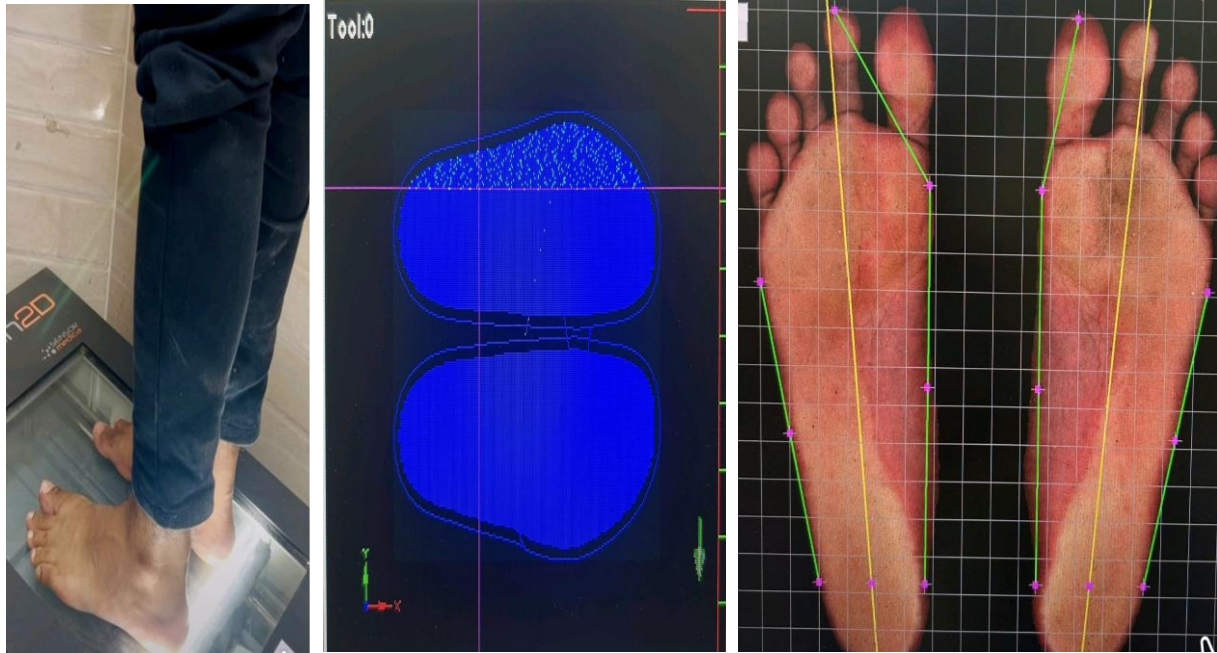
Traditional orthotic fabrication techniques rely on physical foam box impressions, plaster casts, and manual modifications. While effective, these methods lack digital repeatability and require repeated manual fabrication steps whenever modifications are necessary. The integration of 3D scanning, computer-aided design (CAD), and additive

manufacturing provides a reproducible, highly customizable workflow. This study details a patient-specific design and fabrication pipeline intended to optimize plantar pressure distribution and enhance comfort during rehabilitation.

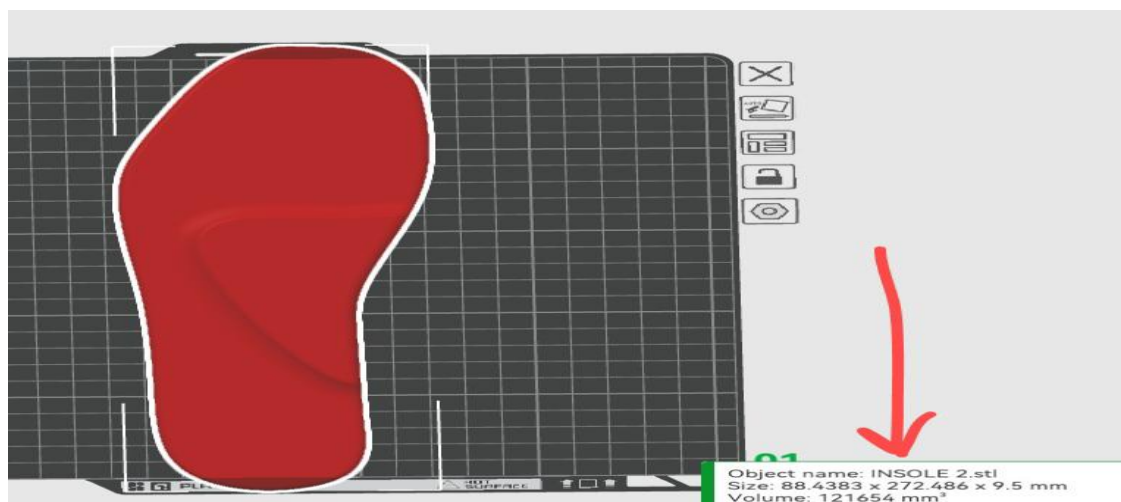
2. Materials & Methods

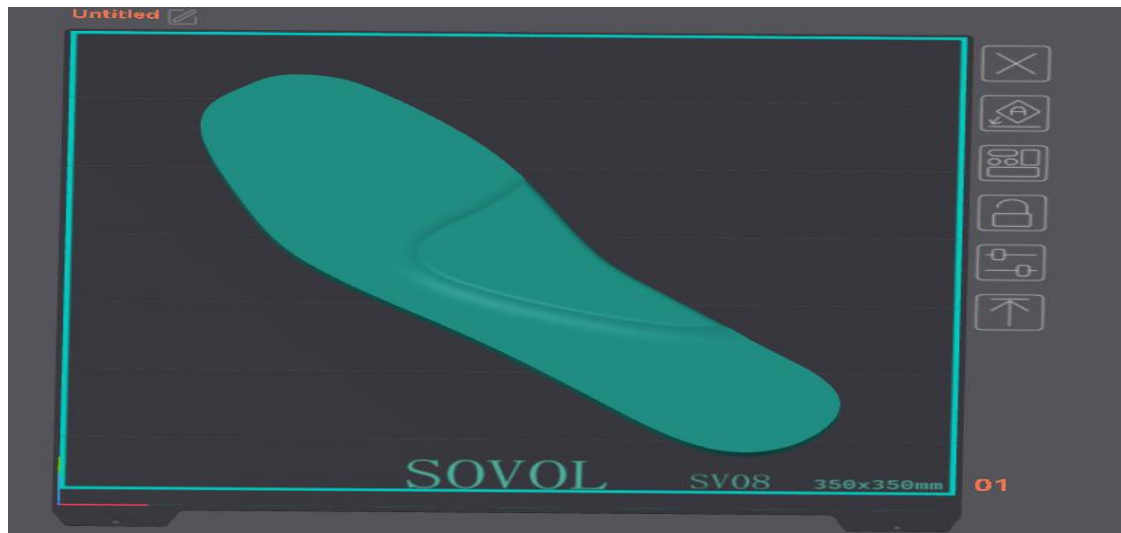
- 1) **Patient Preparation and Assessment:** Clinical history is reviewed, confirming diagnoses such as plantar fasciitis. Standing foot posture, skin condition, ankle dorsiflexion, and baseline pain levels are documented.
- 2) **Scanning:** The patient's foot is positioned on a digital scanner to capture accurate 3D contours of the plantar surface, arch height, and bony landmarks.
- 3) **Digital Model Preparation & CAD Design:** Scanned meshes are imported into CAD software, where artifacts are cleared. The base outline is matched to the targeted shoe size, followed by generating a custom medial arch contour, stabilizing heel cup, and specialized pressure-relief areas.
- 4) **Additive Manufacturing (3D Printing):** The finalized CAD geometry is sliced with appropriate infill densities, layer heights, and wall thicknesses, then printed using flexible TPU filament.
- 5) **Finishing and Assembly:** Edges are trimmed and smoothed, and optional cushioning top covers are bonded.

S. No.	Materials / Components	Purpose / Use
1	3D foot scanner / structured-light scanner	Digital capture of plantar and foot geometry
2	Computer with CAD software	Digital modeling and modification
3	3D printer	Additive manufacturing of the insole
4	TPU / flexible orthotic-grade filament	Flexible printed insole body
5	EVA or cushioning top cover	Comfort and interface cushioning
6	Pressure-mapping system	Assessment of plantar pressure distribution
7	Digital weighing / measurement tools	Dimensional and fabrication checks
8	Finishing tools	Edge smoothing and surface finishing
9	Adhesive / bonding materials	Top-cover attachment where required
10	Footwear of appropriate size	In-shoe fitting and functional assessment



Foot Scanning





3. Result

Additive manufacturing successfully produced a dimensionally accurate, structurally sound insole matching the digital patient model with clean surface finishes and optimal shoe compatibility. Initial fittings demonstrated secure heel seating, complete medial arch contact, proper forefoot clearance, and favorable patient feedback regarding comfort. Pain was evaluated via the Visual Analog Scale (VAS) or Numeric Pain Rating Scale (NPRS) at baseline and follow-up intervals, while function was assessed using validated foot function questionnaires and walking tolerance metrics. Furthermore, plantar-pressure evaluations confirmed successful load-sharing across the midfoot and arch regions, effectively relieving localized hyper-pressure at the calcaneus.

4. Discussion

The biomechanical efficacy of the proposed insole stems from its ability to modify interface compliance and contact geometry, altering how ground-reaction forces are transmitted through the lower limb. Unlike mass-produced inserts, the digital workflow allows systematic modifications

based on objective pressure data rather than manual trial and error.

While additive manufacturing provides distinct advantages such as digital reproducibility, rapid iteration, and lightweight construction certain limitations remain. Material degradation under repetitive cyclic loading, scanning variations due to soft-tissue artifacts, and strict shoe-volume limitations must be considered. Furthermore, custom 3D-printed orthoses should consistently operate as an adjunct to professional clinical oversight, stretching protocols, and strengthening programs rather than a standalone cure.

5. Conclusion

The integration of 3D scanning, computer-aided design, and additive manufacturing represents a modern, highly adaptable paradigm in orthotic care. By customizing device geometry to match individual foot anatomy and pressure distribution, 3D-printed insoles effectively alleviate localized stress associated with plantar fasciitis and flat feet. Although further clinical trials with larger cohorts are necessary to evaluate long-term durability and comparative superiority, this digital approach provides a precise, patient-centered pathway to enhance mobility, comfort, and rehabilitation outcomes.

Declaration by Authors

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Conflict of Interest: The authors declare no conflict of interest.

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