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Research article

3D-printed orthoses vs. traditional plaster cast: a comparative clinical study

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Abstract: Hand immobilization remains the primary approach in the management of fractures, soft tissue injuries and post-surgical rehabilitation. However, prolonged immobilization can negatively impact the rehabilitation process, often leading to muscle atrophy, joint stiffness, and functional impairments. Advances in 3D-printed orthoses offer a promising alternative to plaster casts, providing superior support, greater comfort, and improved clinical outcomes. Through this study, we aim to evaluate the benefits of 3D-printed orthoses on clinical outcomes of patients, compared to the traditional plaster cast method. A total of 54 consecutive patients who sought emergency care for hand injuries were included in the study. Hand functionality (MHQ score), grip strength, hand and forearm circumference, pain levels, total range of motion of the hand, and patient satisfaction (QUEST 2.0 score) were evaluated at baseline, post-immobilization, and after a one-month follow-up. Patients using 3D-printed orthoses reported superior grip strength, improved range of motion, lower pain levels and overall higher satisfaction compared to those immobilized with traditional plaster casts. Our findings support the use of 3D-printed orthoses as a more effective and patient-friendly alternative to traditional plaster cast immobilization, demonstrating better clinical outcomes and enhanced hand rehabilitation. These findings have the potential to reshape clinical practice by replacing conventional casting methods with more adaptable, efficient and patient-specific immobilization orthoses.

Keywords: 3D printed; orthosis; hand; immobilization; plaster cast

1. Introduction

Hand immobilization stands as one of the primary interventions in the management of fractures, soft tissue injuries and post-surgical rehabilitation worldwide [1]. While it provides essential stabilization, extended immobilization is often associated with muscle atrophy, joint stiffness and impaired motor coordination. Even short-term immobilization can induce neuromuscular and cortical changes, frequently leading to prolonged rehabilitation or complications [2-4]. Although early mobilization of the interested area has been recognized for preventing muscle deterioration and adhesion formation, rehabilitation protocols following the immobilization period lack standardization [5]. Plaster casts remain the most commonly used immobilization technique to this day, due to their affordability and structural stability [6]. However, recent studies have shown that it is associated with several disadvantages, including discomfort, poor ventilation, lack of hygiene, pressure ulcers, and patient rejection [7,8]. As traditional rigid immobilization may no longer offer the optimal option in the field, modern alternatives, such as 3D-printed orthoses, are gaining more attention. The advantages of 3D-printed orthoses include enhanced customization, reduced weight, removability, improved ventilation and hygiene. These benefits have led to an increasing amount of research supporting their potential as a modern alternative to traditional immobilization methods. A systematic review by Lieshout et al. confirmed that 3D-printed braces provide effective immobilization while addressing several drawbacks of conventional plaster and fiberglass casts, such as excessive weight and poor breathability. The review also noted a higher acceptance rate among younger individuals, who particularly appreciated the lightweight design, water resistance and modern aesthetics [7,9]. Research comparing traditional methods to 3D-printed immobilization has shown superior pain control and functional recovery, with improved anatomical fit and breathable, lightweight materials contributing to greater comfort and overall patient satisfaction during rehabilitation [9,10]. Some studies also indicate that 3D-printed orthoses may enhance proprioception, as the precise fit and tailored support contributes to improved neuromuscular feedback, promoting faster motor function recovery [5]. Research has demonstrated that 3D-printed orthoses have the potential to reduce complications often associated with traditional immobilization methods, including muscle atrophy, joint stiffness and pressure ulcers. This is particularly effective when these orthoses are incorporated into structured and individualized rehabilitation programs. Oud et al. provided valuable insights by comparing user satisfaction and clinical outcomes in patients using 3D-printed orthoses versus conventional ones. Their findings indicated a significant decrease in skin irritation and overall discomfort for users of 3D-printed devices. This improvement can be attributed to a better anatomical fit and the design's ability to adapt over time, which is crucial for preventing complications related to poor alignment and the inflexibility of plaster casts. Furthermore, the study emphasized that the user experience can significantly benefit from enhanced materials and patient-specific designs, reinforcing the clinical effectiveness and patient-centered nature of 3D-printed orthoses as viable alternatives [11]. Despite the promising initial conducted studies and their potential, data in long-term outcomes and large-scale clinical trials remain limited [9,12]. Most studies assessing the matter of 3D-printed orthoses have been conducted with small sample sizes or in controlled research settings, making it quite difficult to generalize the findings to broader patient populations [13,14]. Despite growing interest in 3D-printed orthoses, plaster casts remain the clinical standard in most healthcare settings. A direct comparison was therefore warranted to provide clinical data on whether these emerging technologies can justify a shift in practice. This study was designed to go beyond theoretical benefits and evaluate, through measurable outcomes, whether 3D-printed orthoses can deliver meaningful improvements over conventional immobilization in real-world patient care.

2. Materials and Methods

We conducted a longitudinal comparative study to evaluate two immobilization techniques in hand rehabilitation. A multidisciplinary committee was established to oversee patient selection, ensure compliance with predefined inclusion and exclusion criteria, and ensure the study adheres to international medical standards and regulations. The committee consisted of a medical doctor responsible for each patient's clinical management, two physiotherapists, an orthotic specialist, and academically affiliated faculty members. Eligible participants were selected from the Polytraumatology Department of Timisoara County Hospital, Romania. The inclusion criteria were: hand injuries (bone, nerve or soft tissue) requiring immobilization; medical attention was sought at the hospital within the first 24 hours following the traumatic event; the patient was a legally competent adult and possessed full cognitive capacity at the time of the study, provided written informed consent and demonstrated willingness to participate. The exclusion criteria were: the injury or condition extended beyond the hand segment; the treatment protocol did not involve immobilization; the patient did not provide all necessary consent documents or failed to attend all evaluations. The final sample of 54 patients was determined by the total number of eligible individuals who met the inclusion and exclusion criteria out of the 97 screened during the three-month enrollment period. This sample size provides a ±10% margin of error at a 95% confidence level. Given the small target population and exploratory nature of the study, it was considered as both statistically appropriate and clinically relevant. The medical doctor determined the selection of the immobilization method after a comprehensive assessment of each patient's clinical condition, associated risks and potential therapeutic outcomes. The two groups were matched for comparability using the Fisher exact test, based on key demographic and clinical variables such as age, gender, manual activity level and type of injury, with no statistically significant differences observed at baseline. Thus, following a quasi-experimental design, the patients were divided into two groups: the experimental group (n = 39), which received customized 3D-printed orthoses, and the control group (n = 15), which received traditional plaster cast splints, as shown in Appendix A. The study included patients with a range of injuries that required immobilization, among them: fractures of the carpal bones (n=4), metacarpals (n=7), phalanges (n=3), multiple (n=9); lacerations or impairments of the nerve- median (n=5), ulnar (n=3), radial (n=1), multiple (n=5); lacerations or impairments of the tendon/ligament- flexors (n=12), extensors (n=5).

A study protocol was designed to enable a comparative evaluation of the study participants, integrating measurement tools validated in the existing literature. These evaluations encompassed both objective performance-based tests to assess hand functionality and subjective self-reported measures to capture patient satisfaction and perceived functional outcomes. Therefore, on the objective component of the study, the implemented assessment methods were dynamometry for measuring grip strength, an indicator of overall hand functionality, particularly relevant in clinical settings [15-17]. Following standardized protocols, the assessment was conducted with the participants seated, maintaining a neutral posture (shoulder adducted and elbow flexed at 90°), having three maximum effort trials using a Smedley (spring type) hand grip dynamometer [18-20]; goniometry to evaluate a total range of motion (TROM) and obtain a comprehensive perspective upon hand movement [21-24]. Following validated measurement protocols, the total range of motion of the radiocarpal, metacarpophalangeal (MCP), proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints were assessed using a universal goniometer at the given anatomical landmarks [22,25,26]; circumference measurements of the hand and forearm, which serve as an indicator of overall physical strength and functional ability in various populations [15,27,28]. Following established and validated measurement protocols, hand circumference was assessed using a standard flexible measuring tape at the level of metacarpal heads (Metacarpal Head Tape Measure Method- MHTM), while forearm circumference was assessed at its maximal girth, positioned midway between the olecranon and the ulnar styloid process [29-32]. Furthermore, shifting focus to the subjective component and emphasizing the patient's experience, the integrated evaluation methods were the Visual Analog Scale (VAS) for pain assessment, one of the most widely utilized tools in both clinical and research settings, due to its reliability and validity [33,34]. Following generally accepted protocols, the VAS printed scale and the applicable instructions were presented to the patients in a distraction-free environment [34,35]; the Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST), a comprehensive instrument largely validated for capturing various dimensions regarding user satisfaction, including functionality, comfort, aesthetics and service quality associated with assistive devices [36-39]. Following standardized methodologies, participants were briefed on the study's objectives and the relevance of their feedback, being invited later to complete the questionnaire in a controlled and supportive environment [40-42]; the Michigan Hand Outcomes Questionnaire (MHQ), a widely recognized instrument designed to evaluate health status in patients suffering from hand disorders [43-45]. Consistent with established methodologies, patients were informed of the questionnaire's purpose and the study's objectives before its administration in a controlled setting [43,46].

Patients were evaluated at three clinical visits: T0- prior to the immobilization period, within the first 24 hours of the traumatic event; T1- immediately after orthoses removal, marking the end of the immobilization period and T2- one-month follow-up. All assessments were conducted at each of these visits except for the QUEST questionnaire, which evaluates satisfaction with the orthoses and was therefore administrated only at T1.

To ensure methodological consistency and reduce measurement bias, all evaluations were conducted by the two physiotherapists, being supervised by a medical doctor. Data collection occurred in a controlled clinical environment within the hospital's rehabilitation department. To ensure the study's validity, various demographic and clinical parameters were analyzed, including mean age, gender, manual activity in daily life and the prevalence of different pathologies among the studied patients.

The statistical analysis of the collected data was performed using GraphPad Prism software (v.10.0 for Windows). Data distribution was assessed using the Shapiro-Wilk test. For between-group comparisons, unpaired t-tests and the Mann-Whitney test were applied, while repeated measures ANOVA was used to evaluate patient progression across the three evaluation time points in the study.

3. Results

The study's outcomes are presented, focusing on both statistical significance and descriptive parameters. Group means and standard deviations are reported to complement p-values, offering context for the observed differences.

No significant differences were found between groups at baseline regarding age, gender, previous manual activity levels or the prevalence of specific injury types, as detailed in Table 1.

Table 1. Baseline characteristics of the study groups

	3D-printed orthoses group (n=39)	**Plaster cast group (n=15)**	**P value**
Age (mean±SD)	44.3±14.8	48.5±14.2	0.345
Gender f/m (n;%)	13/26; 33/67	6/9; 40/60	0.753
Manual activity (n;%)	29; 74	11; 73	0.991
Supervised rehabilitation (n;%)	28; 72	10; 67	0.747
Nerve injury (n;%)	11; 28	3; 20	0.745
Fractures (n;%)	16; 41	7; 47	0.791
Soft tissue lesion (n;%)	12; 31	5; 33	0.911

For each assessed parameter, trends were analyzed within each group across the three evaluation moments, followed by a comparative analysis between the two groups. A representation of these findings is provided in Table 2.

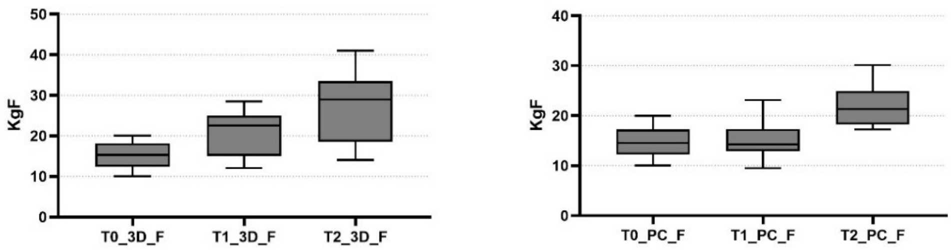
Table 2. Trends of investigated parameters in the study groups

	3D-printed orthoses group				Plaster cast group					
Parameters	**T0**	**T1**	**T2**	***P value***	**T0**	**T1**	**T2**	***P value***	***P value bt.gr._T1***	***P value bt.gr._T2***
Grip strength (kg)	15.2±3	21.4±5.2	27.4±8.2	<0.001	14.7±3	15.3±3.8	22.2±4.1	<0.001	0.001	0.024
TROM (degrees)	109.6±25.5	133.5±13	166.9±9.6	<0.001	98.0±17.3	112.0±12.6	140.4±7.2	<0.001	<0.001	<0.001
VAS score	6.4±1.7	4.5±1.3	3±1.1	<0.001	7.0±1.4	5.3±1.1	4.3±1	<0.001	0.029	0.001
Hand circumf. (cm)	24.2±3.9	22.3±3.8	20.9±3.2	<0.001	24.2±3.4	22.3±3	22.9±3.0	<0.001	0.852	0.044
Forearm circumf. (cm)	25.2±3	23.8±4.3	24.6±4.4	<0.001	24.8±3.7	20.7±3.3	22.9±3.2	<0.001	0.044	0.341
QUEST score	NA	126.1±6.3	NA	NA	NA	66.7±14.5	NA	NA	<0.001	NA
MHQ score	67.4±4.2	66.4±5.9	77.2±5.3	<0.001	70.4±4.6	67.0±5	75.5±5.3	<0.001	0.555	0.331

Data are presented as mean±standard deviation; T0: pre-immobilization evaluation; T1:post immobilization evaluation; T2:one month follow-up evaluation; TROM: the total range of motion; VAS: visual analog scale; Hand circumf.: hand circumference; Forearm circumf.: forearm circumference; QUEST score: QUEST questionnaire score; MHQ score: *Michigan questionnaire score; P value bt.gr._T1: P value between groups at T1; P value bt.gr._T2: P value between groups at T2; NA: nonapplicable.*

2.1. Functional outcomes

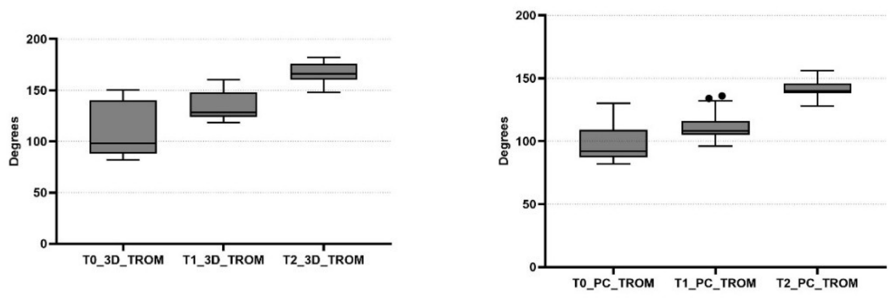
Grip strength significantly improved in both groups (p<0,001). However, the 3D printed orthoses group exhibited higher values than the plaster cast group at T1 (p=0,001; *d*= 1,24-large effect size) and T2 (p=0,024; *d*= 0,93-large effect size), indicating greater prehension associated with 3D printed devices, both immediately post immobilization and after 1 month, as seen in Figure 1.



(**a**) (**b**)

Figure 1. Evolution of grip strength across study groups at T0, T1, T2: (a) 3D printed orthoses group; (b) plaster cast group.

Total Range of Motion (TROM) showed significant improvement in the outcomes of both groups (p<0,001), although the 3D-printed orthoses group demonstrated superior results at T1 (p<0,001; *r*= 0,56-large effect size) and T2 (p<0,001; *r*= 0,75- large effect size), as seen in Figure 2.

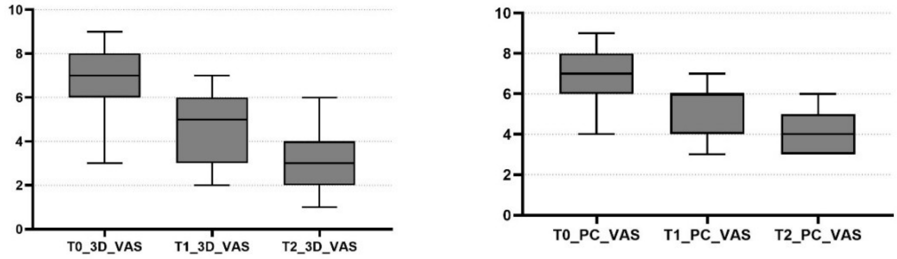


(**a**) (**b**)

Figure 2. Evolution of TROM across study groups at T0, T1, T2: (a) 3D printed orthoses group; (b) plaster cast group.

2.2. Pain perception

Pain levels, measured using the VAS scale, significantly reduced in both groups (p<0,001). Nevertheless, when comparing the two groups, patients who received the 3D-printed orthoses reported lower pain scores at T1 (p=0,029; *r*= 0,3- small effect size) and T2 (p=0,001; *r*= 0,46- medium effect size), as seen in Figure 3.



(**a**) (**b**)

Figure 3. Evolution of grip strength across study groups at T0, T1, T2: (a) 3D printed orthoses group; (b) plaster cast group.

2.3. Anthropometric measurements

Hand and forearm circumferences decreased significantly over time in both studied groups (p<0,001). Between groups at T1, no statistically significant difference was detected in hand circumference measurements (p=0,852), while forearm circumference values were near the statistical significance threshold (p=0,044). At T2, the 3D printed orthoses group showed smaller hand measurement values than the plaster cast group (p=0,44) but no statistically significant difference on the forearm (p=0,34).

2.4. Patient satisfaction and self-functional assessment

Patient satisfaction regarding the immobilization device, measured using the QUEST questionnaire, was higher in the 3D-printed orthoses group after the immobilization period at T1 (p<0,001). These results reflect only the component of the questionnaire that assesses patient satisfaction with the device.

The MHQ questionnaire revealed improvements for both groups in perceived functionality (p<0.001), but no significant differences were observed between groups at T1 (p=0,555) or T2 (p=0,331). These results reflect only the component of the questionnaire that assesses the unilateral functionality of patients' hands.

4. Discussion

Recent advancements in 3D printing technology are revolutionizing the field of orthotics, providing a modern alternative to traditional plaster casts, particularly in managing hand injuries. While traditional immobilization techniques remain widely used, emerging evidence suggests that 3D-printed orthoses offer comparable or superior outcomes in terms of effectiveness, patient comfort, and sustainability. Studies have shown that 3D-printed orthoses offer superior anatomical precision and can answer specific individual needs, reducing pressure-related complications and increasing patients' comfort [7,47]. Comparative studies have highlighted that 3D-printed orthoses provide, in addition to superior support, advantages in terms of weight, ventilation and hygiene, aspects that can significantly impact rehabilitation outcomes, especially in complex cases [7,48]. Additionally, the ability to manufacture a finite product with greater speed and efficiency has established them as a promising alternative, helping to overcome logistical challenges associated with traditional immobilization methods [10,49,50]. Comparative studies in clinical research have systematically evaluated immobilization techniques using various standardized assessment tools that incorporate objective and patient-reported measures. Grip strength, one of the most important parameters for assessing the functional recovery of hands in rehabilitation, is commonly measured with dynamometers [51]. In the context of 3D-printed orthoses, research demonstrated significant improvements in grip strength across various rehabilitation protocols [52,53]. Our findings reinforce this research, as the superior grip strength recovery observed in the 3D printed orthoses group at T1 and T2 suggests that these devices offer enhanced biomechanical support and facilitate a more natural rehabilitation process. Regarding the assessment of range of motion in patients with various hand injuries, studies have reported significant improvements in 3D-printed orthoses compared to plaster cast groups or other immobilization methods [14]. Given that the studies conducted focused on a wide range of pathologies, including rheumatoid arthritis, burns, chronic stroke and fractures, the findings highlight both the broad applicability of 3D printed orthoses and their potential to influence the progression of range of motion in various conditions [14,54-56]. Our total range of motion assessment revealed significant improvements for both groups, with the 3D printed orthoses group showing superior results compared to the plaster cast group at T1 and T2. These findings align with existing research suggesting that lightweight, well-ventilated orthoses promote early mobilization, reducing the risk of joint stiffness and adhesion formation, common complications associated with prolonged immobilization. Pain management, a critical factor in the effectiveness of orthotics, is widely assessed using the Visual Analog Scale (VAS). Studies on fractures and nerve injuries reported significantly lower pain levels on the VAS scale in the 3D-printed groups compared to the plaster-cast groups, while studies on rhizarthrosis suggested that this method may influence the evolution of pain relief [10,52,53,57]. Our findings are consistent with this research, as VAS scores for the 3D-printed orthoses group were lower compared to the plaster cast group at both T1 and T2. This outcome can be attributed to improved weight distribution, minimized pressure points and enhanced ventilation, all of which contribute to greater comfort and a more favorable progression of pain. Hand circumference decreased significantly in both groups over time, with no significant difference between groups at T1, reflecting the expected post-immobilization muscle atrophy. At T2, a significant borderline difference emerged, suggesting that in the 3D printed orthoses group, hand dimensions may have returned closer to their pre-traumatic state. Additionally, these findings may indicate superior neuromuscular potential, facilitating more effective muscle activation during recovery. Likewise, forearm circumference significantly reduced over time in both groups, but no significant differences were detected between groups at T1 or T2. This suggests that forearm muscle recovery progressed similarly, regardless of the method employed for immobilization.

Studies using the QUEST questionnaire to assess patient satisfaction with immobilization methods have generally reported higher satisfaction levels among users of 3D-printed orthoses. This trend has been observed in studies evaluating 3D printed orthoses independently, as well as in comparative analyses against other immobilization techniques [52,54,58]. The significantly higher QUEST scores in the 3D-printed orthoses group highlight the strong preference for this immobilization method. Consistent with prior research, patient satisfaction with modern devices has been attributed to enhanced comfort, improved functionality and greater ease of use compared to traditional methods.

The MHQ questionnaire is a widely utilized tool in literature for assessing hand function. Studies have reported that 3D-printed orthoses have superior overall functionality or improved evolution in several aspects in various conditions, from chronic hand disorders to peripheral nerve injuries [59]. Although the 3D-printed orthoses group demonstrated superior objective improvements in grip strength and total range of motion, our findings in the MHQ questionnaire did not show significant differences between groups at T1 and T2. Although 3D-printed orthoses facilitate measurable improvements in other assessments, patients may not immediately perceive these benefits in their daily activities. Patient-reported measures, such as the MHQ, are influenced by sensory feedback, neuromuscular adaptation, and psychological factors, including pain anticipation and fear of re-injury.

Several limitations should be acknowledged when interpreting the findings of this study. First, the relatively small sample size limits the statistical power and may reduce the generalizability of the results to broader patient populations. Second, the non-randomized, quasi-experimental design introduces the potential for selection bias, as treatment allocation was based on clinical judgment rather than random assignment. This may have influenced the distribution of patient characteristics between groups. Third, the unequal group sizes (39 vs. 15) may have introduced additional bias or affected the robustness of between-group comparisons. Fourth, the inclusion of diverse injury types (ranging from fractures to soft tissue and nerve injuries) may have introduced variability in outcomes, making it more challenging to isolate the effect of the immobilization method alone. Finally, the follow-up period was limited to one-month post-immobilization, which restricted insights into the long-term effects of each intervention on functional recovery and patient satisfaction.

Given the promising results observed, future research should prioritize randomized controlled trials with larger sample sizes to validate these findings and support their clinical integration. Further studies are also needed to establish standardized protocols, refine the technological process and assess long-term outcomes. This study focused on clinical outcomes, while economic factors such as cost and accessibility were not directly evaluated. These aspects could also serve as valuable directions for future research.

5. Conclusions

This study contributes to the growing body of research on 3D-printed orthoses by providing comparative insights into pain management, patient satisfaction, and functional recovery after hand injuries. Our findings support the use of 3D-printed orthoses as a more effective and patient-friendly alternative to traditional plaster cast immobilization, demonstrating better clinical outcomes and enhanced hand rehabilitation.

These findings suggest that 3D-printed orthoses could redefine clinical practice by replacing standardized casting protocols with more flexible, patient-specific immobilization strategies. Their integration may enable more precise treatment planning, reduce the need for follow-up interventions and promote faster rehabilitation processes.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of West University of Timisoara.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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

Appendix A

Application of Orthoses:

Plaster Casts: the application of plaster casts followed the standard hospital protocol. Each patient's injured hand was stabilized and a medical doctor with expertise in orthopedic care applied the cast. The process involved positioning the hand, applying protective padding, and molding the plaster cast to ensure a proper fit and immobilization. Patients were given instructions on how to care for the plaster cast and address any complications.

3D-Printed Orthoses: the fabrication of 3D-printed orthoses began with a detailed assessment and measurement of the patient's hand using a 3D scanner (Structure Sensor Pro II), as seen in Figure A1-a,b,c. The digital scan was used to design a custom orthosis that met the individual's anatomical and functional requirements. Design considerations included fit, comfort and aesthetic preferences, as seen in Figure A1-d,e,f.

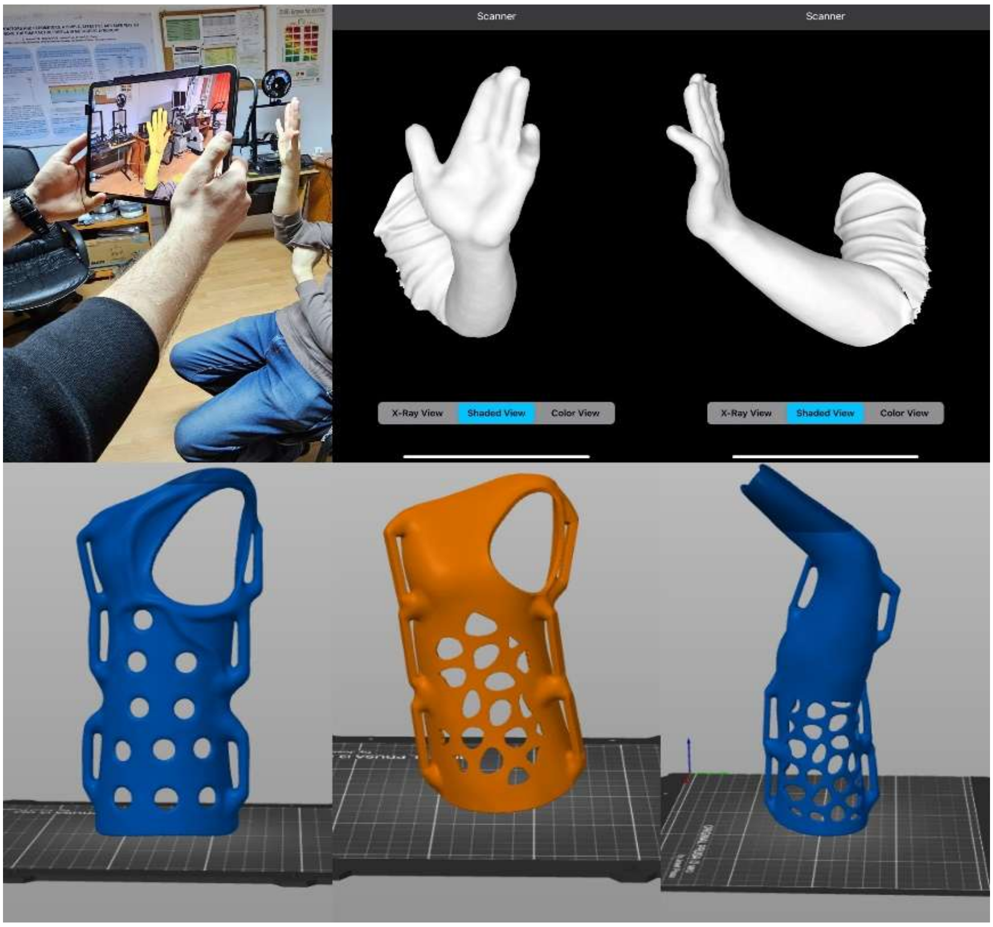

Figure A1. a) top left- Scanning phase; b) top middle- scanned hand; c) top right- scanned hand; d) bottom left- orthosis design; e) bottom middle- orthosis design; f) bottom right- orthosis design;

The orthoses were then printed (Creality Ender S1 Plus) using one of the materials: PETG, PLA or medical ABS, depending on patient-specific requirements and the orthotics specialist's recommendations. This is followed by the fitting step, which involves making minor adjustments to ensure a precise and comfortable fit, as seen in Figure A2. Patients were instructed on the use and care of the orthoses and encouraged to report any issues or discomfort.

Figure A2. Fitting step of 3D printed orthoses

References

1. Skirven, T.; Trope, J. Complications of immobilization. Hand Clinics, 1994, 10(1), 53-61.
2. Karita, T.; Matsuura, A.; Kondo, Y.; Tomimura, K.; Nakada, N.; Mori, F.F. Time course of changes in corticospinal excitability after short-term forearm/hand immobilization. Neuroreport, 2017, 28(16), 1092-1096.
3. Van Buijtenen, J. M.; van Delft, E. A.; Rijsdijk, M., Dobbe, J.G. G.; van der Veen, A., Streekstra, G. J.; Bloemers, F. W. Functional bracing in distal radius fractures: a cadaveric pilot study. Orthopedic Reviews, 2022, 14(3), 36574.
4. Fang, J. J.; Lin, C. L.; Tsai, J. Y.; Lin, R. M. Clinical Assessment of Customized 3D-Printed Wrist Orthoses. Applied Sciences, 2022, 12(22), 11538.
5. Sultana, S. S.; MacDermid, J. C., Grewal, R., Rath, S. The effectiveness of early mobilization after tendon transfers in the hand: a systematic review. Journal of Hand Therapy, 2013, 26(1), 1-21.
6. Ekanayake, C. G.; Gamage, J. C. P. H., Mendis, P., Weerasinghe, P. Revolution in orthopedic immobilization materials: A comprehensive review. Heliyon, 2023, 9(3).
7. Van Lieshout, E. M.; Verhofstad, M. H., Beens, L. M., Van Bekkum, J. J., Willemsen, F., Janzing, H. M., Van Vledder, M. Personalized 3D-printed forearm braces as an alternative for a traditional plaster cast or splint: a systematic review. Injury, 2022, 53, S47-S52.
8. Graham, J. W.; Wang, M., Frizzell, K., Watkins, C., Beredjiklian, P., Rivlin, M. Conventional vs 3-dimensional printed cast wear comfort. Hand, 2020, 15(3), 388-392.
9. 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. Journal of Hand Surgery (European Volume), 2024, 49(3), 350-358.

10. Xiao, Y. P.; Xu, H. J., Liao, W., Li, Z. H Clinical application of instant 3D printed cast versus polymer orthosis in the treatment of Colles fracture: a randomized controlled trial. BMC Musculoskeletal Disorders, 2024, 25(1), 104.
11. Oud, T. K.; Kerkum, Y., de Groot, P., Gijsbers, H., Nollet, F., Brehm, M. A. Production time and user satisfaction of 3-dimensional printed orthoses for chronic hand conditions compared with conventional orthoses: a prospective case series. Journal of Rehabilitation Medicine-Clinical Communications, 2021, 4, 1000048.
12. Onggo, J. D.; Fong, F. J. Y., Munro, Y. L., Yam, M. G. J. Applications of 3D printing in orthopedics: a scoping review. PREPRINT V1. Research Square, 2023, 15.
13. 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.
14. Chen, Y.; Lin, H., Yu, Q., Zhang, X., Wang, D., Shi, L., Zhong, S. Application of 3D‐Printed Orthopedic Cast for the Treatment of Forearm Fractures: Finite Element Analysis and Comparative Clinical Assessment. BioMed Research International, 2020, (1), 9569530.
15. Tonak, H. A.; Kaya Kara, O., Sahin, S. Correlation of hand functionality and grip strengths with anthropometric measurements. Work, 2021, 69(1), 187-195.
16. Das, A.; Dutta, M. Correlation between body mass index and handgrip strength and handgrip endurance among young healthy adults. Journal of Evidence-based Medicine and Healthcare, 2015, 2(27), 3995-4001.
17. Lee, S. C.; Wu, L. C., Chiang, S. L., Lu, L. H., Chen, C. Y., Lin, C. H., Lin, C. H. Validating the Capability for Measuring Age‐Related Changes in Grip‐Force Strength Using a Digital Hand‐Held Dynamometer in Healthy Young and Elderly Adults. BioMed Research International, 2020, 1, 6936879.
18. Ha, Y. C.; Yoo, J. I., Park, Y. J., Lee, C. H., Park, K. S. Measurement of uncertainty using standardized protocol of hand grip strength measurement in patients with sarcopenia. Journal of Bone Metabolism, 2018, 25(4), 243-249.
19. Kamimura, T.; Ikuta, Y. Evaluation of grip strength with a sustained maximal isometric contraction for 6 and 10 seconds. Journal of Rehabilitation Medicine, 2001, 33(5), 225-229.
20. Ward, C.; Adams, J. Comparative study of the test-retest reliability of four instruments to measure grip strength in a healthy population. The British Journal of Hand Therapy, 2007, 12(2), 48-54.
21. Chui, K. K.; Jorge, M., Yen, S. C., Lusardi, M. M. Orthotics and Prosthetics in Rehabilitation E-Book. St. Louis, Missouri: Elsevier Health Sciences, 2019
22. Pham, T. P.; Pathirana, P. N., Trinh, H., Fay, P. A non-contact measurement system for the range of motion of the hand. Sensors, 2015, 15(8), 18315-18333.
23. Reissner, L. F.; Fischer, G., List, R., Taylor, W. R., Giovanoli, P., Calcagni, M. Minimal detectable difference of the finger and wrist range of motion: comparison of goniometry and 3D motion analysis. Journal of orthopaedic surgery and research, 2019, 14, 1-10.
24. Norkin, C.; White, D. J. Measurement of joint motion: A guide to goniometry. Philadelphia, PA: F.A. Davis Company, 2016
25. Carvalho, R. M. Análise da confiabilidade e reprodutibilidade da goniometria em relação à fotogrametria na mão. Acta Ortopédica Brasileira, 2012, 20, 139-149.
26. Lewis, E.; Fors, L., Tharion, W. J. Interrater and intrarater reliability of finger goniometric measurements. The American Journal of Occupational Therapy, 2010, 64(4), 555-561.
27. Seethamma, K. M.; Raj, J. O., Prakash, N., Shetty, K. Correlation of forearm circumference and hand length with grip strength in healthy young adults. Acta Scientific Orthopaedics, 2019, 2(10).
28. Rawat, S. V.; Varte, L. R., Singh, I. J., Choudhary, S., Singh, S. Anthropometry-based prediction of dominant hand grip strength in Indian office-going females. Asian Journal of Medical Sciences, 2016, 7(6), 58-62.
29. Hemberal, M.; Doreswamy, V., Rajkumar, S. Study of correlation between hand circumference and maximum grip strength (MGS). National Journal of Physiology, Pharmacy and Pharmacology, 1970, 4(3), 195.
30. Yamazaki, H.; Sakurai, T., Uchiyama, S., Kato, H. Reliability and concurrent validity of the ring gauge method and the metacarpal head tape measure method of measuring hand size. The Journal of Hand Surgery (Asian-Pacific Volume), 2018, 23(03), 382-38.
31. Rostamzadeh, S.; Saremi, M., Tabatabaei, S. Normative hand grip strength and prediction models for Iranian office employees. Work, 2019, 62(2) 233-241.
32. Alahmari, K. A.; Paul Silvian, S., Reddy, R. S., Kakaraparthi, V. N., Ahmad, I., Alam, M. M. Determining the strength of hand grip for healthy adults in relation with hand length, forearm circumference, BMI and hand dominance. International Journal of Physiotherapy, 2016, 3(5).
33. Bodian, C. A.; Freedman, G., Hossain, S., Eisenkraft, J. B., Beilin, Y. The visual analog scale for pain. Anesthesiology, 2001, 95(6), 1356-1361.
34. Hawker, G. A.; Mian, S., Kendzerska, T., French, M. Measures of adult pain: Visual Analog Scale for pain (VAS pain), Numeric Rating Scale for pain (NRS pain), Mcgill Pain Questionnaire (MPQ), short‐form Mcgill Pain Questionnaire (sf‐MPQ), chronic pain grade scale (CPGS), short form‐36 bodily pain scale. Arthritis care & research, 2011, 63(S11), S240-S252.
35. Kane, R. L.; Bershadsky, B., Rockwood, T., Saleh, K., Islam, N. C. Visual analog scale pain reporting was standardized. Journal of Clinical Epidemiology, 2005, 58(6), 618-623.

36. Demers, L.; Weiss-Lambrou, R., Ska, B. The Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0): an overview and recent progress. Technology and Disability, 2002, 14(3), 101-105.
37. Demers, L.; Weiss-Lambrou, R., Ska, B. Item analysis of the Quebec user evaluation of satisfaction with assistive technology (QUEST). Assistive Technology, 2000, 12(2), 96-105.
38. Durham, J.; Sychareun, V., Santisouk, P., Chaleunvong, K. Users' satisfaction with prosthetic and orthotic assistive devices in the Lao People's Democratic Republic: a cross-sectional study. Disability, CBR and Inclusive Development, 2016, 27(3), 24-44.
39. Galeoto, G.; Colucci, M., Guarino, D., Esposito, G., Cosma, E., De Santis, R., Tofani, M. Exploring validity, reliability, and factor analysis of the Quebec user evaluation of satisfaction with assistive technology in an Italian population: a cross-sectional study. Occupational Therapy in Health Care, 2018, 32(4), 380-392.
40. Burton, M.; Nieuwenhuijsen, E. R., Epstein, M. J. Computer-related assistive technology: Satisfaction and experiences among users with disabilities. Assistive Technology, 2008, 20(2), 99-106.
41. Chen, C.; Teng, Y. L., Lou, S. Z., Lin, C. H., Chen, F. F., Yeung, K. T. User satisfaction with orthotic devices and service in Taiwan. PLoS ONE, 2014, 9(10), e110661.
42. Boiani, J. A. M.; Sandnes, F. E., Paschoarelli, L. C., Medola, F. O. Satisfaction of aged users with mobility assistive devices: A preliminary study of conventional walkers. In Human Systems Engineering and Design II: Proceedings of the 2nd International Conference on Human Systems Engineering and Design (IHSED2019): Future Trends and Applications, September 16-18, 2019, Universität der Bundeswehr München, Munich, Germany (pp. 742-746). Springer International Publishing.
43. Shauver, M. J.; Chung, K. C. The Michigan hand outcomes questionnaire after 15 years of field trial. Plastic and Reconstructive Surgery, 2013, 131(5), 779e-787e.
44. Oh, Y.; Drijkoningen, T., Menendez, M. E., Claessen, F. M., Ring, D. The influence of psychological factors on the Michigan Hand Questionnaire. Hand, 2016, 12(2), 197-201.
45. Waljee, J. F.; Kim, H. M., Burns, P. B., Chung, K. C. Development of a brief, 12-item version of the Michigan Hand Questionnaire. Plastic and Reconstructive Surgery, 2011, 128(1), 208-220.
46. Sierakowski, K. L.; Dean, N. R., Mohan, R., John, M., Griffin, P. A., Bain, G. I. Prospective randomized cohort study to explore the acceptability of patient-reported outcome measures to patients of hand clinics. Journal of Hand Surgery Global Online, 2020, 2(6), 325-330.
47. Skibicki, H. E.; Katt, B. M., Lutsky, K., Wang, M. L., McEntee, R., Vaccaro, A. R., Rivlin, M. Three-dimensionally printed versus conventional casts in pediatric wrist fractures. Cureus, 2021, 13(10).
48. Schlégl, Á. T.; Told, R., Kardos, K., Szőke, A., Ujfalusi, Z., Maróti, P. Evaluation and Comparison of Traditional Plaster and Fiberglass Casts with 3D-Printed PLA and PLA–CaCO3 Composite Splints for Bone-Fracture Management. Polymers, 2022, 14(17), 3571.
49. Von Haller, M.; Couchman, L., Honigmann, P. Production time and practicability of 3D-printed wrist orthoses versus low-temperature thermoplastic wrist orthoses. Hand Therapy, 2024, 29(4), 188-194.
50. Portnoy, S.; Barmin, N., Elimelech, M., Assaly, B., Oren, S., Shanan, R., & Levanon, Y. Automated 3D-printed finger orthosis versus manual orthosis preparation by occupational therapy students: Preparation time, product weight, and user satisfaction. Journal of Hand Therapy, 2020, 33(2), 174-179.
51. Lee, S. H.; Gong, H. S. Grip strength measurement for outcome assessment in common hand surgeries. Clinics in Orthopedic Surgery, 2022, 14(1), 1.
52. Chae, D. S.; Kim, D. H., Kang, K. Y., Kim, D. Y., Park, S. W., Park, S. J., Kim, J. H. The functional effect of 3D-printing individualized orthosis for patients with peripheral nerve injuries: Three case reports. Medicine, 2020, 99(16), e19791.
53. Marinho, F. D.; Santos, P. M. D., Nardi, S. M. T., Sime, M. M., Coutinho, G. C. Use of 3D printed orthosis and occupational therapeutic treatment in rhizarthrosis. Cadernos Brasileiros de Terapia Ocupacional, 2020, 28, 1151-1164.
54. Zheng, Y.; Liu, G., Yu, L., Wang, Y., Fang, Y., Shen, Y., Hua, Z. Effects of a 3D-printed orthosis compared to a low-temperature thermoplastic plate orthosis on wrist flexor spasticity in chronic hemiparetic stroke patients: a randomized controlled trial. Clinical Rehabilitation, 2020, 34(2), 194-204
55. Arulmozhi, R. S.; Vaidya, M., Poojalakshmi, M. G., Ashok Kumar, D., Anuraag, K. 3D design and printing of custom-fit finger splint. Biomedical Engineering: Applications, Basis and Communications, 2018, 30(05), 1850032.
56. Nam, H. S.; Seo, C. H., Joo, S. Y., Kim, D. H., Park, D. S. The application of three-dimensional printed finger splints for post hand burn patients: a case series investigation. Annals of Rehabilitation Medicine, 2018, 42(4), 634-638.
57. Guida, P.; Casaburi, A., Busiello, T., Lamberti, D., Sorrentino, A., Iuppariello, L., Clemente, F. An alternative to plaster cast treatment in a pediatric trauma center using the CAD/CAM technology to manufacture customized three-dimensional printed orthoses in a total hospital context: a feasibility study. Journal of Pediatric Orthopaedics, 2019, B 28(3), p 248-255.
58. Oud, T.; Tuijtelaars, J., Bogaards, H., Nollet, F., & Brehm, M. A. Preliminary effectiveness of 3D-printed orthoses in chronic hand conditions: Study protocol for a non-randomized interventional feasibility study. BMJ open, 2023, 13(4), e069424.
59. Tanja, O. U. D.; Bogaards, J. A., Nollet, F., & Brehm, M. A. Preliminary effectiveness and production time and costs of three-dimensional printed orthoses in chronic hand conditions: an interventional feasibility study. Journal of Rehabilitation Medicine, 2024, 56, 39946.