3D-printed organs are in early research stages. Here's how Baltimore doctors are using the technology

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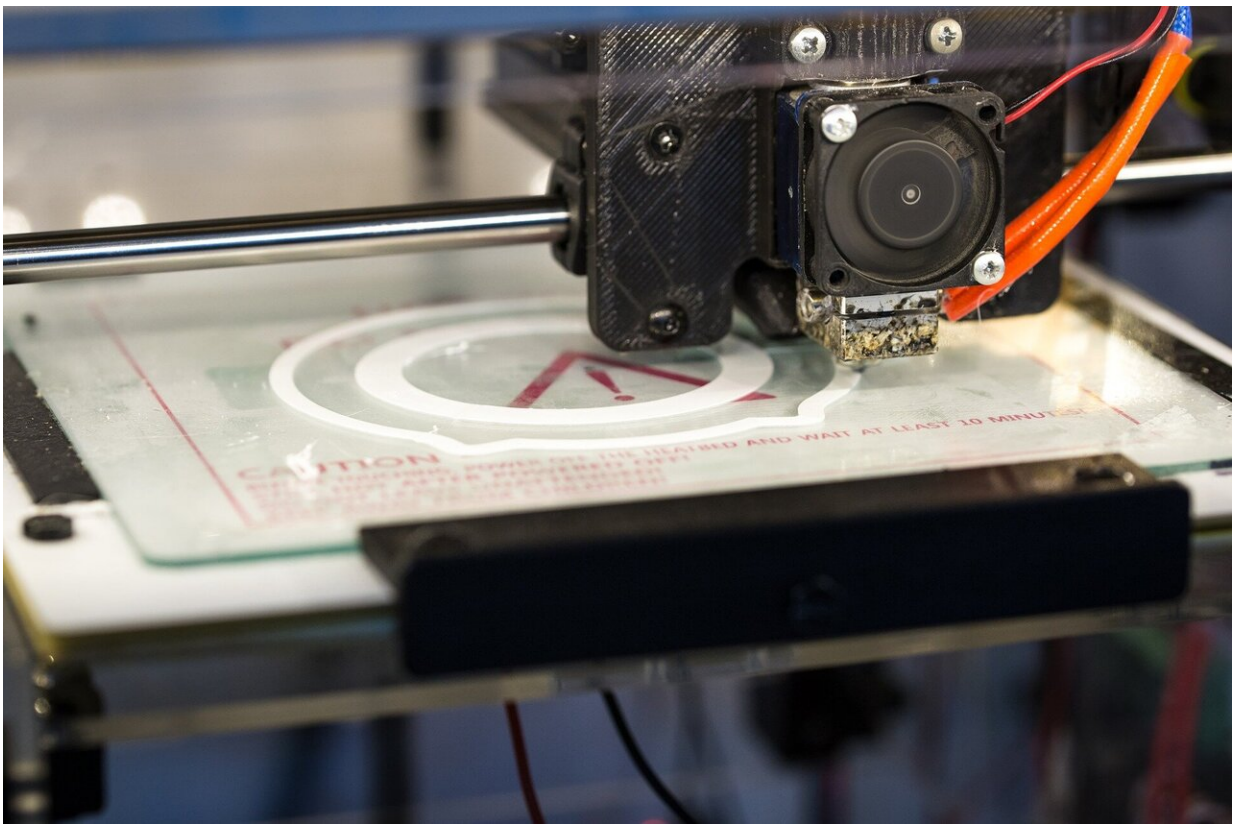

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Scampering around the floor of her father's family room in Cherry Hill, 1-year-old Syah Weddington is quicker on four limbs than two. After a

few passes crawling from one end of the room to the other, her mom scoops her up to her lap.

The baby's labored breathing is audible.

"You hear the panting and you can feel her chest moving rapidly," said her mom, Briana Seimah. "Sometimes I just take her, pull her to the side and let her take a little break before she gets back to playing."

Syah moves and chatters like most other babies her age. But beneath her ruffled pink shirt, her heart is different. Scars down the center of her chest and across her left shoulder blade chronicle two heart surgeries she endured in her first six months. At age 3, she'll have another.

About 1% of babies are born with congenital heart defects. A fraction of those children, like Syah, have severe heart problems. With a kinked aorta, holes in her heart and two right ventricles, the shape of Syah's heart is rare, making surgical repairs complicated. But using 3-D-printed models of her heart, doctors at the University of Maryland Medical Center were able to anticipate the anatomical differences they would find when they cut open Syah's chest, increasing the chances for a shorter and successful surgery.

Such models, made from patients' own images, are becoming more common in U.S. hospitals, allowing doctors to better plan for complicated cardiovascular and orthopedic surgeries. The 3-D-printing technology also is used to make custom prosthetic limbs and surgical tools, and even a drug to treat epilepsy—some of the more than 100 printed medical devices approved in recent years by the U.S. Food and Drug Administration.

There's more on the horizon, such as printed skin made with living cells to cover wounds and burns.

Research into printing human organs is in the beginning stages.

The 3-D printers that layer powder and liquid versions of plastics, ceramics and metals have been around since the 1980s and explored for medical uses since the 1990s. But advances are now propelling the field more quickly, including the printing of living tissue using cells. A forecast from Allied Market Research projects the health care market for 3-D printing to grow to $2.3 billion by 2020, an increase of 26% from 2015. But hurdles remain, analysts say including the high cost of equipment and lack of insurance reimbursements, compatibility with human bodies and lack of expertise.

The University of Maryland Medical Center has been adding to its 3-D capabilities and partnering with the U.S. Department of Veterans Affairs to perfect uses that largely center on modeling body parts including hearts and blood vessels, and more recently shoulders, to aid in surgical planning, said Dr. Jeffrey Hirsch, the section chief of community radiology for the University of Maryland Medical Center who printed models of Syah's heart.

Doctors knew Syah's heart was compromised while she was in utero, though they didn't know the extent of her condition until she was born.

Images of Syah's heart after birth confirmed she had a coarctation, or kink, in her aorta, the main blood vessel that delivers oxygen-rich blood from the heart to the body. She also had a large hole connecting the two lower chambers of her heart, which should not be open to each other. She lived in the neonatal intensive care unit for the first month of her life.

"This is my first child and the day I left the hospital and she wasn't home with me it was like a panic attack," Seimah said.

During Syah's first surgery, doctors repaired her aorta and placed a band on the pulmonary artery to prevent too much blood from rushing to her lungs instead of her body. The second surgery to address the hole in her heart was more complicated, and doctors had several options for procedures to pursue. That's where the models came in.

"It wasn't clear exactly what the relationship was between that hole that divided the two lower chambers of her heart and the two big vessels coming off of the heart," said Dr. Carissa Baker-Smith, Syah's pediatric cardiologist at the University of Maryland Medical Center.

Hirsch's models gave them a better picture. One model, made of gray and black plastic, was enlarged several times and split in two pieces held together by magnets to allow doctors to look inside. The second model was solid and true to size, small enough to cradle in the palm of your hand.

"It was very clear from the 3-D printing of the heart that the hole in the wall that separated the two lower chambers of Syah's heart was too far and distant from the big vessels that come off the heart, and that there was no way in which we'd be able to put a patch in that allows one big artery to come from one chamber and one big artery to come from another," Baker-Smith said. "So ultimately that gave us a game plan and I think resulted in a very good outcome. So less amount of time that she needed to be in the operating room. And she's doing quite well now."

Printing a patient's organ starts with two-dimensional images—CT scans often work best—that are plugged into software to create a printable file. Hirsch printed the plastic model of Syah's heart using one of two tabletop printers in his lab at the downtown hospital at the time, and he sent the other file for the life-size heart to a third-party vendor. The lab has since added a larger, $80,000 printer, acquired through a donation.

Baker-Smith said such models could help other doctors make better decisions for their patients.

"In terms of being able to hold the heart in your hand and really kind of twist it and turn it and look at all the intricacies and sort of the relationships for our kids with complex congenital heart disease, I see it being an invaluable resource," Baker-Smith said.

Syah was the first pediatric cardiac patient whose heart Hirsch printed. He's partnered with several departments at the hospital to create models and prostheses for his colleagues and their patients. In addition to surgical planning, he said he often sees 3-D printing used in procedures like facial reconstruction following trauma, opening up the skull in infant brain surgery, inner-ear prostheses and surgeries to remove bone tumors.

Before modeling with 3-D printing, "the only way to do that was essentially by guesswork, and so they get a much cleaner result," said Hirsch, also an assistant professor in the University of Maryland School of Medicine's department of radiology.

Recently, Hirsch has been working with Dr. Kenneth C. Wang, a fellow radiologist and assistant professor who also serves at the Veterans Affairs hospital in Baltimore. They've worked to create models for shoulder replacement surgeries.

Shoulder replacements have a far higher fail rate over a decade than knees because the bones are thinner and made far more fragile by trauma, arthritis and age, Wang said. Modeling someone's specific shoulder allows a surgeon not only to see the anatomy more clearly but also to map where all the new hardware will go.

"We can show them the pictures, but when we put a model in their hands

it's an epiphany for them," Wang said. "They say, 'I can see what's going on.' "

Wang and colleagues from the VA, Walter Reed National Military Medical Center, the University of Maryland and elsewhere published a paper in the Journal of Digital Imaging that found 3-D printed models were more beneficial for surgical planning than CT images.

Wang is waiting for approvals from the FDA to use specific software before expanding use of shoulder modeling.

Government statistics show that there are about 53,000 shoulder replacement surgeries annually, and Wang said many could be modeled first.

Eventually, the actual joints could be widely printed and implanted. Wang said research is needed to determine such things as what is the most durable printed materials and how to avoid titanium or plastic splinters, for example. And study is needed to see whether patients fare better over time with printed parts.

At Maryland and the VA center, he and Hirsch largely design and print models on their own time with a lot of donated materials. They need to determine a more formal and funded process to handle requests from surgeons. In addition to staff time, the supplies of plastic, resin, gypsum or metal can work out to under $10 a model to $100 or more.

But they expect the 3-D technology will continue to advance and the uses to proliferate.

The technology had spread largely as a result of individuals tinkering with personal 3-D printers, said Bill Decker, chairman of the Association for 3-D Printing, a national industry organization.

"There are people just playing in that space," Decker said.

But the medical implications are serious. Some popular applications of 3-D printing in health care have become household names—like Invisalign, a braces alternative, and cochlear implants for restoring hearing.

University and industry researchers are working on printing living things, from bacteria to organs made from stem cells.

"It's futuristic," Decker said. "You can mix bacteria with another substance, and the substance prints and the bacteria stays alive. ... If they can 3-D print bacteria, they can 3-D print vaccines."

For Syah and her parents, the clearest benefit, however, was simply letting doctors see how her defective heart worked before they cut into her tiny chest.

"I think it gave them the clearest idea of what was going on," Seimah said.