The Use of Orthoses Made With 3D Printer in Upper Extremity Rehabilitation: A Review

Üst Ekstremite Rehabilitasyonunda 3D Yazıcıyla Yapılan Ortezlerin Kullanımı: Derleme

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Abstract

Recent advancements in technology have brought about a significant transformation in the healthcare industry, particularly in the rehabilitation services sector, with the adoption of 3D (3 Dimensional) printing. This technology plays a crucial role in designing customized, aesthetically pleasing, lightweight, and eco-friendly orthoses for upper extremity rehabilitation. 3D scanning systems accurately predict the production process of orthoses, making it easier to maintain records of orthotic models. These recorded models make repetitive and batch production processes more efficient and accessible. However, the use of 3D printers in developing countries is limited due to high costs. Additionally, there is a lack of evidence-based practices. To overcome these challenges, efforts are underway to improve software interfaces for orthotic production and integrate 3D printed orthoses into upper extremity rehabilitation models. Further research is necessary to explore the optimal parameters for 3D printing in upper extremity orthotic production across diverse demographics.

Keywords: Assistive technology, printing, rehabilitation, three-dimensional, upper extremity

Öz

Son yıllarda teknolojideki gelişmeler, sağlık hizmetleri sektöründe özellikle rehabilitasyon hizmetleri alanında 3D (3 Boyutlu) baskının benimsenmesiyle önemli bir dönüşüm yaratmıştır. Bu teknoloji, üst ekstremite rehabilitasyonu için özelleştirilmiş, görsel olarak çekici, hafif ve çevre dostu ortezlerin tasarlanmasında önemli bir rol oynamaktadır. 3D tarama sistemleri, ortezlerin üretim sürecini doğru bir şekilde öngörerek, ortez modellerinin kayıtlarını tutmayı kolaylaştırır. Bu kayıtlı modeller, tekrarlı ve seri üretim süreçlerini daha verimli ve erişilebilir hale getirir. Ancak, yüksek maliyetler nedeniyle gelişmekte olan ülkelerde 3D yazıcıların kullanımı sınırlıdır. Ayrıca, kanıta dayalı uygulamaların eksikliği bulunmaktadır. Bu zorlukların üstesinden gelmek için, ortez üretimi için yazılım arayüzlerini geliştirme ve 3D baskılı ortezleri üst ekstremite rehabilitasyon modellerine entegre etme çabaları sürdürülmektedir. Farklı demografik gruplar arasında üst ekstremite ortez üretiminde 3D baskı için optimal parametreleri araştırmak üzere daha fazla araştırma gereklidir.

Anahtar Kelimeler: Baskı, rehabilitasyon, üç boyutlu, üst ekstremite, yardımcı teknoloji

1. Introduction

Orthotics are medical therapeutic devices widely accepted in clinics, and applied externally to a part of the body to modify the structural or functional properties of the neuromusculoskeletal system. These devices are designed for many conditions and purposes such as assisting the functions of the human body, preventing or correcting deformities that restrict movement, supporting weak or ineffective joints or muscles, and providing stability while performing daily life activities. The use of orthoses in the upper extremity include flexor-extensor tendon injuries, finger deformities, stroke-induced spasticity, fractures, dislocations, subluxations, arthropathy, osteoarthritis and spinal cord injuries (Baroni et al., 2016; De Jesus Faria, 2017).

In the field of orthopedic rehabilitation, there is a growing interest in the design of customized upper extremity orthoses that can accommodate interpersonal anatomic variations in human body. In clinical practice, occupational therapists and specially trained certified hand therapists are the practicioners of orthoses. Upper limb orthoses are complex and delicate structures that are accepted to complement treatment, especially around a wrists which have been subjected to various injuries. Examples of these structures include prefabricated orthoses within traditional orthoses and personalized orthoses manufactured manually with thermoplastic material (Baroni et al., 2016; De Jesus Faria, 2017; Wagner et al., 2018). With the developements in technology, 3D scanning and printing applications have been used in the production of medical therapeutic devices. Personalized orthoses produced with 3D printers, which have various advantages and disadvantages compared to traditional ones, are examples of complex and sensitive structures (Wagner et al., 2018; Aydın and Küçük, 2017). Traditional orthoses are auxiliary medical devices made of metal, steel, leather, aluminum, titanium, magnesium, wood, plastic and composite, thermoplastic, thermoset material, thermoformed, foamed plastic, etc., and they are produced by rehabilitation staff and technicians through traditional methods specifically for the users for various purposes (Baroni et al., 2016; Aydın and Küçük, 2017).

The steps involved in the orthosis production phase vary according to the limb to which the orthosis is applied. In a traditional orthosis application, the treatment goals are determined first. Afterwards, the appropriate material and design are selected, and then measurements are taken with the correct positioning. By paying attention to biomechanical properties and pressure points, various strap additions and corrections with heating devices may be preferred. Recently, the use of 3D printing technologies in medical applications has also increased rapidly. Especially with 3D printing technologies used in the manufacture of assistive devices, personalized orthoses in orthopedic rehabilitation can be designed (Baroni et al., 2016; Wagner et al., 2018; Aydın and Küçük, 2017).

The advantages and disadvantages of 3D printing technology are still being discussed with evidence-based applications. 3D printing technologies involve certain steps as in traditional orthoses that are manufactured manually. Unlike traditional orthoses, some of these steps take place in digital environments. There are four main steps in 3D printing technologies: modeling, slicing, printing and finishing. Modeling involves creating a 3D digital model. A computer-aided orthotic design is possible through optical scanners. A 3D printer works mainly by extruding molten material through a small nozzle that moves, controlled by a computer. The printer prints a layer, waits for it to dry, and then prints the next layer on top, making it possible to create three-dimensional solid objects from a digital file (Wagner et al., 2018; Yılmaz et al., 2013; Choo et al., 2020; Koldaş and Selamet, 2018).

3D printers taking advantage of additive manufacturing technology usually use thermoplastic materials called filaments. The most common raw materials used in 3D printers include PLA (Polylactic Acid), ABS (Acrylonitrile Butadiene Styrene), TPU (Thermoplastic Polyurethane), PETG (Glycol Modified Polyethylene Terephthalate) and Nylon. PLA in which corn starch and sugar cane is used as raw material is durable and resistant to impacts. Also, it is easy to print, and its flexibility is moderate when compared to other materials. ABS with petroleum as raw material is more laborious to print than PLA. As its raw material is petroleum, it is not recommended for use with food/beverages, and it has low flexibility. TPU is a material with high abrasion resistance and flexibility. It is also easy to process and has very low heat conduction. In terms of

strength, it is superior to other polymers. Nylon possesses great mechanical properties, and in particular, the best impact resistance for a non-flexible filament. It has excellent chemical resistance and is very strong. Finally, PETG is plastic soaked in glycol. PETG is more flexible than ABS and PLA. Highly rigid and durable PETG can be used with food and beverages. Figure 1 below shows the properties of the materials (Kerteriz Blog, 2022; 3D Printing Expert-Boyut Kat, 2021).

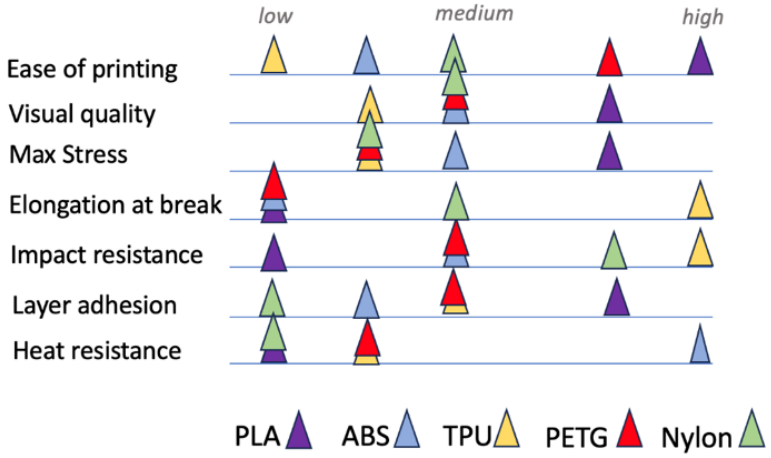

Figure 1. Polymers for FDM 3D printing (Artıboyut Group, 2022)

3D scanning is a way to capture the exact size and shape of a physical object on our computer as a digital three-dimensional representation. 3D scanning captures the complex geometry, irregular shape, colored texture, and other details of the scanned 3D object. There are different types of 3D scanning methods and the principles that they are based on (Simplify 3D Group, 2022; HUBS A Protolab, 2021).

This review aims to examine the advantages and the disadvantages of orthoses produced with 3D printers, which are used in upper extremity rehabilitation and are increasingly used in clinics with the development of technology, compared to orthoses produced by traditional methods.

2. Method

We followed a number of steps in conducting this study. First, we decided on the research topic before identifying the inclusion and exclusion criteria. We then used the keywords considering the specified criteria for the research. We reviewed the abstracts of the studies to ensure that the selected works met all the criteria. In this line, we excluded the studies that did not meet the inclusion criteria, whereas we examined the ones that met the inclusion criteria, and read them in detail.

We used the databases Pubmed, Google Scholar, OTSeeke and OTDbase to get access to the related articles. The keywords we used included “orthoses or cast”, “3d printer”, “upper extremity or upper limb” and “rehabilitation” (Figure 2). We also reviewed the keywords in the MeSH glossary. We then reviewed the references of the studies we had chosen. The review included studies focusing on the use and construction of orthoses produced with 3D printers in upper extremity rehabilitation. We scanned the studies conducted in the last 5 years in the databases. In this line, we included the studies between 2017 and 2023-April. We scanned the titles and abstracts, and we kept the articles that we thought were relevant to review the full text later. In this way, we identified the appropriate articles to include in the study. We excluded the publications such as books and reviews from the study. We also excluded the articles that did not have full text access and were not written in Turkish or English. Figure 3 below shows the flow chart about the data collection process.

orthoses ***or*** cast	***AND***	3d printer	***AND***	upper limb ***or*** upper extremity	***AND***	rehabilitation

Figure 2. Keywords

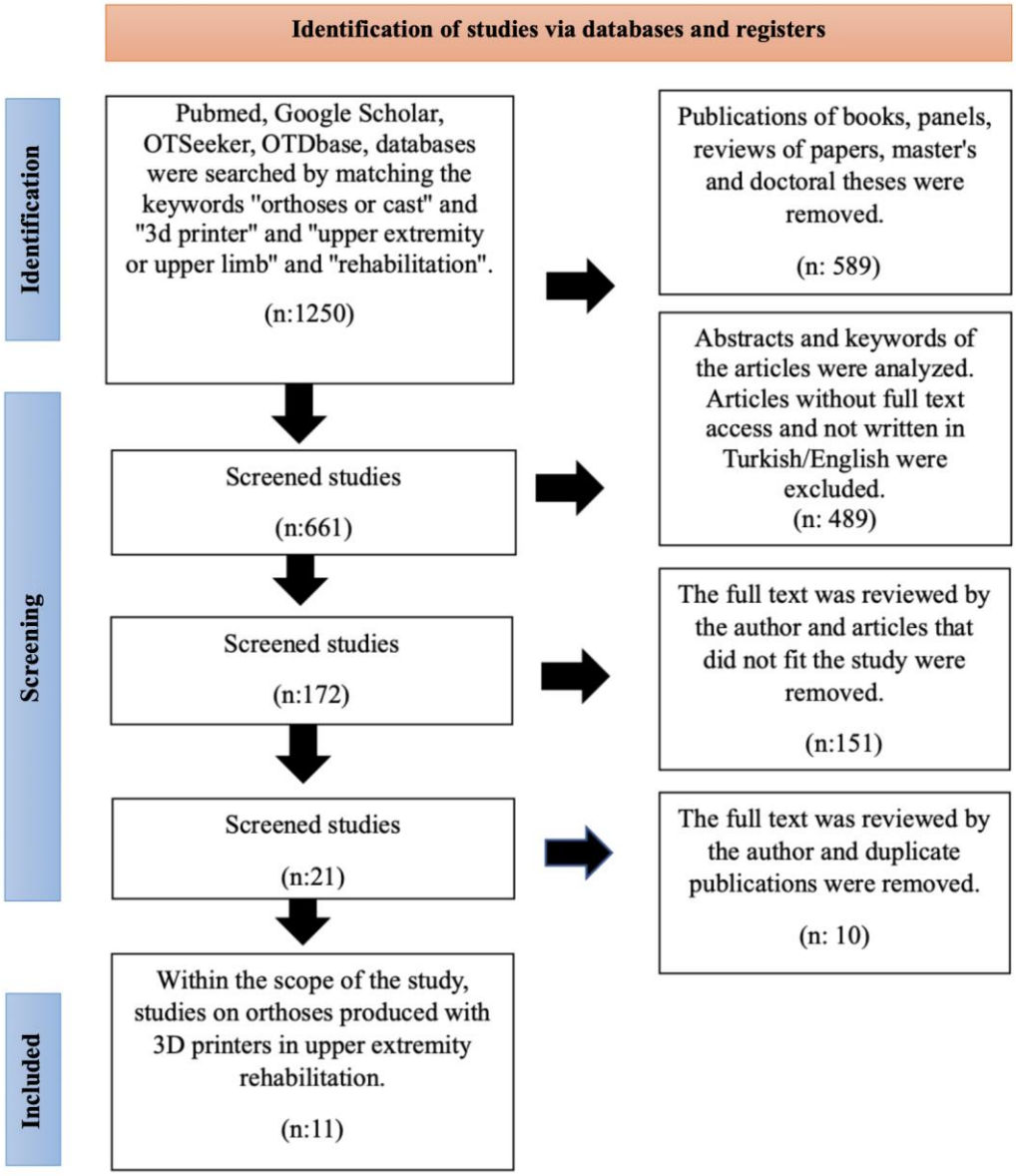

Figure 3. Flow Chart

3. Results

In the current study, we identified 1250 articles describing the use of 3D printed orthoses. As the study focuses on upper extremity, we excluded the 3D printing studies conducted on lower extremity, dental devices and other assistive devices apart from the ones having the features of exclusion criteria listed above. In this line, two of the 11 studies were randomized clinical trials; one of them was a prospective observational trial; one was a case series, one was a cross-sectional study, one was a project, one was a pilot study, and four of them were case reports.

This review aims at examining the advantages and disadvantages of using 3D printed orthoses and traditional methods in upper extremity rehabilitation. Some of the articles reviewed within the scope of this study showed that the orthosis produced via printing technology met the basic requirements of the treatment by providing various advantages such as being light, washable and functional, using a biodegradable material, and offering the opportunity of a personalized design (Portnoy et al., 2020; Zheng et al., 2020; Agudelo-Ardila and Prada-Botia, 2019; De Souza et al., 2017). Another study found out that the use of 3D orthosis added to the intervention together with treatment or therapeutic activities/exercises was effective in pain relief, grip strength and lateral grip (clamp) gain through joint protection techniques (Huber et al., 2023).

It was stated in some other studies that 3D printing technology could offer solutions for the pediatric population and other groups with limited options for orthosis production in the future. It was also stated that due to the high cost of 3D printers and equipment in developing countries, 3D printing production may not provide an advantage in terms of price when compared to traditional products. This can have a negative impact on using this resource in developing countries (Marinho et al., 2020; Chen et al., 2017; Chu et al., 2022). However, 3D printing production is expected to reduce the cost compared to traditional hand orthosis production with the development of technology as user interfaces will improve and it will take less time to complete the production (Portnova, 2018; Kim SJ, 2018; Wang, 2018).

Table 1 and Table 2 below show the study design of the articles included in the review, clinical characteristics as well as the number of participants, the body part for which the orthoses were produced, the material which was preferred in orthosis use and information about the post-use period.

4. Discussion

The modern advancements in technology, both in our country and around the world, have brought about significant improvements in several healthcare services. With the latest technological developments, 3D printing technologies have become increasingly popular and are now widely used in the rehabilitation process, which falls under the scope of healthcare services. Their applications have expanded, making them an invaluable resource in the healthcare industry.

According to our study, orthoses manufactured using 3D printers can be an effective treatment option since they are lighter in weight and more functional than orthoses produced using traditional methods. This invention is also supported by other studies in the literature. For instance, a study conducted by Oud et al. in 2021 suggests that using 3D scanning systems in orthosis production reduces the production time compared to traditional methods.

According to Oud et al., one advantage of orthosis design is that it can be stored digitally. Orthoses produced with traditional methods and those produced with 3D printers are reportedly similar in terms of user satisfaction (Oud et al., 2021). Additionally, a study conducted in 2021 found that 3D printing systems offer advantages in production and application compared to traditional methods (Hasibuzzaman et al., 2021).

It has been found that 3D printing is a faster process than traditional production methods when it comes to creating the final product. A study also found that orthoses produced with 3D scanning and printing systems use less material compared to those produced with traditional methods. Moreover, a 2020 study highlighted that using 3D printing systems shortened the time that is needed to produce an orthosis. Additionally, patients with peripheral nerve injury who used orthoses produced with 3D printing were evaluated using QUEST (Quebec User Evaluation of Satisfaction with Assistive Technology). Results from QUEST showed that these patients were satisfied with the orthoses (Chae et al., 2020).

It has been noted that 3D printers have some disadvantages. One of them is that the technology relies on the user to manually remove the finished parts from the printer table in order to start a new production. This constraint prevents 3D printing from being used as a mass production tool. Furthermore, it has been mentioned that certain skills are required to operate and produce with 3D printing systems, as highlighted by Oud et al. (2021).

In our study, we discussed the pros and cons of using 3D printing systems for upper extremity rehabilitation. Existing literature also supports our results. While there are currently limited studies on the production of upper extremity orthoses using 3D printing technology, the field is rapidly expanding.

5. Conclusion

Among all printing technologies, in a customized area such as 3D printers and upper extremity rehabilitation, it is possible to produce aesthetic, lightweight and environmentally friendly orthoses in a short time. 3D scanning systems make it possible to foresee the production process and final output of the orthosis, and to

record the upper extremity orthosis models. The records of models can provide an advantage in accessibility, repeatability and multiple production. However, the limited number of evidence-based practices as well as the high cost of 3D printers and equipment in developing countries can adversely affect resource availability for both service providers and recipients.

The use of 3D printer-generated orthoses in upper limb rehabilitation is expected to be more widespread soon with the improvements in the interface of the programs used to produce orthoses via 3D printing, the design of models in which 3D printer-generated orthoses are integrated into upper limb rehabilitation, and the development of technology. Further evidence-based multidisciplinary research is needed to examine the parameters of the use of 3D printing technologies in the production of upper extremity orthoses.

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Table 1. The articles used in this study and their results

Author/Year	Study design	Participants	Body part	Type of orthosis	Digital fabrication method	3D printer's method	Material used	Conclusion
Portnoy et al./ 2020	Cross-sectional Study	n:36, occupational therapy student	Upper extremity (finger)	Swan Neck Orthosis	3D scanner	FDM (Fused deposition modelling)	ABS	The method of 3D printing provides higher satisfaction in terms of convenience, aesthetics and overall preparation process.
Zheng et al./ 2020	Randomized controlled trial	n:40, flexor spasticity	Upper extremity (wrist)	Wrist Orthosis	CAD	SLA (Stereolithography)	Resin	3D printing orthosis is more beneficial in reducing wrist flexor spasticity, shimmy, improving wrist motor function and passive wrist extension.
Ardila et al./ 2019	Project (methodology)	n:1, inclusion criteria not specified	Upper extremity (hand)	Hand and Wrist Orthosis	3D scanner	SLS (Selective laser sintering)	Thermo plastic (nylon)	3D-printed orthosis meets certain treatment goals such as comfort, hygiene, aesthetics, lightness, removability and immobilization.
Souza et al./ 2017	Case study	n:1, distal radius fractures	Upper extremity (wrist)	Hand and Wrist Orthosis	3D scanner	Low Budget 3D Printer (Graber i3)	PLA	3D printing has advantages such as low cost, accessible and lightweight design, customised production, functionality, washability and use of biodegradable material.
Huber et al./ 2023	Pilot study	n:5, stroke	Upper extremity (hand)	Hand and Wrist Orthosis	Unspecified	SLS	TPU	A dynamic WHFO (wrist hand finger orthosis) may be feasible using 3DP elastic materials. Such devices may present advantages when compared to the current commercially available competitors.
Marinho et al./ 2020	Case series	n:6, rhizoarthrosis	Upper extremity (thumb)	Thumb orthosis	Unspecified	Unspecified	PLA	When 3D printing orthotic equipment is used as an adjunct to treatment, it is effective in alleviating pain, gaining grip strength and tweezer grip. Monitoring the production process, ease of use and comfort are the three main advantages for satisfaction.

Table 2. The articles used in this study and their results

Author/Year	Study design	Participants	Body part	Type of orthosis	Digital fabrication method	3D printer's method	Material used	Conclusion
Chen et al./ 2017	Prospective observational trial	n:10, distal radius fractures	Upper extremity (forearm and wrist)	Cast	BT and MR	SLS	PP and PA (Polyamide and polypropylene)	3D printing production, ventilated structure and fashionable design increase patients' satisfaction and comfort.
Chu et al./ 2020	Case study and model development	n:120, healthy	Upper extremity (forearm)	Short thumb orthosis	3D scanner	FDM	TPE (Thermoplastic elastomer)	Thanks to the 3D parametric hand model, the scanning process can be neglected in production, model creation can take a very short time, and it can be practical.
Portnova et al./ 2018	Case study	n:3, spinal cord injury	Upper extremity (thumb)	Wrist Operated Orthosis	CAD	FFF (Fused filament fabrication)	ABS	3D printing orthosis may provide advantages such as increasing accessibility, reducing the time spent for production, and improving potency on ADL functions of individuals with SCI. It can also provide a solution to limited orthotic options for the paediatric population.
Kim et al./ 2018	Randomized controlled trial	n:22, wrist pain	Upper extremity (forearm and wrist)	Wrist Orthosis	3D scanner	FDM	TPU	When printing technology develops and becomes widespread, 3D printed orthoses can be used instead of traditional ready-made orthoses. In addition, high satisfaction was shown in 2 activities (using a touch phone, applying toothpaste to the brush and applying the brush to the teeth) with the 3D printed orthosis.
Wang et al./ 2018	Case study	n:18, hand spasm caused by cerebral stroke	Upper extremity (hand)	Finger pad	3D scanner and palm moulding	FDM	PLA	There is a statistically significant difference for spasm and range of motion when compared to conventional products. However, 3D production does not provide an advantage in terms of price.

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