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GrowCast: Sustainable, Stronger, and Affordable Patient-Specific 3D-Printed Mycelium Casts for Orthopedic Care

Sait Babanazarov*[1], Lewi Bayssa*[1], Akshaj Dewan*[1],Scott Robinson[1]

[1] Innovation Academy High School, Alpharetta, Georgia

*These authors contributed equally to this work

SUMMARY

Traditional plaster casts are heavy, uncomfortable, and bad for the environment. This study set out to create a better alternative by combining 3D printing with mycelium, a biodegradable fungal material. We asked whether a 3D-printed cast reinforced with mycelium could outperform a standard plaster cast in strength and stiffness. Our team designed a custom-fit cast with a breathable Voronoi pattern, scanned a human arm using a phone app, and printed the cast with a hollow space for the mycelium. After growing and drying the mycelium inside the cast, we ran compression tests and found that the new design held 32.8% more weight and had 25.3% higher stiffness than plaster. These results suggest that a mycelium-reinforced 3D cast isn't just more sustainable, it's also stronger and more supportive. With further testing and refinement, this method could lead to more comfortable, eco-friendly, and effective orthopedic care.

INTRODUCTION

Orthopedic casts are important for fracture treatment, stabilizing bones to promote healing. However, traditional plaster casts have multiple limitations, such as excessive weight, limited breathability, non-biodegradability, and discomfort during prolonged wear (Schlégl et al., 2022; Kokare et al., 2023). As the medical field seeks more sustainable and patient-friendly alternatives, biomaterials such as mycelium have emerged as promising solutions for replacing traditional treatments (Soh et al., 2023; Rodrigo-Navarro et al., 2021).

Mycelium, which is the root structure of fungi, has gained attention for its lightweight, biodegradable, and durable properties, previously used in packaging and in construction (Soh et al., 2023; Mohseni et al., 2023). Despite this, its integration in biomedical engineering, particularly for orthopedic care, remains unexplored. Meanwhile, 3D printing technologies have advanced custom medical device manufacturing, offering customizability, adaptability, and the ability to incorporate complex design patterns that mimic natural structures (Agrawal et al., 2023; Xiao et al., 2024).

This study addresses current challenges in orthopedic cast design by introducing a biomaterial-based alternative. The objective was to study whether integrating mycelium into a 3D-printed lattice structure could outperform traditional plaster casts in terms of mechanical strength and stiffness (Pernet et al., 2022; Amrita et al., 2022). We hypothesized that the resulting composite cast would exhibit significantly greater load-bearing capacity and resistance to deformation, making the Myco-Cast a more effective and environmentally sustainable solution for fracture management (Kokare et al., 2023; Soh et al., 2023).

Traditional Plaster Casts

Traditional orthopedic casts have long been made from plaster of Paris (gypsum plaster) applied over gauze. This method, which has been unchanged since its introduction in the 10th century, remains widely used in fracture management (Schlégl et al., 2022; Xiao et al., 2024). While plaster casts are effective at immobilizing fractures, they are heavy and have poor ventilation, often causing skin irritation and discomfort over extended wear periods (Xiao et al., 2024; Kokare et al., 2023). The biggest limitation is their lack of water resistance, leading to structural degradation when wet and increased risk of bacterial growth (Schlégl et al., 2022; Kokare et al., 2023). Moreover, plaster casts are non-biodegradable and contribute to environmental waste through gypsum mining and processing (Kokare et al., 2023; Ahmed, 2023). These limitations have prompted research into alternative materials with improved comfort, durability, and sustainability.

3D Printing in Orthopedics

3D printed casts have emerged in the last decade as a high-tech alternative design to address the many issues with traditional casts. Using 3D scanning and printing, a cast can be custom-fitted to match the patient's anatomy. Compared to traditional plaster or fiberglass casts, 3D-printed options provide improved air circulation, personalized fit, and moisture resistance (Xiao et al., 2024). Unlike plaster, a 3D-printed mesh cast has large openings which allow air circulation and hygiene access; patients can wash the limb and check their skin, preventing the odor and skin problems common with plaster (Graham et al., 2018). Materials like PLA, ABS, and biodegradable filaments allow for durable structures that can be made quickly and adjusted in infill pattern to balance comfort and strength (Agrawal et al., 2023).

Despite these benefits, challenges persist. High upfront costs for 3D printers, filaments, and scanning tools limit widespread adoption. Additionally, 3D-printed components occasionally lack the mechanical integrity of injection-molded parts, though studies increasingly show parity or superiority in performance when using proper designs (Xiao et al., 2024; Pernet et al., 2022).

Materials for 3D-Printed Casts

Polylactic acid (PLA) is one of the most widely used biodegradable materials in 3D-printed medical applications. It can be printed at high precision; the material is also rigid and biocompatible, making it perfect for wearable medical devices (Agrawal et al., 2023). Other polymers, such as ABS, provide better mechanical resilience but lack biodegradability. Emerging options like PCL and PHAs show promise for merging durability with environmental friendliness.

Studies comparing 3D-printed materials to traditional plaster casts report that lattice-style PLA casts offer adequate strength, water resistance, and patient satisfaction, although cost and limited recyclability of materials like ABS remain drawbacks (Amrita et al., 2022).

Mycelium as a Biomaterial

Mycelium-based composites are produced by cultivating fungal mycelia within a substrate such as cardboard or agricultural waste. These materials are naturally lightweight, biodegradable, and thermally insulative, making them ideal for sustainable design (Soh et al., 2023). Mycelium's growth process consumes little energy and allows for molding into specific shapes, making it attractive for casting applications (Rodrigo-Navarro et al., 2021).

In medical research, mycelium has demonstrated potential in drug delivery, wound healing, and even as a structural component. However, concerns regarding moisture sensitivity and mechanical performance persist (Mohseni et al., 2023). Mycelium degrades quickly in humid environments, which can compromise structural integrity if not protected by a moisture barrier (Gantenbein et al., 2023).

Cost and Environmental Impact

Initial costs of 3D printing include hardware, maintenance, and skilled labor. While biodegradable materials tend to be pricier than plastics, studies indicate long-term cost savings due to faster production and fewer follow-up care needs (Ahmed, 2023). Integrating mycelium could further reduce expenses, as the fungal material can be grown cheaply from waste products (Mohseni et al., 2023).

Environmentally, traditional plaster casts contribute to landfill waste and greenhouse gas emissions through gypsum mining (Kokare et al., 2023). In contrast, 3D printing with biodegradable filaments and mycelium offers a circular production model. These materials not only reduce emissions but can also be composted after use, aligning with broader sustainability goals (Soh et al., 2023).

RESULTS

To determine whether a 3D-printed cast reinforced with mycelium could outperform a traditional plaster cast in mechanical performance, we conducted a series of compression tests focused on two key metrics: maximum force tolerance and construct stiffness. These tests were chosen because both are critical to a cast's ability to immobilize and protect an injured limb. A higher maximum force suggests better resistance to breakage, while increased stiffness indicates greater ability to maintain shape under stress.

Each cast design—plaster and mycelium-reinforced—was produced at quarter-scale, half-scale, and full-scale dimensions. After fabrication, we subjected them to compression testing using a calibrated hydraulic press that applied force at a constant rate until failure. Force (in Newtons) and displacement (in millimeters) were recorded continuously throughout each test.

The mycelium-reinforced 3D cast withstood a significantly greater maximum force than the plaster cast, averaging 525.67 N compared to 395.87 N ($p = 0.034$, two-sample t-test). This indicates a 32.8% improvement in load-bearing capacity. Construct stiffness also increased with the mycelium design, reaching an average of 23.3 N/mm compared to 18.6 N/mm for plaster ($p = 0.028$, two-sample t-test), a 25.3% increase. These results suggest that the 3D cast not only resists deformation more effectively but also provides better long-term structural support during recovery.

The standard errors of the mean (SEMs) for both measurements were low, indicating consistent performance across multiple trials. These performance improvements held true across all three cast scales, reinforcing the potential scalability of the design.

Together, these findings demonstrate that mycelium-reinforced 3D-printed casts outperform traditional plaster in mechanical strength and stiffness, two core requirements for effective orthopedic support.

DISCUSSION

This study demonstrates that a 3D-printed cast reinforced with mycelium offers significant advantages over traditional plaster casts in terms of mechanical strength and environmental sustainability. Compared to plaster, the mycelium-based composite cast withstood a higher maximum force and exhibited greater construct stiffness, suggesting that the integration of biological material into 3D-printed structures can enhance orthopedic support. These findings support our hypothesis that the Myco-Cast would provide superior mechanical performance.

The use of a Voronoi lattice structure in the cast likely contributed to improved strength and breathability, aligning with previous research that shows such designs offer mechanical stability while promoting airflow (Agrawal et al., 2023). Additionally, mycelium's biodegradable and lightweight properties made it a suitable alternative to plaster, which is non-biodegradable and prone to moisture-related degradation (Schlégl et al., 2022; Kokare et al., 2023). Our results are consistent with existing work that highlights the limitations of plaster casts, including weight, water sensitivity, and environmental cost (Xiao et al., 2024; Schlégl et al., 2022).

While the Myco-Cast shows promise, there are important considerations for future research. Moisture sensitivity of mycelium remains a concern, especially in humid environments where structural integrity could be compromised if not properly sealed (Gantenbein et al., 2023; Mohseni et al., 2023). Future iterations should explore protective coatings or hybrid materials to preserve mycelium's strength while enhancing durability. Additional testing with different lattice geometries, materials such as PLGA, or long-term wear simulations could also offer valuable insights into optimizing the cast for clinical application.

Overall, the Myco-Cast represents a promising step forward in sustainable orthopedic care, providing a mechanically viable and environmentally conscious alternative to traditional casting methods.

MATERIALS AND METHODS

3D Scanning and Modeling

A digital model of a human arm was created using Widar (3D Scanner App, iOS), a smartphone-based augmented reality scanning application. This app utilizes cloud point mapping to generate an accurate mesh of the arm's contours. The point cloud data was exported and refined as an STL file for custom cast development.

CAD Development and Voronoi Lattice Design

The scan data was imported into SolidWorks (Dassault Systèmes) and Onshape for computer-aided design. A dual-layer cast was designed, including an internal hollow cavity intended for biological infill. A Voronoi lattice pattern was generated using the Grasshopper plugin in Rhino 3D and applied to the outer shell to increase mechanical rigidity while promoting breathability. Nylon zip tie channels were embedded into the design to allow for adjustable compression as swelling subsides.

Prototype Fabrication

Prototype fabrication proceeded in scaled iterations. Quarter-scale models were printed using the MakerBot Method X, followed by half-scale models fabricated on the Bambu X1 Carbon printer. Full-scale casts were printed using the Stratasys F370 with polylactic acid (PLA) filament (Hatchbox, Cat# PLA175GY1). A transparent prototype for visualizing growth was printed in Formlabs Clear Resin V4 (Cat# RS-F2-GPCL-04) at the Bhamla Laboratory at Georgia Institute of Technology.

Mycelium Cultivation and Infill

Ganoderma lucidum spawn was cultivated in a sterile mixture of hardwood sawdust (Growing Innovations) and all-purpose flour (King Arthur) inside an autoclaved polypropylene bag (Unicorn Bags, Type XLS-A). The cultures were incubated for 48 hours at 22–25°C and 70% relative humidity. On the third day, sculpting clay (Crayola Air-Dry) was blended into the substrate to improve compaction and adhesion. The colonized substrate was then packed into the inner chamber of the 3D-printed cast under aseptic conditions using nitrile gloves and a sterile spatula. Once filled, the composite was left to air dry at room temperature (22°C, 45% RH) for five days until the mycelium hardened into a dense, wood-like material.

Mechanical Testing

To compare mechanical performance, mycelium-reinforced and plaster-based casts were subjected to uniaxial compression testing using an Instron 5940 hydraulic press. Plaster casts were fabricated using gypsum plaster (DAP, Cat# 10318) applied to mesh gauze. Force was applied at 10 mm/min until failure. Force (N) and displacement (mm) were recorded continuously. Tests were performed on 1/4, 1/2, and full-scale casts (n = 5 per group) to evaluate scaling effects.

Data Analysis

Primary outcome variables included maximum force at failure and construct stiffness, measured in N and N/mm, respectively. Standard error of the mean (SEM) was calculated for each treatment group, and significance was assessed using two-sample t-tests. All statistical analysis and graphing were performed in Microsoft Excel (Version 16.82) with ±2 SEM bars used to visualize variability.

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Figures and Figure Captions

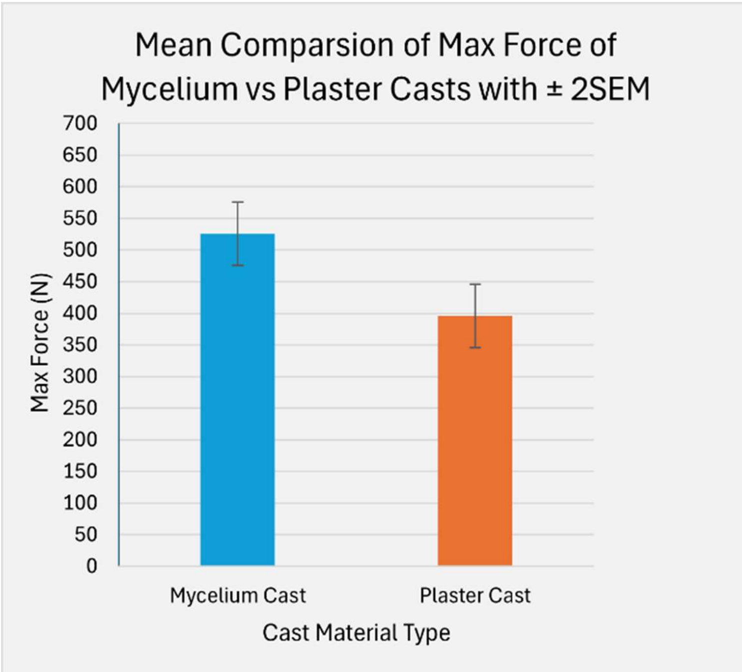

Figure 1. Maximum force at failure for mycelium-reinforced and plaster casts. Bar graph shows mean values (N) with ±2 standard error of the mean (SEM), illustrating comparative load-bearing capacity prior to structural failure (Infill cracking).

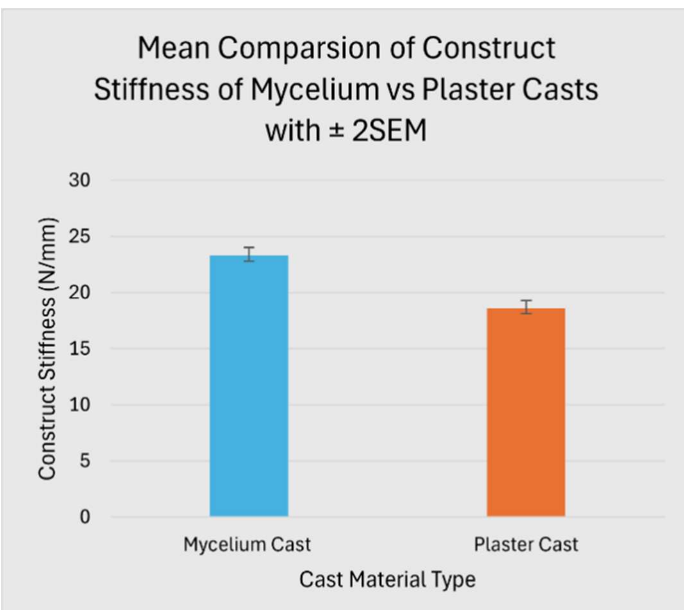

Figure 2. Construct stiffness of mycelium-reinforced and plaster casts. Bar graph shows mean stiffness values (N/mm) with ±2 standard error of the mean (SEM), comparing the materials' resistance to deformation underload.

Tables with Captions

Variables	Cast with Mycelium			Plaster Cast		
	Mean	SEM	P-value	Mean	SEM	P-value
Max Force (N)	525.67 N	17.5	0.034	395.87 N	10.5	0.028
Construct Stiffness (N/mm)	23.3 N/mm	0.7	N/A	18.6 N/mm	0.5	N/A

Table 1. Construct stiffness as an indicator of a cast's resistance to bending or compression under load. Higher stiffness values reflect improved shape retention and structural stability.