Technical Note

Development and Evaluation of a Personalized 3D-Printed Forearm/Wrist Splint

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ABSTRACT

This study explores the development and application of a 3D-printed forearm/wrist splint as an innovative alternative to traditional casts. In this study, 3D scanning was used to obtain the 3D model of the patient's hand sculpture. The obtained 3D model was processed using reverse engineering to design a personalized splint, and fabricated using fused deposition modeling with polylactic acid filament. The lightweight, washable, and hygienic properties of 3D-printed splints enhance patient comfort and overall satisfaction. By utilizing customized clamps, the splints ensure ease of use and aesthetic appeal. These splints hold promise for personalized healthcare. The production time of the custom forearm/wrist splint in this study was 24 hours. Their ability to prevent skin complications, provide better hygiene and ventilation, and enable physiotherapeutic techniques during immobilization underscores their potential in modern medical practices. Developing limb sculptures for the production of 3D-printed hand splints enables these splints to be manufactured in healthcare centers without the need for 3D scanners, highlighting the accessibility and practicality of utilizing 3D printing technology in various medical settings. Future advancements in 3D printing technology are anticipated to reduce production time and costs, making these splints more accessible and efficient. The study highlights the promising role of 3D-printed splints in adaptive wearable technologies and their suitability for improving patient care through personalized treatment options.

Keywords

Forearm; Fused Deposition Modeling; Printing, Three-Dimensional; Splints; Reverse Engineering; Wrist

Introduction

Orthotics, a branch of medicine focusing on supportive devices like splints and braces, utilizes various materials, such as thermoplastics, composite carbon fiber, and polypropylene [1, 2]. Orthoses are essential for supporting or immobilizing limbs or the spine and address fractures, soft tissue sprains, tendon injuries, or deformations pending orthopedic treatment [3]. Various types of splints include volar wrist splints, finger splints, thumb spicas, ankle stirrups, sugar tongs, ulnar gutters, and wrist/arm splints. Fractures common in trauma patients benefit significantly from cast immobilization [1]. An optimal cast must be lightweight, long-lasting, and patient-specific, providing comfort while minimizing potential issues like pressure sores and compartment syndrome [4]. The advent of three-Dimensional (3D) printing has revolutionized casting, providing these benefits more effectively than traditional methods. 3D-printed casts offer superior comfort, compliance, aesthetics, and reduced skin irritation, enhancing clinical efficacy and patient satisfaction. In orthopedics and rehabilitation, Additive Manufacturing (AM) technologies, especially 3D printing, are increasingly personalizing patient care [5]. Rapid Prototyping (RP) techniques are gaining prevalence in the medical field, particularly in the field of orthotics. The use of 3D printers is expanding, driven by advances in materials and reduced production costs [6]. Research on 3D-printed splints spans upper and lower limbs and fingers, including clinical trials and algorithmic design studies [1, 5, 7, 8].

The AM technologies, such as Fused Deposition Modeling (FDM), create 3D objects by layering materials. Polylactic Acid (PLA), a popular FDM material, is readily available for producing functional prototypes and end-use products [9]. Studies highlight the efficacy of 3D-printed splints [10-14]. PLA orthoses exhibit superior biomechanical properties over traditional plaster casts. The application of 3D digitizing and printing in creating bespoke splints, particularly for hand and mallet finger injuries, confers significant clinical advantages. These include superior patient comfort, improved fit and efficacy, enhanced hygiene, reduced skin complications, and high patient and clinician acceptance. Together, these benefits underscore the transformative potential of personalized rehabilitation devices [15-17].

This study aimed to design and fabricate a personalized 3D-printed upper limb splint using reverse engineering. This study introduces a straightforward procedure through a case study that creates a 3D model by casting and scanning a hand sculpture. This approach makes the technique applicable to diverse healthcare settings lacking a 3D scanner.

Technical Presentation

Molding of the Hand

A 32-year-old volunteer was selected as the subject for this case study. Chromogel molding alginate was employed to create a hand mold. The subject's hand was immersed in the gel, and after the gel hardened, the hand was carefully removed. The resulting mold was then filled with industrial wax to produce an accurate hand sculpture.

3D Modeling of the Hand and Splint

The wax hand sculpture was scanned using a Tripod 3D Scanner of Rexcan 4 (Solutionix) to obtain a detailed 3D model of the hand. Utilizing reverse engineering techniques, a 3D model of the hand splint was developed by Computer-Aided Design (CAD). This model was then processed using Rhinoceros software to design a personalized hand splint tailored to the individual's anatomy. Ventilation holes were integrated throughout the splint design. A thickness of 4 mm was selected to ensure the mechanical stiffness of the splint. The intricate design process was outsourced to experts at InoFab, ensuring precision and expertise.

3D Printing of the Splint

Once the design was finalized, the Stereolithography (STL) file of the splint was prepared for 3D printing. FDM technology with a Keytec printer was selected for the printing process, using PLA filaments.

Following the 3D printing process and the attachment of the two parts using hinges on one side, the necessary clamp sizes were measured and subsequently fabricated using a laser cutting machine.

Results

This study successfully implemented a reverse engineering procedure, which involved casting and 3D scanning a hand sculpture, to create a digital model and design a personalized splint. The splint was then fabricated via 3D printing. The final device demonstrated the necessary rigidity to ensure hand immobility.

Molding of the Hand

Figure 1a illustrates the hand sculpture manufacturing process, highlighting the ease with which the chromogel mold was removed, leaving an accurate wax hand sculpture.

3D Modeling of the Upper Limb and Splint

Figure 1b presents the software environment used for splint design, showcasing the ventilation holes integrated throughout the splint to promote skin airflow.

3D printing of the Splint

The splint was 3D printed using FDM

technology with PLA filaments, as depicted in Figure 2a. The splint was printed in two parts with two colors and subsequently assembled using mini hinges on one side. Designed holes facilitated the closure mechanism of the splint, with clamps of three different sizes fabricated for this purpose. The 3D printing process was implemented in 12 hours. The whole process of splint preparation, including sculpture preparation, 3D scanning, 3D modeling, 3D printing, shipping, and delivery, was completed in one day.

Splint Fitness Test

Figure 2(b-e) demonstrates the proper fit and alignment of the splint on both the hand sculpture and the subject's hand, confirming the accuracy of the design and manufacturing process. The successful implementation of these steps validates the use of 3D printing technology in creating personalized, functional splints with enhanced mechanical stiffness and patient comfort [18-21]. Figure 3 provides a visual summary of the production process of the personalized 3D-printed

Figure 1: a) Hand sculpture manufacturing process. The chromogel mold was removed, leaving an accurate wax hand sculpture. **b**) The software environment displays the splint design, highlighting the strategically placed ventilation holes integrated across the splint for enhanced airflow. The designed splint is divided into two separate parts and exported as the StereoLithography (STL) files, ready for use in the 3D printing workflow

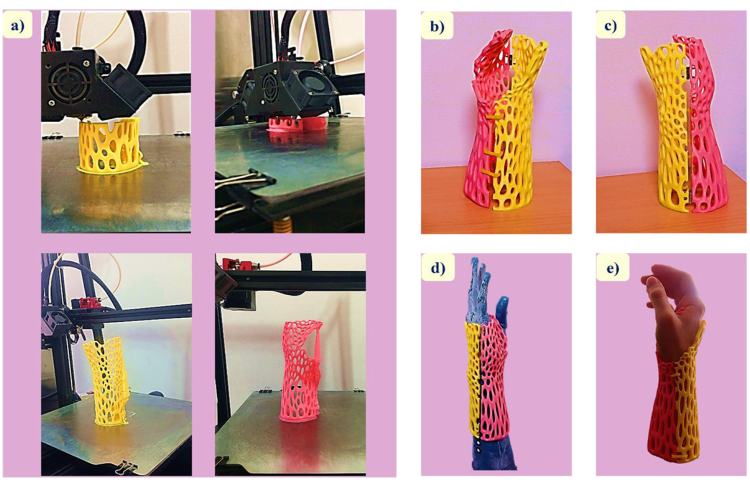

Figure 2: a) The splint 3D printing process using Fused Deposition Modeling (FDM) technology with Polylactic Acid (PLA) filaments. The 3D-printed splint from **b**) front and **c**) back view. The precise fit and alignment of the splint on both **d**) the hand sculpture and **e**) the subject's hand, validate the accuracy of the design and manufacturing process

Figure 3: Schematic workflow of the personalized 3D-printed forearm/wrist splint fabrication process

forearm/wrist splint.

Discussion

This study represents a significant advancement in the design and production of 3D-printed splints, highlighting the benefits of customized clamps in terms of ease of use and improved aesthetics. The innovative application of 3D printing for the final splint product, rather than merely prototypes, represents a noteworthy departure from traditional cast methods. In various studies, imaging and scanning techniques, such as Computed Tomography (CT) scan [22], Magnetic Resonance Imaging (MRI) [23], and 3D limb scanning [24], have been employed to create accurate models for splint design. Furthermore, multiple 3D printing technologies, including FDM [1, 8], DLP [10, 25], PolyJet [26], and SLS [23] with various materials, have been utilized to produce splints tailored to different anatomical regions and medical conditions.

In this study, a hand sculpture was fabricated, leading to the utilization of this technology in hospitals and clinics without any 3D scanners. In addition, the introduction of uniquely designed clamps provides a practical alternative to traditional velcro straps [27, 28], rubber bands [26], and zip ties [24]. These clamps not only enhance ease of use but also offer the potential for aesthetic customization, improving overall patient satisfaction. These modifications highlight the benefits of integrating modern technology into medical devices [8, 29]. These splints offer significant practical benefits, including comfort, washability, and aesthetic customization options. Clinically, they enable therapeutic techniques during immobilization and help prevent skin issues, positioning them as a foundation for future adaptive wearables [29].

3D-printed splints are applicable for various medical conditions and anatomical regions. Studies highlight their use in treating fractures [24, 30], carpal tunnel syndrome [31], peripheral nerve injuries [31], and rheumatoid arthritis [26, 30], with designs adaptable to fingers [17, 32], forearms/wrists [16, 18], and legs [33, 34].

The total production time of a personalized 3D-printed forearm/wrist splint in this study was approximately 24 hours. The process time was as follows: sculpture fabrication (2 hours), transportation for scanning (2 hours), 3D scanning (1 hour), digital model processing and splint design (3 hours), 3D printing (12 hours), and final delivery to the healthcare center (4 hours). This production time, poses a limitation for emergency cases requiring immediate immobilization. However, the potential benefits, including improved hygiene, ventilation, and overall patient comfort, outweigh the drawbacks in non-emergency scenarios.

Conclusion

This study demonstrates the advantages of 3D-printed splints over traditional casts, including customizable design and material properties, which make them hygienic and allow ventilation. The overall benefits of these splints result in enhanced patient comfort. Despite the dominant role of 3D printing in prototype production, the end product of the splint was successfully fabricated in this case study. This showcases its viability as a replacement for traditional casts. These advantages highlight the potential of 3D-printed splints for personalized healthcare.

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Authors' Contribution

S. Piretarighat contributed to the methodology, formal analysis, investigation, data curation, visualization, writing of the original draft, and review and editing of the manuscript. P. Keyhanvar contributed to the supervision, conceptualization, validation, data curation, project administration, and review and editing of the manuscript. B. Amirshakeri contributed to the validation, review, and editing of the manuscript. All authors read and approved the final version of the manuscript.

Ethical Approval

The study procedure was approved by the Ethical Committee of Tabriz University of Medical Science, Tabriz, Iran (Ethical Code: IR.TBZMED.REC.1401.252).

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Conflict of Interest

None

References

1. Arulmozhi RS, Vaidya M, Poojalakshmi MG, Ashok Kumar D, Anuraag K. 3D design and printing of custom-fit finger splint. *Biomed Eng (Singapore)*. 2018;**30**(05):1850032. doi: 10.4015/S1016237218500321.
2. Sarvari R, Keyhanvar P, Agbolaghi S, Gholami Farashah MS, Sadrhaghighi A, Nouri M, Roshangar L. Shape-memory materials and their clinical applications. *International Journal of Polymeric Materials and Polymeric Biomaterials.* 2022;**71**(5):315-35. doi: 10.1080/00914037.2020.1833010.
3. Sala F, D'Urso G, Giardini C. Customized wrist immobilization splints produced via additive manufacturing—a comprehensive evaluation of the viable configurations. *Prosthesis*. 2023;**5**(3):792-808. doi: 10.3390/prosthesis5030056.
4. Fitzpatrick AP, Mohanned MI, Collins PK, Gibson I. Design of a patient specific, 3D printed arm cast. *KnE Engineering*. 2016:135-42. doi: 10.18502/keg.v2i2.607.
5. Alshawaf SM, Burhamah W, Alwazzan S, AlYouha S. A Streamlined Algorithmic Process for Creating Three-dimensional Printed Forearm Casts. *Plast Reconstr Surg Glob Open.* 2023;**11**(3):e4824. doi: 10.1097/GOX.0000000000004824. PubMed PMID: 36875921. PubMed PMCID: PMC9984158.
6. Baronio G, Harran S, Signoroni A. A Critical Analysis of a Hand Orthosis Reverse Engineering and 3D Printing Process. *Appl Bionics Biomech.* 2016;**2016**:8347478. doi: 10.1155/2016/8347478. PubMed PMID: 27594781. PubMed PMCID: PMC4993931.
7. Baronio G, Volonghi P, Signoroni A. Concept and Design of a 3D Printed Support to Assist Hand Scanning for the Realization of Customized Orthosis. *Appl Bionics Biomech.* 2017;**2017**:8171520. doi: 10.1155/2017/8171520. PubMed PMID: 29234219. PubMed PMCID: PMC5695095.
8. Blaya F, Pedro PS, Silva JL, D'Amato R, Heras ES, Juanes JA. Design of an Orthopedic Product by Using Additive Manufacturing Technology: The Arm Splint. *J Med Syst.* 2018;**42**(3):54. doi: 10.1007/s10916-018-0909-6. PubMed PMID: 29404793.
9. Kamran M, Saxena A. A comprehensive study on 3D printing technology. *MIT Int J Mech Eng*. 2016;**6**(2):63-8.
10. Guebeli A, Thieringer F, Honigmann P, Keller M. In-house 3D-printed custom splints for non-operative treatment of distal radial fractures: a randomized controlled trial. *J Hand Surg Eur Vol.* 2024;**49**(3):350-8. doi: 10.1177/17531934231187554. PubMed PMID: 37458129.
11. Jang K, Jang EJ, Min YH, Shim KM, Bae C, Kang SS, Kim SE. Application of Patient-Specific 3D-Printed Orthopedic Splint for Bone Fracture in Small Breed Dogs. *J Vet Clin.* 2023;**40**(4):268-75. doi: 10.17555/jvc.2023.40.4.268.
12. Cheng T, Thielen M, Poppinga S, Tahouni Y, Wood D, Steinberg T, et al. Bio-Inspired Motion Mechanisms: Computational Design and Material Programming of Self-Adjusting 4D-Printed Wearable Systems. *Adv Sci (Weinh).* 2021;**8**(13):2100411. doi: 10.1002/advs.202100411. PubMed PMID: 34258167. PubMed PMCID: PMC8261511.
13. Chu CH, Wang IJ, Sun JR, Liu CH. Customized designs of short thumb orthoses using 3D hand parametric models. *Assist Technol.* 2022;**34**(1):104-111. doi: 10.1080/10400435.2019.1709917. PubMed PMID: 31891329.

14. Fang JJ, Lin CL, Tsai JY, Lin RM. Clinical assessment of customized 3D-printed wrist orthoses. *Appl Sci.* 2022;**12**(22):11538. doi: 10.3390/app122211538.
15. Grabar Branilović M, Hajdarović P, Ban A, Mihalic Pokopec I. Design and Production of the Splint Using Reverse Engineering and Additive Manufacturing. *Trans of FAMENA*. 2024;**48**(2):101-10. doi: 10.21278/TOF.482043222.
16. D'Amado MP, Bezold W, Crist BD, Cook JL. Biomechanical comparison of traditional plaster cast and 3D-printed orthosis for external coaptation of distal radius fractures. *Ann 3D Print Med*. 2024;**14**:100146. doi: 10.1016/j.stlm.2024.100146.
17. Cronin U, O'Sullivan A, Sheerin M, O'Sullivan KJ, Cummins NM, Ryan D, et al. Evaluating the clinical benefit and acceptance of a bespoke 3D-printed splint for the treatment of mallet finger injury: A pilot study in a cohort of patients. *Int J Bioprint.* 2024;**10**(2):518-30. doi: 10.36922/ijb.1963.
18. Dave H, Prajapati A, Narkhede R, Kakadiya D, Tailor D, Dave B, Shah J. 3D printing of wrist splint using low-temperature thermoplastic (LTTP) based polycaprolactone (PCL) material. Advances in Materials and Processing *Technologies*. 2024;**10**(4):3581-94. doi: 10.1080/2374068x.2023.2255425.
19. Lebowitz CM, Vosbikian MM, Seigerman DA, Paglia DN, Kadkoy Y, Rivlin M, Beredjiklian PK. Orthosis Material Properties: A Mechanical Testing Evaluation of Fiberglass, Plaster, and Three-Dimensional Printed Splints. *Plast Reconstr Surg.* 2023;**151**(1):179e-81e. doi: 10.1097/PRS.0000000000009752. PubMed PMID: 36576844.
20. Aziz AU, Yassin NA, Seng GH, Ramlee MH. Development and Analysis of Three-Dimensional Printed Hand Cast: Finite Element and Comfortability Analysis. *J Phys: Conf Ser.* 2021;**2071**(1):1-8. doi:10.1088/1742-6596/2071/1/012015.
21. Chen L, Xiong Y, Mi B, Yan C, Xie X, He Z, et al. A Novel Instant 3-Dimensional Printing System for Postoperative Fracture Patients: A Comparative Cohort Study. *Med Sci Monit.* 2021;**27**:e928240. doi: 10.12659/MSM.928240. PubMed PMID: 33385316. PubMed PMCID: PMC7784143.
22. Chen YJ, Lin H, Zhang X, Huang W, Shi L, Wang D. Application of 3D-printed and patient-specific cast for the treatment of distal radius fractures: initial experience. *3D Print Med.* 2017;3(1):11. doi: 10.1186/s41205-017-0019-y. PubMed PMID: 29782603. PubMed PMCID: PMC5954789.
23. Chen Y, Lin H, Yu Q, Zhang X, Wang D, Shi L, et al. Application of 3D-Printed Orthopedic Cast for the Treatment of Forearm Fractures: Finite Element Analysis and Comparative Clinical Assessment. *Biomed Res Int.* 2020;**2020**:9569530. doi: 10.1155/2020/9569530. PubMed PMID: 32775455. PubMed PMCID: PMC7399740.
24. Buonamici F, Furferi R, Governi L, Lazzeri S, McGreevy KS, Servi M, et al. A practical methodology for computer-aided design of custom 3D printable casts for wrist fractures. *Vis Comput.* 2020;**36**(2):375-90. doi: 10.1007/s00371-018-01624-z.
25. Keller M, Guebeli A, Thieringer F, Honigmann P. In-hospital professional production of patient-specific 3D-printed devices for hand and wrist rehabilitation. *Hand Surg Rehabil.* 2021;**40**(2):126-33. doi: 10.1016/j.hansur.2020.10.016. PubMed PMID: 33309787.
26. Cazon A, Kelly S, Paterson AM, Bibb RJ, Campbell RI. Analysis and comparison of wrist splint designs using the finite element method: Multi-material three-dimensional printing compared to typical existing practice with thermoplastics. *Proc Inst Mech Eng H.* 2017;**231**(9):881-97. doi: 10.1177/0954411917718221. PubMed PMID: 28689470.
27. El Khoury G, Libouton X, De Boeck F, Barbier O. Use of a 3D-printed splint for the treatment of distal radius fractures: A randomized controlled trial. *Orthop Traumatol Surg Res.* 2022;**108**(5):103326. doi: 10.1016/j.otsr.2022.103326. PubMed PMID: 35595196.
28. Factor S, Atlan F, Pritsch T, Rumack N, Golden E, Dadia S. In-hospital production of 3D-printed casts for non-displaced wrist and hand fractures. *SICOT J.* 2022;**8**:20. doi: 10.1051/sicotj/2022021. PubMed PMID: 35608413. PubMed PMCID: PMC9128606.
29. Graham J, Wang M, Frizzell K, Watkins C, Beredjiklian P, Rivlin M. Conventional vs 3-Dimensional Printed Cast Wear Comfort. *Hand (N Y).* 2020;**15**(3):388-92. doi: 10.1177/1558944718795291. PubMed PMID: 30146902. PubMed PMCID: PMC7225892.
30. Chhikara K, Gupta S, Saharawat S, Sarkar S, Chanda A. Design, manufacturing, and trial of a 3D printed customized finger splint for patients with rheumatoid arthritis. *Rheumato.* 2023;**3**(1):51-62. doi: 10.3390/rheumato3010004.
31. Chae DS, Kim DH, Kang KY, Kim DY, Park SW, Park SJ, Kim JH. The functional effect of 3D-printing individualized orthosis for patients with peripheral nerve injuries: Three case reports. *Medicine (Baltimore).* 2020;**99**(16):e19791. doi: 10.1097/MD.0000000000019791. PubMed PMID: 32311991. PubMed PMCID: PMC7440222.
32. Choi H, Seo A, Lee J. Mallet Finger Lattice Casts Using 3D Printing. *J Healthc Eng.* 2019;**2019**:4765043. doi: 10.1155/2019/4765043. PubMed PMID: 31354931. PubMed PMCID: PMC6636505.
33. Blaya F, Pedro PS, Pedro ABS, Lopez-Silva J, Juanes JA, D'Amato R. Design of a Functional Splint for Rehabilitation of Achilles Tendon Injury Using Advanced Manufacturing (AM) Techniques. Implementation Study. *J Med Syst.* 2019;**43**(5):122. doi: 10.1007/s10916-019-1247-z. PubMed PMID: 30915598.
34. De Agustín Del Burgo JM, Blaya Haro F, D'Amato R, Blaya A, Juanes Méndez JA. Development of a Smart Leg Splint by Using New Sensor Technologies and New Therapy Possibilities. *Sensors (Basel).* 2021;**21**(15):5252. doi: 10.3390/s21155252. PubMed PMID: 34372488. PubMed PMCID: PMC8348511.