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Application of 3D printing in healthcare of the elderly

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Abstract

In most cases the applications of 3D printing in healthcare are not age-specific but, similarly to hearing aids (fully overtaken by 3D printing), hip prostheses or teeth implants, they are more frequently used by older people. Planning surgeries using 3D printed models obtained on the basis of CT or MRI is frequently used for complicated surgeries. The planning brings a shortening of duration of operation and improved precision, contributing to accurate reconstruction of anatomical relations and faster patients' recovery. 100 000 hip prostheses produced by Arcam and implanted exemplify the widespread use of 3D printed (other than dental) implants and prostheses. 3D printed medical devices of good quality, often printed using free files, are inexpensive. Great prospects are expected for 3D printed food for people with swallowing problems and for 3D printed pills. 3D bioprinting, i.e. 3D printing with cells, will bring replacement organs in future. (Gerontol Pol 2019; 27; 293-299)

Key words: *3D printing, virtual surgery planning, implants, prostheses, devices, bioprinting*

Streszczenie

W większości przypadków zastosowania druku 3D w służbie zdrowia nie są związane z wiekiem, ale podobnie jak aparaty słuchowe (całkowicie przejęte przez druk 3D), protezy bioder czy też implanty zębów, są one częściej używane przez osoby starsze. Planowanie operacji przy użyciu drukowanych modeli 3D uzyskanych na podstawie tomografii komputerowej lub rezonansu magnetycznego jest często stosowane w przypadku skomplikowanych operacji. Skraca ono czas trwania operacji i poprawia jej precyzję, przyczyniając się do dokładnej rekonstrukcji relacji anatomicznych i szybszego powrotu do zdrowia pacjentów. 100 000 protez biodrowych wyprodukowanych przez firmę Arcam i wszczepionych stanowi przykład powszechnego zastosowania innych niż dentystyczne implantów i protez drukowanych w 3D. Urządzenia medyczne wydrukowane w 3D są dobrej jakości i niewiele kosztują. Są one często drukowane przy użyciu bezpłatnych plików. Oczekuje się, że żywność drukowana w 3D dla osób z problemami z przełykaniem i leki drukowane w 3D będą szeroko stosowane. Jeszcze większe nadzieje wiąże się z drukowaniem w 3D komórkami (czyli biodrukiem w 3D), które w przyszłości będzie źródłem narządów zastępczych. (Gerontol Pol 2019; 27; 293-299)

Słowa kluczowe*: druk 3D, wirtualne planowanie chirurgiczne, implanty, protezy, urządzenia medyczne, biodruk*

Introduction

3D printing, 3DP, is a method of manufacturing a three-dimensional object consisting in depositing material layer by layer (with subsequent fusing of the layers) according to a numerical model [1]. In addition to massive applications in numerous industries, it has become a leading manufacturing technique in healthcare and medicine in such areas as dentistry, surgery, medical devices, anatomical models and others [2]. Bioprinting, that is 3D printing with cells, will in future deliver implants limiting, or even eliminating organ donors [3].

3DP enables manufacturing of complex, anatomically matched and patient-specific devices allowing on-demand fabrication with high productivity and cost-effectiveness. The method also becomes of importance in tissue engineering and engineered organ and tissue models. Its great advantage is personalization that guarantees better adjustment of a device, an implant or prosthesis to the patient's body, thus fostering the patient recovery.

Most 3DP applications in healthcare are also applied for elderly but very few are age-specific. For instance, preoperative planning (also called virtual surgical planning) [4], in which the models for the planning are 3D printed on the basis of CT and/or MRI examination, allows doctors to better prepare for carrying out the surgery. Implants and prostheses are also usually not age-specific as are most 3D printed medical devices, such as high-quality stethoscopes that cost less than $5 (Figure 1) [5].

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Figure 1. 3D printed stethoscopes developed by Dr. Tarek Loubani.

Hearing aids

The market of hearing aids was the first to have been fully taken over by 3DP. Their traditional manual and labor intensive manufacturing was transformed into fast automated patient-oriented industry with much more than 10 million devices used worldwide. The production involves scanning, modeling and printing usually taking less than a day. Today, only 2% of the devices cannot be produced by 3DP [6].

Dentistry

Dentistry is the second domain to be taken over by 3DP soon [7]. By combining oral scanning, CAD/CAM design and 3D printing, dental labs can accurately and rapidly produce crowns, bridges, plaster/stone models, and a range of orthodontic appliances such as surgical guides and aligners. A 3D scan, taken instead of uncomfortable impressions, is later transformed into a 3D model and 3D printed. The model can be used to create a full range of orthodontic appliances, delivery and positioning trays, aligners and retainers. Moreover, the models can be conveniently stored digitally as 3D CAD (Computer Assisted Design) files.

Implants (excluding dental ones) and Prostheses

One of the first examples of 3D printed implant was the jaw part created for an 83-year-old British woman as early as 2012 [8]. Today several manufacturers produce high-quality 3D printed replacements/implants for, among others, hip [9, 10], spine [11], pelvis [12], vertebrae [13], trachea [14] and airway splints [15], great part of a human skull [16]. A somewhat cyborg-looking 3D printed titanium sternum [17] is shown in Figure 2.

Two approaches are applied in manufacturing hip replacements using 3D printing: personalized 3D printed prostheses on the basis of CT and/or MRI of the patient precisely for his/her size or 3D printing of prostheses in large variety of sizes much larger than that used in the standard procedure. More than 100 000 hip prostheses produced by Arcam AB in the latter way were implanted in patients until 2018 [9]. A loss in accuracy in comparison to the personalized prosthesis is outweighed by a lower price and the possibility to help more patients with prostheses better adjusted to their bodies than the traditional ones. A specific case of a 71 year old who underwent six hip replacements [18] can be mentioned here. She was in great pain and close to be wheelchair-bound after having walked with crutches and sticks for years. She was saved by an unprecedented approach by British surgeons who implanted a 3D-printed hip joint held in place with the patient's own stem cells.

Age is the major risk factor for osteoarthritis of the knee and knee arthroplasty surgery is helpful in end-stage disease. 3DP has several applications in this domain: cartilage, implants as well as realignments [19]. Jones and coworkers reviewed the application of 3DP in unicompartmental knee arthroplasty [20] concluding that this technique can be beneficial in such cases partially due to the improved accuracy of implant positioning.

Knee realignment is an operation developed to prevent patients from total knee replacement using the 3DP [21]. To carry the realignment, doctors create totally custom-made surgical guides or even joints on the basis of the CT scans of the patients, using 3D printing and perfectly fitting the morphology of the patient. Today, to my best knowledge, knee implants are not bioprinted. However, according to Gaget [21] this can be changed in the future. Then, knee replacement could be 3D bioprinted yielding really accurate knees that fit exactly the unique anatomy of an individual patient. They will enable the growth of cells and a fast and natural healing process.

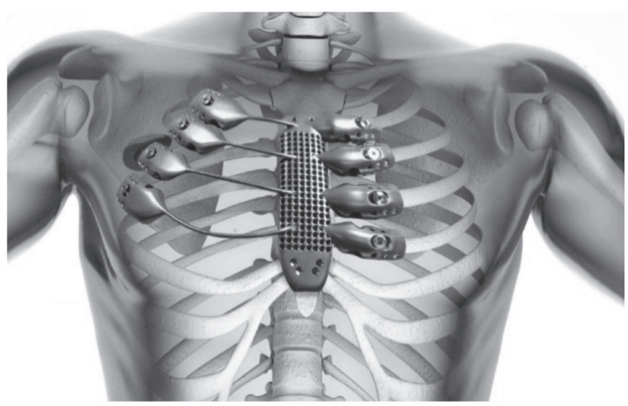

Figure 2. 3D printed titanium sternum with parts of the ribs [17]

Virtual Surgical Planning, VSP

VSP consists in 3D printing models of the organs that should undergo surgery on the basis of CT and/or MRI allowing doctors to visualize the place to be operated, better plan the surgery and effectively communicate with patients, leading to a shortening of duration of operation and improved precision, thus, contributing to faster patients recovery. It is not age-specific and the most spectacular applications of VSP consisted probably in multidisciplinary oncologic chest wall resection and reconstruction [22]. According to Shilo and coworkers [23] “The future lies in 3D bioprinting of viable cells which will compose the missing bone and soft tissue”. However, for the moment bioresorbable implants are of importance. The researchers from Xi’an Jiatong University, China, Georgia Institute of Technology, USA, and Singapore University of Technology and Design developed a printing method applied to a breast implant for a cancer patient after she had a mastectomy. The implant was composed of porous biodegradable material which enables the human tissue to grow into the pores with the subsequent decomposition of the implant material [24].

With world population getting older and a simultaneous rapid development of 3DP technology it is becoming less expensive to contribute to a significant growth of 3D printed medical implant market [25]. Acetabular hip implants are the most popular 3D printed implants. As discussed above, their manufacturing by Arcam AB crossed the border from piecewise to mass production. Titanium is the material of choice for jaw, hip, and skull implants [8,10,16] while special materials like CT-Bone® are applied for bone implants [26]. In the latter case mimicking the porous bone structure is a real challenge [2].

Design and manufacturing of medical devices

3DP is used in countless 3D printed medical devices that are often patient-specific and specifically adapted for elderly. For medical devices that are not 3D printed, the method is often used in their prototyping.

3D printing of surgical instruments

Similarly to stethoscopes mentioned earlier, forceps, hemostats, scalpel handles, clamps, and other sterile surgical instruments can be produced inexpensively using 3D printers. Moreover, they can be made very small allowing doctors to operate precisely on tiny areas without causing unnecessary damage to the patient [27].

Age-specific medical devices

a. Cancer is considerably more frequent in an elderly population. In addition to SVP, 3DP is applied to cure the patients either by drug delivery (drug-loaded implants) [28] or drug soaking systems [29] patient-specific prostheses (breast, bones, sternum (Fig. 2), etc.), boluses to increase radiation dose into a desired area [30], dosimetry phantoms allowing doctors to control the patient radiotherapy [31], and in numerous other ways.
b. The Polish Company ZMORPH in cooperation with the Faculty of Wood Technology at the University of Life Sciences in Poznań developed Age Simulator (Fig. 3), a device that should help designers of furniture, public transport vehicles, homes, clothes or cars to better understand the needs and limitations faced by older people [32]. The simulator is a kind of 3D printed suit developed on the basis of a careful analysis of the movement of a 75 year old woman who performed daily activities such as walking, bending or reaching objects from a shelf. The suit is accompanied by a set of glasses mimicking vision problems of older people (Figure 3).

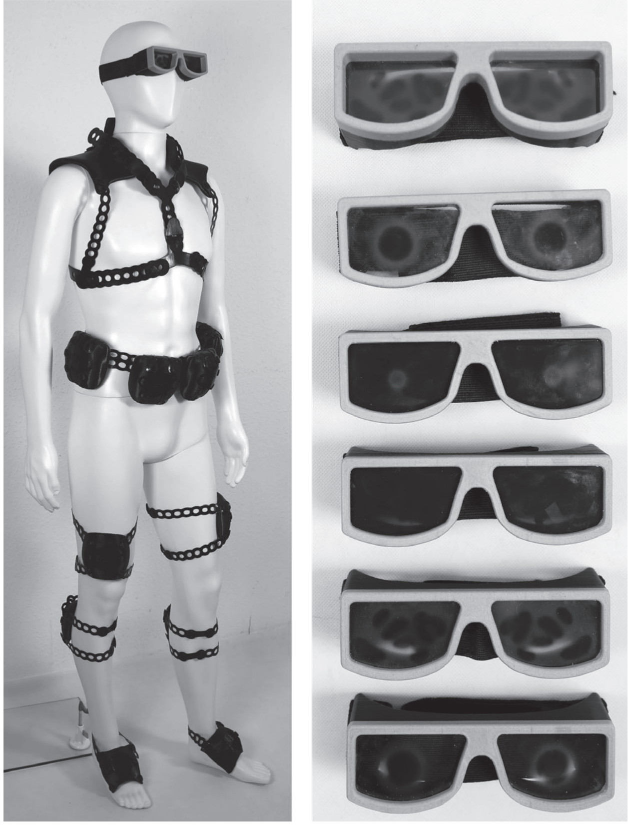

Figure 3. a. Age Simulator (left) and accompanying glasses (right)

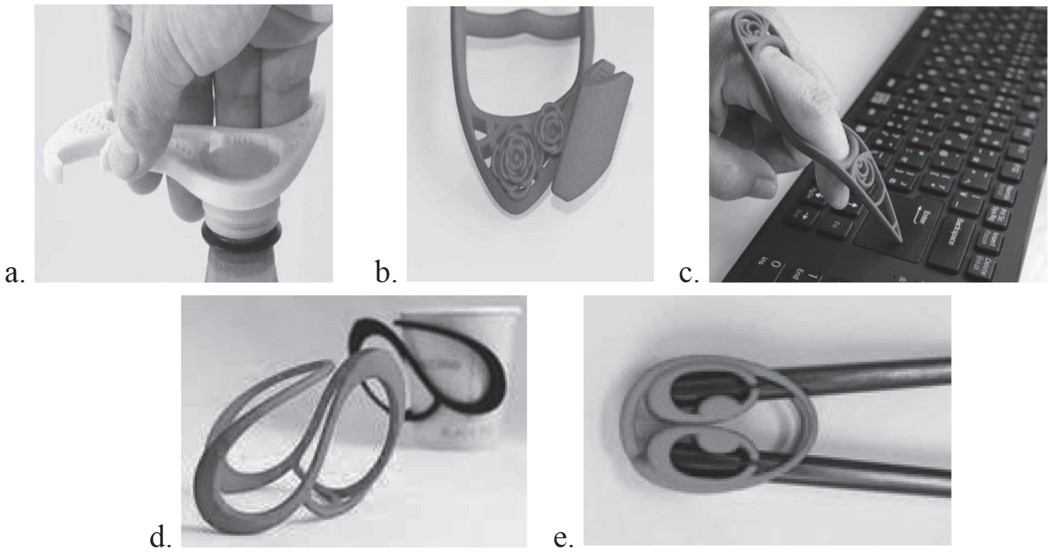

Figure 4. a. bottle opener, b. writing assist holder tool, c. finger input device, d. cup holder, e. chopsticks helper created by Tatsuo Ishibashi © Mizu Laboratory

Practical and beautiful devices helping elderly disabled patients in everyday life

Japanese designer Tatsuo Ishibashi created 3D printed devices helping elderly and/or disabled persons to tackle everyday activities [33]. Such devices can be very inexpensive, since one can download free files for printing them from internet portals like thingivers [34].

Additional considerations on 3D printing and elderly healthcare

In the article "How 3D Printing Can Support Elderly Care", in addition to the above self-help devices helping elderly people in everyday life [35], two other important points are raised:

1. Tools to facilitate better communication between care-givers and care-receivers are needed. For instance, medical equipment might be constructed in fun shapes (or in bright colours)) to help overcome any negative perceptions.
2. The creation of educational objects to help care-givers learn how to perform various therapy actions. For instance, a semi-transparent cranial model was used to practice the insertion of a special tube to vacuum phlegm from the patient's throat. Of course, 3DP can be applied in all such devices.

Smooth food with different textures for the elderly

Chewing and swallowing difficulties can result from stroke or dementia. The illness is characterized by the inability of the larynx to close properly while swallowing. Because of this condition 60% of nursing home residents eat liquefied, mostly unappealing and nutritionally inadequate food [36]. 3DP is applied to production of visually appealing, well tasting food for people with swallowing problems. Pureed and strained food is brought back into its original shape, yielding the same texture and look, and providing additional health benefits. In this way 3DP could contribute greatly to the quality of life of the elderly people with dysphagia.

3D printed drugs [37]

Spritam®, the anti-epileptic seizure drug levetiracetam developed by Aprecia Pharmaceuticals is the first, and to my best knowledge at present the only 3D printed drug approved by the American Food and Drug Administration, FDA [38]. The drug has a layered, highly porous structure that cannot be achieved using traditional manufacturing methods. Therefore, the drug rapidly sucks in liquid, collapsing to form an easily absorbable suspension. Such a unique structure cannot be achieved using traditional manufacturing methods.

In addition to high solubility exhibited by Spritam tablets, 3DP can provide an opportunity to manufacture drugs in specific dosages for small kids and/or elderly, those enabling its controlled release or multidrug combination. Of course, the latter will demand a special care to avoid the unfavourable drugs' interaction.

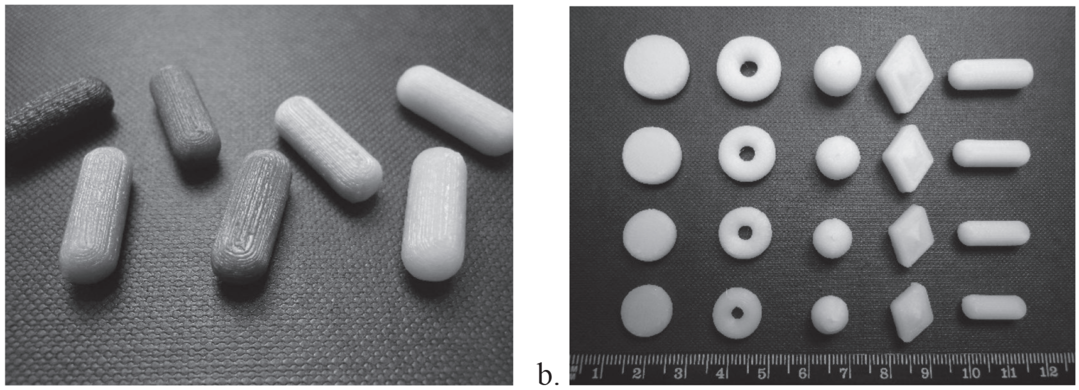

Figure 5. Nonstandard drug pills in various coulors (a) and shapes (b) 3D printed by FabRx company © H. Dodziuk

3D bioprinting

As mentioned earlier, 3D bioprinting is the printing with cells. Today (August 2019), to my best knowledge, the only commercialized device involving bioprinting is FDA approved ExVive™ model of human liver tissue for in vitro testing of drug toxicity [39]. Other human tissues, such as among others kidney, heart, cornea, bones, ligament, tendons [40] are bioprinted today with the goal to 3D print whole organs for implantation, thus limiting or even suppress the need for the donor organs.

Conclusions

The present and future applications of 3DP in healthcare are enormous and bring several benefits for doctors and, also older, patients. The 3D bioprinting of organs is particularly awaited as it is hoped to counteract the donor shortage. The medical applications of 3DP create significant legal problems [41, 42], in particular in the domain of *intellectual property rights* and *liability*. The American FDA agency [43] and EU introduced some regulations of 3D printed medical devices [44].

Notes added in proof: (a) Fall protection suits for senior sitizens 3D printed in Korea are worth mentioning [45] (b) Six different grugs are 3D printed in multi-layered polypill [46].

Conflict of interest
None

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