# Using 3-D printing, MakerBot and Feinstein Institute repair tracheal damage

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Investigators at The Feinstein Institute for Medical Research have made a medical breakthrough using 3D printing on a MakerBot Replicator 2X Experimental 3D Printer to create cartilage designed for tracheal repair or replacement. The results were reported today at the 51st Annual Meeting of The Society of Thoracic Surgeons in San Diego, in a presentation by Todd Goldstein, an investigator at the Feinstein Institute, part of the North Shore-LIJ Health System. This is a first for medical research where regular MakerBot PLA Filament was used to 3D print a custom tracheal scaffolding, which was combined with living cells to create a tracheal segment.

Mr. Goldstein, a PhD candidate at the Hofstra North Shore-LIJ School of Medicine, has been working with a team of surgeons at the North Shore-LIJ Health System for the past year on determining if 3D printing and tissue engineering could be used for tracheal repair and replacement. Tracheal damage can be caused by tumor, endotracheal intubation, blunt trauma, and other injuries. Narrowing and weakness of the trachea can occur and are often difficult to repair. There have been two traditional means of reconstructing a damaged trachea, but both techniques have limitations. Lee Smith, MD, chief of pediatric otolaryngology at Cohen Children's Medical Center and David Zeltsman, MD, chief of thoracic surgery at Long Island Jewish Medical Center, both part of the North Shore-LIJ Health System, came to Mr. Goldstein and Daniel A. Grande, PhD, director of the Orthopedic Research Laboratory at the Feinstein Institute, and asked if 3D printing might offer a solution. Drs. Smith and Zeltsman originally surmised that incorporating 3D printing and tissue engineering to grow new cartilage for airway construction might be possible in ten to 20 years. Mr. Goldstein and Dr. Grande did it in a month.

The Feinstein Institute's research combined two emerging fields: 3D printing and tissue engineering. Tissue engineering is like other kinds of engineering, except instead of using steel or computer code to make things, living cells from skin, muscle or cartilage are the raw material. Researchers at the Feinstein Institute know how to make cartilage from a mixture of cells called chondrocytes, nutrients to feed them, and collagen, which holds it all together. Shaping that cartilage into a nose or a windpipe is another matter. That's where 3D printing comes in. A 3D printer can construct scaffolding, which can be covered in a mixture of chondrocytes and collagen, which then grows into cartilage.

"Making a windpipe or trachea is uncharted territory," noted Mr. Goldstein. "It has to be rigid enough to withstand coughs, sneezes and other shifts in pressure, yet flexible enough to allow the neck to move freely. With 3D printing, we were able to construct 3D-printed scaffolding that the surgeons could immediately examine and then we could work together in real time to modify the designs. MakerBot was extremely helpful and consulted on optimizing our design files so they would print better and provided advice on how to modify the MakerBot Replicator 2X Experimental 3D Printer to print with PLA and the biomaterial. We actually found designs to modify the printer on MakerBot's Thingiverse website to print PLA with one extruder and the biomaterial with the other extruder. We 3D printed the needed parts with our other MakerBot Replicator Desktop 3D Printer, and used them to modify the MakerBot Replicator 2X Experimental 3D Printer so that we could better iterate and test our ideas."

"The ability to prototype, examine, touch, feel and then redesign within minutes, within hours, allows for the creation of this type of technology," says Dr. Smith. "If we had to send out these designs to a commercial printer far away and get the designs back several weeks later, we'd never be where we are today."

The Feinstein Institute had looked previously at other 3D printers that can extrude living cells, but the options are few and expensive. One special bio printer cost $180,000, an amount that the Institute would not allocate. They wanted to test their concept and see if it would be viable, so they decided to use the more affordable and accessible MakerBot Replicator 2X Experimental 3D Printer that retails for $2,499 and is a size that fits on a desktop.

Originally, Mr. Goldstein thought that he would need special PLA to maintain sterility and have the ability to dissolve in the body. However, in light of time, they decided to try regular MakerBot PLA Filament. "The advantage of PLA is that it's used in all kinds of surgical implant devices," says Dr. Smith. Through testing, Mr. Goldstein found that the heat from the extruder head sterilized the PLA as it printed, so he was able to use ordinary MakerBot PLA Filament.

The bio-ink, which stays at room temperature, is extruded during the 3D printing process and fills in gaps in the PLA scaffolding, then cures into a gel on the heated build plate of the MakerBot Replicator 2X. A two-inch-long section of windpipe—shaped like a hollowed-out Tootsie Roll—takes less than two hours to print. Once the bio-ink adheres to the scaffolding, it goes into a bioreactor, an appliance like a rotisserie oven that keeps the cells warm and growing evenly. A new bioreactor costs between $50,000 and $150,000, so Mr. Goldstein customized an incubator for his needs, making gears and other parts on their MakerBot Replicator Desktop 3D Printer to produce a brand new bioreactor.

"The research being done at the Feinstein Institute is exciting and promising," noted Jenny Lawton, CEO of MakerBot. "We are continually amazed by what is being created with 3D Printers. To know that a MakerBot Replicator 3D Printer played a role in a potential medical breakthrough is inspiring."

The results of the study, as presented by Mr. Goldstein and Dr. Zeltsman at The Society of Thoracic Surgeons, illustrate how the 3D printed windpipe or trachea segments held up for four weeks in an incubator. According to Mr. Goldstein's abstract, "The cells survived the 3D printing process, were able to continue dividing, and produced the extracellular matrix expected of tracheal chondrocytes." In other words, they were growing just like windpipe cartilage.

The Feinstein Institute describes this work as a "proof of concept." The team still has work to do before establishing a new protocol for repairing damaged windpipes. Medical research can take years to move from bench to bedside, as can US Food and Drug Administration (FDA) approval. However, if there is no approved treatment for an ailment, the FDA has a compassionate therapy exception that allows the patient to agree to try an experimental approach.

According to Dr. Smith, at least one patient comes through the North Shore-LIJ Health System each year who can't be helped by the two traditional methods, and he expects in the next five years to harvest a patient's cells, grow them on a scaffolding, and repair a windpipe. This customized approach may prove to be especially useful for treating children, says Dr. Smith. "There's really a limitless number of sizes and permutations you might need to reconstruct an airway in a child."

When speaking about his work with 3D printing and this research, Mr. Goldstein notes, "It's completely changed the trajectory of my academic career." Mr. Goldstein originally came to the Feinstein Institute as a molecular biologist, working with cells, chemicals and drugs. Combining this knowledge with 3D printing and getting into tissue engineering is something he didn't expect that at all when he joined the Feinstein Institute.

Now he is the Feinstein Institute's 3D printing specialist, printing models of organs for pre-operative planning and tools to improve the lab. He is the presenting author on a paper being presented to thousands of surgeons, and applying for major grants to continue his research. "Knowing that I can make a part that will save someone's child—that's life-changing," said Mr. Goldstein.

"This project will probably define my scientific career," says Dr. Smith. "As we produce something that can replace a segment of trachea, we'll constantly be modifying and optimizing, the correct bio materials, the correct way to bond the cells to the scaffold. 3D printing and tissue engineering has the potential to replace lots of different parts of the human body. The potential for creating replacement parts is almost limitless."

MakerBot has also supplied the Feinstein Institute with early samples of its just-announced MakerBot PLA Composite Filaments in Limestone (calcium carbonate) and Iron, which will be available commercially later this year, so the Feinstein Institute can start investigating how to engineer other kinds of tissue, like bone or 3D print custom-made shields for cancer and radiation treatment.

"Do you remember the Six Million Dollar Man?" asks Dr. Grande. "The Bionic Man is not the future, it's the present. We have that ability to do that now. It's really exciting."

To watch a video about 3D printing at the Feinstein Institute, click the following link: 3d-printer/" target="_blank">www.feinsteininstitute.org/3d-printer/

Provided by North Shore-Long Island Jewish Health System