Using 3D printing for complex pediatric transplantation: an interview with Pankaj Chandak

Pankaj Chandak speaks to Alexandra Thompson, Senior Editor Pankaj Chandak is a Specialist Registrar in Transplant Surgery at Guy's, St Thomas' and Great Ormond Street Hospitals and a Royal College of Surgeons of England Research Fellow at King's College London under Professor Nizam Mamode, Professor Anthony Dorling and Mr Chris Callaghan. Having qualified from Guy's, King's and St Thomas' University of London, Pankaj was Anatomy Demonstrator under Professor Harold Ellis and is currently a member of the Teaching Faculty of Surgical Anatomy at the Royal College of Surgeons. He has been awarded The Royal College of Surgeons of England Arnott Lecture and Medal for 2016 and The Royal College of Surgeons of England Lister Essay Prize and Medal. His interests include pediatric transplantation, organ perfusion, innovation and public engagement in science. His multidisciplinary work on integrating 3D printing into complex pediatric transplantation as a world first was awarded The Royal Society of Medicine Norman Tanner Medal and the prestigious Worshipful Company of Cutlers' Clarke Medal and Prize, 2016. He has been invited lecturer at The British Science Festival, The Royal Institution in London and The Royal College of Surgeons Hunterian Museum amongst others. The original 3D model created by the team has been accepted by The Science Museum (London, UK) for permanent exhibition in the Medical Gallery. Mr Chandak was elected a Fellow of the Royal Asiatic Society.

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Could you talk us through your background & how you became involved in the medical 3D printing field?

I am a transplant surgeon in training at Guys and St Thomas' Hospital (London, UK), which is one of the largest kidney and pancreas transplant centers in the UK and one of the largest for pediatric kidney transplants in the world. I am also a research fellow under Professor Nizam Mamode at Kings College London (UK) at Guys and St Thomas' Hospital on a Royal College of Surgeons Research Fellowship. There are two aspects to my research: the first is looking at *ex vivo* normothermic perfusions of organs, which is essentially a new technique perfusing organs

outside the human body to try and see how we can therapeutically modulate them. The second is 3D printing, which we are trying to use to overcome and address some challenges in difficult surgery.

I became involved in 3D printing when I went to a lecture about a year ago organized by the department of medical physics at St Thomas' on 3D printing. After the lecture it occurred to me to try to use this technology for our most difficult pediatric kidney transplants and integrate some of that technology into the operative field.

Coincidentally, the department of medical physics was organizing a competition for new ideas, which I entered and won. That collaboration was set up and I am delighted

to say we work with an outstanding dedicated team. This includes my surgical transplant mentors Professor Nizam Mamode and Mr Nicos Kessarisi; Interventional Radiologist, Dr Narayan Karunithy; Clinical Scientist, Mr Nick Byrne, from the Department of Medical Physics and Biomedical Engineering at King's; and Dr Andy Coleman, who is the head of Non-ionizing Radiation Physics at Guy's and St Thomas' Hospital. It is a fantastic collaboration and a very dedicated team trying to apply this new technology for use in complex pediatric transplantation.

You were recently awarded the Royal Society of Medicine's Norman Tanner Medal, as well as the Cutler's Surgical Prize 2016, following your use of 3D printing in the planning of a kidney transplant operation. Please could you tell us a little about these prizes & the project?

The Royal Society of Medicine is one of the UK's oldest societies – it goes back to about 1805 – and is prestigious, with honorary fellows in the past including Darwin, Pasteur and Paget. It is a society that provides postgraduate medical education and also promotes an exchange of ideas in science and the practice of medicine. The surgical section of the Royal Society of Medicine holds an annual meeting where they award the Norman Tanner prize medal to trainee surgeons for original ideas or innovation and application to surgery. You have to apply for the award and it is a competitive process. If you're selected, you have to present your research to learned academic audience. I presented some work that we did on the outcomes of 350 children who we have been transplanted over the last 10 years, comparing children who are very small, (less than 20 kg), compared with children who are more than 20 kg and looking at their outcomes and graft survival after kidney transplantation. I also spoke about some of the work we do with 3D printing as a translational model into operative surgery to help us look at more complex children and how we can help with their transplants. The medal was awarded for that work, which we were delighted about.

The Cutler's prize goes back to the Worshipful Company of Cutlers, which is one of the most ancient City of London livery companies. They used to produce swords, knives and surgical instruments, so they worked quite closely with the Royal College of Surgeons of England and they instituted the Cutler's Prize and the Clark Medal, for applications of surgical technology or design of a new instrument for innovation into surgery. We applied for that this year and again we were very fortunate to get that award too.

Why there was a need for such technology in pediatric transplants?

One of the challenges in pediatric transplantation is fitting an adult-sized kidney into a very small abdomen (a child weighing less than 20 kg). Not only is this technically challenging, but also a new adult kidney requires a higher blood pressure to drive its physiology compared to a child's kidney, so there is also a peri-operative management issue with transplanting adult-sized kidneys into very small babies. Sometimes these children also have congenital malformations or abnormalities with their blood vessels that we join the new kidney onto. This could mean that the blood vessels are missing or are twisted, or the anatomical arrangement is slightly abnormal, which can complicate an already complicated operation.

Currently we rely on the interpretation of a CT or MRI scan of the relevant anatomy and discuss this in a multidisciplinary team with surgeons, radiologists, nephrologists, ITU staff and plan how to perform or approach that particular case. We have seen that this new technology offers an additional layer of planning and safety to what we already have and already know. It allows us to have a hand-on simulated approach to a case, which we can discuss among a group of surgeons to give us the combined knowledge of all those individuals in planning a particularly difficult case.

Please talk us through the models – how were they used to prepare for surgery?

We have produced, for example, a model of the abdomen of a 10-kg child born with kidney failure due to abnormal heart rhythm. She also had previous extensive abdominal surgery because the blood supply to her bowels was compromised at the time. We also produced a model of the kidney from her father that we took out eventually through keyhole laparoscopic surgery. There was a huge size discrepancy there, and being able to see them together helped us to help us plan the approach to the case. The model of the child's abdomen showed the liver, pelvis, lateroabdominal walls and blood vessels: the aorta and the vena cava. The model essentially enabled us to think about the best approach of the kidney's blood vessels to the baby's blood vessels and think about the position of the kidney within the abdomen. The model provided us some indication of space and the best approach to the recipient's anatomy, and the appropriate site on the blood vessels in which to perform our suturing. In addition, we could see the native kidneys, only the size of a walnut, which gave our team an indication that we perhaps did not have to remove the native kidneys to create space for the new one, but of course that is a decision we also take at the time of the operation.

With another child we transplanted, the adult kidney was going into a very small child of approximately 10–12 kg. We again printed the abdomen and transplant kidney, and with the abdomen model we could see that this child had an abnormality coming from the aorta, an aneurysm from the inferior mesenteric artery. Again the models helped us establish the best approach of joining the blood vessels of the donor kidney onto the aorta and vena cava of the child. Additionally, it helped us think about what we may do with this aneurysm at the time of surgery, so we decided to transect this aneurysm off and ligate it just at its base.

How were the models produced?

The printing process itself essentially involves the interpretation of CT and MR data. The 3D printer then moulds the liquid polymer resin and cures it under UV light for approximately 12 h to produce these morphologically specific models.

One of the limitations of this model is that the elasticity of the tissue does not exactly represent the properties of human elastic tissue, which is something we are trying to work on at the moment. However, the printer does have the ability to print in different physical properties: the pelvis is printed in a very hard material, whereas the liver, which is quite soft, is printed with a soft material – quite useful in the model.

Do you plan to use this technology in future surgeries?

We are hoping to use this technique in future complex cases to further evaluate its full potential. It is a very promising start with the cases that we have done so far. This type of technology is not for every case – it is suited for complex cases where the feasibility of implantation is uncertain. We do feel it allows surgeons to discuss different strategies in a multidisciplinary setting in cases where you are expecting some challenges, and it allows preoperative reflection on some of the anatomical issues, and great value in supporting family consent.

How did your patients react when they saw their models, & how do you anticipate that the models could be used to improve the consenting process?

We wanted to look at ways in which we could make the consent process more informed for the families undergoing this type of transplant, as you can imagine it is very stressful for a family to have their child in the operating theatre in the children's hospital and then their partner, (mother or father), in Guy's Hospital having their kidney removed through keyhole surgery, sometimes at the same time. Occasionally we have to operate on the child first to determine feasibility of the actual

procedure before we can give the go-ahead to removing the donor kidney, but often it happens at the same time.

We wanted to make the process of consenting more informed. When I show these models to the families, their initial reactions is “wow, is that my kidney?” or “is that my baby's abdomen?": the whole perception of the operation and the procedure immediately becomes clearer when you can see, hold, touch and feel a 3D reconstruction of their anatomy.

They can relate to it because it is specific to them. It is not a generic model, so they can readily appreciate some of the problems we may encounter and some of the technical issues, which is important when the operation that we are doing is high risk and when some of those risks are not entirely quantifiable at times. We therefore believe it is a very useful consenting tool and the children are delighted to see their models because it is their anatomy, allowing the child to be more involved in the whole process. We need to do more cases to evaluate its full potential but this is a very promising start.

Do you anticipate that 3D printing for surgical planning will become commonplace in the clinical environment?

We are certainly hoping to employ this technology in routine clinical practice. We feel that, after evaluation of more cases, it might become a reality for complex cases where the feasibility of kidney implantation is uncertain.

Also, we feel that this technology will be of use to other centers performing complex pediatric transplantation, as it offers additional training opportunities for surgeons as well: we are essentially offering an archive of collected models that are disease- and morphologically specific for a particular case, and that is a good training opportunity for the future generation of pediatric transplant surgeons. There is lots of value with these models and we are certainly hoping they will be employed in clinical practice in the future, but we have some way to go before that.

What are the main limiting factors that must be overcome for the technology to be used more commonly in the clinical environment?

I think one of the limitations is obviously finance as with any major research initiative. The whole process for us involves a dedicated, integrated multidisciplinary team approach and this requires careful co-ordination.

Looking ahead, what do you see as the most exciting new avenue for 3D printing in medicine?

The next big step is bioprinting organs: there have been some successes with various bioprinted tissues that have been transplanted, such as bone, liver and

cartilage. Kidneys are a very difficult organ to transplant, as it has quite a complex arrangement and function of different cell types. One of the problems with kidneys is trying to vascularize it and trying to determine if we can generate the blood vessels required to actually vascularize the organ itself.

In addition, bioprinting involves complexities such as choosing appropriate growth factors, cells and materials, and how we will integrate that entire bioinfrastructure into generating a new organ. What we are doing here as surgeons and clinicians is trying to remove some complexities in the actual operation itself, and we are hoping to look at bioprinting in our unit very soon as well.

Further reading

- <https://spotlight.kcl.ac.uk/2016/11/07/innovation-in-surgery-how-far-have-we-come/>
- <http://www.insight.mrc.ac.uk/2016/09/08/transforming-transplantation/>
- www.rcseng.ac.uk/blog/how-i-used-3d-printing-to-practise-complex-transplant-operation-1
- www.bbc.co.uk/news/uk-northern-ireland-35407477
- www.guysandstthomas.nhs.uk/news-and-events/2016-news/january/20160125-Worldfirst-3Dprintingusedinlife-changingkidneytransplant.aspx

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