3D printing in Healthcare

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Healthcare has a broad range of 3D printing developments that seems amazing today but that will probably seem commonplace in a few years, as even more impressive advances eclipse them. Walter Reed Army Medical Center has 3D printed titanium cranial implants [1], and replaced a woman's jaw with a 3D printed prosthetic [1]. In 2013 doctors replaced 75% of a man's skull with a 3D printed implant made by a company called Oxford Performance Materials [2]. In the UK, doctors replaced half of the pelvis in a man with a rare type of cancer [3]. Tens of thousands of replacement hip cups have been printed and implanted into patients [4].

Other 3D printing developments in health care include noses [5], skin [6], customized coverings for artificial limbs [1], cosmetic ears [7,8] and bionic ears [9]. About 95% of all hearing aid shells are 3D printed [1,10]. The molds for about 17 million teeth aligners are 3D printed every year [5,11,12]. 3D printed tracheas and tracheal splints are almost routinely saving newborns with serious

breathing problems [13–15]. The 3D printers used for this work are not always expensive, high-end machines. Consumer-grade 3D printers and materials have been used for tracheal implants. Doctors at the Feinstein Institute for Medical Research used a MakerBot machine (about US\$2000) and ordinary PLA filament to 3D print custom scaffolding on which living cells were cultured for a tracheal implant [16]. MakerBot machines have also been used to 3D print patient-specific, biodegradable medicinal implants for treating bone infections and cancers [17].

The human heart is the subject of considerable 3D printing efforts. Aorta cells have been 3D printed at Sabanci University in Turkey [18]. The University of Louisville expects to 3D print a human heart by 2023 [19,20]. Kentucky-based Advanced Solutions intends to use its BioAssemblyBot printer to accomplish the feat [21]. In 2013, a California high schooler 3D printed a proof of concept customizable artificial heart [22]. And, to save existing hearts, Washington University in

St Louis is developing an elastic, 3D printed membrane that wraps around the heart like a glove. Its embedded sensors detect impending problems, and embedded electrodes deliver a life-saving shock when serious arrhythmias are detected [23].

Organovo, of San Diego, CA, USA, is 3D printing tissue used for drug testing and is working on a 3D printed human liver, which could eliminate animal testing of new drugs and enable safe and effective drugs to be brought to market much faster and at lower cost than they are today [24,25]. Others are working on 3D printable drugs, to be printed at home or where they are needed [26,27].

Low-cost 3D printers are being used in war-torn developing countries, such as the Sudan and Uganda, to make prosthetics for amputees, of which there are 50,000 in the Sudan alone [28,29]. The US Army also wants to use 3D printing to counter some of the horrors of war. In a joint project with the University of Nevada, the army plans to 3D scan soldiers, from head to toe, and store the data in case the soldier loses a limb in

combat. As Dr James Ma said [30]: *“The idea is to image someone when they are in a healthy state so that the data is available if it’s needed at a later point... We have soldiers who get injured. They lose limbs and other tissues and it’s a challenge to reconstruct them in the field. But if they are imaged beforehand, you can send that over the internet and have a 3D printer in the field to produce the bone.”*

The Oak Ridge National Lab’s award-winning, lightweight, low-cost 3D printed hand may be used in robotics, prosthetics, surgery and hazardous materials handling (Figure 1) [31]. A hydraulic pump powered by an electric motor located in the palm of the hand provides pressurized fluid to the finger joints, which cause gripping motion. An electric motor turns a cam that drives two master pistons each connected to five slave pistons, which cause the fingers to open or close. Since the fingers are hydraulically coupled, the digits will naturally conform to any device they grasp.

3D printers have also been used to aid facial reconstructive surgery, with impressive results, including a full-face replacement in Belgium [32–34]. Researchers at Michigan Tech are using graphene and 3D printed scaffolds to rebuild damaged nerve tissue [35].

Italy’s Del Bene Orthopedic Laboratory switched from traditional manufacturing to 3D printing for its human prosthetics and cut its production times by 75%. Biomedical engineer Marco Avaro says [36]: *“For a tibial prosthesis, I used to need eight hours. Now, I only need two.”* They have found that 3D printing prosthetics has other advantages. According to Avaro: *“If we take the case of degenerative diseases, the geometries can become particularly difficult, very asymmetric, and the 3D printer can reproduce exactly what we need.”*

A great medical application for 3D printing is surgical models and guides. Models of patient organs are being 3D printed and studied by surgeons before the first incision. Better to find anatomical anomalies and formulate strategy while studying models than while a patient lies on the operating table [37]. Surgeons at Miami Children’s Hospital 3D printed a replica of a 4-year-old girl’s heart to plan her complicated surgery [38]. Doctors at Boston’s Children’s Hospital practiced on a 3D printed model of a teenager’s brain before operating on the real thing [39]. Texas Children’s Hospital 3D printed the hearts, lungs, stomachs and kidneys of twins conjoined at the chest and abdomen so that surgeons could plan and practice their separation, which was a success [40]. Similarly, Chinese surgeons used a life-sized 3D printed model to practice separating conjoined twins who shared a single digestive tract. The model included many of the anatomical features they would encounter during surgery, such as bone joints and skin connections, which the surgeons practiced cutting to determine how best to separate the

Figure 1. 3D printed hand.

Photo courtesy of Oak Ridge National Laboratory.

infants [41]. 3D printed models are also being used to train tomorrow's brain surgeons [42]. 3D printed surgical guides, such as guides customized for a patient's knee, enable surgeons to locate cuts precisely [43,44]. The printing of such guides is aided by software that turns 2D x-rays into 3D models [45]. Some hospitals are 3D printing surgical models and guides in-house. For example, Belgian 3D printing company Materialise opened a 3D printing center in Fuwai Hospital, China's largest cardio facility. According to the hospital, this collaboration will enable Fuwai to [46]: “..become China's leading center for 3D printed heart model education, spreading knowledge of the technology and how it can be used by surgeons to the benefit of the Chinese public.”

3D printing is also being used for cosmetic surgery. A New York start-up, MirrorMe3D, 3D prints models showing what you will look like after cosmetic

surgery [47]. Many Hollywood stars probably wish this company had existed before they went under the knife.

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