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Review Article

Upper limbs orthesis and prostheses printed in 3D: an integrative review

Órteses e próteses de membro superior impressas em 3D: uma revisão integrativa

Sandra Yoshie Uraga Morimoto[a], Ana Karina Pessoa da Silva Cabral[a], Danielle Carneiro de Menezes Sanguinetti[a], Elvis da Silva Rodrigues de Freitas[a], Giselle Schimidt Alves Diaz Merino[b], José Ângelo Peixoto da Costa[c], Weldma Karlla Coelho[d], Daniela Salgado Amaral[b]

[a]Universidade Federal de Pernambuco – UFPE, Recife, PE, Brasil.
[b]Universidade Federal de Santa Catarina – UFSC, Florianópolis, SC, Brasil.
[c]Instituto Federal de Pernambuco – IFPE, Recife, PE, Brasil.
[d]Centro de Reabilitação e Medicina Física Professor Ruy Neves Baptista – IMIP, Recife, PE, Brasil.

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Abstract

Introduction: Three-dimensional (3D) printing is capable of making advanced and specialized physical products using computerized technologies and specific software. Some of these products are orthosis and prostheses which can support patients' functionality in their daily lives. **Objective:** To identify the type, the usage, and the applicability of 3D printing on the development of upper limbs' orthosis and prostheses. **Method:** Integrative review carried out on the following databases: Pubmed, LILACS, Web of Science, Scopus e Science Direct, with no specific publication period, written in English, Spanish or Portuguese. It also had to fit the following criteria: experimental and observational studies and case reports which had 3D printed orthosis and prosthesis as the object of study with patients of any age or diagnosis of upper limb damage. **Results:** Nine studies were included. Seven referred to the use of 3D printing to make prosthesis and 2 to make orthosis. Many studies were directed to children and the most used materials were PLA and ABS. The multidisciplinary team was fundamental in the process of evaluation, creation, and testing of the devices. **Conclusion:** Despite the analyzed studies mention initial phases of development and investigation of the applicability of 3D printing in the creation of orthosis and prostheses, it was observed that cost-benefit improvements generated by the use of this technology already exist, as well as the possibility of generating more versatile products. It's a promising field to amplify the applicability of 3D printing as a resource facilitating the rehabilitation process.

Keywords: Orthotic Devices, Artificial Limbs, Printing; Three-Dimensional, Upper Extremity, Rehabilitation.

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Resumo

Introdução: A impressão tridimensional (3D) é capaz de confeccionar produtos físicos avançados e especializados por meio de tecnologia computadorizada e *softwares* específicos. Alguns desses produtos são as órteses e próteses, que podem favorecer a funcionalidade do sujeito em seu cotidiano. **Objetivo:** Identificar o tipo, o uso e a aplicabilidade da impressão 3D na confecção de órteses e próteses para membro superior. **Método:** Revisão integrativa realizada nas bases de dados PubMed, LILACS, Web of Science, Scopus e Science Direct, sem delimitação de tempo, na língua portuguesa, inglesa ou espanhola, seguindo os critérios de elegibilidade: estudos do tipo experimental, observacional e relatos de casos, cujo objeto de estudo foram as órteses e próteses impressas em 3D, com pacientes de qualquer idade e qualquer diagnóstico de comprometimento do membro superior. **Resultados:** Foram incluídos nove artigos, sete referentes ao uso da impressão 3D na confecção de prótese e dois referentes à confecção de órteses. Muitos dos estudos foram direcionados ao público infantil e os materiais mais utilizados para confecção foram o PLA e o ABS. A equipe multidisciplinar foi apresentada como fundamental no processo de avaliação, criação e testagem dos dispositivos. **Conclusão:** Apesar dos estudos analisados tangenciarem fases iniciais de desenvolvimento e investigação da aplicabilidade da impressão 3D na criação de órteses e próteses, observou-se que já existem melhorias do custo-benefício gerado pelo uso desta tecnologia, bem como a possibilidade de gerar produtos mais versáteis. Apontando-se como um campo promissor para ampliar a aplicação da impressão 3D como recurso facilitador do processo de reabilitação.

Palavras-chave: Aparelhos Ortopédicos, Membros Artificiais, Impressão Tridimensional, Extremidade Superior, Reabilitação.

Introduction

Three-dimensional (3D) printing also called additive manufacturing or rapid prototyping is characterized by the manufacture of physical products using computerized technology. Three-dimensional virtual models developed by specific software are used to give greater freedom of production and design, especially in the materials and varied shapes to those who make them (Gerstle et al., 2014; Maia, 2016).

This type of technology has been developed for over 30 years; however, only in the last decade it has grown and became significantly accessible, both for the general population and for those who study it. This was because of its wide diversity use and the low cost of products that can be made, valuing its exploitation by several markets, including the health area (Gerstle et al., 2014; Baronio et al., 2016; Maia, 2016).

In the health area, 3D printing is gaining space and is increasingly legitimized since it is capable of nimbly producing more advanced and specialized prototypes such as the printing of specific organs, parts of the body, and different Assistive Technology devices (AT), for example (Gerstle et al., 2014; Baronio et al., 2016).

As in this research, we approach orthoses and prostheses printed in 3D, comprising Assistive Technology resources, we have that AT can be any product, equipment, resource, product system, methodologies, or strategies that aim to restore and maintain the functionality of individuals with disabilities or reduced mobility and their social participation (Brasil, 2009; Costa et al., 2015; Brasil, 2015a; Cook & Polgar, 2015).

AT is classified according to specific areas, such as the aid for daily and practical life; the augmentative and alternative communication; computer resources and computer accessibility; architectural designs for accessibility; mobility aids; environmental control systems; postural adequacy; aids to expand the visual function and resources that translate visual content into audio or tactile information; aids to improve hearing function and resources used to translate audio content into images, text and sign language; vehicle mobility; sports and leisure; in addition to orthoses and prostheses (Brasil, 2009; Costa et al., 2015; Bersch, 2017).

According to the International Organization for Standardization (1989), orthosis also called an orthopedic device is defined as a device used to modify structural and functional characteristics of the neuromusculoskeletal system. Prostheses or also prosthetic devices are devices used to replace, totally or in part, a segment of the limb, or part of the human body that is absent or disabled.

Orthotic and prosthetic devices can be made and developed from different materials, selected and targeted to each individual, considering factors such as financial condition, level of impairment of function, and type of material most appropriate to the purpose of the device. Some materials are wood, metal, rubber, leather, and thermoplastic polymers, which vary according to their properties and constitutions (Agnelli & Toyoda, 2003; Gonçalves & Francisco, 2011; Maia, 2016). Nowadays, it is possible to produce sophisticated and adjustable devices that allow more refined and complex movements based on innovative technologies such as three-dimensional printing (Baronio et al., 2016; Maia, 2016).

Orthoses and prostheses are some of the resources to promote the habilitation and rehabilitation of patients with a physical impairment that has implications for functionality. Thus, the use of these resources helps in the treatment of patients, favoring the recovery of their organic functions and contributing to the best prognosis of the impairment (Agnelli & Toyoda, 2003; Cavalcanti & Galvão, 2011; Radomski & Latham, 2013).

The manufacture of orthoses and prostheses printed in 3D has become even stronger, increasing the visibility by health professionals and increasingly requiring studies to deepen the knowledge of its use. 3D printing allows the manufacture of these products with high levels of customization, which can guarantee patients a smoother and more comfortable return to their routine (Gerstle et al., 2014; Baronio et al., 2016). In this perspective, this study aimed to group and synthesize the research that is being carried out around the world, regarding the manufacture of orthoses and prostheses for upper limbs printed in 3D, to analyze them, describe them and provide clinical and scientific progress for the area. Thus, the study aims to identify the type, use, and applicability of 3D printing in the manufacture of orthoses and prostheses for the upper limbs.

Method

This is an integrative review. It is a method widely used today aiming at evidence-based practice. This type of review can identify, study and critically analyze data resulting from various researches, generating a synthesis of the publications on a theme and providing the basis for a significant study (Souza et al., 2010).

The collection was carried out in August 2018, accessing PubMed, LILACS, Web of Science, Scopus and Science Direct databases, via the network of the *Comunidade Acadêmica Federada* (CAFe) of the Federal University of Pernambuco, which is a service maintained by the National Research Network and offers easy access to the content of the CAPES Journal Portal. The terms used for the search were crossed using the Boolean operators “AND” and “OR”. For the Scopus and Web of Science databases, all descriptors were crossed. In the case of Science Direct, we used isolated searches only for terms related to 3D printing, and in the PubMed and LILACS databases, we used the descriptors Mesh/Decs (in bold).

Orthoses

1. (**Orthotic devices** *or* **splints** *or* orthosis *or* custom orthosis)
2. (**Printing, three-dimensional** *or* **computer-aided design** *or* rapid prototyping *or* additive manufacturing *or* computer-aided drafting *or* computer-aided manufacturing *or* three-dimensional design *or* three-dimensional)
3. (**Rehabilitation**)
4. #1 *and* #2 *and* #3

Prostheses

1. (**Artificial limbs** *or* prostheses)
2. (**Printing, three-dimensional** *or* **computer-aided design** *or* rapid prototyping *or* additive manufacturing *or* computer-aided drafting *or* computer-aided manufacturing *or* three-dimensional design *or* three-dimensional)
3. (**Rehabilitation**)
4. #1 *and* #2 *and* #3

We included articles in Portuguese, English, and Spanish with experimental and observational methodological designs and case reports, which had orthoses and prostheses printed in 3D as the object of study and that the product was intended for patients with upper limb disorders, regardless of diagnosis and/or age. We excluded papers that discussed 3D products other than upper limb orthoses and prostheses. The period of publication of the articles was not limited because it is a recent component in the health area.

Two reviewers (reviewer A and B) selected the articles from an initial reading of the titles, abstracts, and texts in full, using the established eligibility criteria. Subsequently, they discussed the final samples of each author to reach a consensus between the divergent texts presented in the collection of each one. A third author, who remained impartial, was necessary to verify the questions raised about the divergent texts between each author of the peer analysis and, finally, to judge the results concerning the research. In the end, all references of the selected texts were analyzed and those that met the eligibility criteria were included. All authors responsible for analyzing the collected articles are health professionals or students from the areas of Occupational Therapy and Physical Therapy.

The included articles were analyzed and extracted from the same places as the relevant information for their characterization, such as the study design, study population, types of devices studied, a place where they were performed, and professionals involved (Table 1 and 2). Table 3 shows the general overview of each of the texts regarding their objectives, main results, limitations, and suggestions. Table 4 shows the details of the development of the devices, bringing aspects of the development process, of the evaluation and re-evaluation methods of the studies, as well as the costs presented by each one. The results were presented descriptively and discussed based on the inferences contained in the literature until the authors' conclusions were explained.

Results

With the search in the literature and the considerations of the eligibility criteria, we obtained a total of the five databases used and a sample of 9 articles that were analyzed in this review. The complete results are presented in Figure 1.

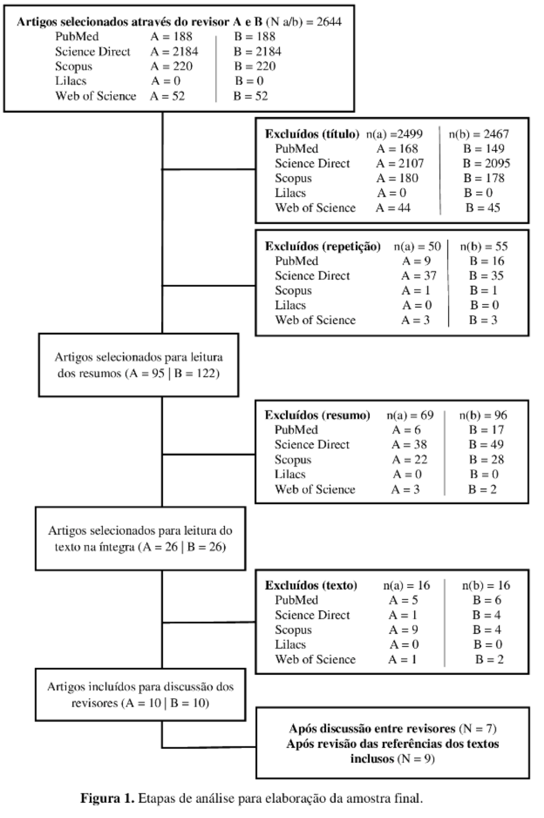

Figura 1. Analysis steps for preparing the final sample.

Table 1 shows the 9 articles included, organized in chronological order of publication, and all the following tables.

Table 1. Included articles.

AUTHOR (YEAR)	Place	TITLE
Yoshikawa et al. (2013)	Japan	Trans-radial prosthesis with three opposed fingers
Zuniga et al. (2015)	USA	Cyborg beast: a low-cost 3d-printed prosthetic hand for children with upper-limb differences
Yoshikawa et al. (2015)	Japan	Rehand: realistic electric prosthetic hand created with a 3D printer
Gretsch et al. (2016)	USA	Development of novel 3D printed robotic prosthetic for transradial amputees
Zuniga et al. (2017)	USA	The development of a low-cost three-dimensional printed shoulder, arm, and hand prostheses for children
Xu et al. (2017)	China	Three-dimensional-printed upper limb prosthesis for a child with a wrist. A case report
Silva et al. (2018)	Brazil	Interdisciplinary-Based Development of User-Friendly Customized 3D Printed Upper Limb Prosthesis
Merchant et al. (2018)	Mexico	Integrated wearable and self-carrying active upper limb orthosis
García-García et al. (2018)	Mexico	Development of a Customized Wrist Orthosis for Flexion and Extension Treatment Using Reverse Engineering and 3D Printing

The analyzed articles were published in the last 5 years, except for the study by Yoshikawa et al., Published in 2013. The places where they are exploring 3D printing for orthoses and prostheses varied between the United States of America, Japan, Brazil, China, and Mexico, all of which are made in the referred country and published in international media, with Brazil as a reference (Table 1). Table 2 shows that prostheses have been studied more than orthoses, appearing in 7 of 9 articles. Among these categories, dynamic orthoses and myoelectric prostheses were the most addressed. We also found that most studies of prosthetic development relate to children.

In general, the works presented the participation of more than one professional category, often including health professionals. The categories cited were: The prostheticians who performed anthropometric assessments, and the occupational therapist who was responsible for assessing functionality; the doctors for medical consultation and patient evaluation; the physiotherapist for rehabilitation training and preparation for the use of the prosthesis; and the technical advisor and designer, for making the products. However, in some studies, the categories were not specified and were identified as a multidisciplinary team (Table 2).

Table 2. Characterization of the studies.

Author (year)	Study Design	Study population	Device type	Professionals involved
Yoshikawa et al. (2013)	NI	A 60-year-old patient with transradial amputation	Electric prosthesis	NI
Zuniga et al. (2015)	NI	Children with reduced limb	Prosthesis	Prostheticians and occupational therapist
Yoshikawa et al. (2015)	NI	Forearm amputation	Myoelectric prosthesis	NI
Gretsch et al. (2016)	Case report	13-year-old female patient with transradial amputation	Myoelectric prosthesis	Physician, technical advisor
Zuniga et al. (2017)	Technical note	A child with a shoulder amputation	Myoelectric prosthesis	NI
Xu et al. (2017)	Case report	child with amputation	Prosthesis	Multidisciplinary health team and parents (caregivers)
Silva et al. (2018)	Case report	A child with a bilateral transtibial amputation	Mechanical prosthesis	Occupational therapist, prostheticians, and designer
Merchant et al. (2018)	NI	People with some type of spinal cord injury	Dynamic orthosis with robotics component	NI
García-García et al. (2018)	Case report	A 60-year-old patient with a range of motion difficulty	Dynamic orthosis	Multidisciplinary team

NI: Not Informed.

In all studies that met the inclusion criterion, one of the main objectives of using 3D printing for making orthoses and prostheses was the low cost and the greater precision in the development of parts and products. Still in this perspective, although everyone obtained positive results after the use and testing of the final products, some limitations were raised, such as the low grip strength and the difficulty in performing the fine motricity movement in the case of prostheses and the difficulty related to the high consumption of time in the acquisition of images of the anatomy of the hand and subsequent printing of the 3D model in the case of the orthosis (Table 3). The most used materials for making the products were two: Polylactic Acid (PLA), used in 5 of 9 articles, and Acrylonitrile Butadiene Styrene (ABS), used in 6 of 9 articles, and some of these studies, both materials were used.

Table 3. Overview of the included articles.

Author (year)	Objective	Main results	Limitations	Suggestions
Yoshikawa et al. (2013)	To design and develop a low cost and lightweight transradial prosthesis.	The participant was able to wear the prosthesis alone, grab abstract objects, and intuitively operate the prosthesis. A socket supported the short stump.	NI	To improve hand stiffness and evaluate the usability, versatility, and durability of the prosthesis in more amputees.
Zuniga et al. (2015)	To describe a low-cost, three-dimensional printed prosthesis for children	The prosthesis was positive for QOL and ADL. It had a low cost and good adjustment capacity.	NI	New studies to examine functionality, validity, durability, benefits, and bounce rate.
Yoshikawa et al. (2015)	To report to *Rehand*, a realistic electric prosthesis.	The *Rehand* provides the basic grip function in ADL with forearm amputations.	Poor performance in handling heavy objects and fine movements.	To improve hand stiffness and control box size. To assess the hand with the most amputees in the ADL.
Gretsch et al. (2016)	To develop a low-cost prosthetic arm to address Robohand's limitations.	Product with opposable thumb movement, grip with five fingers, low weight, and low cost.	Battery limitations, durability, grip strength, and noise.	Development of improvements to the prototype.
Zuniga et al. (2017)	To design a low-cost shoulder prosthesis for bimanual and unilateral activities.	The device allowed improvement in spinal deviation, balance, and performance in bimanual activities.	Low grip strength and low device durability.	To improve the functioning of MCF joints and 3D printing technology.
Xu et al. (2017)	To report the case of a child with a prosthesis after traumatic wrist amputation.	The prosthesis had low cost, good fit, and customization. After training and rehabilitation, there was an improvement in functionality.	The prosthesis is not applicable for some fine and bimanual movements.	To compare long-term prostheses in 3D with conventional prostheses and perform more advanced training.
Silva et al. (2018)	To describe the development of a transradial mechanical prosthesis for a child with bilateral UL amputation.	Good durability and prosthesis fixation. Light and effortless device. Comfortable, easy to adjust, and sanitize.	Difficulty in fine motor skills, such as writing (solved using an adapter) and zipping.	NI
Merchant et al. (2018)	To develop a prototype of an orthotic system to be used in the rehabilitation of the UL.	The device can be adjusted to different users and easily transported. It allows adjustment for different movements.	NI	NI
García-García et al. (2018)	To propose a methodology based on reverse engineering for the development of dynamic or static progressive orthoses for the hand.	High level of acceptance in rehabilitation, especially for patients with acute CVA. The reverse engineering method offers a high degree of customization of orthoses.	There was a high cost of time in acquiring images of the anatomy of the hand.	To conduct clinical trials for more evidence. To make the device lighter and allow the skin to breathe, improving its use.

NI: Not informed. UL: Upper Limb. MCF: Metacarpophalangeal. ADL: Activities of Daily Living. QOL: Quality of Life. CVA: Stroke.

In the value of the product, we observed that the prostheses varied between 20 and 1250 dollars, depending on the public and the type of prosthesis. The figures for the costs of orthotic materials were not available in the studies. In the product development, six of nine articles presented the process of assessment, ideation, and the making of the device but elaborated in different ways. We also identified that only one of the studies presents physical rehabilitation and training for specific uses for the use of manufactured devices, and five studies performed some type of functionality test of the products developed. The tests employed were: Southampton Hand Assessment Procedure (SHAP), which verifies the effectiveness of the prosthesis by analyzing the patterns of grip and its frequency of use in activities of daily living; The Children Amputee Prosthetics Projects (CAPP) Score and The University of New Brunswick Test of Prosthetic Function for Unilateral Amputee (UNB test), which assesses the daily functionality of the prosthesis; observational assessment by the therapist of the performance of activities in which the patient had greater difficulty; and device performance simulation for each joint involved during therapy.

Table 4. Detail of the device development.

Texts	Development Process	Assessment	Reassessment	Total cost
Yoshikawa et al. (2013)	NI	Adjustable transradial amputation prosthesis	SHAP	<$400
Zuniga et al. (2015)	Assessment - calibration of the metric scale - use of a graph to estimate the size of the prosthetic hand - confection.	Anthropometric measurements of the UL	NI	$50
Yoshikawa et al. (2015)	Assessment - gripping mechanism was designed in 3D CAD software - 3D printing - fitting the parts	Based on a commercial prosthetic model (scanner)	SHAP	<$1250
Gretsch et al. (2016)	Assessment - printing - electronic components - Arduino system programming	Measurement of affected and unaffected limbs	Report of the patient and his family after use	+/- $300
Zuniga et al. (2017)	NI	Medical questionnaire	Report of the patient and his family after use	$200
Xu et al. (2017)	Assessment - scanning - model customization - printing of the prosthesis components - joining of the components	Clinical questionnaire; open-source design; measurement of affected and unaffected limbs + scanning	CAPP Score and UNB test after follow-up, use training and rehabilitation (pre-prosthetic and post-prosthetic)	$20
Silva et al. (2018)	Assessment - choosing the best type of prosthesis - prototyping and design process - prosthetic testing - final product design - final test	Clinical and functional questionnaire; measurement of the mold for the limb; scanning	Observational assessment of activities by the therapist	NI
Merchant et al. (2018)	Assessment - mechanical sections of the orthosis were modeled in CAD software - transfer of the mechanical model to the Simulink – MATLAB interface - execution of the controller on a digital plate	Mechanical analysis of the components needed to perform arm movements	Simulation and real implementation in an individual	NI
García-García et al. (2018)	Assessment - identification of orthosis elements - acquisition of limb images by MRI - scanning for a model generation - printing	Clinical questionnaire to understand the patient's demands and the best type of treatment	NI	NI

NI: Not informed. UL: Upper Limb. SHAP: Southampton Hand Assessment Procedure. CAPP: The Children Amputee Prosthetics Projects. UNB test: The University of New Brunswick Test of Prosthetic Function for Unilateral Amputee. CAD: Computer-assisted Design. MRI: Magnetic Resonance Imaging.

Discussion

3D printing or additive manufacturing has been growing worldwide for its use and scientific research, including in the health area (Guerra Neto et al., 2018). However, this integrative review carried out with orthoses and prostheses for upper limbs shows that there are still few studies and practices that involve the use of 3D printing in this area, considering the bases used. The analyzed articles deal with recent works, still in the initial stages of testing and methodological improvement, in which a predominance in the development of prostheses was observed, with orthoses being the less frequent.

In a systematic review by Diment et al. (2018) on the prosthesis, we also found studies with low levels of evidence, with only one being strong enough to demonstrate a clinically significant effect. Another systematic review by Guerra Neto et al. (2018) on 3D printed orthoses and prostheses points out that, with this technology, these devices can establish better cost-benefits.

Prostheses are important resources used in the scope of rehabilitation since they are characterized by the replacement of a lost or malformed member (Polis, 2009; Cavalcanti & Galvão, 2011). They can be classified into different types and models of equipment, such as static, active, and myoelectric prostheses (Polis, 2009).

Myoelectric prostheses were the most frequent in that study. According to Radomski & Latham (2013) and Pereira (2016), they are devices that use electromyographic signals (EMG), captured through electrodes that are in contact with the skin to amplify muscle contraction in a residual limb. This prevalence suggests the possibility that this occurred due to its higher level of manufacturing complexity due to the need for integration with electromyographic systems when compared to other prosthetic models. Thus, from 3D printing, these devices can be made generating more versatile models, that is, more specialized and perfected, which allow more precise and refined movements (Polis, 2009; Maia, 2016).

Five of the nine studies focused on the development of prostheses for children. A similar result is found in the study by Diment et al. (2018), in which these people were predominant. In this period of life, the process of growth and development occurs more quickly, leading to several changes in the individual's body, which makes the possibility of monitoring the production of a new prosthesis in response to this growth in each stage (Krebs et al., 1991). Because of this, many studies explore the development of these devices, based on 3D printing technology, considering that it allows greater speed and lower cost in their production.

In the orthoses, Gonçalves & Francisco (2011) explain that it is all devices that can be applied for external use to the body. Despite being under different models and functionalities, their main objectives are: to protect an inflamed region with proper positioning, to guarantee the stability of a specific body segment, to restore and rehabilitate lost or compromised movements, to prevent contractures, and to modify muscle tone. These can differ in static or dynamic, molded to the body, or prefabricated (Gonçalves & Francisco, 2011; Radomski & Latham, 2013; Guerra Neto et al., 2018). In the study, the orthoses presented were of the dynamic type, which is characterized by the application of a gentle and intermittent force to the movement of a specific joint in its correct angulation, from the stretching of the tissues, and that allow that these movements are carried out more functionally, restricting inadequate muscle patterns (Radomski & Latham, 2013).

Only 2 of the 9 articles included had the orthosis as the object of study. Thus, different questions can be raised, for example, despite the aid of the 3D scanner that allows the acquisition of three-dimensional virtual anatomical models of the limb for printing, there may be still a deficiency of this technology in the feasibility of finishes and final adjustments, which are usually performed on the limb of the individual to better fit the orthosis to the limb. Another issue is regarding the costs of making and purchasing these devices. Because they are characterized as products more accessible to the population, in terms of cost, unlike prostheses, they are less explored in the context of 3D printing and, when they are, they are related to dynamic orthoses which, among the types of orthosis, some models require a higher level of complexity in the making and slightly higher costs.

Observing the development process of the 3D printed products found, the articles identified the indication of limitations that may have interfered with the results. Bearing in mind that most of the studies addressed the manufacture of prostheses, difficulties with the use of these devices were most frequently observed. The main one was the low grip strength and limitations for carrying out activities that demand greater manual dexterity. This demand is a great challenge for traditional upper limb prostheses since for the most part, they do not allow the recognition of touch in a reliable manner such as that performed by the mechanoreceptors of a human hand (Martins, 2018). Despite this, most of these studies did not present specific suggestions for these difficulties, reporting only the need for further studies in the area to generate alternatives for these problems.

Another reported limitation was the need to conduct studies with higher levels of evidence, which can prove the efficiency of using 3D printing in the development of products, such as orthoses and prostheses. This confirms that research is still recent on the subject and permeate methodologies with weaker levels of evidence. Thus, clinical trials, characterized as the studies that best prove the effectiveness of a treatment or intervention (Nedel & Silveira, 2016), and usability studies, which correspond to ergonomics and product design tests (Paschoarelli & Menezes, 2009) can be types of research that may contribute to the scientific growth of the use of 3D printing of upper limb orthoses and prostheses.

A multidisciplinary team is essential in the product development process, both orthotic or prosthetic since each professional performs a different role that will contribute cooperatively to the final result, and considers the different aspects encompassed by the process of evaluating and making the products. Several studies have already addressed the importance of implementing and maintaining the communication of this team to achieve the highest levels of customization and meet the specific demands of each subject (Baronio et al., 2016; Rodrigues Júnior et al., 2018; Wagner et al., 2018).

The team is composed of professionals trained in the handling of mechanics and techniques used for the proper functioning of technology, such as engineers, designers, architects, and prostheticians, as well as health professionals who are fundamental for understanding more deeply the clinical demands, biological, anatomical and functional and social participation of the individual to provide greater comfort, safety, and ease of use of the device (Bersch, 2017).

Although most articles mentioned health professionals in their studies, only Xu et al. (2017) indicated a specific use of training and rehabilitation by a physical therapist. The training was able to facilitate the control of the prosthesis by the individual through repetitive movements, contributing to the performance of daily activities. Although the others did not have the training process for using the device in their study methodologies, we observed that 5 out of the 9 studies carried out some type of evaluation of the product's functionality using standardized instruments or through the occupational therapist, which is characterized by the professional responsible for assessing the functionality and occupational performance of the individual's daily life activities, reducing their functional difficulties (Rodrigues Júnior et al., 2018).

According to Resolution No. 458, of November 20, 2015 (Brasil, 2015b), it is up to the occupational therapist to act in Assistive Technology practices and services, with orthoses and prostheses as one of their areas of professional practice, identifying the need for the use or not of orthoses and prostheses, prescribe, develop and manufacture them or other devices for assistance and technical assistance, enhancing their treatment process, minimizing sequelae and improving the person's occupational performance in their daily lives and, consequently, their social participation. We also observed in this research that the studies that demonstrated some type of training or functional test of the individuals to verify the efficiency of the devices, in general, had fewer limitations in their results. One of these studies was able to solve the problem only with an adaptation made by the occupational therapist (Silva et al., 2018).

Regarding the materials used to print the devices, PLA and ABS were the most cited. Both are types of thermoplastic widely used in the practice of 3D printing today but with different properties and characteristics. PLA is a biodegradable material made from natural resources, such as cassava, corn, and sugar cane. It is considered very rigid and resistant, that is, with little flexibility and low tensile strength, which hinders to development of devices that need more complex fittings and that require a higher level of movement complexity (Aguiar & Yonezawa, 2014; Mallmann, 2018).

PLA also has several advantages such as sustainability, attributed to renewable resources (Drumright et al., 2000), biocompatibility, which prevents toxic and carcinogenic effects (Athanasiou et al., 1996), processability due to the better thermal processing when compared to other biopolymers (Auras et al., 2004), and energy-saving, when compared to petroleum-derived polymers (Vink et al., 2003), which also makes it a promising alternative in the market. ABS is a material derived from petroleum, which may make it less recommended since from an ecological point of view, it takes longer periods to decompose. However, among its properties, it presents greater flexibility, which allows the development of prototypes that offer greater freedom of movement to the patient (Aguiar & Yonezawa, 2014).

In the studies analyzed, although PLA and ABS were not the only materials used, we observed that the costs of these materials, in general, were reduced. However, these values are still very variable between one search and another. According to McGimpsey & Bradford (2008), a myoelectric prosthesis for the upper limb, which was the most recurrent resource in the articles analyzed in this study, can cost up to more than 30,000 dollars, which can make it impossible for a large portion of the population to acquire it. In studies on the myoelectric prosthesis, for example, the cost varied between 200.00 and 1250.00 dollars, pointing out that these materials, combined with 3D printing, are capable of enabling acquisition by socioeconomically disadvantaged people.

The limits of this research were related to the lack of standardization of the search terms used to identify the term “three-dimensional printing” since several keywords are used to refer to it, which created difficulties among researchers during the data collection phase.

Cross-references with different descriptors were also used in different databases, which may have led to the loss of some studies. We suggest future research in other databases focused on the areas of technology, engineering and design, and also the health area, and including other parts of the body in addition to the upper limb so more studies may be located and the analysis further expanded.

Conclusion

Based on this study, we could identify that the use of 3D printing occurred more frequently for the manufacture of prostheses of the myoelectric type and with children. Orthoses were less studied and the most common ones found were dynamic ones. The main materials used for printing the devices were PLA and ABS. We also identified that studies in the area of making orthoses and prostheses for the upper limb from 3D printing until today are in the early stages of development and still do not show their efficiency and effectiveness with large population groups and/or types of disabilities. However, the initial results proved to be relevant due to the cost-benefit of assistive products and the possibility of generating versatile models, which suggests that it is a promising field to expand and deepen the application of 3D printing as a facilitating resource in the process of rehabilitation.

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Author's Contributions

Sandra Yoshie Uraga Morimoto: Text design; organization of instruments for data collection; data collection, tabulation, and analysis; article writing. Ana Karina Pessoa da Silva Cabral, Danielle Carneiro de Menezes Sanguinetti, José Ângelo Peixoto da Costa, Weldma Karlla Coelho, Giselle Schimidt Alves Diaz Merino: Data analysis and text review. Elvis da Silva Rodrigues de Freitas: Data collection, tabulation, and analysis. Daniela Salgado Amaral: Data analysis, text review, and research orientation. All authors approved the final version of the text.

Corresponding author

Sandra Yoshie Uraga Morimoto
e-mail: sandrap_ucca@hotmail.com, sandra.syum@gmail.com

Section editor

Marcia Maria Pires Camargo Novelli