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Occupational Therapy Practitioners' Perceptions of the Utilization of Three-Dimensional Printing in Upper Extremity Practice

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A Research Project Entitled

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By

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Abstract

Three-dimensional (3D) printing technology is thought to enhance developments in the medical field by printing products for the use of patients and health care providers. Researchers have investigated the use and impact of 3D printing technology in different health care professions; however, research regarding its use in occupational therapy practice, specifically upper extremity rehabilitation, is in early stages. Additionally, the perceptions occupational therapy providers have concerning the use of 3D printing in practice are currently unknown. In this study, investigators explored the perceptions and applications of 3D printing technology among occupational therapy practitioners through an online survey. Researchers received 268 completed surveys from participants who met inclusion criteria and analyzed responses using a mixed methods approach. Only seven participants (2.61%) reported using a 3D printer in their practice to print items such as prosthetics, orthotics, educational tools and models, and assistive devices. Non-users of the technology varied in their opinions regarding the potential impact 3D printing technology would have on their clinical practice. Furthermore, three themes emerged as barriers to implementing 3D printing into practice: 1.) lack of knowledge, 2.) clinician apprehension, and 3.) limited resources. The authors suggest there is a need for more research and provider education to improve understanding of 3D printing technology and its role in occupational therapy and upper extremity rehabilitation.

Occupational Therapy Practitioners' Perceptions of the Utilization of Three-Dimensional Printing in Upper Extremity Practice

Technology has become an integral component to the daily lives of all people and is changing the ways of health care (Smith, 2017). One specific technology is three-dimensional (3D) printing (Ventola, 2014). 3D printing, also referred to as additive manufacturing or rapid prototyping, is thought to enhance the developments in the medical field by printing products for the use of both patients and health care providers (Bagaria, Rasalkar, Bagaria, & Ilyas, 2011). The process begins with a 3D image taken from a scanner or computed tomography (CT) image, and ends with a tangible 3D model created with layers of plastic, thread-like filaments (Bagaria, Shah, Chaudhary, Shah, & Bagaria, 2015). 3D printing technology has many diverse applications in the medical field and among health care professionals (Bernhard et al., 2015; De Crescenzio, Fantini, Ciocca, Persiani, & Scotti, 2011; Papandrea & Chen, 2014; Qiao et al., 2015; Rengier et al., 2010; Salmi, Paloheimo, Tuomi, Ingman, & Mäkitie, 2013; Salvador & de Menendez, 2016; Silva, dos Santos, Souto, de Araujo, & da Silva, 2013; Starosolski, Kan, Rosenfeld, Krishnamurthy, & Annapragada, 2014; Yanping, Shilei, Xiaojun, & Chengtao, 2006).

Although there is an abundant amount of research on 3D printing technology use in health care, many questions exist surrounding its utility regarding cost and time-effectiveness, as well as the durability of the printed products compared to traditional production methods (Cazon, Kelly, Paterson, Bibb, & Campbell, 2017; Fenske, 2014; Ganesan, Jumaily, & Luximon, 2016; Hagedorn-Hansen, Oosthuizen, & Gerhold, 2016; Herbert, Simpson, Spence, & Ion, 2005; Schrank & Stanhope, 2011; Zuniga et al., 2015). In addition, the potential impact on patients and health care providers is still being examined (Herbert et al., 2005; Wagner, Dainty, Hague, Tuck, & Ong, 2008). Further research in these areas is needed to better inform health care providers of evidence-based practices to enhance patient-centered care and outcomes (Gibson, Woodburn, Porter, & Telfer, 2014; Silva et al., 2013; Zuniga et al., 2015).

In his Eleanor Clarke Slagle Lecture, Smith (2017) challenged occupational therapy (OT) practitioners to continue integrating knowledge and skills of technology into practice due to its abundance in society; however, in the field of OT specifically, 3D printing technology use is limited and not yet mainstream (Ganesan et al., 2016; Gibson et al., 2014). In reviewing published literature, occupational therapists have used 3D printing in the making of orthoses (Ganesan et al., 2016; Huotilainen et al., 2014; Li & Tanaka, 2018; Paterson et al., 2015), adaptive equipment (Ganesan et al., 2016; Huotilainen et al., 2014;), rehabilitation tools (Bagaria et al., 2015), and assessment tool supplies (Mailloux, Parham, Roley, Ruzzano, & Schaaf, 2018). However, the perceptions occupational therapists have concerning the integration and use of 3D printing in practice are currently unknown. Therefore, the purpose of this study was to examine current uses of 3D printing in upper extremity rehabilitation by OT practitioners as well as investigate the perceptions they have regarding the technology.

Literature Review

What is 3D Printing?

3D printing technology is widely-regarded as a profound scientific triumph due to the ability to create and print a variety of physical objects from a digital image or design (Aufieri, Picone, Gente, & Paolillo, 2015; Bagaria et al., 2015). Images can be uniquely created by skilled technicians or obtained through various methods including 3D modeling software or 3D scanners (Aufieri et al., 2015). The 3D printer enables the object in the image to become tangible by printing multiple, overlapping, and precise layers of a plastic, thread-like material into the specified design (Bagaria et al., 2015; Fitzpatrick, Mohanned, Collins, & Gibson, 2017). The 3D printing process is relatively fast and often considered to be time-effective when evaluating the finished product's performance and use (Bagaria et al., 2011).

3D printing technology is especially of interest to those in the area of medical science due to its potential effects of faster production times, improved quality, and lower cost (Bagaria et al., 2011; Santos, Soares, Leite, & Jacinto, 2017). Specifically, the technological influence of 3D printing is becoming more prevalent in the health care field with several opportunities for use (Bagaria et al., 2011; Santos et al., 2017).

Uses of 3D Printing in Health Care

Utilization of 3D printing technology occurs in a variety of health care settings. Practitioners in medical fields such as orthopedics (Cha et al., 2017; Santos et al., 2017; Starosolski et al., 2014) and prosthetics (Lee et al., 2017; Liacouras et al., 2017; Rengier et al., 2010; Silva et al., 2013; Tanaka & Lightdale-Miric, 2016) have implemented 3D printing technology into their practice providing many benefits for both the medical professional and the patient (Bernhard et al., 2015; Rengier et al., 2010; Starosolski et al., 2014; Trace et al., 2016; Wagner et al., 2008). For example, 3D printing technology provides additional methods that allow providers to fully assess and understand results from CT scans and magnetic resonance imaging (MRI) by printing a physical model of a patient's anatomy (Diment, Thompson, & Bergmann, 2017; Starosolski et al., 2014; Trace et al., 2016). According to researchers, this novel opportunity for tactile experience and visual representation enhanced the medical professional's understanding of complex anatomy and pathology and improved the patient's understanding of the condition and operation plan (Bernhard et al., 2015; Friedman, Michalski, Goodman, & Brown, 2016; Rengier et al., 2010; Starosolski et al., 2014; Trace et al., 2016). In the field of urology, researchers investigated the impact of 3D printed models on patient understanding and discovered a statistically significant ($p < 0.05$) increase in knowledge after surgeons educated patients about anatomy and physiology of the disease, tumor characteristics, and the operation plan with use of a 3D printed model (Bernhard et al., 2015).

3D printed models also allowed surgeons to design an operation plan and physically practice the surgical intervention prior to performing it on a patient (Rengier et al., 2010; Starosolski et al., 2014; Trace et al., 2016). Rengier et al. (2010) and Starosolski et al. (2014) discussed how surgeons refined and experimented with various techniques by using the 3D printed models to practice before surgical intervention was performed, thereby increasing their surgical skills and knowledge. Orthopedic surgeons specifically stated that 3D printed models allowed them to better correct conditions during operations (Starososki et al., 2014). Other surgeons reported 3D printed models to be useful for surgery preparation, reporting higher levels of confidence when entering the operating room to perform surgical interventions (Rengier et al., 2010; Tetsworth & Mettyas, 2016).

Researchers in the field of prosthetics have also found 3D printing to be beneficial, especially in circumstances where traditional fabrication methods for a prosthesis are unsuccessful (Liacouras et al., 2017). In some cases, experts can use 3D printing technology to create a starting shape or pattern that can later be customized to a client's specific needs (Liacouras et al., 2017). However, 3D printed prostheses are currently somewhat limited in function due to unavailability of durable materials and lack of designer experience, especially in prostheses that require precise fitting and ability for load-bearing (Liacouras et al., 2017; Steenhuis, 2016).

Health and Safety

Several researchers have investigated health and safety considerations regarding 3D printing technology (Cazon et al., 2017; Love & Roy, 2016; Ryan & Hubbard, 2016; Short, Sirinterlikci, Badger, & Artieri, 2015; Tanaka & Lightdale-Miric, 2016). Love and Roy (2016) and Ryan and Hubbard (2016) both revealed several harmful chemicals associated with 3D printing; however, the amount of chemicals was below the regulatory limit and therefore was not considered a significant hazard (Love & Roy, 2016; Ryan & Hubbard, 2016). In contrast, other researchers discovered safety concerns that were significant, including chemical interactions, contact with dangerous materials, and radiation exposure to the eyes with some types of 3D printers (Cazon et al., 2017; Short et al., 2015; Tanaka & Lightdale-Miric, 2016). For example, researchers found using ultraviolet radiation for liquid-based prototyping damaged the operator's eyes (Short et al., 2015). In addition, researchers found that improper ventilation or disposal of wastes could lead to an accumulation of harmful chemicals within the area of the printer (Short et al., 2015).

Advantages of 3D Printing

Although safety concerns of 3D printing technology may exist, (Short et al., 2015; Tanaka & Lightdale-Miric, 2016), several potential advantages of the technology have been determined, including the ability to customize products with the reduction of fabrication time and expense (Cha et al., 2017; Chen et al., 2017; Fitzpatrick, et al., 2017; Hagedorn-Hansen et al., 2016; Lee et al., 2017; Rho, Lee, Kim, Lee, Chang, 2017; Santos et al., 2017; Schrank & Stanhope, 2011; Swartz, Turner, Miller, & Kuiken, 2017; Tetsworth & Mettyas, 2016; Weller, Kleer, & Piller, 2015; Zuniga et al., 2015). Furthermore, many 3D printers are small and relatively inexpensive, therefore they are easily integrated into existing workspaces (Bortolloto et al., 2016).

Several researchers have found the cost of 3D printing materials to be lower than traditional fabrication methods (Hagedorn-Hansen et al., 2016; Lee et al., 2017; Portnova, Mukherjee, Peters, Yamane, & Steele, 2018; Rho et al., 2017; Santos et al., 2017; Schrank, & Stanhope, 2011; Thomas, 2016; Zuniga et al., 2015). Clients and practitioners can benefit from this technological gain as the production of devices such as prosthetics, rehabilitation devices, and adaptive equipment become more affordable with use of the technology (Herbert et al., 2005; Lee et al., 2017; Paterson et al., 2015; Rho et al., 2017; Silva et al., 2013; Silva et al., 2015; Zuniga et al., 2015). Additionally, the 3D scanning and storage of digital client data leads to the elimination of recasting of devices that are damaged or incorrectly fitted, decreasing both the cost of wasted materials and time spent on re-molding (Herbert et al., 2005; Santos et al., 2017).

Several researchers have also determined the time required for printing 3D objects is more efficient than traditional methods of fabrication (Hagedorn-Hansen et al., 2016; Lee et al., 2017; Portnova et al., 2018; Santos et al., 2017; Schrank, & Stanhope, 2011; Tsai & Wu, 2014). Within the surgical field, researchers found it took less time when a 3D printer was used to create artificial bone (Tsai & Wu, 2014; Verstraete et al., 2016) and tissue (Chia & Wu, 2015), which shortened the overall time required for reconstruction and rehabilitation (Chia & Wu, 2015; Tsai & Wu, 2014; Verstraete et al., 2016). Additionally, 3D printing was found to be faster than traditional casting methods when manufacturing prosthetics and orthotics due to the digital scanning and printing occurring within the facility itself (Alam, Choudhury, Mamat, & Hussain, 2015; Hagedorn-Hansen et al., 2016; Herbert et al., 2005; Lee et al., 2017; Portnova et al., 2018; Wagner et al., 2008).

In one study, researchers investigated possible benefits of a 3D printed prosthetic hand for children and found the method of production and materials needed were less expensive compared to non-3D printed methods (Zuniga et al., 2015). The 3D printed prosthetic hand required less time to fabricate due to the distance-fitting procedure, which involved designing the prosthetic through 3D scanning technology and was conducted off-site (Zuniga et al., 2015). Traditional methods of production, such as using a plaster mold, increased fabrication time due to the patient and health care professional needing to be in the same location at one time (Zuniga et al., 2015). Additional researchers investigated the design of ankle orthoses and reported improved time-efficiency, reasonable expenses, and opportunity for customization as benefits to 3D printed orthotics (Lee et al., 2017; Santos et al., 2017; Schrank & Stanhope, 2011).

Implications in Occupational Therapy

3D printed products such as orthotics, prosthetics, and adaptive equipment are becoming more prevalent in rehabilitation, especially due to reduced time and cost for patients (Bagaria et al., 2011; Hagedorn-Hansen et al., 2016). In the field of OT, assistive technology is integral in helping clients improve their performance in meaningful occupations (Rho et al., 2017; Swartz et al., 2017) and 3D printing technology used in this capacity may positively impact the OT profession (Bagaria et al., 2011; Ganesan et al., 2016). There is an abundant amount of research regarding 3D printing technology in different health care professions; however, research regarding the use of 3D printing technology in OT is in early stages (Ganesan et al., 2016). In addition, there is limited research about the utilization of 3D printing technology specifically in upper extremity rehabilitation.

As stated in the Occupational Therapy Practice Framework (OTPF), upper extremity rehabilitation is valuable and important because it aligns with the client-centered focus of OT which is "the therapeutic use of everyday life activities with individuals or groups for the purpose of enhancing or enabling participation in roles, habits, and routines in home school, workplace, community and other settings" (American Occupational Therapy Association [AOTA], 2014, p. S1). The authors of the OTPF best describe the goal of OT as giving the client the ability to achieve the best possible health, well-being, and participation in meaningful occupations of daily and assistive technology may be necessary to help clients accomplish this goal (AOTA, 2014). As previously stated, research on the use of 3D printing in upper extremity rehab is scarce, and as a result, occupational therapists' perceptions of the technology are largely unknown (Ganesan et al., 2016). Therefore, the aim of this study was to investigate current uses of 3D printing technology in upper extremity rehabilitation and discover the perceptions that OT practitioners have regarding the technology.

Methods

Sampling Procedures

Researchers at the University of Indianapolis obtained email addresses of prospective participants from the publicly-accessible member directory on the American Society of Hand Therapy (ASHT) website (ASHT.org). Participants met inclusion criteria if they were 18 years of age or older, practicing in the United States, and a licensed occupational therapist. Participants also had to state agreement with the informed consent document to begin the survey which included disclosure of risks and/or possible discomforts associated with the study, data security procedures, and how to contact the principal investigator (PI) if needed. Participants who did not provide consent were not allowed to continue with the survey. Researchers instructed participants to access and complete the electronic survey within four weeks. Those who did not initially complete the survey received two subsequent reminder emails in three-week increments. The University of Indianapolis Human Research Protection Program approved the study with exempt status.

In total, researchers distributed electronic surveys to 2,206 valid email addresses belonging to members of ASHT after excluding those with no email address listed and subtracting duplicate email addresses. Researchers hoped to have 13.50% (n = 309) of surveys completed and returned to develop valid and responsive results (Stein, Rice, & Cutler, 2013). Researchers received 287 completed responses leading to a 13% overall response rate. Of the total number of surveys started (n = 349), 287 (82.23%) were completed. Data from partial responses were not analyzed. Additionally, responses from participants practicing outside of the United States and/or practicing therapists who were not occupational therapists were not included in data analysis.

Survey Development

Utilizing a mixed methods approach, researchers designed an electronic survey consisting of multiple choice and open-ended questions to investigate perceptions and applications of 3D printing based on information gathered through a review of the literature. The researchers used Qualtrics® for survey design to keep information anonymous, including internet protocol (IP) addresses. Two content experts, occupational therapists practicing in hand therapy, reviewed the survey prior to distribution. The researchers incorporated their feedback on survey content prior to releasing the survey; the content experts were subsequently removed from the participant contact list.

Data Analysis

Researchers utilized software capabilities in Qualtrics® to analyze quantitative data through descriptive statistics. Some questions allowed participants to select multiple answers; therefore, the frequency of responses for these questions exceeded the number of total respondents. Several questions were designed to maintain inclusion criteria or deemed highly important to the study's purpose by the research team. These specific questions were labeled "mandatory response" and participants had to answer before proceeding with the survey (Table 1).

The research team analyzed the open-ended survey responses using inductive analysis and investigator triangulation (Stein, Rice, & Cutler, 2013). Data were first examined individually and then as a group to determine common themes and codes. Once themes were discussed and agreed upon by the researchers, each researcher coded all qualitative data according to the named themes. Researchers maintained coding consistency by clarifying with the group and concluding on an appropriate theme.

Table 1

Mandatory Response Questions (n = 268)

Questions Asked to All Participants (*n* = 268)	Do you currently practice in the United States? What is your health care profession? What is your age in years? Are you a Certified Hand Therapist (CHT)? On average, what percentage of your caseload is reimbursed by the following? Do you use a three-dimensional (3D) printer in your practice as an OT?
Questions Asked to Those Not Using 3D Printer in Practice (*n* = 261)	Do you have a 3D printer available for use at your work site? Do you think 3D printers would have an impact on clinical practice? Do you have any health or safety concerns in regard to using a 3D printer in practice?
Questions Asked to Those with Access but Not Using 3D Printer in Practice (*n* = 1)	Why do you not use the 3D printer?
Questions Asked to Those Using 3D Printer in Practice (*n* = 7)	On average, what percentage of items are customized for clients as opposed to mass-produced? Have you found any health or safety implications when working with a 3D printer?

Results

Demographics

Of the 287 completed surveys, 93.37% (*n* = 268) met inclusion criteria and were considered for further data analysis. The bulk of respondents reported practicing in the Northeast (25.28%, *n* = 67), Midwest (23.02%, *n* = 61), and Southeast (20.75%, *n* = 55) regions of the country (Table 2). Almost half of the participants were between the ages of 53 and 71 years (40.89%, *n* = 110), and most participants had between 11 and 30 years of experience working as an occupational therapist (52.99%, *n* = 142) (Table 3).

Table 2

Demographic Information: Current Practice Regions (n= 265)

Practice Regions	*n*	%
Pacific	36	13.58%
West	24	9.06%
Midwest	61	23.02%
Northeast	67	25.28%
Southeast	55	20.75%
Southwest	22	8.30%

Table 3

Demographic Information: Number of Years in Practice (n= 268)

Years in Practice	*n*	%
5 or below	33	12.31%
6-10	23	8.58%
11-20	71	26.49%
21-30	71	26.49%
31-40	60	22.39%
40+	10	3.73%

Of the respondents, 83.96% (*n* = 225) were Certified Hand Therapists (CHT). Participants also reported certifications held in addition to the CHT. Of those who answered the question, 29.21% (*n* = 78) reported additional upper extremity training that resulted in certification such as Certified Lymphedema Therapist, Instrument Assisted Soft Tissue Mobilization (Graston Technique® or Astym® Soft Tissue Therapy), and/or Kinesio Taping® Method. Respondents were asked to list their certifications in a follow-up question. Additionally, respondents selected their current primary practice setting using AOTA's terminology (AOTA, 2014). Of the respondents who answered, most practiced in a hospital-based outpatient (44.30%, *n* = 35) or freestanding outpatient (45.57%, *n* = 36) facility.

In addition, participants reported the average number of hours worked per week in direct patient care, with most respondents spending 35 to 40 hours (34.08%, *n* = 91). Respondents were asked to report their entry-level degree into the OT profession with the majority of respondents, 59.93% (*n* = 160) having a bachelor's degree, 36.33% (*n* = 97) having a master's degree, and 3.75% (*n* = 10) having a doctoral entry-level degree.

Of the 268 valid respondents, only 2.61% (*n* = 7) reported using a 3D printer and associated technology in their practice as an occupational therapist. Of these seven participants, only three (42.86%) had access to a printer on site, while four (57.14%) did not. From the remaining participants who did not use a 3D printer (97.39%, *n* = 261), only six (2.30%) reported having a 3D printer available to them at their worksite; another six (2.30%) were unsure if they had access to the technology.

Current Applications and Impact on Practice

Users of 3D printing technology (*n* = 7) defined the products they printed for use in their OT practice. These included prosthetics (42.86%, *n* = 3), orthotics (42.86%, *n* = 3), educational tools and models (28.57%, *n* = 2), and assistive devices (adaptive equipment) (28.57%, *n* = 2).

Respondents also delineated which factors influenced their decision to use a 3D printer. The majority of respondents reported that customization (85.71%, *n* = 6) influenced their decision. Participant A stated technology that allows to “design (or print from ready-to-print files) prototypes or end-use objects that can be easily customized is incredible!” Participant B stated the ability to “make sizing changes or add a logo in an instant” influenced the decision to use a 3D printer. Additionally, three respondents (42.85%) reported “cost” influenced their decision to use a 3D printer. Participant A stated, “particular assistive devices, educational models, etc. can be created with a 3D printer at a fraction of the cost to purchase from a vendor.” Participant B reported “time” and stated, “it takes less time to print a model and mass produce it vs. making models out of clay.” Participant B also stated it gave the “ability to prototype designs.”

Respondents were asked to rate to what extent using a 3D printer impacted their practice on a scale of 0 (greatly diminished) to 10 (greatly enhanced). Three participants (42.86%) thought the printer "greatly enhanced" their practice, one participant (14.29%) thought the printer "enhanced" practice, and three participants (42.86%) felt neutral about the printer's impact. None of the respondents reported that using a 3D printer diminished their practice. Respondents were also asked to describe how a 3D printer has impacted their practice. Participant A stated use of 3D printing to "create educational models to enhance student learning and assistive devices," while Participant B stated "I use my models now to educate my patients, who in turn, do better in therapy because they too have a better understanding of their bodies and [injuries]." Participant C stated 3D printing offered "another option to [patients] in terms of cost and customization." Participant A reported 3D printing impacted practice through the creation of a personal invention.

Participants who used a 3D printer in practice were also asked if the use of the technology impacted direct care time with clients. Three participants (42.86%) stated use of the 3D printer allowed more time in direct client care, two participants (28.57%) felt the 3D printer did not affect time spent with clients in any capacity, and two participants (28.57%) were unsure. No participants felt the use of a 3D printer decreased time for direct care. Furthermore, four of these participants (57.14%) reported spending an average of at least 30 hours per week in direct client care, with one participant (14.29%) working more than 40 hours per week.

Possible Applications and Impact on Practice

In general, the 261 participants (97.39%) who did not use a 3D printer in OT practice had similar ideas regarding utilization of the technology. A large number of respondents (43.30%, *n* = 113) stated 3D printing custom orthoses for clients as a possible application, though opinions were quite varied and will be discussed further in this manuscript. Many participants (20.69%, *n* = 54) also mentioned printing adaptive equipment and other assistive devices for client use. Only a few participants reported the technology could be used for educational tools and models (1.53%, *n* = 4) and for prosthetics (5.36%, *n* = 14). Furthermore, 14.18% of respondents (*n* = 37) stated they were unsure how a 3D printer could be utilized in occupational therapy practice.

Over half of participants (52.87%, *n* = 138) who did not use a 3D printer thought the technology would influence clinical practice, as compared to 8.43% (*n* = 22) who did not think practice would be impacted, and 38.7% (*n* = 101) who were unsure. Of those who believed practice would be impacted by the technology, 43.48% (*n* = 60) thought the printer would have a neutral effect on their practice. Most respondents, 46.38% (*n* = 64), thought 3D printers would "enhance" or "greatly enhance" their practice, and only 10.14% (*n* = 14) thought the printer would "diminish" or "greatly diminish" practice.

Additionally, participants who did not use the 3D printer were largely unsure if use of the technology would have an impact on time spent in direct care with clients (56.93%, *n* = 78). Of those who thought utilization of the printer would affect time spent with clients, 18.25% (*n* = 25) stated they would have more time for direct care and 13.14% (*n* = 18) stated they would have less time for direct care.

Barriers to Implementing 3D Printing Technology in OT Practice

During data analysis, three broad themes emerged regarding why OT practitioners were not using 3D printers and associated technology in practice: 1.) lack of knowledge, 2.) clinician apprehension, and 3.) limited resources.

Lack of Knowledge

The majority of participants who did not use a 3D printer specifically stated their limited knowledge (64.14 %, *n* = 161) as one reason that prevented them from using the technology in practice. Additionally, 81.23% (*n* = 212) of participants answered "unsure" to at least one of three key questions: (a) what practice settings do you think could use a 3D printer to influence patient care, (b) do you think 3D printers would have an impact on clinical practice, and (c) do you have any health or safety concerns in regard to using a 3D printer in practice. After counting each participant only once, a total of 93.49% (*n* = 244) of participants who did not use a 3D printer in practice reported limited knowledge regarding the technology in some form. This theme was reciprocated throughout open-ended responses by participants who reported "[I] didn't know there was such a thing" and "[I am] not sure how it's used or what I would use it for." Three participants (1.15%) specifically stated the reason for their unfamiliarity was limited available research as to how the technology would benefit the profession. Another participant stated "I have not read any research to support its use over the skill of a CHT to fabricate a custom orthosis."

Clinician apprehension.

Participants who did not use a 3D printer also expressed apprehension to using it in clinical practice. During the coding process, researchers found two sub-themes or reservations OT practitioners had regarding the technology: 1.) 3D printing technology could potentially infringe upon the skill set of a licensed and certified OT practitioner and 2.) the 3D printing process and fabricated items may be unsafe or cause harm for clients and/or themselves.

Of the 138 (52.87%) current non-users who believed 3D printing would impact OT practice, 18.12% (*n* = 25) expressed concern that the technology may encourage non-skilled users to fabricate common therapy items and/or detract from the expertise of occupational therapists specifically related to fabrication of custom orthoses. One participant stated "concern about the general lay person creating orthoses and marketing as off the shelf products or setting up shop without the added treatment knowledge." Another respondent stated, "I feel that part of what makes us special as practitioners is that we have the skills to make custom splints [orthoses]. I fear that 3D printers could take that away from us." Echoing this viewpoint, another participant stated that 3D printing technology might lead to a "lack of creativity fabricating [orthoses]." A third participant stated the use of a 3D printer to fabricate orthoses, "seems counterproductive, [and I] prefer to fabricate other ways."

In contrast however, several participants who did not use the technology in practice reported potential benefits (34.09%, $n = 30$) to use of 3D printers to fabricate custom orthoses. One participant stated a 3D printer could "increase ease/speed of splinting." Another stated that use of a 3D printer could "reduce time spent in fabrication of splints" as well as "offer more variety of splints, reduce the cost of splints, [and] reduce wear on therapist hands." One participant mentioned that 3D printed orthoses would be more beneficial over traditional thermoplastic and stated, "Fabricating custom orthotics is a time-consuming, in-exact [*sic*] practice. It takes away much needed direct patient care. Thermoplastic material is hot, ugly, and we have poor compliance in our hot climate. I think 3D printed orthotics would save time, allow for more 1-1 patient time, and improve compliance due to improved comfort and fit." Another participant stated that the technology "would open a whole new realm of possibilities for orthotics."

Additionally, researchers asked participants to report any concerns regarding the safety of the printer and its printed products. Of the 261 total participants who did not use a 3D printer, 57.85% (n = 151) did not express any safety issues, while 9.20% (n = 24) reported having concerns about safety, and 32.95% (n = 86) reported being unsure of safety issues. Of the participants who expressed specific safety concerns, five responses (20.83%) included a common worry of fumes given off by the printer and need for proper ventilation. Specifically, one participant who did not use a 3D printer in practice noted having fear related to "carcinogens released by the 3D printer," and another individual who did not use a 3D printer in practice stated concern about "safety of printing in a non-ventilated area." Another potential issue noted by 58.33% (n = 14) of non-user participants was related to the overall safety of the printed product. For example, one respondent stated worry of "any patient allergies to materials, sharps/detachable pieces [and] general cleaning, and maintenance of device." Five respondents (20.83%) also reported common anxieties regarding making modifications to orthoses after being printed. One participant stated, "Splints [orthoses] cannot be modified to easily accommodate swelling changes or pressure areas." Eight participants (33.33%) echoed this concern regarding pressure areas and difficulty making modifications of 3D printed orthoses.

Of the individuals who reported using a 3D printer in practice, four (57.14%) stated they have not found any health or safety implications, two (28.57%) did have safety concerns, and one (14.29%) was unsure of any concerns. Of the two participants who reported safety issues, Participant B specified concerns with fumes emitted by the 3D printer, difficulty with adjusting the printed product, overall fit of a printed orthosis, therapists printing products without adequate training, electrical shock, potential for hand burns, proper ventilation, and the safety of the printed item for patient use (e.g., sharp edges, allergies). Participant B continued to discuss concerns with the durability and strength of the product and reported potential safety issues with the tools used post-printing such as hobby knives, drills, and heat guns. Participant A noted fear with the sharp edges of the finished product and questioned the safety of the printer itself stating "the plate is hot" which could potentially lead to burns for an inexperienced user.

Limited resources.

From the 268 survey responses, 92.91% (*n* = 249) reported not having a 3D printer available due to lack of resources. Participants noted a variety of specific limited resources related to cost, time, and decision to implement was outside of clinician authority (Table 4).

Table 4

Barriers to Implementing 3D printing (n = 519)

Barriers	*n*	%
Cost	146	28.13
Time	69	13.29
Knowledge	155	29.87
Not Required	85	16.38
Other	32	6.17
Unknown	32	6.17

Approximately half (54.63%, *n* = 146) of the participants who did not use a 3D printer in practice reported cost as a barrier to obtaining and/or using 3D printing technology, such as the upfront cost of the printer and materials. One participant reported a barrier was the "cost initially for the system." Additionally, many participants (34.13%, *n* = 85) also stated they were not using a 3D printer because it was not required by their facility, or it was outside of their authority. One respondent stated, "Not my decision in the clinic." Furthermore, 27.71% of participants (*n* = 69) stated insufficient time to learn the technology and 3D printing process.

Applicable Practice Settings

Each survey participant was instructed to select potential OT practice settings in which 3D printing may benefit patient care from the provided list. Of the 929 total responses, 17.65% (*n* = 164) selected freestanding outpatient, 16.47% (*n* = 153) selected hospital-based outpatient, 9.15% (*n* = 85) selected skilled nursing facility/long-term care, 8.72% (*n* = 81) selected hospital-based inpatient, 7.75% (*n* = 72) selected academia, 5.38% (*n* = 50) selected home health, 4.31% (*n* = 40) selected community-based, and 1.83% (*n* = 17) selected mental health as potential settings in which 3D printers may be utilized.

Additionally, the majority of respondents who used a 3D printer in practice (57.14%, *n* = 4) reported that a 3D printer could be beneficial in all OT practice areas. Participants also stated they have used the 3D printer in multiple settings including: hospital-based outpatient (11.11%, *n* = 1), freestanding outpatient (33.33%, *n* = 3), home health (11.11%, *n* = 1), academia (11.11%, *n* = 1), and other (33.33%, *n* = 3). The participants who selected "other" were asked to specify; Participant B reported use of the 3D printer in a "student outreach clinic," Participant C stated use at a local library, and Participant E stated "VA [Department of Veterans Affairs Hospital]."

Discussion

Through data analysis, researchers fulfilled the purpose of the study to examine current uses of 3D printing in upper extremity rehabilitation by OT practitioners as well as investigate the perceptions they have regarding the technology. The results of this study demonstrate that only a few OT and hand therapy practitioners were using 3D printing technology in their practice. The majority of participants surveyed were uninformed about its use or have apprehensions or restrictions integrating the technology into OT practice. Study authors identified limited knowledge and unfamiliarity about 3D printing as a prominent theme throughout survey results. In addition, many non-user participants had misconceptions about 3D printing technology regarding its established benefits to use in health care. Lastly, participants who were using or familiar with the technology recognized safety concerns that may have implications for OT practitioners and their clients.

Unfamiliarity and Misconceptions about 3D Printing

The limited awareness and unfamiliarity by study participants of 3D printing technology was pervasive throughout survey results. The research team coded many of the open-ended comments made by participants as insufficient knowledge regarding the properties and applications of 3D printers. Additionally, a few participants ($n = 7$, 3%) stated they were unaware of any research that had been conducted regarding 3D printing and its use in OT practice.

Furthermore, participants seemed to have misconceptions about the previously established advantages and disadvantages of 3D printing supported in the literature, including its cost-effectiveness, time-saving, and the ability to better customize products for client use. For example, 57.09% ($n = 149$) of participants not using a 3D printer, reported “cost” as a barrier to use; however, many researchers have previously reported that 3D printing can be less expensive than traditional methods of fabricating orthoses or other medical products (Hagedorn-Hansen et al., 2016; Lee et al., 2017; Rho et al., 2017; Santos et al., 2017; Schrank, & Stanhope, 2011; Silva et al., 2015; Thomas, 2016; Zuniga et al., 2015). Additionally, it has been established that use of a 3D printer over time is cheaper than traditional methods of product fabrication even after factoring in the upfront cost of purchasing the printer and associated supplies (Hagedorn-Hansen et al., 2016; Lee et al., 2017; Santos et al., 2017; Schrank, & Stanhope, 2011; Thomas, 2016; Zuniga et al., 2015).

Previous researchers have also found that use of 3D printing technology can be more time efficient (Hagedorn-Hansen et al., 2016; Santos et al., 2017; Schrank & Stanhope, 2011). In these studies, researchers qualify “time-efficient” as reduced production time compared to traditional methods of fabrication, mainly for prosthetic devices and lower extremity orthotics. It is important to clarify and understand that this differs in meaning for OT practitioners, especially those who fabricate custom upper extremity orthoses out of low-temperature thermoplastics. In our study, 28.35% (*n* = 74) non-user participants reported “time” was a barrier to using a 3D printer in practice. One participant stated, “time to print 3D [*sic*] is longer than I can make an orthosis.” Li & Tanaka (2018) reported that 3D printed orthoses can take approximately two to five hours to print, which does not include the time needed to obtain a 3D scan of the client’s limb, designing the orthosis model using computer-aided design (CAD), and post-printing procedures such as removing rough edges and supports. Not mentioning the obvious need for the clinician to possess the skills to follow and be successful in this modeling process, a two to five hour printing time is significantly longer than the approximately 20 minutes it takes to fabricate an orthosis out of traditional thermoplastic (Li & Tanaka, 2018). While 3D printing a complete custom orthosis is slower compared to use of thermoplastic, there is potential to mass-print portions of orthoses, such as outriggers or hinges for mobilizations needs, that may save time overall in the fabrication process. It should also be noted that it does take many hours of time upfront to learn and become proficient in 3D printing technology before one can start printing products easily and for optimal patient use. Li & Tanaka (2018) have developed a programmable 3D modeling technique to help circumvent this issue by including engineers in the CAD process; however, it is still too lengthy to replace traditional methods for emergent client needs.

Previous researchers have also established the ability to customize items more easily is a benefit to use of 3D printing technology (Li & Tanaka, 2018; Liacouras et al., 2017; Santos et al., 2017; Schrank & Stanhope, 2011; Smith, 2017; Ventola, 2014; Weller, Kleer, & Piller, 2015; Zuniga et al, 2015). The majority of our participants using a 3D printer reported “customization” as an influence in their decision to use a 3D printer (85.71%, n = 6) and mentioned the ease of printing customized products for clients. Participants we surveyed who did not use a 3D printer stated one way to use the technology could be to fabricate custom orthoses (43.30%, n = 113) and assistive devices (20.69%, n = 54). Due to the time barriers mentioned above when creating custom orthoses (Li & Tanaka, 2018), one may argue that 3D printing technology is not yet entirely feasible for the practicing occupational therapist when utilized in this manner. However, there is potential for creating customized versions of adaptive equipment and other assistive devices that may be more beneficial to improve a client’s independence compared to an off-the-shelf item (Ganesan et al., 2016). Furthermore, many clients have complex and multiple needs and a truly customized assistive device for that individual client may not be available to purchase, yet available through 3D printing technology. Clinicians can also customize 3D printed educational tools and models as well to reflect a specific client’s unique anatomy, which may be more meaningful to the client and lead to improved understanding (Bernhard et al., 2015; Friedman, Michalski, Goodman, & Brown, 2016; Rengier et al., 2010; Starosolski et al., 2014; Trace et al., 2016).

Current Implications for OT Practice

Even though many non-user participants were unfamiliar or confused about 3D printing technology, 46.83% (n = 64) stated use of a 3D printer would enhance practice due to the purported benefits previously discussed. Only 12.31% (n = 17) participants thought the printer would diminish practice. Overwhelmingly, participants reported fear of infringement upon the skills and scope of practice of OT practitioners and CHTs by users of the technology outside of the profession, especially in terms of orthosis fabrication. Participants felt this could also pose risks and safety concerns for clients if unskilled users were fabricating medical devices for client use (Lupton, 2014, 2016; Steenhuis, 2016).

Additionally, study participants reflected on changes to the amount of available direct care time with their clients. One positive impact of using a 3D printer in practice is increased time spent on direct patient care (Liacouras et al., 2017). Three of our participants (42.86%) who use a 3D printer in practice stated using the 3D printer increased available time spent with their clients. Of our participants who did not use a 3D printer and thought it would impact time with patient care, 18.25% (n = 25) stated it would increase time spent with patients. Thomas (2016) stated that practitioners have increased time for direct patient care when using a 3D printer in practice as it can decrease the time required to develop and manufacture medical devices.

In regards to possible safety concerns, the issue of unfamiliarity and misconceptions about 3D printing continued to be present throughout survey results. Of all survey respondents, the majority 57.84% (n = 151) reported no safety concerns with using a 3D printer. Researchers acknowledge this lack of concern may be related to insufficient knowledge regarding 3D printing. Only 14 respondents (60.87%) not using a 3D printer expressed concern related to the overall safety of the product and materials for client use. In addition, respondents who did not use a 3D printer (22.73%, n = 5) reported concerns with making modifications to the product. In review of the literature, other researchers have stated 3D printing prosthetics and medical equipment allowed for proper customization and there were no concerns with the impact of material on the client (Tanaka & Lightdale-Miric, 2016; Ventola, 2014). This contradiction likely exists due to the limited research on 3D printed materials and devices specifically for occupational therapy clients (Ganesan et al., 2016).

Furthermore, 2% of all participants (*n* = 6) reported concerns over fumes emitted by the printer. Love and Roy (2016) and Ryan and Hubbard (2016) reported presence of chemical emissions from 3D printers, but called for more research into the implications of various material emissions. Love and Roy (2016) reported that those operating 3D printers should not be excessively concerned about operation of 3D printers as long as operators are using polylactic acid (PLA) plastic material and in an area that has sufficient ventilation. These researchers even stated that most new 3D printers have built in ventilation filters, though it is always safest practice to use 3D printers in well-ventilated rooms (Love & Roy, 2016). With this information, the use of a 3D printer in practice might be dependent on appropriate ventilated space within the facility. Further research and clarification on this possible health concern is needed to determine its relevance for occupational therapy practitioners and their clients.

Limitations

Researchers acknowledge limitations of the study. Limitations included having a small portion of participants currently using a 3D printer in practice (2.6%, *n* = 7), which may have led to limited data about the perceptions and current uses of a 3D printer in practice. Participants in the study were recruited due to their membership in ASHT and this may have excluded additional OT practitioners that use 3D printing technology in their practice.

Considerations for Future Research

Future researchers should investigate the influence of a 3D printer on OT practice and explore how 3D printed products could potentially affect a client's quality of life, occupational engagement, and occupational performance. Additionally, it will be important to discover how clients view the 3D printed products (adaptive equipment, orthoses) and gather insight regarding specific client needs relative to their daily occupations. Other areas of future research include investigating reimbursement procedures of 3D printed products for client use and determining the possible implications of using customizable and cost-effective 3D printed products in practice. The development of continuing education courses and additional practitioner education opportunities may help to rectify the limited knowledge about 3D printing that participants expressed directly and indirectly throughout the survey. The authors of this study recommend further research on 3D printing technology as it directly relates to OT and its implications on practice.

Conclusion

The purpose of this study was to investigate current uses of 3D printing technology in upper extremity rehabilitation and discover the perceptions that OT practitioners have regarding the technology. The results showed those who use a 3D printer in OT practice felt it gave them the ability to customize products while reducing cost and increasing time spent in direct patient care. Participants not using a 3D printer in practice reported the main barrier to its use was their lack of knowledge about the technology, partly stemming from limited research conducted and published about 3D printing technology effects and uses in OT practice. Because this continues to be a changing technology, more research is needed to explore current and potential uses of 3D printing technology in OT.

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