3D printing human body parts: science fiction or the new world of surgical innovation?

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'The greatest misfortune that ever befell man was the invention of printing.' (Benjamin Disraeli)

INTRODUCTION

As we enter a new era of 'paperlite' medicine and hospital staff are instructed to stop printing medical records, it is ironic that scientists and surgeons are finding new ways to use printing technology in their efforts to improve the outcomes of surgical procedures. This article was inspired by the first case in the UK of a British orthopaedic surgeon (Mr Craig Gerrand) replacing the hemi-pelvis with an implant produced by a 3D printer. We will give a brief outline of this interesting case and we will also explore the principles of this technology, current usage and potential future applications for surgical disciplines.

3D PRINTING

Inorganic materials

3D printing can also be described as 'additive manufacturing', because it involves the process of creating a solid object of virtually any shape by printing successive layers of material from a digital model. Incredibly, these printers can print with a wide variety of materials including, wax, plastic, plasticine, clay and metal.

The most useful materials for surgical applications are plastics and metal. The process of printing metal objects involves a method called 'direct metal laser sintering'. The printer produces a product in layers using metal powder, eg titanium powder. The machine fuses metal powder into a solid object by melting it locally, using a focused laser beam. Layers are built up additively, typically using layers 20 micrometres thick. This process allows for highly complex geometries to be created directly from the 3D CAD data, fully automatically, within a few hours. Honeycombed sections and surface effects can also be applied.

An American company (conforMIS) has developed patient-specific 3D printed knee replacement implants using personalised imaging data, describing this as 'iFit technology'. This software uses the computerised tomography (CT) data of a patient's knee to create digital models of the knee. These models are used to create both the implants and the tools to install them. These tools, called jigs, are cutting guides that allow the surgeon to make precise cuts to remove a minimal amount of bone. These have been available for UK patients since 2012, and at the current time it is unclear whether these custom knee replacements and jigs offer significant advantages for patients over standard jigs and implants.

3D printing is a valuable technology which appears to have advantages in relation to the speed of manufacturing custom implants and the cost involved. In orthopaedics, models for

teaching, operation rehearsal, cutting jigs and custom implants are all potential uses.

3D printing has also been used in other surgical specialities. For example, maxillofacial surgeons at Morriston hospital in south Wales have been using 3D printed metal plates to reconstruct complex fractures of the maxilla and mandible with good results.

Figures 1 and 2. 3D printed hemi-pelvis implant and X-ray

Historic case: printing the pelvis

In late 2010, Craig Gerrand (consultant orthopaedic surgeon at Newcastle-upon-Tyne Hospitals NHS Foundation Trust) operated on a 60-year-old male patient diagnosed with a rare bone tumour; chondrosarcoma of the pelvis. 3D CT and magnetic resonance imaging (MRI) scans of the pelvis were used to calculate the precise dimensions of the implant required to replace the hemi-pelvis involved. Using this data, Stanmore Implants at Elstree produced a bespoke 3D printed implant of the hemi-pelvis, achieving an accurate three dimensional match to the remaining hemi-pelvis. The ends of the implant were coated in hydroxyapatite to allow integration with the host bone and a sacral bolt and screws used for fixation. The operation was performed utilising surgical

navigation technology, including a standard hip replacement fitted within the titanium socket of the implant (see figures 1 and 2). Now, over three years later, the patient is able to walk with the aid of a stick and is still very happy with his 3D printed implant. Dr Paul Unwin at Stanmore Implants has confirmed that this was the first 3D printed hemi-pelvis to be implanted in the UK and that since then a further ten 3D printed pelvic implants and nine 3D printed scapulae have been implanted. None of the patients have required revision operations.

Organic materials

In 2000, bioengineer Thomas Boland of Clemson University, Carolina, filled an ink cartridge in an old Lexmark inkjet printer with collagen and printed his initials with collagen onto paper. After this experiment he modified a Hewlett Packard inkjet printer to allow it to print cells, starting with bacteria and, later on, using cells from hamsters and rats. He achieved a 90% cell survival rate. In 2003, Boland applied for his first patent for printing cells.

Another team of scientists in Carolina, led by Anthony Atala (consultant urologist and professor at the Wake Forest Institute for Regenerative Medicine) began to seed cells onto artificial scaffolds. Made from biodegradable polymers or collagen, the scaffolds provide a temporary matrix for cells to cling to until they're robust enough to stand alone. Atala's team worked on creating an artificial bladder. Subsequently, he successfully implanted the first laboratory-grown bladders into seven patients at Boston Children's Hospital between 1999 and 2001. These bladders have had good longterm outcomes. Although these organs were produced without the use of printing technology, this success with artificial bladders led Atala to continue his research into creating more complex artificial organs. Realising that 3D printing technology would be the best way to achieve this, about three years ago Atala's team developed a technique using a 3D printer to produce prototype artificial 'kidneys'. Their team is also trying to develop a method of 'printing' cells directly into patient's

wounds to fill soft tissue defects. Other research units are trying to create artificial ears, liver, pancreas and heart tissue. At the time we write this article, no internal organ produced by 3D printing has been implanted in a human body. There are still hurdles to overcome, including the creation of blood and nerve supply to artificial organs, but scientists remain confident these will be achieved.

CONCLUSION

3D printing of pelvic and scapula metal implants is now an established technique with advantages in both accuracy and cost. It seems likely that, in due course, the use of this technology will increase in complex surgical cases.

Printing with human cells is a technology in its infancy. Whilst the limited availability of organ donors will continue to provide a huge incentive for scientists involved in this field of research, it appears that the production of viable 3D printed organs for transplantation is some years away.

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FURTHER READING

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