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# Conventional vs 3-Dimensional Printed Cast Wear Comfort

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## Abstract

**Background:** The objective of this study was to determine the functionality of 3-dimensional (3D) printed orthoses for upper extremity immobilization compared with conventional immobilization. **Methods:** Twelve healthy volunteers were fitted with a 3D custom printed short arm cast and a short arm fiberglass cast in separate sessions. The Jebsen Hand Function Test (JHFT) was used to test function and dexterity in each cast. All volunteers completed a modified version of the Patient-Rated Wrist Evaluation (PRWE). Skin complications were recorded. **Results:** There were no significant differences during the JHFT between casts, although one-third of the participants in the 3D cast could perform the tasks in a normal time, which they could not in the fiberglass cast. The average PRWE function score was lower in the 3D cast group than in the fiberglass group (45.5 vs. 80.8). Minor skin irritation was noted in 42% of patients in the fiberglass cast group compared with only 1 patient (8%) in the 3D cast group. One patient in the fiberglass group required a cast change due to inappropriate fit. **Conclusions:** Both casting techniques demonstrate similar objective function based on the JHFT. Patient satisfaction, comfort, and perceived function are superior in the 3D printed casts.

**Keywords:** casting, 3D printing, upper extremity, fracture care, custom 3D casting

## Introduction

For centuries, injuries have been immobilized in similar ways. Plaster or, more recently, fiberglass casts have been used to immobilize the ill and injured limbs. Plaster of Paris has been described as a method of immobilization since the 10th century by Arabic scientists.[1] To date, minor changes have been made to this technique. Waterproof options, breathability, skin pressure tolerance, and weight of cast wear have yet to be fully addressed. New developments of 3-dimensional (3D) technologies offer multiple possible new frontiers to improve patient care and satisfaction, and offer potential comfort as new materials are used in devices patients wear.

Benefits of 3D orthosis fabrication include custom fit, breathability, and affordable material. The orthosis can also be designed to accommodate customization such as openings over wounds and injured areas. Furthermore, the innovative construction and simple uniform design allows for waterproof, washable, and dirt- and sand-proof immobilization.

The aim of this project was to determine the functionality of using 3D printed orthoses for upper extremity immobilization compared to conventional immobilization methods. We hypothesize that similar wear attributes and function is noted in both the conventional and 3D printed cast groups.

## Materials and Methods

Institutional review board approval was obtained for this study. We performed an evaluation of healthy volunteers with no active hand pathology. Individuals 8 years of age or older who were willing to participate in the study met inclusion criteria. Exclusion criteria were having any known skin conditions, hand or wrist pathology, and sensitivity and/or allergies to topical substances or materials.

The volunteers were randomly selected to have their dominant or nondominant upper limbs casted, and the selected extremity was fitted with a conventional fiberglass short arm cast and a 3D printed short arm cast (3D cast) in separate sessions. The fiberglass casts were either fitted by

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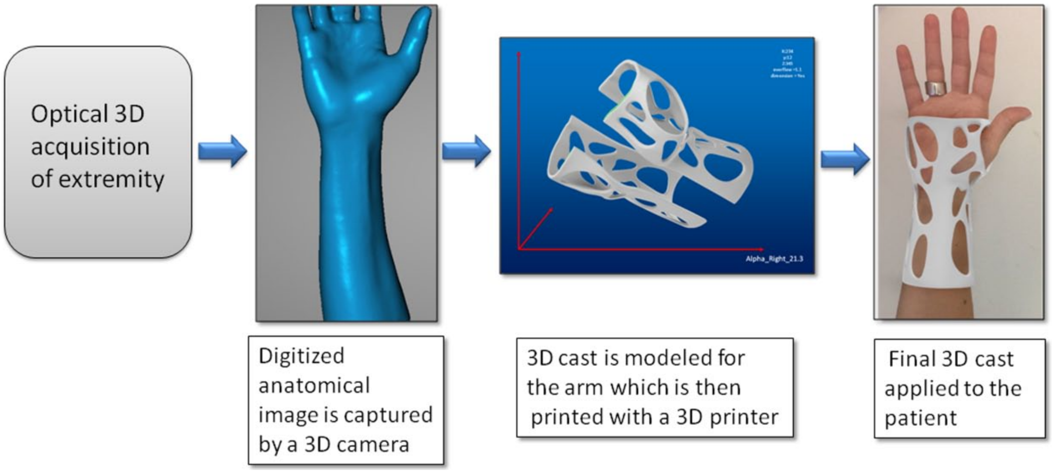


**Figure 1.** Process of 3-dimensional (3D) printed cast production.

an orthotist or an orthopedic surgeon using standard technique with a stockinette, webril, and fiberglass rolls (3M, ScotchCast Plus, Maplewood, Minnesota). For the 3D cast, the limbs were digitized using an optical scanner (no radiation), a process that takes less than 3 minutes. The scanned file was then digitally processed, and the 3D casts were manufactured using Food and Drug Administration–approved materials (DimensionCast, Dimension Orthotics, LLC, Philadelphia, Pennsylvania) (Figure 1). The 3D cast was fitted to the participant and checked for fit by an orthotist or hand therapist with orthotics training. The cast can be made removable or fixed dependent on patient characteristics and fit. Prior to fitting, cast padding is placed on the skin.

The Jebsen Hand Function Test (JHFT) was used to assess function and dexterity in the 2 casts.[3,7] This test is a validated quantitative outcome test utilized for assessment of an individual's ability to complete 7 separate subtests related to everyday unilateral use of the hand. The JHFT is a standardized test which can be easily and efficiently administered in an office or clinic setting. Use of both weighted and nonweighted items allows for a dossier of functional tasks to be addressed, which include writing, "page turning" through turning of 3×5-inch index cards, picking up small common objects, and picking up large heavy objects. Both standardized and objective data may be obtained through use of the JHFT through performance times assessed along with the clinician's observations made during administration. Performance of both the dominant and nondominant hands is recorded via stopwatch, with time to completion recognized as the quantitative value for each subtest.

The test was performed with the dominant, nondominant, fiberglass (Figure 2) and 3D casts (Figure 3) in a random sequence for each participant. The assessment was administered by a certified hand therapist (CHT) who was blinded for the purpose of the study and was not involved in study design, analysis, or subject recruitment, but not blinded to the type of cast. The individual's performance of the task was recorded in the amount of time (ie, seconds) until task completion, correlating better function with less time. All scores were recorded and data analyzed to determine which method of immobilization gives way to greater functional use of the affected upper extremity. The casts were worn on average for about 2 hours between fitting and going through the test.

**Figure 2.** Conventional fiberglass short arm cast.

**Figure 3.** Three-dimensional printed short arm cast.

**Table 1.** Demographics.

| | Number |
|---|---|
| Hand dominance | |
| Right/left | 12/0 |
| Casted limb | |
| Right/left | 7/5 |
| Gender | |
| Male/female | 5/7 |
| Median age (SD, range) | 31 (13.7, 11-65) |
| Total | 12 |

**Table 2.** Statistical Comparison of Performance During Tasks Utilizing the Jebsen Hand Function Test.

| Mean time to complete task(s) (low numbers demonstrate better result) | Fiberglass cast | 3D cast | *P* value |
|---|---|---|---|
| Lifting large, light objects | 21.51 | 17.38 | .801 |
| Lifting large, heavy objects | 5.88 | 5.83 | .898 |
| Lifting small, common objects | 8.69 | 10.55 | .307 |
| Simulated feeding | 13.04 | 12.09 | .533 |
| Simulated page turning | 4.51 | 3.91 | .947 |
| Stacking checkers | 4.94 | 4.78 | .446 |
| Writing | 4.63 | 4.69 | .269 |

*Note.* $P < .05$ considered significant.

All individuals participating in the study completed a modified version (eliminating the pain portion and adding functional activities that use electronic devices) of the Patient-Rated Wrist Evaluation (PRWE) representative of their experience in the 3D cast and the fiberglass cast. The PRWE is a questionnaire directed toward patients as a means of self-assessment of their participation in activities of daily living.[4] The questionnaire has both function and pain scales for the patient to assess. Lower scores indicate improved function.

Skin integrity was evaluated for pressure, scrapes, scratches, abrasions, or other signs of friction after wearing both casts. Satisfaction with the casts, the need for adjustment, and subjective burden were also tabulated as reported by the volunteers.

Statistical analysis was performed using a paired Student *t* test to evaluate for differences in task performance and functional questionnaire with significance at $P < .05$.

## Results

Twelve healthy volunteers were enrolled for the trial, 7 females and 5 males. Demographics are included in Table 1. No variable was significantly different between the 3D and the fiberglass casts during the JHFT (Table 2). However, one-third of the participants were able to perform tasks normally (time within the normal range) in a 3D cast that they could not with a fiberglass cast. Posttest skin was evaluated for cuts, scrapes, and bruises. All participants had intact skin after wearing either the fiberglass or the 3D cast.

The average PRWE function score for patients in the fiberglass group was higher than in the 3D cast group (80.8 vs. 45.5, $P = .00015$, lower number denotes improved function). Comfort was assessed, and subjects rated the 3D cast higher (fiberglass = 82.1, 3D = 53.3, lower number denotes improved comfort, $P = .016$). Similarly, satisfaction was rated higher in the 3D cast (fiberglass = 92.1; 3D = 50.8; $P = .001$, lower number denotes increased satisfaction).

Wear characteristics were assessed on all patients on the questionnaire. One participant (8%) in the fiberglass group required cast adjustment. No casts needed refabrication or modification in the 3D group. Minor skin irritation was noted in 5 patients (42%) in the fiberglass cast group compared with only 1 patient (8%) in the 3D cast group. The mean cast wear burden was rated "moderate" in the fiberglass cast group compared with "no hassle" in the 3D cast group. Using the visual analog scale (VAS; 1 = most dissatisfied; 10 = most satisfied), the mean score in the fiberglass cast group was 5 vs 9 in the 3D cast group.

## Discussion

Plaster and other conventional casting techniques for fracture care and immobilization have been utilized for centuries with minimal change to the process during this time. Recently, fiberglass casts have become more popular in developed countries. While regarded highly from a clinical standpoint for their low cost, strength, and ease of application, limitations such as heavy weight, low breathability, inability to get wet or be cleaned, and limited transparency are drawbacks to traditional casts. With regard to upper extremity immobilization, custom 3D printed orthoses for nondisplaced or incomplete fractures may add comfort with the benefit of direct visualization of skin, all the while minimizing the need to keep it dry.

Three-dimensional printing is already being utilized to construct highly accurate bone models derived from advanced imaging for preoperative planning purposes.[2] In the realm of orthopedic upper extremity treatment, 3D printing can be used to advance practice through the fabrication of custom 3D printed orthoses with precise scanning of the patient's upper extremity and the expertise and skill of the hand therapist.[5] Due to the fact that this technology is still in its infancy, the actual costs of producing a 3D cast or a splint are in flux. While there are fixed costs of purchasing a scanner and a printer, the print material is relatively cheap. It is expected that the fixed costs of 3D printing will decrease over time. Currently, the costs of applying a waterproof fiberglass cast is about $30.00, independent of the cost of cast reapplication and the cast technologists' time.

The creation of a waterproof, washable, lightweight, static, or removable padded cast is the goal to improve the quality of life and compliance of patients with immobilization regimens. These cast qualities can have a tremendous impact on the wearer's experience, especially in children, the elderly, athletes, and those whose skin needs to be observed regularly.

However, the cast must be safe and functionally not inferior to currently available traditional orthoses. Wear characteristics were clearly superior in the 3D cast group, likely due to the more streamlined design and lightweight construction of the 3D casts compared with the fiberglass casts. Function, comfort, and satisfaction were all independently superior in the 3D group. One patient needed a cast change in the fiberglass group due to inappropriate fit. This was not required in the 3D cast group. Mean VAS satisfaction scores in the 3D cast group were nearly double that of the fiberglass cast group. Forty-two percent of subjects in the fiberglass cast group reported skin irritation after completing all tasks compared with 1 participant (8%) in the 3D cast group. This may explain why the results of the satisfaction, comfort, and function assessments were superior in this group.

Fiberglass casting for fracture care and immobilization has been long utilized in both emergency departments of hospitals and orthopedic practices alike.[8] In terms of user attributes, fiberglass is preferred to plaster for casting, and this was chosen as the gold standard in our investigation. While highly regarded from a clinical standpoint for their low cost, strength, and ease of application, fiberglass casts are often a focus of frustration and viewed as problematic by the individual wearing them or the parent of the child casted.[6] The factors that pose problems for parents and the child alike include heavy weight; decreased functional use of the upper extremity for preferred activities because of perspiration or fear of getting wet; decreased functional use of the affected upper extremity for tasks related to hygiene; and an inability to remove or see beneath the cast to sufficiently perform checks of the skin for breakdown, ulcers, or sores.[9] Fenestrations and openings built into the 3D cast allow for frequent skin checks (see Figure 1).

Within appropriate and safe boundaries, cost and time are 2 factors that weigh heavily on the determination of treatment from clinical standpoints as well as the burden felt by the patient. In addition, a 3D printed orthosis has benefits that are hypothesized to far outweigh all of the shortcomings experienced through fiberglass casting, thermoplastic orthoses, or prefabricated orthoses. Benefits of a 3D printed orthosis include, but are not limited to, the precision of fit, aesthetic appeal, lightweight construction, waterproof design, and improved capability for hygiene and skincare.

Our study showed that 3D casts are functionally noninferior to traditional casting techniques while providing a waterproof, lightweight, and breathable alternative. Neither group experienced any adverse effects on the skin in the short term beyond minor irritation or signs of friction. Our study demonstrated trends of functional superiority in the 3D cast group on the JHFT, but the major statistically significant difference was seen on the PRWE portion. The PRWE better illustrates how hindrance affects the patients subjectively. This result, although correlated, may not be as apparent on the JHFT portion, as the power of this test may be unable to distinguish minute changes in participants who compensate well for certain limitations.

Limitations include the fact that this was a functional wear and safety trial, and no medical illness or injury was treated. Subjective results may be skewed toward favoring the 3D cast due to the "coolness factor" of the emerging technology. Further studies blinding volunteers as to the process as to how the cast was generated may help to mitigate this problem. There is potential for more complications with extended wear and in patients with injuries or fragile skin. Future investigation is required to assess the safety and benefit profile of 3D printed casts in patients with orthopedic conditions or injuries. Well-designed randomized controlled studies are needed to clearly elucidate the application of this new device. In addition, the CHT who assessed the JHFT was not blinded to the type of cast, which may have introduced bias to the results of the JHFT. Next, one-third of the PRWE relates to pain and as such this does not apply to the volunteers in this study. Finally, the casts were worn on average for about 2 hours between fitting and going through the test. This may not be enough to evaluate skin reaction, but with manual testing (JHFT), friction areas were seen in the fiberglass cast group in this short time period, which was less apparent in the 3D cast group.

Emerging technology allows for use of better orthoses and casts with a more precise fit while providing reliable, seamless, and waterproof immobilization. Successful utilization of this technology has tremendous implications in injury care and patient satisfaction, especially in the field of hand surgery. Three-dimensional printed orthoses have the potential to greatly impact quality of life in patients with orthopedic injuries requiring immobilization and chronic conditions such as arthritis and joint deformity that may necessitate bracing.

## Ethical Approval

This study was approved by our institutional review board.

## Statement of Human and Animal Rights

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.

## Statement of Informed Consent

Informed consent was obtained from all patients for being included in the study.

## Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: P.B., M.R., and C.W. have interest ownership in Dimension Orthotics, LLC.

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## References

1. Bacon LW. On the history of the introduction of plaster of Paris bandages as a fixation dressing. *Bull Soc Med Hist Chicago*. 1923;3:122-132.
2. Chung KJ, Hong DY, Kim YT, et al. Preshaping plates for minimally invasive fixation of calcaneal fractures using a real-size 3D-printed model as a preoperative and intraoperative tool. *Foot Ankle Int*. 2014;35(11):1231-1236.
3. Jebsen RH, Taylor N, Trieschmann RB, et al. An objective and standardized test of hand function. *Arch Phys Med Rehabil*. 1969;50:311-319.
4. MacDermid JC. The patient-rated wrist evaluation (PRWE) user manual. http://www.handweb.nl/wp-content/uploads/2015/10/PRWE_PRWHEUserManual_Dec2007.pdf. Published December 2007. Accessed March 7, 2018.
5. Paterson AM, Donnison E, Bibb RJ, et al. Computer-aided design to support fabrication of wrist splints using 3D printing: a feasibility study. *Hand Ther*. 2014;19(4):102-113.
6. Plint AC, Perry JJ, Tsang JL. Pediatric wrist buckle fractures. Should we just splint and go? *CJEM*. 2004;6(6):397-401.
7. Raad J. *Jebsen Hand Function Test*. Shirly Ryan ability lab. https://www.sralab.org/rehabilitation-measures/jebsen-hand-function-test. Published October 26, 2012. Accessed March 8, 2018.
8. Solan MC, Rees R, Daly K. Current management of torus fractures of the distal radius. *Injury*. 2002;33(6):503-505.
9. Williams KG, Smith G, Luhmann SJ, et al. A randomized controlled trial of cast versus splint for distal radial buckle fracture: an evaluation of satisfaction, convenience, and preference. *Pediatr Emerg Care*. 2013;29(5):555-559.