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Material Matters: A Comparative Analysis of Hand Immobilization Orthoses Using 3D-Printed, Thermoplastic, and Fiberglass Cast

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Material Matters: A Comparative Analysis of Hand Immobilization Orthoses Using 3D-Printed, Thermoplastic, and Fiberglass Cast

Abstract

Background: Orthosis fabrication is a widely used technique in occupational therapy, and there is growing evidence supporting the use of 3D printing in the fabrication of cost-effective orthotics. Nevertheless, further research is needed to enable informed decision-making when selecting appropriate orthotic materials.

Method: A comparative analysis was conducted to evaluate the fabrication processes and final products of thumb immobilization orthosis made with three different materials from the fabricator's perspective. Factors examined included the required equipment and materials, assessment of time and skills involved in the fabrication process, evaluation of ease of adjustment during fabrication, and objective measurements of functional outcomes.

Results: Among the different orthosis materials evaluated, the 3D-printed orthotic demonstrated the highest level of cost-effectiveness and replicability. However, it was also found to be the most time-consuming to fabricate, requiring a significant learning commitment and initial investment.

Conclusion: Thermoplastic may be better suited for functional orthoses, while fiberglass cast may be more appropriate for short-term and non-functional orthoses. It is crucial for fabricators to have a comprehensive understanding of orthotic materials and their properties to select the most suitable option based on the user's specific condition and occupational requirements.

Comments

The authors declare that they have no competing financial, professional, or personal interest that might have influenced the performance or presentation of the work described in this manuscript.

Keywords

orthosis thermoplastic, 3D-printed, fiberglass cast, splint material, hand therapy

Cover Page Footnote

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Credentials Display

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Orthosis fabrication is common practice in occupational therapy (OT) to immobilize or stabilize an area of the body to promote healing, relieve pain, prevent or reduce deformity, decrease spasticity, and increase functional capacity (Adrienne & Manigandan, 2011; Jackman et al., 2014; Kjeken et al., 2011). Thermoplastic is one of the most used materials to fabricate orthotics, while synthetic cast materials are an alternative growing in popularity (Waldburger et al., 2022). In addition, increased development and availability of 3-dimensional (3D) scanning and printing technology has triggered widespread applications of 3D printing in the health care field, such as the fabrication of dental and surgical implants, prostheses, and orthoses (Ganesan et al., 2016; Tyminski et al., 2019). In OT, these technologies could provide innovative and cost-effective methods to create assistive devices, adaptive equipment, and orthoses for clients (Schwartz, 2018; Waldburger et al., 2022). Given the development of new technologies and materials, it is critical for health care professionals to have objective information about all available orthotic materials to make an informed decision when creating an orthotic device. This study evaluated three different orthotic fabrication techniques from a fabricator's perspective.

3D Printing in Health Care

New technological devices are often expensive and less available; however, they become more accessible to customers over time (Benham & San, 2020). 3D printing is one of these technologies that has become more accessible and has been increasingly used in the health care field (Bogue, 2013; Ganesan et al., 2016; Prato & Britton, 2015). From artificial joints and hearing aids to prosthetics and implants, 3D printing technology has been widely applied to create customized devices in the health care field (Eltorai et al., 2015; Ventola, 2014; Wang et al., 2017). 3D-printed items have a distinct value in health care because they are customizable, replicable, and cost-effective (Dodziuk, 2016). In OT, the technology has been mainly used in fabricating assistive devices, adaptive equipment, and orthotics (Lee et al., 2019; Portnoy et al., 2020; Schwartz et al., 2020).

3D Scanning in Health Care

3D printing can also involve the use of 3D scanners. 3D scanners capture an object image in a three-dimensional format with great accuracy in a matter of a few seconds (Grazioso et al., 2018; Haleem & Javaid, 2019). 3D scanning technology is applied in health care in various ways. An instant 3D whole-body scanner is used to create implants and prostheses (Grazioso et al., 2018). It can also be used to detect orthopedic anomalies of the human body, such as scoliosis of the spine and foot deformities (Haleem & Javaid, 2019). In addition, 3D models created by a 3D scanner allow medical doctors to measure parameters, such as distances and volume of human bodies to estimate bleeding in hemophilia and lung capacities (Haleem & Javaid, 2019). The benefits of 3D scanning technology are that it eliminates the process of manual measuring and provides quick and accurate measurements (Haleem & Javaid, 2019).

3D Scanning and Printing in OT

3D printing is being used to create assistive devices and adaptive equipment using customizable and cost-effective methods (Ganesan et al., 2016; Hunzeker & Ozelie, 2020; Morgan & Schank, 2018). Hunzeker and Ozelie (2020) completed a cost analysis of adaptive equipment that was 3D-printed compared to those commercially available and found that 3D-printed adaptive equipment was, on average, 10.5 times more cost-effective than commercial alternatives. Occupational therapists also use 3D scanning and printing technologies in the fabrication of orthoses. Portnoy et al. (2020) compared 3D-printed finger orthoses to manual-made orthoses and found that 3D-printed finger orthoses were lighter in weight and scored a higher satisfaction rating from the fit and overall process. Similarly, Lee et al. (2019) investigated the efficacy of hand orthoses created by 3D scanners and printers for individuals with traumatic brain injury and found that the individuals who used 3D-printed orthoses demonstrated increased hand function with activities of daily living, like feeding and typing as compared to those that used over-the-counter orthoses.

Indications to Analyze Different Materials for Orthotic Fabrication

Recent studies have explored orthoses made from different materials and their impact on users. In a study with 35 patients suffering from carpometacarpal joint osteoarthritis, those using custom-made orthoses experienced a significant reduction in pain levels compared to those using commercial orthoses (Bani et al., 2013). In addition, 3D-printed short thumb orthoses were found to offer greater flexibility and support compared to traditional ones (Chu et al., 2022). A review of 22 articles revealed that 3D-printed orthoses generally had similar or superior effects on factors like wrist-hand function and joint range of motion, leading to higher satisfaction and comfort among users (Choo et al., 2020). Furthermore, a study comparing 3D-printed wrist orthoses to those made from fiberglass cast material found similar function scores but higher satisfaction, comfort, and perceived function with the 3D-printed orthoses (Graham et al., 2020).

Investigation of 3D-printing applications in orthosis fabrication cannot be completed by examining only users' perspectives. It must also be examined from the fabricator's perspective to compare fabrication processes and usability of 3D-printed orthoses. A comparison of the materials to test feasibility, benefits, and limitations is also warranted. It is the ethical responsibility of occupational therapists to be informed of the limitations and benefits of novel interventions, such as 3D printing, to support the standards of beneficence and nonmaleficence for clients (American Occupational Therapy Association [AOTA], 2015; Hunzeker & Ozelie, 2021). Therefore, the goal of this study was to conduct a comprehensive analysis of orthoses fabrication processes and final products using various materials. The analysis encompassed several factors, including the examination of required equipment and materials, assessment of time and skills involved in the fabrication process, evaluation of ease of adjustment during fabrication, and objective measurements of functional outcomes. By taking these aspects into account, the study aims to offer a heightened understanding of the orthosis fabrication process and its resulting products.

Method

Design

This study was a comparative analysis of thumb immobilization orthosis fabricated with 3D-printed, thermoplastic, and fiberglass cast material with consideration to the fabrication processes, functions, cost-effectiveness, and replicability. This is a fabricator analysis of the fabrication and function of a hand-based thumb spica orthosis. This study did not require approval from the institutional review board as it did not include any interaction or intervention with human subjects other than the authors or include any access to identifiable private information.

Procedures

Hand-based thumb immobilization orthoses were fabricated using 3D scanning/printing, thermoplastic, and fiberglass casting material. The knowledge and skills gained from university coursework and 3 months of fieldwork experience at a hand therapy clinic, making multiple orthotic devices per day, were applied to fabricate orthoses using thermoplastic and fiberglass casts. 3D scanning and printing were learned and practiced for 3 months of preparatory learning with approximately 2 to 4 hr per week and then four dedicated full-time weeks of 4 to 6 hr/day before the fabrication of the 3D-printed orthoses. One author (fabricator) fabricated three of each orthosis for analysis and averaged findings to ensure the most accurate results. Orthoses were fabricated by one author (the "fabricator") on the other author (the “user”). All orthoses were analyzed using the required equipment, materials, skills, time, ease of adjustment, replicability, skin integrity, and fine motor control.

Hand-Based Thumb Immobilization Orthosis

A hand-based thumb immobilization orthosis was chosen as the orthosis subject for this study. Hand-based thumb immobilization orthosis limits the mobility of the thumb carpometacarpal joint and metacarpophalangeal joint and is often prescribed for clients with arthritis, low median nerve injury, or first metacarpal fracture to allow healing, rest, and/or protecting involved structures (Gammons, 2021; Jacobs & Austin, 2014). For this study, hand-based thumb immobilization orthoses were fabricated based on the protocols in Jacobs and Austin (2014), with slight metacarpophalangeal joint flexion and the thumb positioned in opposition. Additional fabrication requirements included clearing the distal palmar crease, the interphalangeal (IP) joint of the thumb, and the radiocarpal joint to allow an unobstructed range of motion of the finger flexors, thumb IP flexion, and wrist flexion (Jacobs & Austin, 2014). All protocols were strictly followed when fabricating all orthoses to ensure consistency among orthoses.

3D Printed Hand-Based Thumb Immobilization Orthosis

A 3D scan of the hand must first be completed to provide measurements of the hand before fabricating a 3D-printed thumb immobilization orthosis. POP Scanner and RevoScan were used to scan the hand and convert the image into stereolithography (STL) format. Then, the image was imported into nTopology 3D modeling software to develop a 3D modeled thumb immobilization orthosis based on the scanned hand image. The model was imported into FlashPrint 5, a free slicing software, to be prepared for print and printed by FlashForge Adventurer 3. This printer takes polylactic acid (PLA) filament, a durable and cost-efficient filament that is made from cornstarch and is biodegradable (Simplify3D, 2023). A spool of 1.75 mm PLA 0.5 kg filament was used in this study. Once printed, the orthoses were fitted, and some grinding and filing were required to account for skin integrity concerns. No strap was used with this orthosis, as there was an opening on the ulnar side of the orthosis in which the user could don the orthosis, which fit without the need for a strap. The process was completed three times to average the time required.

Thermoplastic Thumb Immobilization Orthosis

For the fabrication of thermoplastic thumb spica, one-eighth of Rolyan Aquaplast T, 19% Optiperf 1/16” x 18” x 24” material was used. This specific material was chosen because of its thin and lightweight nature, which was ideal for hand-based orthosis with perforations providing increased ventilation for the hand (Performance Health, 2023). A pattern for hand-based thumb immobilization orthosis was developed, and then a piece of thermoplastic was cut and heated to the required temperature. The softened thermoplastic was placed and shaped on the hand according to the hand-based thumb immobilization orthosis pattern (Jacobs & Austin, 2014). Scissors, an orthotic pan, and a heat gun were used to make adjustments. The orthosis was fitted to the hand and adjustments were made to ensure an appropriate fit. The process was completed three times to average the time required.

Fiberglass Cast Thumb Immobilization Orthosis

A thumb spica stockinette was placed directly onto the hand, and the hand was positioned according to the hand-based thumb spica protocol. A roll of Delta-Lite Conformable Fiberglass Cast Tape, 2-inch width, was soaked in a bucket of water and used to wrap the hand and thumb over the stockinette. During the next few minutes, the hand was supported in the position according to the protocol while it hardened. A plastic stick was inserted in the dorsum part of the hand between the skin and the stockinette for skin protection, and then, the cast was cut with a pair of bandage scissors along the plastic stick. After being removed, the cast was trimmed, and the edges rounded off with a pair of orthotic shears to be formed into a hand-based thumb spica. Once fitted on the hand and checked for protocol adherence and comfort, the thumb spica was lined with fleece edger and added with hooks and a loop Velcro closure. This process has been completed three times to average the time required.

Outcome Measures

Equipment Required

All items used in the process to create the orthosis itself and can be used repeatedly are classified as equipment in this study. Equipment is items that facilities can often purchase one time and then use repeatedly. While the cost per orthotic may be inconsequential, it is an important consideration for upfront budgetary costs associated with the various types of orthoses analyzed in this study. All equipment required to fabricate an orthotic was analyzed for its cost. The cost of such equipment as an orthotic pan, orthotic shears, and heat guns were referenced on the websites of rehabilitation supply companies and the average prices of these sites were listed in the results. The sites included, but were not limited to, Performancehealth.com, Rehabmart.com, and ncmedical.com. The cost analysis of 3D-print-related equipment was retrieved from the associated manufacturer of the 3D printer, scanner, and filaments.

Materials Required

All materials required to fabricate an orthotic were analyzed for their cost. Any items used in the process and used to create the orthosis itself that have only a single use were classified as materials in this study. The cost of filament to fabricate a hand-based thumb spica is calculated by the length of filament used multiplied by the cost per meter. Each 1.75 mm PLA 0.5 kg filament spool costs $17.99 (FlashForge 3D Printer, 2023a). A spool of 1 kg has 335.3 meters of PLA filament (2016, 2020); hence, a spool of 0.5 kg has 167.65 meters of PLA filament. The cost per meter was calculated using the following equation: (the cost of a spool of filament / the length of filament in the spool) multiplied by the length used to fabricate a thumb spica. The cost of the hook and loop velcro straps, as well as the cost of the fiberglass cast fleece edger, were calculated in the same way as above. The piece of thermoplastic used was an eighth of the original sheet of thermoplastic; hence, the cost was calculated by the following formula: the price of the original sheet / eight. The cost of fiberglass cast was calculated by the roll, not by length, because a remaining roll of fiberglass cast cannot be saved for later use due to the chemical reaction that occurs with air and water exposure. The cost-effectiveness was calculated using the following equation: the total material cost required to fabricate an orthosis / the cost required to fabricate the most cost-effective orthosis among the three.

Skills Required

All skills and knowledge required to operate equipment, use materials, and fabricate a thumb immobilization orthosis were analyzed. Biomechanical principles are defined as the knowledge of hand anatomy, physiology, and function relative to orthotic fabrication.

Time Required

The amount of time required to fabricate the three orthoses was analyzed using minutes and seconds. Time is broken down into the time required for a user to be present and the time required for the fabrication process. The recorded data on the 3D printer for the actual print time was used in this analysis for the 3D printed orthosis. Three of each hand-based thumb immobilization orthoses were fabricated with thermoplastic and fiberglass cast materials to calculate the average time required for the process and ensure accurate analysis. The time-effectiveness was calculated using the following equation: the total time required to fabricate an orthotic / the time required to fabricate the most time-effective orthotic among the three.

Ease of Adjustment

The level of ease or difficulty in adjusting an orthosis during the fabrication process is examined from the fabricator's perspective. The levels were rated as easy (able to make adjustments to the orthosis in a short amount of time and make adjustments to all aspects of the orthosis), medium (able to make adjustments in a moderate amount of time and make adjustments to some aspects of the orthosis), or difficult (able to make adjustments to the orthosis requiring a significant amount of time or unable).

Replicability

The ability of the fabricator to recreate the exact orthosis is examined in this section. Replicability is important in instances when patients lose or damage their orthoses and require replacements. The levels of replicability were rated as perceived by the fabricator. The levels of replicability were rated as high (able to replicate the exact same orthosis without requiring the presence of user), medium (able to replicate the same orthosis to a moderate degree, does need user for final modifications), or low (unable to replicate the exact same orthosis; must repeat entire process with user).

Skin Integrity

The condition of the skin was examined after the 3 hrs of the user wearing each orthosis and performing similar activities (cooking tasks, writing, phone use) during a similar period during the day. The condition of the skin was rated excellent (no redness or other signs of skin irritations), good (minor redness), or fair (multiple areas of redness), according to the presence of red spots or any other signs of skin irritations.

Fine Motor Control

The fabricator evaluated the functionality of each orthosis as measured by the nine-hole peg test (NHPT). The NHPT is a standardized assessment tool used to gauge finger dexterity. Among test subjects of healthy adults, it demonstrated excellent test-retest reliability and excellent correlation with the Bruininks-Oseretsky Test of Motor Proficiency (Wang et al., 2011) and excellent interrater reliability (Grice et al., 2003). With each orthosis, the NHPT was performed three times, and the average of the three was calculated. One-way ANOVA was used to investigate if the difference between the three orthoses material had a measurable effect. The statistical analysis was run using Microsoft Excel. Significance was set at $p < 0.05$.

Results

Overall, thermoplastic and fiberglass cast materials demonstrated similar results in many categories, while 3D-printed orthoses demonstrated distinct differences in several categories analyzed.

The material cost of 3D-printed orthoses was significantly lower than the other two alternatives, specifically 14.62 times more cost-effective than thermoplastic and 12.64 times more cost-effective than fiberglass cast. The fiberglass cast demonstrated the most time-effectiveness, with an average of fewer than 15 min, making it more than 30 times more time-effective than 3D-printed orthoses, which required over 7 hrs to complete. Comparative analysis of equipment, materials, skills, and time required in the fabrication process, ease of adjustments during fabrication and replicability, as well as skin integrity after 3 hrs of wear and fine motor functions are presented in Table 1. The cost and time-benefit analyses are presented in Table 2. Table 3 provides a summary of the results of the ANOVA data analysis of fine motor performance.

Table 1
Analysis of Thumb Spicas Made with Different Materials

	3D-Printed	Thermoplastic	Fiberglass Cast
Pictures			
Equipment required**	**Total: $698 + Cost of 3D modeling software** -3D scanner: POP scanner ($399) -3D modeling software: nTopology (Free for academics/students) -3D printer: FlashForge Adventurer 3 ($299)	**Total: $293.57~ $1,951.50** -Commercial Orthotic pan ($1,722) -OR electronic fry pan ($64.07)* -Slotted turner ($8) -Orthotic shears ($52.50) -Heat gun ($169)	**Total: $392.50** -Orthotic shears ($52.50) -Bandage Scissors ($171) -Heat gun ($169)
Materials required	**Total: $0.74** -PLA filament (6.86 m / $0.74)	**Total: $10.82** -Thermoplastic (Aquaplast-T 19% Perforation 15cm x 23cm / $10.61) -Velcro hook (2.5 cm / $0.06) -Velcro loop (11 cm / $0.15)	**Total: $9.35** -Fiberglass Cast (Delta-Lite Conformable $6.50) -Stockinette ($1.62) -Fleece edger (52 cm / $1.02) -Velcro hook (2.5 cm / $0.06) -Velcro loop (11 cm / $0.15)
Skills required	-Biomechanical principles - 3D scanning - 3D modeling software - 3D printing -Overall skills with technology	-Biomechanical principles -Types of thermoplastic -Fabrication/adjusting orthosis	-Biomechanical principles -Types/size of synthetic cast materials -Fabrication/adjusting orthosis
Time required	**Total: 7 hr 17 min** -Scanning hand: 8 min -3D modeling: 30 to 45 min (with established workflow 15 min) -3D printing: 6 hrs 31 min -Modifications & adjustments: 8 min	**Total: 19 min 36 s** -Making pattern -Fitting -Placing straps -Real-time orthosis adjustments	**Total: 14 min 38 s** -Fitting -Placing straps -Real-time adjustments
Ease of adjustment (Easy-Medium-Difficult)	**Difficult** Need to re-scan, re-model, and/or re-print the entire orthosis	**Medium** Able to adjust shape by reheating the area; may deform other area; may leave fingerprints	**Easy** Able to adjust shape by trimming with scissors; minimal fingerprints or deformity to other areas when adjusting
Replicability (High-Medium-Low)	**High** Able to replicate the exact same orthosis without requiring presence of user	**Low** Unable to replicate the exact same orthosis; must repeat entire process with user	**Low** Unable to replicate the exact same orthosis; must repeat entire process with user
Skin integrity (after 3 hr of wear / Excellent-Good-Fair)	**Good** Very minor redness by vent holes Least water retention during light cooking tasks	**Excellent** No redness or other signs of skin irritations Some water retention during light cooking tasks	**Good** Minor indentations at first metacarpal joint Very comfortable Remove for tasks using water
Fine motor control (Measured by NHPT)	**Average: 18.05 s** 18’95”, 17’18”, 18’01”	**Average: 17.90 s** 17’68”, 18’17”, 17’85”	**Average: 16.96 s** 15’91”, 18’54”, 16’44”

* Given the variation of options for orthotic pans used by clinicians, both a commercially available orthotic pan and an electric fry pan are included in the table.
**Equipment can be used repeatedly and is often a one-time purchase.

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Table 2

Cost and Time Benefit Analysis

	3D-Printed	*Thermoplastic*	*Fiberglass Cast*
Cost-effectiveness (material)	**Most cost-effective** 14.62x more cost-effective than thermoplastic 12.64x more cost-effective than fiberglass cast	**Least cost-effective**	**Moderately cost-effective**
Time-effectiveness	**Least time-effective**	**Moderately time-effective**	**Most time-effective** 30.89x more time- effective than 3D-printed 1.34x more time- effective than thermoplastic

Table 3

One-way ANOVA for the Nine-Hole Peg Tests

Source of Variation	*Sum of Squares*	*df*	*Mean Square*	*F*	*P-value*
Between Groups	2.0725	2	1.0362	1.1179	**0.3867**
Error	5.5615	6	0.9269		
Total	7.634	8	0.9543		

Discussion

Equipment

Equipment is defined as items that have been used in the process to create the orthosis itself and that can be used repeatedly. It is crucial to recognize that equipment represents one-time purchases for facilities, allowing for repeated use. Hence, while the per-orthotic cost might seem insignificant, it plays a significant role in the initial budgetary expenses linked to the different types of orthoses examined in this study. The equipment cost required for fabricating a hand-based thumb spica was the lowest using fiberglass cast. The fabrication process of fiberglass cast also requires minimal specialized equipment. Similarly, the fabrication process of thermoplastic requires minimal equipment, except for an orthotic pan, which can range in cost, and, potentially, the use of a heat gun. It is important to note that the cost of the orthotic pan can vastly differ depending on the type of pan the clinical site uses. Commercially available pans from therapeutic supply companies that are larger are significantly more expensive; however, there are much more cost-effective options that are smaller in size but can accommodate this type of orthosis.

The equipment cost of 3D-printed thumb spica can vary greatly depending on the type and grade of scanners and printers. The scanner used in this study, the POP scanner ($399; Revopoint, 2023), is a basic model, but the majority of 3D scanners in the market range roughly from $800 to $1,200. 3D printers can also vary widely depending on the size and capabilities. Models range from $200 to $1,500 for hobbyists, while professional models can cost up to $20,000. There are many free 3D modeling software available that are great for beginners to learn 3D modeling basics and explore their interests (Frey, 2023), while professional 3D modeling software is predominantly subscription or license contract-based, which can cost up to several thousand dollars a year. Fabricators must seriously consider the upfront costs of the equipment when making decisions about orthosis fabrication processes.

Materials

The material cost required for fabricating the 3D-printed thumb spica was significantly less than that of thermoplastic and fiberglass cast. As shown in Table 2, a 3D-printed orthosis using PLA filament was 14.62 times (93%) more cost-effective than a thermoplastic orthosis and 12.64 times (92%) more cost-effective than a fiberglass cast orthosis. Various filaments can be used to print a hand-based thumb spica, and the prices vary according to their types (Monofilament Direct, 2021). A spool of nylon or carbon fiber filament, which is more durable and heat resistant than PLA, can cost up to $90/kg, ranking in the higher end of the filament price range (Monofilament Direct, 2021). Even in this case, the cost of fabricating an orthosis would be $1.85, which is still much more cost-effective compared to the other two, proving a strong cost-benefit of fabricating a 3D-printed orthosis. The cost of orthoses was identified as one of the barriers for users of orthoses for functional or rehabilitation means (Nam et al., 2018; Souza et al., 2016). Thus, the cost-effectiveness of 3D-printed orthotics may increase the accessibility of orthotics for users.

Skills

It is essential to have knowledge of biomechanical principles and orthotic-specific fabrication protocols to fabricate any type of orthotic properly. To fabricate an orthotic with thermoplastic, a fabricator must know the types and properties of different thermoplastics and how to adjust them for individual fittings. Similarly, fiberglass cast materials require the fabricator to have knowledge of the types, sizes, and properties of synthetic cast materials and how to adjust them for individual fittings. These skills to "assess the need for orthotics, and design, fabricate, apply, fit and train in orthoses and devices" are the required skills for entry-level occupational therapists mandated by the Accreditation Council for Occupational Therapy Education ([ACOTE], 2018 pp. 30) and continue to develop throughout careers.

Fabricating a 3D-printed orthosis, however, requires an extensive learning process involving 3D modeling software. The internet is flooded with 3D modeling online courses, learning centers for individual software, and related YouTube videos and articles. With the advancement of technology, Howard (2021) discussed that learning 3D modeling has never been easier; however, it would still take 6 months to 1 year for a fabricator to become comfortable designing with 3D modeling software. NTopology, the 3D modeling software used in this study, provided step-by-step instructions to model a thumb spica along with access to the learning center and application support via email along with a free license to the software. The instruction consisted of 46 steps detailed with screenshots. The application support personnel were very responsive and provided extensive help with the modeling process. NTopology demonstrated great capabilities to model an orthosis, especially a workflow palette that provided a solid base for repeated modeling of thumb spica and contributed to increased time-effectiveness. In addition to nTopology, there are multiple other software available. Geomagic Freeform is another 3D modeling software that features an intuitive interface and enables curvy designs with the use of a haptic device (Geomagic Freeform, 2023). Pohlig produces very aesthetically pleasing orthoses and prostheses that can incorporate a watch or fitness devices into them (Pohlig, 2017). However, these programs require fabricators to have additional skills almost similar to the level of professional prosthetists. Considering a fabricator's technological skills and propensity to technology would be important for the use of 3D-printed orthotics in clinical settings.

Time

A comparison of the fabrication time resulted in fiberglass cast material being the most time-efficient. Notably, the fiberglass cast was 30.89 times more time-effective than the 3D-printed orthotic.

However, it is important to note that a user only needs to be present for an average of 8 min during the fabrication process of a 3D-printed orthotic, while one needs to be present for the entire time of 14 to 20 min of the fabrication process for fiberglass cast and thermoplastic. Notably, about 87% of the fabrication time (6 hr and 31 min) for a 3D-printed orthotic was spent printing, which mostly required no attendance of the fabricator or a client. The fabricator's time spent with 3D modeling software varies from 15 min to 45 min, depending on the use of an established workflow (the fabricator can establish the steps needed and create a workflow to reduce the number of individual actions needed with the software), which may or may not be an option, depending on 3D modeling software. It is important to consider that because of the long print time required for the orthosis, the user would need to return to get the completed orthosis. This is an important consideration for the fabricator in relation to the client, contextual factors, and reimbursement implications.

Another consideration related to time when choosing orthotic materials is billing codes. The most commonly used reimbursement codes for orthotic fabrication are L-Codes, the numbers associated with the specific orthotics for smooth communication with insurance carriers (Jacobs & Austin, 2014). L-Codes are determined by the anatomical structure that orthotics support and if they are custom-made and rendered timeless (Jacobs & Austin, 2014). Hence, the reimbursement rate is the same whether an orthotic fabrication takes 10 min or 10 hr. Therefore, it should be considered before hospitals and clinics make initial investments in the equipment and when clinicians choose a material.

Ease of Adjustment

With a 3D-printed orthotic, the hand should be scanned in the position according to the protocol because 3D modeling software may or may not allow adjustments in joint angles. In this study, when the hand was scanned with the thumb too far opposed or the palmer abducted, it required re-scanning of the hand in the proper position. In addition, there were no adjustments possible once the printing started. Both thermoplastic and fiberglass casts allow for adjustments during the fabrication process. Thermoplastic can be adjusted by reheating the area using either hot water or a heat gun, but this may result in deformation or fingerprints to the area or surrounding area. Fiberglass cast can be adjusted with scissors, which minimizes the possibility of deformity or fingerprints. The adjustability of thermoplastic and fiberglass cast is a benefit of using these materials, as they allow real-time adjustments, while 3D-printed orthotics are only allowed for trials after full completion of the 3D-print. Thermoplastic and fiberglass cast materials also allow for adjustments as the patient's condition changes (e.g., changes in edema, arthritic changes, etc.), whereas a 3D-printed orthosis would require the fabricator to create an entirely new template.

Replicability

With 3D-printed orthotics, a fabricator can replicate the same orthotic without requiring the presence of the user. In contrast, the fabricator must repeat the entire process with the user present when using thermoplastic or fiberglass cast. This high replicability is a strong advantage of using 3D-printed technology to deal with the issue of a lost or broken orthotic. This feature may be especially important for users with chronic conditions who may encounter such situations more often and require replacements.

Skin Integrity

After three hours of wear, all three orthotics demonstrated good to excellent skin integrity.
The 3D-printed orthosis consists of repeating patterns of lattice structures to reduce the weight and provide increased ventilation for the hand. This lattice structure, at times, can result in some harsh surfaces even after careful sanding and filing, causing minor skin irritation on the dorsum of the hand. Therapists can avoid this by using Acrylonitrile butadiene styrene filament and removing the top layer with acetone

solvent (Carolo et al., 2022). Initial research supports the superior comfort of 3D-printed orthoses compared to other materials (Choo et al., 2020; Graham et al., 2020); however, this study may add to growing research that meticulous finishing or special treatments may be required to achieve maximum comfort. Notably, when the 3D-printed orthotic was worn during the occupation of cooking, it retained the least amount of water inside the orthotic due to increased ventilation from the lattice structures and allowed for comfortable task completion without a wet fabric strap touching the skin.

The thermoplastic orthosis was evaluated as excellent in relation to skin integrity because of its minimal conformable nature among the three materials. The thermoplastic orthosis was used during the occupation of cooking with minimal issues. The perforated thermoplastic retained a degree of water inside the orthotic and the fabric strap became saturated, causing minimal discomfort during the cooking task and interaction with water.

With the fiberglass cast, minor indentations appeared in the dorsum of the first metacarpal joint. The first metacarpal joint is a potentially high-pressure area in the orthotic fabrication process (Jones et al., 2022), and it has been recommended to expand the thumb hole manually once removed from the hand before it hardens with the fiberglass cast-making process. The inner surface of the fiberglass cast consisted of stockinette and fleece edger, making the fiberglass cast feel comfortable to the skin. It also felt warm and slightly sweaty because of the resulting orthotic having the least ventilation among the three. Fiberglass casts can be washed in a washer and air-dried. However, it was recommended to remove the cast from the hand during tasks using water, so it was not tested with the occupation of cooking. These characteristics of fiberglass casts may suggest that it may be a suitable material for short-term and non-functional orthotics, such as immobilization of joints after injury or surgery.

Fine Motor Control

Fine motor control of the hand measured by the NHPT demonstrated just over a 1-s difference among the three orthotics, and the difference was not statistically significant ($p = 0.387$). This result suggests that all three orthotics maintained the same levels of fine motor control of the hand and that the orthotic material did not impact fine motor control. As fine motor control is an important client factor consideration for occupational therapists, this is an important consideration when considering orthotic materials.

Limitations

There were several limitations to this study. One limitation of this study was the use of one fabricator for analysis. An increased sample of fabricators may provide a greater representation of skills and increase the validity of the findings. Future studies should consider recruiting multiple occupational therapists as participants.

Another limitation was that this study only explored one 3D scanning/modeling/printing technology while there were multiple options for each. 3D-related technologies are diverse and ever-evolving. Although the author dedicated many hours to learning and received generous assistance, there is more to learn. Future studies should consider the time and process of learning the technologies and choosing equipment and materials best suited for orthotic fabrication. The efficacy of 3D-modeling software designed for orthotic fabrication to increase the feasibility of 3D-printed orthotics in clinical settings is also warranted.

Finally, this study was based on the perspective and function of a fabricator with no hand impairments. Future studies should focus on users' perspectives and the functional outcomes of each orthotic for persons with hand impairments.

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Conclusion

The results of this study support that 3D-printed orthotics are cost-effective and have a high degree of replicability; however, it is time-consuming to fabricate and requires an extensive learning commitment and investment for equipment and software. Further research on the feasibility of offering 3D-printed orthotics in clinical settings is warranted to provide the best client-centered and evidence-based services to clients of OT. Thermoplastic and fiberglass cast are comparable in many ways, but thermoplastic may be more suited for functional orthotics, as it allows for water-related tasks, such as cooking and cleaning. Fiberglass cast may be more suitable for short-term and non-functional orthotics because these orthoses are quick to fabricate and comfortable; however, they need to be removed for water-related tasks. It is critical for occupational therapists to understand orthotic materials and provide the most appropriate one for a user's condition and occupational demands because professional reasoning and client-centered practice are the cornerstones of OT practice. This ensures that the chosen material aligns well with the individual's needs and facilitates optimal therapeutic outcomes.

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