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The Future of Organ Donation

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ABSTRACT: The Research Paper explores and analyses the success of traditional organ donation in a developing country like India, in close comparison with a developed country like the United States of America. Moreover, it delves into an investigation of 3D Organ Printing: what it entails, the instrumentation needed, the step-by-step process, and the progress that's been made in this field so far. The purpose of the study is to examine if 3D Organ Printing is the future, and if it could effectively solve the problems currently being faced in the space of traditional organ transplants. The gravest problem of them all being the lack of donors.

KEYWORDS: Organ, Donation, Donor, Recipient, Transplant, Surgery, Brain Death, Tissues, 3D Organ Printing, 3D Bio Printing, and Bio Ink.

OBJECTIVE: This Research Paper attempts to analyse the rate and success of traditional organ transplants in India as compared to the United States of America, over a period of 5 years - from 2013 to 2017. It also aims to investigate the future of organ donation with regards to 3D Organ Printing and how successful that might prove to be, alongside an evaluation of traditional organ donation and the possibility of 3D Organ Printing.

METHOD: Secondary Data and Information - The internet (Hospital campaigns, official government websites, news articles, and videos).

I. TRADITIONAL ORGAN DONATION

As per the Online Cambridge Dictionary, Organ Donation is "The act of a person giving permission for a part of their body to be taken, while they are alive or after they are dead, and put into someone else's body to replace an organ that is not working correctly". This process is more commonly known as *Transplantation* and takes place surgically, where a donor's organ(s) is/are retrieved from the brain dead or volunteer donor and is transplanted into the recipients, whose organ(s) has/have failed or has/have been damaged due to an accident.

There are several organs that can be donated successfully: kidneys, liver, lungs, heart, intestine, and pancreas. However, tissues such as cornea, middle ear, skin, bone, bone marrow, heart valves, and connective tissue can also be donated.

These donations can be divided into two main categories; *deceased donation* and *living donation*. The deceased donation, like the name suggests, takes place after the donor is declared brain dead. The team of doctors evaluate the patient and run tests to be certain, after which, the process of harvesting the organs tends to begin. Each organ has a certain viable period after which it's rendered useless, unable to serve its purpose to the recipient. On the other hand, living donation takes place when a person, aged 18 or above, voluntarily decides to donate his/her kidney, liver, lobe (part of the lung), pancreas or intestine(s).

Organ	Function	State of donor during donation	Causes of failure (faced by the recipient).	Number/ Part	How long can the organs survive inside and outside of the body? (In cold preservati on.)	Statistics in India (2018)
Kidney	<ul style="list-style-type: none"> - Removal of waste products and excess fluids from the body. - Regulation of the salt, potassium and acid concentration. - Production of hormones for red blood cells production, blood pressure regulation and calcium metabolism. 	<ul style="list-style-type: none"> -Deceased donation -Living Donation 	<ul style="list-style-type: none"> -Physical injury - High blood pressure - Diabetes 	<ul style="list-style-type: none"> - 2 - 1 	30 hours	150,000 people await for a kidney every year.
Liver	<ul style="list-style-type: none"> - Production of bile - Prevention of blood clots - Filtration of the blood - Vitamin and mineral storage -Maintaining glucose levels 	<ul style="list-style-type: none"> -Deceased donation -Living Donation 	<ul style="list-style-type: none"> -Physical injury -Alcohol abuse - Liver cancer -Cirrhosis - Hepatitis -Fatty liver disease -Genetic diseases 	<ul style="list-style-type: none"> - Donated to several people in parts, as it can regenerate. - A part of the liver is donated, which will regenerate. 	6 to 12 hours	200,000 people die due to a liver disease every year

Lungs	-Respiration - pH balance - Filtration of small blood clots - Mucociliary clearance	Deceased donation	-Physical injury -Cystic fibroses -Chronic obstructive pulmonary disease -Pulmonary fibroses -Pulmonary hypertension - Tumors	-1 -2	4 to 6 hours	
Heart	Pumps oxygenated blood around the body and transports the deoxygenated blood to the lungs (alveoli)	Deceased donation	-Physical injury -Dilated cardiomyopathy -Coronary artery disease -Restrictive myopathy - Hypertrophic cardiomyopathy -Valvular heart disease - Congenital heart disease	-1	4 to 6 hours	500,000 people die due to a heart disease every year.
Intestines	Part of the gastrointestinal tract, responsible for the digestion of food.	Deceased donation	-Physical injury - Short bowel syndrome -Non-functioning bowel.	-1	6 hours	
Pancreas	- Production of enzymes for digestion - Production of insulin and glucagon	Deceased donation	-Type 1 diabetes -Type 2 diabetes (low insulin resistance and production) -Pancreatic cancer	-1	6 hours	

The process of receiving an organ transplant is a long one. It starts with a detailed evaluation of the recipient's health, to see if he/she is medically a good candidate. Then, the recipient is added on to the National Transplant List, where donors are matched with recipients. Multiple factors including blood type, body size, waiting time, and the diagnosis/prognosis are matched between the donor and the recipient. Once the matching is complete, through the National Organ Procurement Center's software, a surgical team retrieves the organs from the donor and transport it to the recipient. Then, another surgical team would transplant the organ(s) into the recipient, and with a healthy lifestyle and medications the organ is likely to survive in the recipient.

II. ORGAN DONATION IN INDIA



Figure 1: Organ Donation Rate in India, 2017

Complications with Harvesting Organs in India:

Organ donation is a process with many challenges, the initial challenge would be to match the recipient with the right donor. However, even when this is made possible, complications can occur in the harvesting process. For example, in India, there's a need for two lakh kidneys, 50,000 hearts and 50,000 livers for transplantation, every year. Even if 5%-10% of all brain deaths are harvested properly for organ donation, technically, there would be no requirement for a living person to donate organs (Nallusamy, Shymalapriya, Balaji, Ranjan and Yogendran, 2018).

Additionally, poor training and lack of good coordination can also cost recipients their lives. A heart transplant hasn't been conducted in Mumbai in many years, only because the required programme for the retrieving and harvesting processes hasn't been installed. Not only this, only 301 hospitals in India are equipped to perform a transplant, hence, amounting to a ratio of 1 hospital to 43 lakh people. Therefore, crippling deficiencies surrounding training, coordination, and infrastructure pose huge challenges for India when it comes to Organ Donation.

III. INDIA'S ORGAN TRANSPLANTS VS AMERICA'S ORGAN TRANSPLANTS

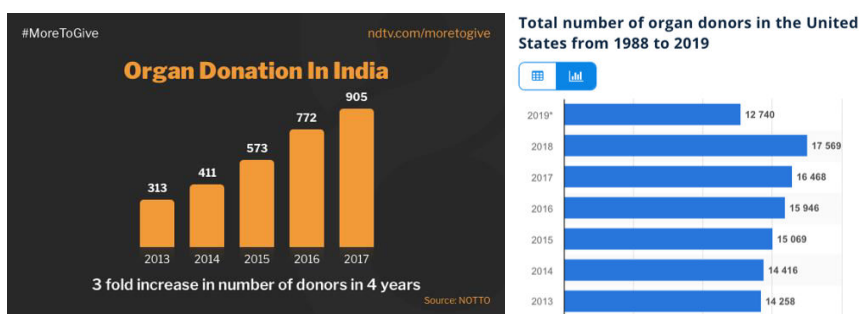


Figure 2: Organ Donation over the years in India

Figure 3: Organ Donation over the years in The United States of America

The figures depicted above, show the trends for Organ Donation in India and in the United States of America, from 2013 to 2017 and 2019, respectively. From the year 2013 to 2017, Organ Donations in India have significantly increased from 313 to 905, which is approximately thrice the starting point. On the other hand, Organ Donations in the United States stood at 16466 in 2013, and increased to 17569 in 2017. From these figures it can be deduced that yes, both the countries have seen development in their organ donation rates, however, the starting point for both were very different. There could be several reasons for this. Firstly, India is a developing country that lacks the resources (highly trained surgeons and equipment) that a developed country such as United States is bound to possess. Moreover, India is also a very religious country, and each religion has a different mindset when it comes to death, hence, Organ Donation is not topic openly spoken about or discussed. Lastly, the myths and misconceptions that surround this sensitive topic also contribute to its low rates.

IV. 3D ORGAN PRINTING

3D Organ Printing is defined as “Computer-aided, jet-based 3D tissue-engineering of living human organs” (Mornov Boland, Trusk, Forgacs, and Markwalk, 2003). This technological advancement aims to solve many problems that accompany traditional organ transplant.

This methodology falls under the overarching category of Bioprinting, defined as “an additive manufacturing process where biomaterials such as cells and growth factors are combined to create tissue-like structures” (Mashambanhaka, 2018). In order to make printing possible, *Bioink* composed of cells alongside carrier material, which in most cases is *Biopolymer gel*, is used. Moreover, the *Biopolymer gel* performs the function of 3D molecular scaffolds and the cells attach to this gel, thereby enabling growth.

The larger process of Bioprinting can be broken down into three key steps:

- 1) Pre-bioprinting:
 - Creation of the digital model
 - Technology used to create the digital model: CT Scans (Computed Tomography) and MRI scans (Magnetic Resonance Imaging)
 - Bio Ink is prepared through the help of live-cell imaging system in order to make sure that ample cells are available to print the desired product
- 2) Bioprinting:
 - Bio Ink is placed in the printer cartridge
 - The correct type of print head (depending on the product) is chosen
- 3) Post-Bioprinting:
 - Structures can be cross-linked with the help of ionic solution or UV light
 - The product is placed in an incubator for cultivation

Detailed procedure:

The bioprinting methods may differ with regards to the extrusion, inkjet, acoustic, or laser techniques. However, the underlying process remains the same for all.

- 1) 3D Imaging: In order to obtain the precise dimensions of the tissue the first step would be to conduct a CT or an MRI scan. These scans provide dimensions which should be exactly the size needed.
- 2) 3D Modelling: The AutoCAD software is used to produce a blue print, which gives out layer-by-layer instructions for the printer.
- 3) Bio Ink Preparation: The Bio ink developed for each tissue would be different, as it is personalized to the patient needing the tissue and the tissue’s function. Thus, the cells can be combined with collagen, gelatin, hyaluronan, silk alginate or nanocellulose, all of which act as a scaffolding for the cells to grow on.
- 4) Printing: The printer prints each layer individually, stacks them on top of each other. The thickness of each layer is usually 0.5 mm or less.
- 5) Solidification: The bio ink, as it comes out of the nozzle, is liquid and solidifies to hold its shape. Hence, the process is also known as crosslinking, and UV light or other chemicals as well as heat can be used to aid the process.

Technology/ Printers:

The printers in our homes print in two dimension – *X axis* (Horizontal) and *Y axis* (Vertical). However, while printing a 3D object, done by more advanced printers, another dimension – *Z axis* (Depth) - is added. Thus, allowing the printer to move up, down, left, right, backwards, and forwards.

In order to create a 3D object using a 3D printer, a virtual blueprint needs to be created using a modelling software. Post this, the model is sent to the printer and the desired ink is loaded into it – Bio Ink for 3D Organ Printing. These

steps allow the printer to get to its job and print layers, one on top of the other, and after some cooling time, the final product is ready.

For 3D printing in the medical industry, the key difference lies in the type of ink used. Bio Ink, which as discussed before, is developed from living cells collected from the patient with regards to the type of organ being developed. These cells can be specific to that organ such as Kidney cells or they can even be Stem cells.

Additionally, after the cells have been layered, they innately know where they are supposed to “go” and get started on their function. This process is comparable to the embryos develop and tissues repair damage.

V. HOW FAR HAVE COME? AND WHERE DO WE STAND NOW?

To this date, 3D printing has been utilized in the field of medicine and dentistry to design dental implants, prosthetics, and models for surgeons to practice on. However, a fully functioning organ is yet to be designed. In the hopes of achieving the same, scientists from all over the world have made some promising strides.

- Bio Printed Mini-Heart

In April 2019, a team of Israeli researches used a patient’s fat tissue to 3D print a heart the size of a cherry. The printing process for this miniature heart was about 3 to 4 hours. Moreover, the mini-heart is the first to be printed with replete cells, blood vessels, ventricles and chambers, but lacks the ability to pump.



Figure 4: Bio Printed Mini-Heart by Israeli Researchers, 2019

- Bio Printed Kidney

In 2011, Professor Anthony Atala and his team from Wake Forest Institute for Regenerative Medicine were able to print a Kidney from stem cells. This kidney was printed in 7 hours; however, it was a prototype. Since then, researchers at Harvard have been able to print a vascularized proximal tubule, a segment of the nephron in the kidney, to better understand its structure and function.



Figure 5: Bio Printed Kidney by Professor Anthony Atala, 2011

- Bio Printed Corneas

In 2019, researchers at the University of Newcastle successfully printed human corneas. The researchers scanned a patient’s eyes to gather the dimensions of the cornea and used a combination of alginate and collagen as the Bio Ink. The ink is unique and serves the purpose of keeping the stem cells alive, allowing the cornea to hold its shape while being soft enough to be squeezed from the nozzle of the 3D Printer. In addition, the stem cells used in the Bio Ink were human corneal cells from a donor cornea, and the cornea was printed in 10 minutes. But, it would be several years of testing before these corneas can be transplanted into a recipient’s eyes.

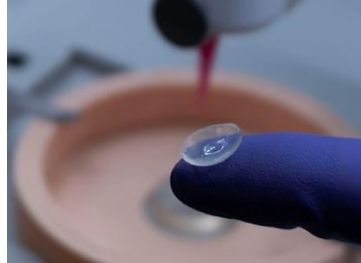


Figure 6: Bio Printed Corneas by the University of Newcastle, 2019

- Bio Printed Ovaries

In May 2017, researchers at Northwestern University were able to 3D print ovaries and implant them in a mouse. The female mice were sterilized, their ovaries were removed surgically and the 3D printed ovaries were implanted. Furthermore, after mating the female mice with the 3D printed ovaries was able to give birth to her litter. However, this litter was smaller 1 to 2 instead of 6 to 8 mice.

- Bio Printed Mini-Livers

Researchers from the University of Sao Paulo have successfully created miniature livers, similar to the human liver, in just 90 days. The mini livers were able to achieve their purpose – production of proteins, storing vitamins and the secretion of bile. Departing from the conventional method, researchers grouped the cells as spheroids instead of printing individualized cells, thus tackling the common issue of cells losing their ability to stick to each and eventually not functioning. Moreover, the spheroids were then combined with the Bio Ink and hydrogel-like fluid and then printed. These organoids then mature for 18 days in a culture.

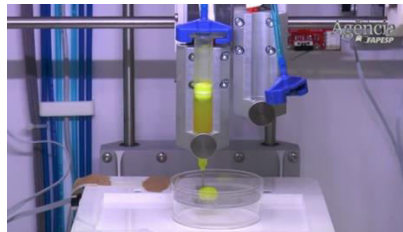


Figure 7: Bio Printed Mini-Livers by the University of Sao Pualo

- Bio printed Ear

The aim of this project was to restore the hearing of a young girl, which was made successful by the collaboration between Queensland University of Technology and Maia Van Mulligan. The 3D printed ear was constructed from the patient's cartilage and was fully functional. Over the years, many researchers have been able to achieve the same.



Figure 8: Bio Printed Ear by the Queensland University of Technology and Maia Van Mulligan

- Bio printed Pancreas

In March 2019, scientists from the Foundation of Research and Science Development and BIONIC Consortium, developed bionic pancreas which was a fully vascularized prototype. The prototype, 3x3x5 cm in size, was able to complete its functionality and viability tests while being kept alive in a bioreactor.

Since then, scientists have had trials on mice which were proven successful, and plan to go ahead with trials on pigs and other mammals.

- Bio printed Skin

Unlike the other organs, skin which is the largest organ is printed using 4D technology. Poietis is the first company to develop this methodology with the aim of helping patients with severe burns or skin diseases. In addition, a special software, Cytocentric CAD is developed for the same. This process is different than the 3D technology because the components are precisely placed and the cells participate in self-organization.



Figure 9: Bio Printed Skin by Poietis

VI. THE ETHICS

The concept of 3D printing organs can be defined as man playing God, trying to save lives through their experimental technology. Thus, there are many ethical aspects that prevent the technology from developing at a faster rate.

Firstly, researchers across the globe are working hard and long for creating a successful 3D printed organ that's fully vascularized and can carry out its innate function. However, all of the prototypes, like discussed above, need to go through several stages of testing on several different types of animals before a green light is given for a human transplant to occur. This would include, testing on smaller species such as mice and then moving on to other animals like pigs. Thus, an ethical question regarding animal testing is raised. Some even question, if testing on mice provides enough evidence or sound reason to transplant a 3D printed organ into a human, while others refuse to support this methodology owing to its inhumane and cruel nature.

Secondly, the introduction of a new life-saving technology may result in an increase in its demand. Therefore, the increase in demand will invisibly result in an increase in cost of the treatment. As the aim of the technology is to save lives, would it be fulfilling its purpose if people can't even afford the treatment? For example, developing countries like India have high rates of poverty and its citizens probably would not be able to make use of this technology. Thus, it's possible that the new technology ends up being so costly that the ones most in need won't even be able to access it.

Lastly, with the progress being made in the field of 3D organ printing, a larger question about technology in medicine is raised. That is, if technology can help us replace our internal organs, then can it also be used to enhance human capacity? For example, "should we consider implanting new lungs that oxygenate blood more efficiently, even in a more polluted environment?" and "Should we replace our existing bones with artificial ones that are stronger and more flexible, less likely to break" (Susan Dodds, 2015). Thus, with the development of technology that can help save lives, many more questions about human existence are raised.

VII. CONCLUSION

To conclude, organ donation is a medical procedure that aims to save lives of the ones in need of an organ by, in lay man terms, "recycling" an organ. However, the lack of donors in India, and many other countries, leads to a significant amount of deaths every year. Hence, in order to solve this issue of lack of donors, scientists have been working long and hard to use technology to 3D print organs for the ones in need. But, like any other procedure, traditional organ donation included, this too comes with its own merits and demerits. Yet, significant progress has been made in this field and scientists continue to work and improve their techniques in hopes of printing a fully vascularized functioning organ one day.

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