The remarkable potential of 3D printing in healthcare

3D printing has become a highly versatile and progressively cost-effective technology, permeating a variety of fields, including healthcare, say our R&D writers, led by **Ian Portelli**

When she was six months old, a spark from an oil lamp set fire to Veronica's sleeping mat on the ground – she sustained burns over much of her body and lost one arm. With her family unable to care for her, she was taken in by The Giving Circle, which gave her a home at an orphanage. A volunteer for e-NABLE said that they made three different sized prosthetic arms because Veronica will grow and they wanted to make sure she would have a prosthetic that was a perfect fit. Lourds Lane, Founder of The SuperYou FUNdation was also involved. She said: "Meet our little superhero, Veronica. When I met her, she was a bit shy, at least with me. But when I sat with her and the other orphans at the Koi Koi House, all the children, especially Veronica, began to show their true colours. Using art and music, I began to teach the children how to find their inner superhero selves." Veronica chose to name her inner superhero 'Super Healer'

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A 3D printer is made up of the printing machine, the software that contains the design and instructions for printing and the ink.

The ink is arguably the most important part of a 3D printer, as it becomes the object that is to be created and, as such, is the element that provides the great versatility of these machines. The ink can be molten glass that fashions glass art, steel, titanium, nylon, photopolymers, plastic or even food. 3D printers used in healthcare, often called bioprinters, use a different kind of ink, consisting of organic materials, whose composition varies depending on the desired end product.

In the medical field, 3D printers have expanded fields of research, which ideally will some day result in the printing of organs for transplant, eliminating the need for a donor. But organs are incredibly complex systems, and the ability to create a functioning heart, liver or lung is still far away.

Creating prostheses or devices that perfectly match the patient's needs on site and in a short period of time however, is a goal that is near realisation. Prostheses have been created cost-effectively and quickly using 3D printers, although it is not yet standard practice.

While the ultimate goal would be to prevent loss of limbs, we must discover new ways of treating and helping patients when amputations become necessary. Although bones are generally very regenerative tissues, major bone loss is very difficult to treat.

Current treatments for such patients usually require bone grafts or amputation, though the latter is considered only when it is clear a limb cannot be saved or its presence is risking the patient's life.

Patients who can heal with a bone graft must cope with the associated risks. In autografts, the source graft is taken from the patient. This means that they must undergo two surgeries; one to harvest the autograft, which needs to be shaped, and another surgery to insert it into place. These processes involve doubled risk of infection and pain.

The other option is an allograft, which can be taken from a matching donor or created synthetically. Donor allografts are difficult – and take a lot of money and time – to obtain, whereas synthetic grafts might be rejected and don't have the same adaptability and bioactivity as bone.

3D printing presents an alternative to bone grafts. Previous research involved creating the bones themselves using hydroxyapatite and other minerals. However, this was not without difficulty owing to the secondary function of bones wherein they produce blood cells in the marrow – a difficult process to reproduce. Instead, new techniques are focusing on creating a scaffold composed of bone powder and polycaprolactone, then layering it in stem cells and growth hormones.

The growth hormones promote differentiation of the stem cells and, once implanted, continue to grow and create bone, using the scaffold as a foundation and the host's system to revascularise the growing tissue and cause it to harden.

These scaffolds are biodegradable and as time passes and tissue growth is stimulated, the scaffold breaks down to leave behind regenerated bone tissue.

The rapid creation of perfectly tailored scaffolds would provide a fast, relatively inexpensive and, if effective, a lifelong solution for major bone damage injuries.

In this way, 3D printing could enable swift construction of products tailored to the specific individual's injury and needs on site.

For those who are born with limb reduction defects or people who have had an amputation, 3D printing provides an exciting and affordable solution. The ability to create 3D-printable prosthetics is changing the way physicians and patients approach prosthetics.

In recent years physicians and engineers have developed wearable, comfortable, and customised prosthetics for a wide range of people, from young children to adults. These prosthetics are also much less expensive and quicker to make than traditional options

Engineers, designers, physicians, amputees and the public have come together in many places to make 3D printable prosthetics a reality. One group, e-NABLE, is a network of individuals from around the world working towards making these printable prosthetics available to people in need.

Feel vs function

These printable prosthetics are highly customisable and 'patient-specific', fitted to each individual based on features of their unique anatomy. A spokesperson for e-NABLE told *CRJ*: "While these devices have just a simple basic grasp and cannot lift much weight, it seems that one of the most treasured function is a self confidence boost in the recipient who gets it. There is something to be said for how it makes them feel versus function alone. There are many who opt for trying an e-NABLE device over their traditional claw and hook devices, simply because it makes them feel like they blend in more."

Researchers at MIT's Lincoln Laboratory's Technology Office Innovation Laboratory have been working to improve comfort and functionality. Using Magnetic Resonance imaging (MRI) and quantitative measurements of residual limbs, researchers created a 3D printed socket that allows for optimal comfort. To improve functionality, designers have added nonelectoral temperature and tactile feedback to aid finger motion.

A tactile component would allow a patient to feel pressure through flexible tubing, running from the fingertips of the prosthetic to his or her forearm.

3D printed prosthetics are also a favourable alternative to conventional ones in children. Since children tend to outgrow a prosthetic limb about once a year, families will save money if they buy a 3D printed prosthetic, as these have stretchable and expandable features.

Currently only external hand prosthetics are available, but in the future 3D printing of more prosthetics, including arms, feet, and legs appears promising.

Investigators are also looking into the application of 3D printing in manufacturing living organs, such as liver, heart, or lungs, but this research is still very new.

3D Printing may also prove useful as a training tool for surgical residents and practising physicians. When preparing for a procedure, many surgeons will mentally rehearse their strategy. Although surgery is significantly skill-based, surgeons will often be confronted with novel procedures that they are not comfortably familiar with. In such instances, they have to rely on the intuitive knowledge they have cultivated from performing procedures in the past and in observing other surgeries.

Dr Peter Weinstock, an Intensive Care Unit physician at Boston Children's Hospital and director of the hospital's Simulator Programme (SIMPeds), points out the incredible reality that there is no physical run-through of a surgery prior to 'game time'. Yet, similar high-stakes industries – such as nuclear power and airlines – routinely run through simulations that help workers prepare for worst-case scenarios.

According to Dr Weinstock, it is time that surgeons and surgical teams also have the opportunity to refine their skills by practising in a realistic context of their trade.

A report by Kahol et al finds that surgeons can improve their performance via a 'preoperative warm-up.' Participants in this study were asked to use a 15 to 20 minute surgical simulation using an FLS Training Box. A 33 per cent reduction in errors was demonstrated after the standardised exercises had been repeated following the warm up. The time of performance was also shortened, while gesture proficiency, smoothness of hand and tool movement all increased.

3D printing can be an ideal training tool. It provides surgeons the opportunity to perform a designated operation as many times as they would like on a lifelike model of their patient, before entering the operating room.

Dr Weinstock speaks fondly of collaboration between Hollywood and medicine, which has allowed his team create ultra-realistic models of patient's anatomy, so as to improve relevant training techniques for surgeons and, ultimately, enhance their performance. CRJ

An individual 3D model printed by surgeons at Boston's Children's Hospital, USA, for pre-surgical planning and practise

Boston Children's Hospital

Authors

SILVI DORE *is a Clinical Research Co-ordinator at Vassar Brothers Medical Center and is currently in the process of applying to medical schools;*

ANNA ROSELLE *is a junior at Vassar College majoring in Neuroscience and Behaviour, with a correlate in Chemistry. She is a Clinical Research Intern at Vassar Brothers Medical Center and an independent research assistant for the Neuroscience laboratory at Vassar College. Anna plans to pursue an MD or MD/PhD after finishing her BA;*

FRIDA VELCANI *is a junior at Vassar College majoring in Science, Technology & Society (STS) with a correlate in Hispanic Studies. She is a Clinical Research Intern at Vassar Brothers Medical Center;*

CARLY ESTEVES *MS, AGACNP, CCRN is the Lead Trauma Nurse Practitioner at Vassar Brothers Medical Center; and*

IAN PORTELLI *BCDM, PhD, is AVP, Medical Research and Operations at HealthQuest Systems Inc; AVP for Trauma at Vassar Brothers Medical Centre; and Associate Professor Emergency Medicine New York University School of Medicine. Dr Portelli is* CRJ*'s Chief Scientific Editor*