Manufacturing Technology in Rehabilitation Practice: Implications for its Implementation in Assistive Technology Production

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Abstract. This study addressed the participation of rehabilitation professionals in the use of Additive Manufacturing to produce assistive technology devices. A literature review based on articles published in scientific journals indexed in the Scopus database was conducted by searching for papers addressing the use of Additive Manufacturing Technologies in the development of orthotic and prosthetic devices in rehabilitation programs. The 46 articles that met the inclusion criteria were analyzed in terms of the participation of the health professionals in the process of design of orthotic and prosthetic devices. The analysis revealed that in most cases the use of 3D printing technologies in the design of assistive devices do not comprise interdisciplinary teams with active participation of rehabilitation professionals.

Keywords: 3D Printing - Assistive Technologies - Rehabilitation Practice.

1 Introduction

Additive manufacturing (AM) is considered an indispensable tool for reducing the development time of a product. Although accounts of MA can be found even as early as the 70s, its use in the health domain did not take off until the end of the 90s. For example, in Brazil accounts of AM within dentistry can be found as early as the 90s [1,2].

Additive manufacturing technology has caught the attention of rehabilitation professionals for the development of orthotic and prosthetic devices due to its ability to provide complex product geometry. Recently, dummies manufactured with AM have been used in medical teaching because of the low cost and rapid manufacturing [3]. Despite the potential benefits of AM technologies in rehabilitation and the many successful experiences documented, many rehabilitation centers still employ traditional processes for the design and provisioning of orthotic and prosthetic devices.

In the area of Assistive Technologies, rapid prototyping has been used as means to develop anatomically designed wheelchair handrims aimed at improving the ergonomics of manual propulsion [4,5], which was later implemented in a prototype of a

handrim-activated power assisted wheelchair [6,7]. Inkjet plaster printing was used for printing a part of the handrim that was subsequently replicated in polyurethane resin using a silicon mold. More recently, 3D printing was used together with the FFF process to develop a customized upper limb prosthesis for a child. This was achieved through an interdisciplinary collaborative design approach [8], which is part of a Brazil-Norway bilateral project on the design of products for independent living mainly focused on Assistive Technologies [9].

Despite the potential benefits of applying 3D printing to the development of customizable assistive technology devices, the configuration of an interdisciplinary team as well as the role of each specific professional in the development process is still not fully defined. As the area of AT merges knowledges in the frontier of technological and health sciences, it is important to comprehend how the collaborative work between these areas have been developed in practice. Ultimately, this knowledge may provide the basis for proposing a basic framework for collaborative health-technological approaches in the design of ATs. This paper presents a review on participation of rehabilitation professionals in the design and manufacturing of assistive devices by means of the use of 3D printing technologies.

2 Methods

This study employed a methodology based on a literature review of articles published in scientific journals indexed in Scopus. Scopus is a well-established interdisciplinary database of abstracts and academic information sources, patents and journals. We searched for documents that addressed the use of Additive Manufacturing Technologies in the development of orthotic and prosthetic devices in rehabilitation programs. We used the following search terms: *3D printing*, *prosthesis*, *orthosis* and *assistive technology*. Hence, we submitted the following queries:: *"3D printing OR additive Manufacturing OR rapid prototyping" AND "prosthesis OR orthosis OR assistive technology"*. Only articles published during the last five years were included in the subsequent analysis. We manually inspected the selected papers for evidence indicating the active participation of health professionals in the design and printing processes.

3 Results

The first search returned 78 articles of which many reported the use of 3D printing technology in medical and orthodontic contexts, but not related to the design of assistive technology devices. After reviewing the titles and abstracts in terms of the content of the papers, a total of 46 articles were included [9-54] as they met the inclusion criteria. These were subsequently were analyzed in terms of the participation of health professionals during the design process of orthotic and prosthetic devices. Of these studies, 29 articles had no mention of the participation of rehabilitation professionals during the design and manufacturing process. Only seven studies mentioned the health professionals and only five studies mentioned the health professionals as collaborators in the project. This only represents about 10% of the papers (see Fig. 1).

These five paper addressed the following topics: 1) AM for the fabrication of an accurate auricular prosthesis that enables the clinician to refabricate the prosthesis whenever the patient returns [21]; 2) a design methodology for working with Assistive Technology in a multidisciplinary team [30]; 3) effective experience sharing between clinicians, designers and engineers [34]; 4) design of orthoses that are fully responsive to the therapeutic needs of patients where hand orthosis clinicians have indicated the pressure zones [41]; 5) the development and validation of an AM interfacial stress sensor made by a multidisciplinary team, including clinicians [53].

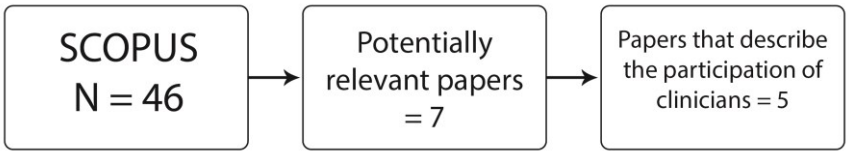

Fig. 1. Search results.

Thirty-four articles were published in journals and two were published as conference proceedings. Eleven of the papers were published in 2015, ten in 2016, fourteen in 2017 and eleven papers where published in 2018. The seven articles that mentioned rehabilitation professionals are listed in Table 1.

Table 1. Relation of papers that related rehabilitation professionals.

Authors	Year	Publication channel	Contribution
Laszczak, et al.	2015	Medical Engineering and Physics	The development and validation of a AM interfacial stress sensor made by a multidisciplinary team, including clinicians.
Buehler, et al.	2015	ACM SIGCHI	Development of GripFab, 3D modeling software based on feedback from occupational therapists.
Baronio, et al.	2016	Applied Bionics and Biomechanics	Clinicians that indicated pressure zones and created orthoses fully responsive to the therapeutic needs on a AM made hand orthosis.
Hofmann, et al.	2016	ACM ASSETS	New ways for clinicians to share their expertise with designers and engineers to supporting a collaborative design process.
Thomann, et al.	2017	Producao	An adapted design methodology for Assistive Technology to work in a multidisciplinary team
Sandnes, et al.	2017	EPD&E	The approach between rehabilitation professionals and designers
Yadav, et al.	2017	J. Prosthodontics	Fabrication of an accurate auricular prosthesis that enables the clinician to refabricate the prosthesis whenever the patient returns.

Fig. 2 shows the distribution of rehabilitation professionals reported in the papers. Occupational Therapists and Prosthetists were reported twice in the articles, while Physiotherapists and Orthotists were only mentioned once. Some articles did not specify the discipline of the professionals that participated in the study, but instead mentioned “rehabilitation professionals” and “clinicians”.

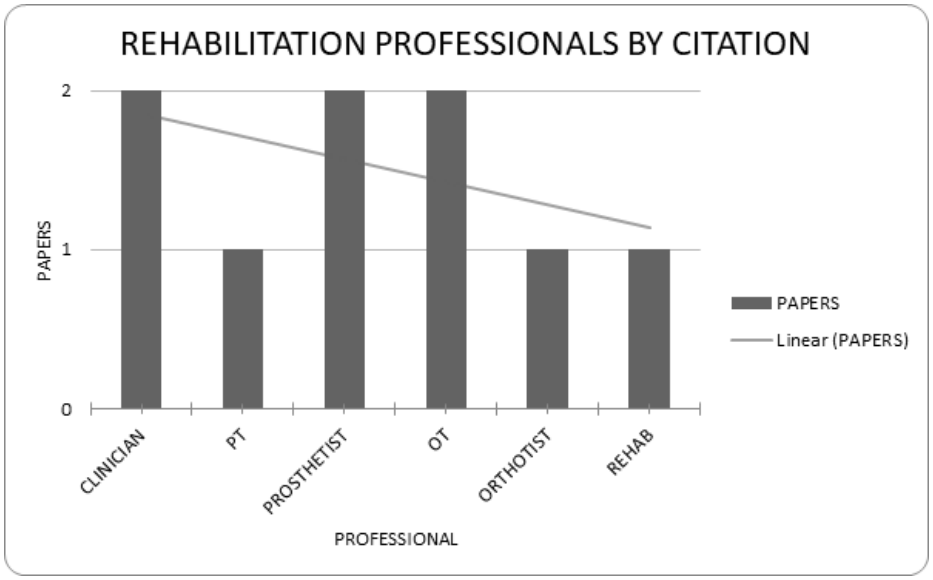

Fig. 2. Distribution of rehabilitation professionals reported throughout the papers.

One of the papers [21] that mentioned health professionals only described their participation as responsible for refabricating deteriorated ear prosthesis returned by patients.

Some articles mentioned CAD/CAM systems and the interaction with rehabilitation professionals and the challenges for the use of AM technologies. One of them mentioned that using CAD/CAM systems could assist prosthetists developments [53].

Another paper related the creation of GripFab, a 3D modeling software based on feedback from occupational therapists, allowing them to use a 3D printer to create a custom prosthesis. The team assisted therapists in the design and printing of a 3D object as a prototype to encourage the therapists' exploration of this technology [39].

4 Discussion

The results obtained in this study suggests that although additive manufacturing has been used in the clinical area since the 90s [2, 55], less than a quarter of the total papers published in the last five years mentioned the active participation of rehabilitation professionals during the design and 3D printing process. This might be explained by the skills required for 3D modeling and operating 3D printers. Even though 3D modeling software has become more intuitive and easy to learn, and 3D printers have become more popular and accessible, many rehabilitation professions still rely on traditional methods for manufacturing orthoses and prosthetic devices [33].

Although the current study consisted of a literature review that might have a limited scope of results restricted by the terms and search strategy, the small number of papers reporting the active participation of rehabilitation team in the design and manufacturing of 3D printed assistive devices indicates that, in most of the times, this part of the process is under the responsibility of designers and engineers, with insufficient interchange of knowledge and skills in designing and printing pieces. The use of a 3D CAD modeling software requires specific skills that are not familiar to most of the clinicians and orthopedic/orthotics technicians [41]. Therefore, rehabilitation professionals require training in 3D modeling and printing for a more effective participation in the development process of assistive devices produced by additive manufacturing. Future studies should explore the needs from rehabilitation professionals in terms of specific knowledge and skills to implement the use of 3D printing technology in their practice.

It must be noted that, despite the lack of information of rehabilitation teams participating more intensively in the development process, we cannot affirm that there are no clinicians involved during the process of manufacturing orthotic and prosthetic devices, as these are the professionals that initiate the development of this equipment and that have the clinical authorization to prescribe such assistive technologies [41]. Also, it is possible that, due to the specific terms used in the search strategy, some key papers might have not been identified.

On the other hand, we cannot simply disregard the questions and results presented in this article once the identification of the effective participation of the professionals involved in the development process will give us a better understanding about the

usage, knowledge and challenges in the use of additive manufacturing and in which areas of knowledge this technology is partially understood and dominated.

5 Conclusion

This review study explored the participation of rehabilitation professionals in the development process of orthotic and prosthetic devices with the use of 3D printing technology. The findings show that a small number of papers report the participation of occupation therapists, physiotherapists and other rehabilitation professionals in the development of orthotic and prosthetic devices using 3D printing technology. Although rehabilitation professionals lead the manufacturing of orthotic, prosthetic and other assistive devices with conventional tools and processes, the current findings suggest that, when it comes to the use of 3D printing technologies, the participation of these professionals is still insufficient. The potential applications of additive manufacturing technologies in the development of assistive devices that improves the design from both practical and aesthetic perspective, emphasize the importance of finding ways to establish a framework for the collaborative work between rehabilitation professionals and designers and engineers. The first steps towards this goal is to comprehend the conventional tools and methods used by therapists for manufacturing custom devices for their clients, as well as to investigate the gaps in terms of knowledge and skills that these professionals face while 3D modeling and printing.

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