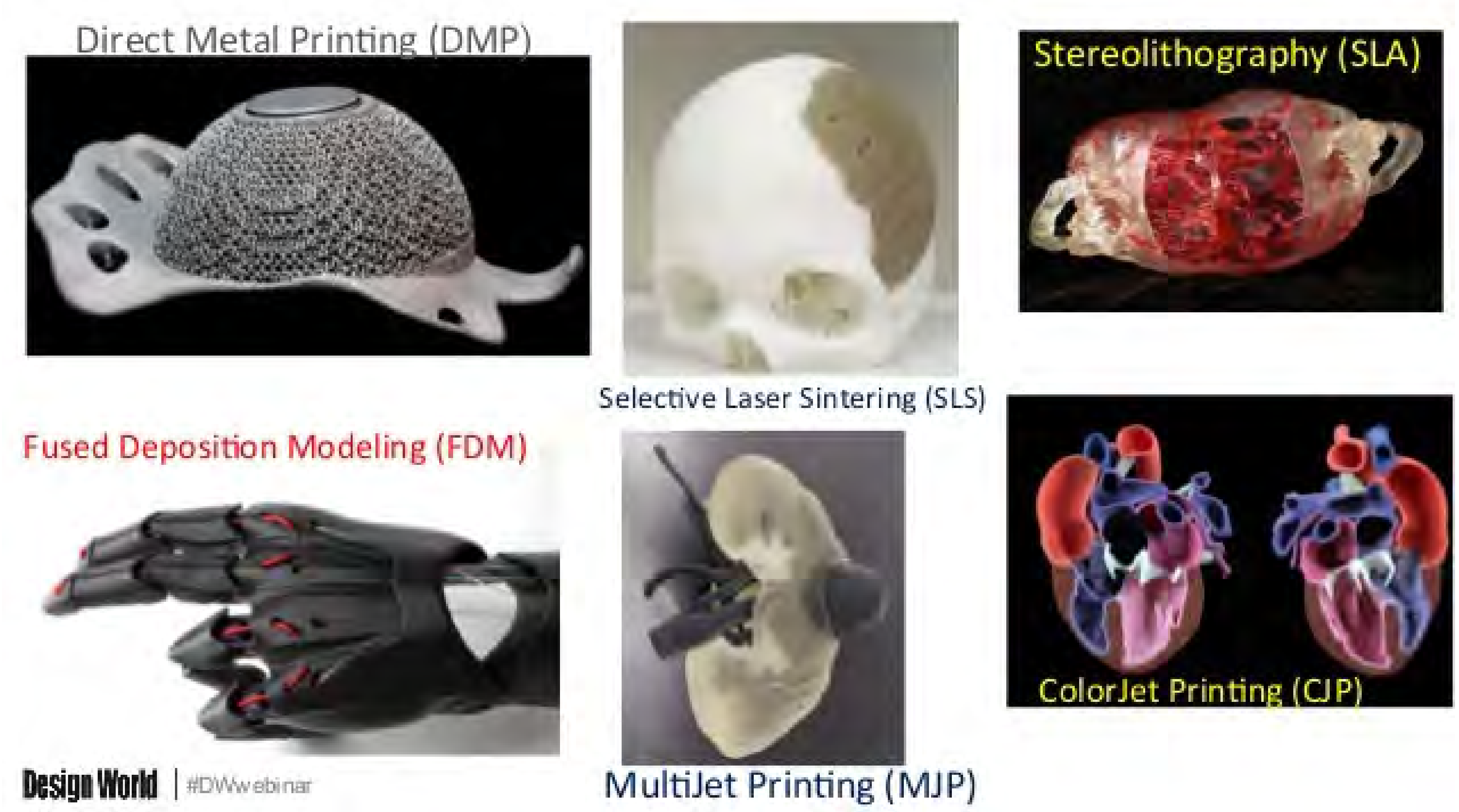
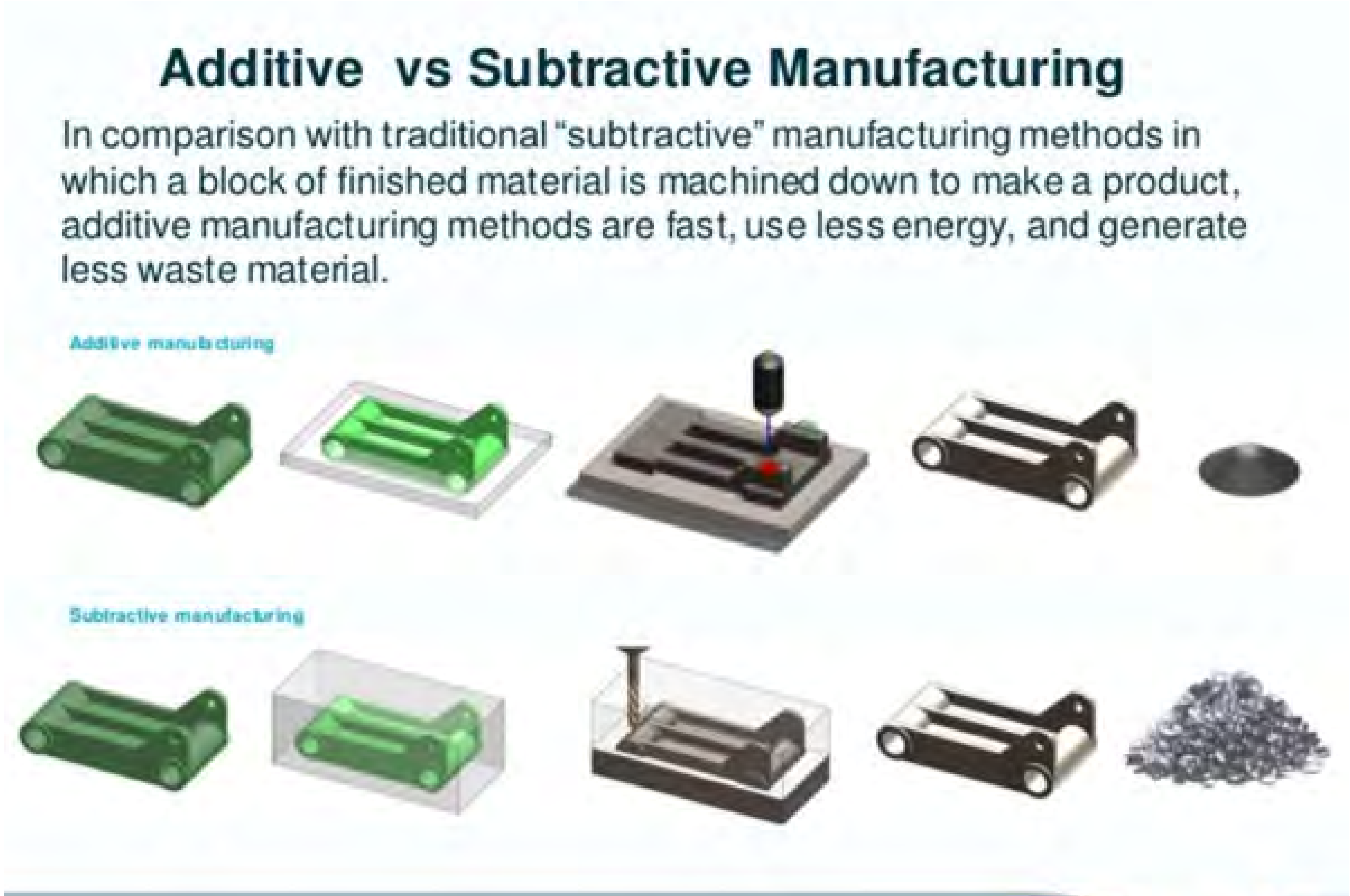
NEW MEDICAL USES OF 3D AND 4D PRINTING



COMPILED BY HOWIE BAUM

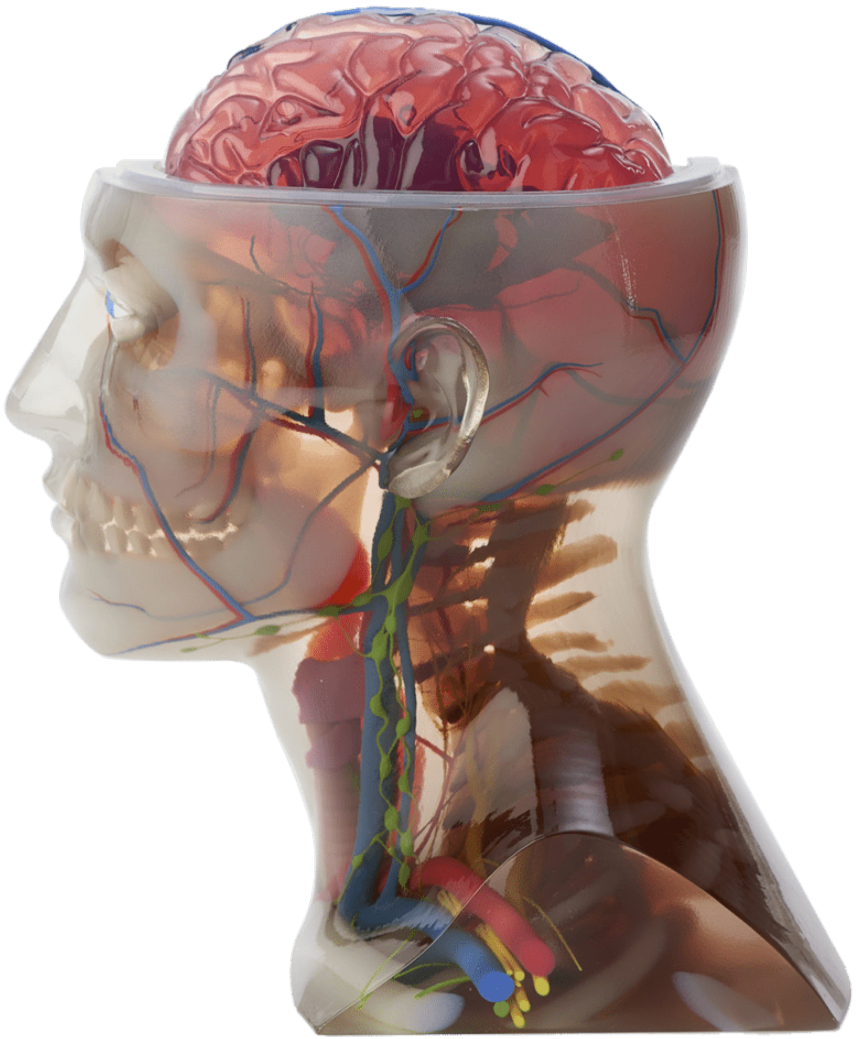
3D Printing has been used for making a wide variety of parts for years and is also called Additive Manufacturing.

Instead of machining away material to get to a finished part size, it does the opposite by building the part in layers, from the bottom up.



Medical uses for 3D printing can be organized into several broad categories, including:

1. **Medical models (for surgery or diagnostics assistance)**
2. **Surgery guides (to ease and optimize the surgery process)**
3. **Body implants (customized replacements)**
4. **Tissue and organ fabrication**
5. **The creation of customized prosthetics**
6. **Pharmaceutical research about drug dosage forms, delivery, and discovery.**
7. **Manufacturing of pills and other medication forms.**



Bio-printing of Tissues and Organs
Unique Dosage Forms
Personalized Drug Dosing
Complex Drug Release Profile
Customized Implants and Prostheses
Anatomical Models for Surgical Preparations
Medical Applications of 3D Printing

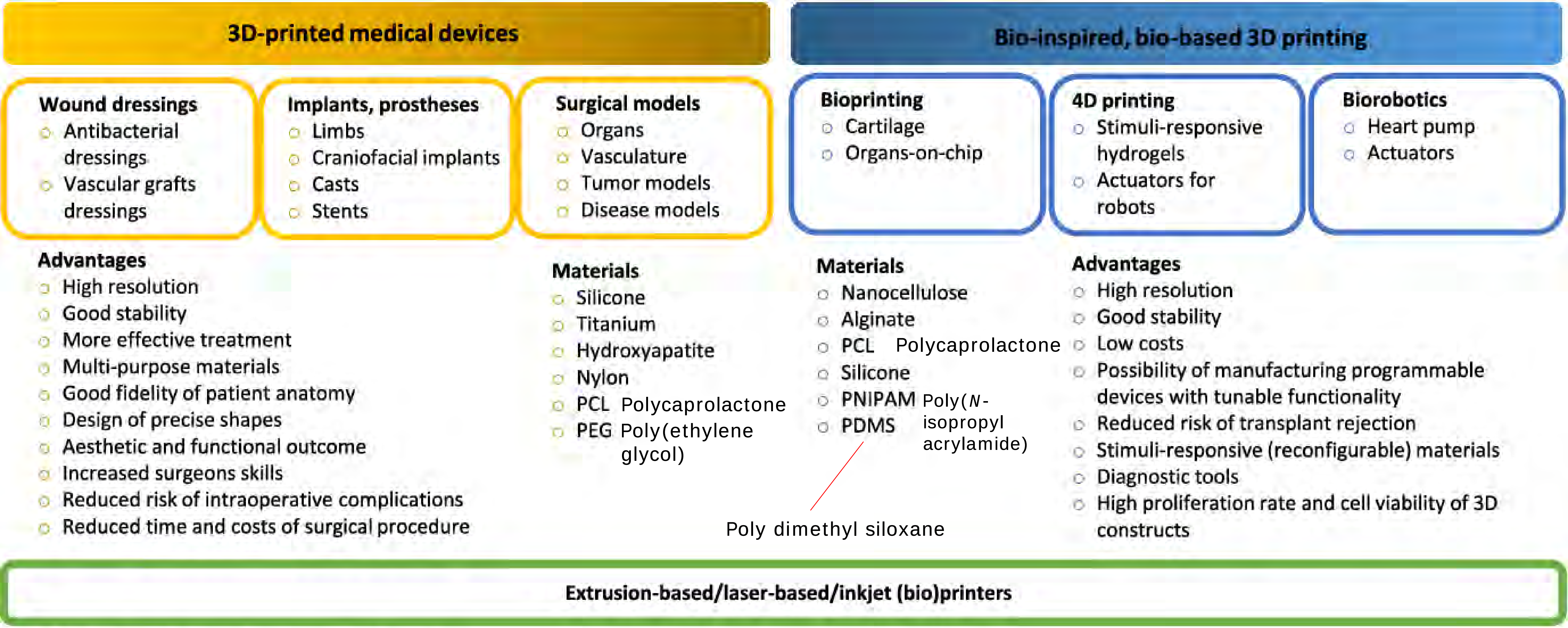


Fig. 11 Biomedical applications of 3D printing.

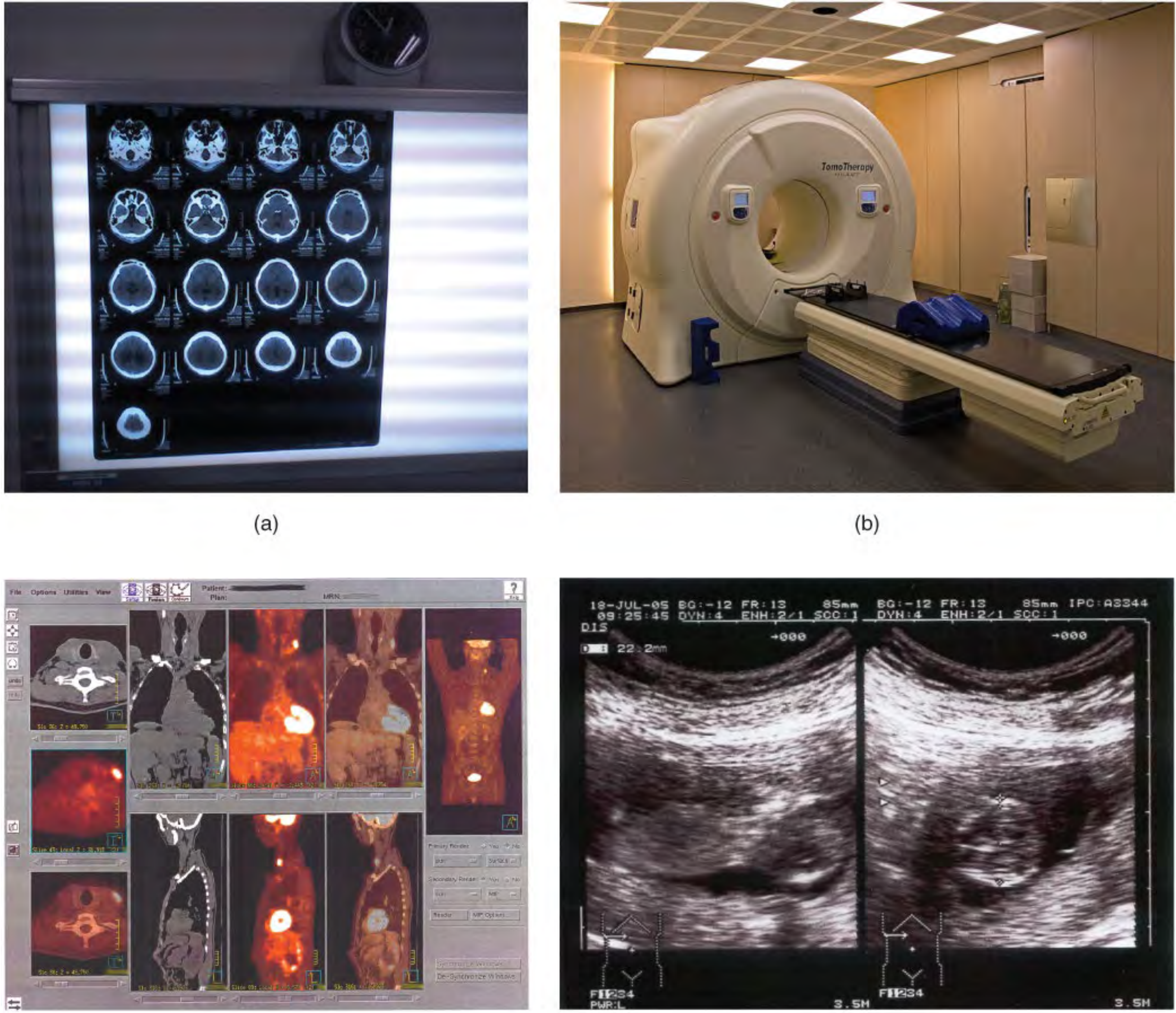
THE 4 MEDICAL SCANNING METHODS

(a) The results of a CT scan of the head are shown as successive transverse sections.

(b) An MRI machine generates a magnetic field around a patient.

(c) PET scans use radio-pharmaceuticals to create images of active blood flow and physiologic activity of the organ or organs being targeted.

(d) Ultrasound technology is used to monitor pregnancies because it is the least invasive of imaging techniques and uses no electromagnetic radiation.



(a) (b) (c) (d)

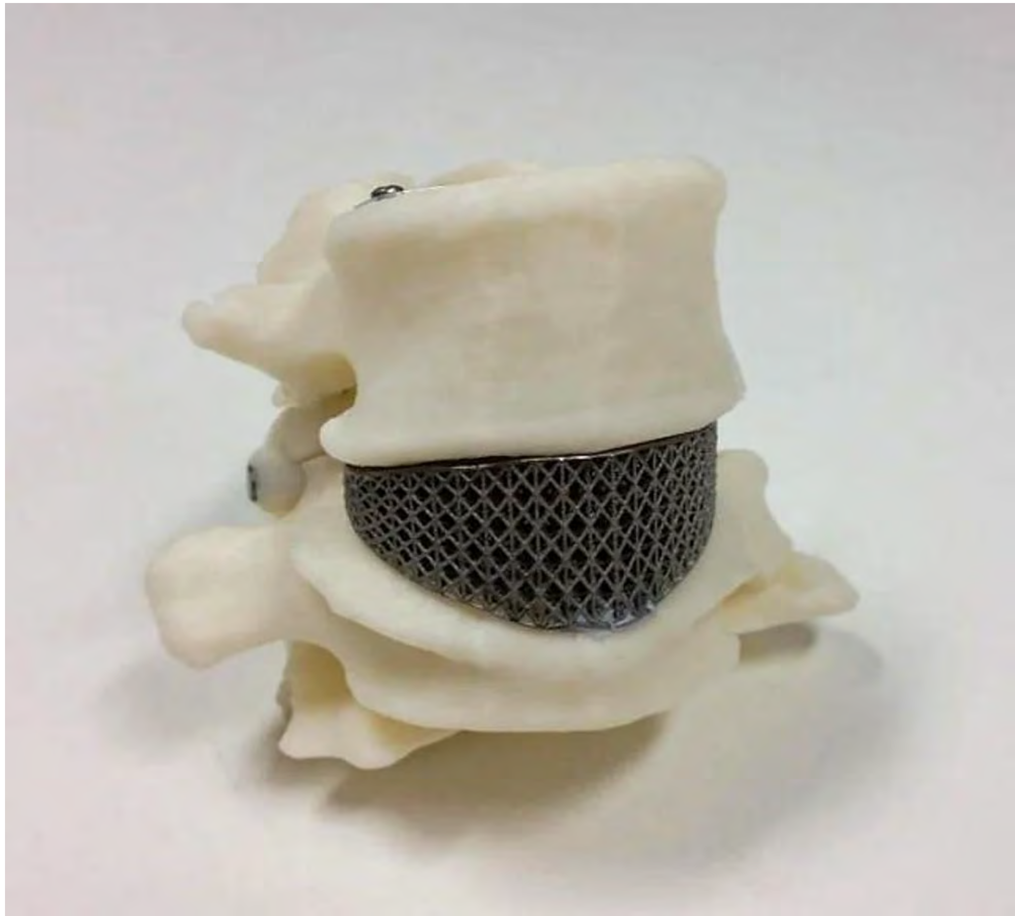
The Process

The first step in manufacturing a 3D printed PSI (patient-specific-implant) is the generation of detailed and accurate **3D scanned images**.

Currently, computer tomography (CT), ultra-sound, and magnetic resonance imaging (MRI) are the 3 widely used methods.

The resulting images are generally stored in a DIGITAL IMAGING AND COMMUNICATIONS IN A MEDICINE (DICOM) format, which is an International standard so it can be used by everyone with a 3D printer who creates Medical parts.

These three-dimensional images of the part are used to design the implant designs.



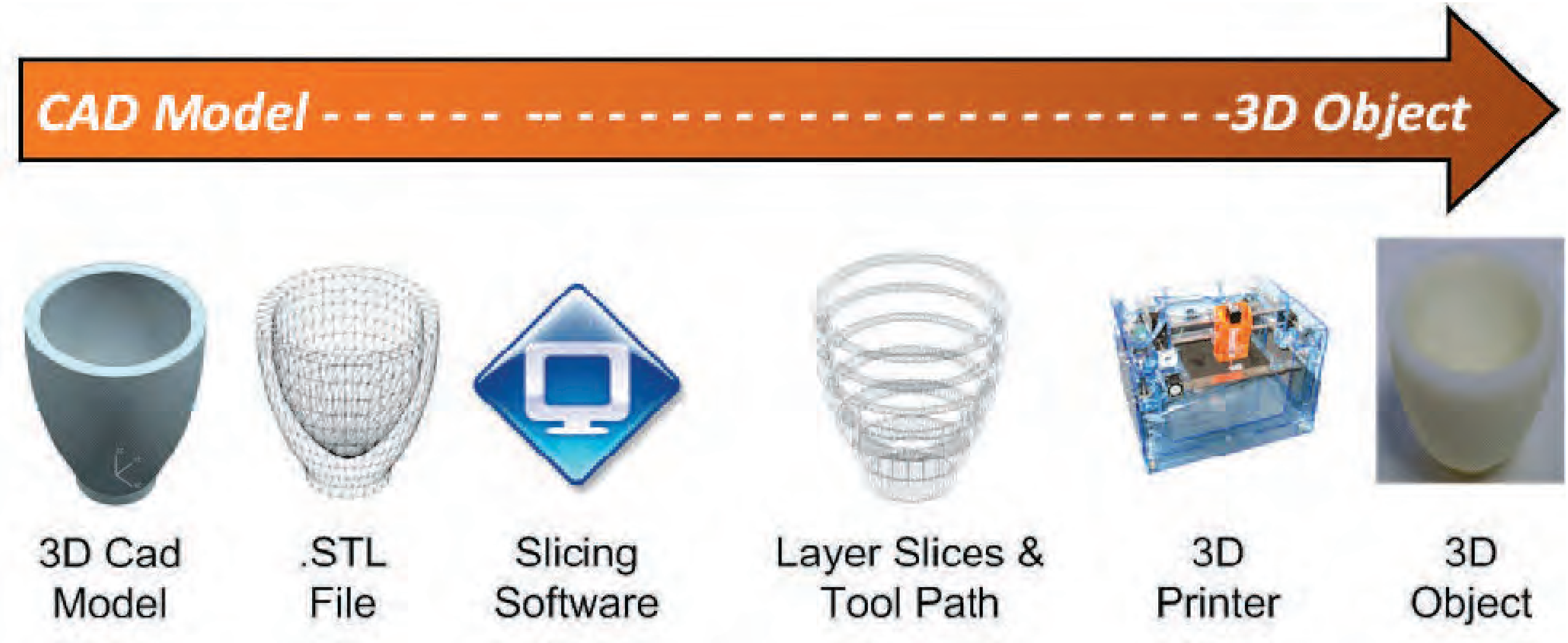
The first 3D printed spinal implant
Source: RMIT University

ADDITIVE MANUFACTURING

Additive manufacturing, otherwise known as 3D printing, was first developed in the 1980s.

It works by taking a digital model of the subject that is then printed in successive layers of an appropriate material, to create a new version of the subject.

Materials for it can be in the form of powder, a long strand of plastic that is melted, or liquid materials that are deposited from a nozzle.

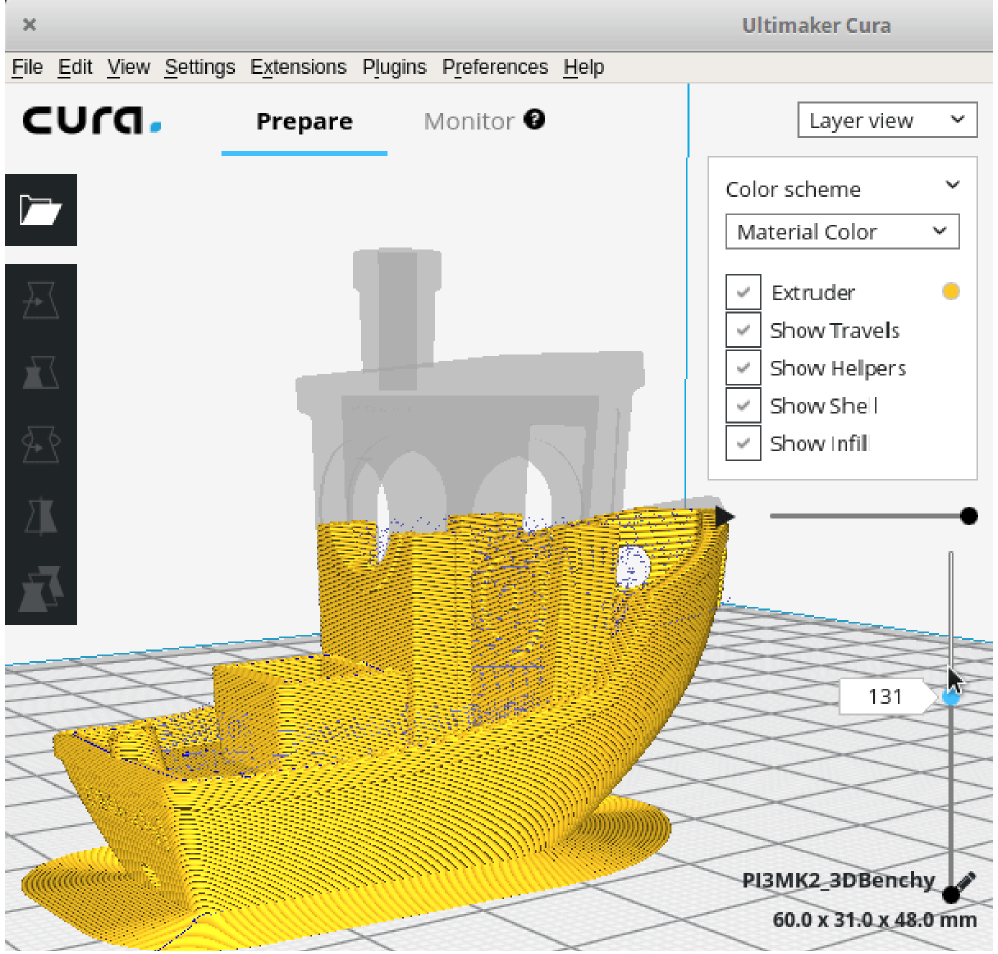


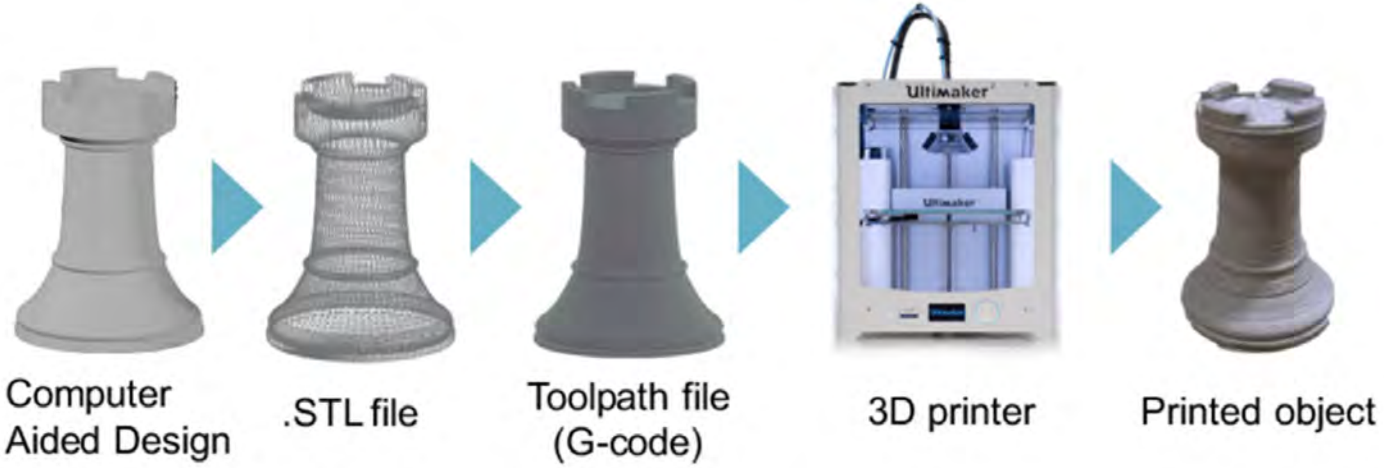
What is slicer software?

Once you have modelled the object you would like to 3D print, you will have it in an STL (Stereo-Lithography) file.

The slicer converts the STL model into a series of thin layers and produces a G-code file containing instructions tailored to a specific type of printer.

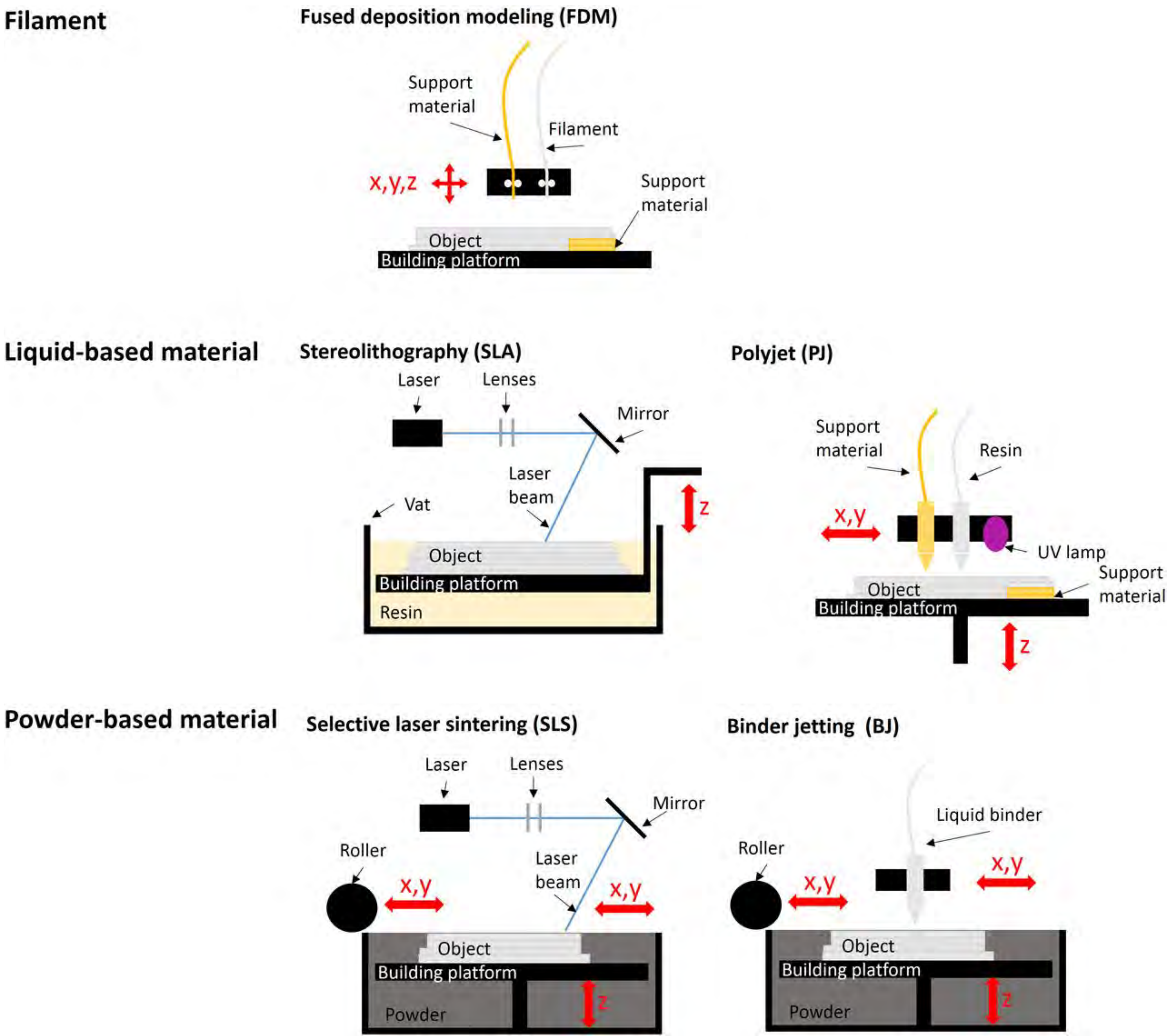
These commands tell your 3D printer exactly what actions to perform – where to move, what speed to use, what temperatures to set, and much more.





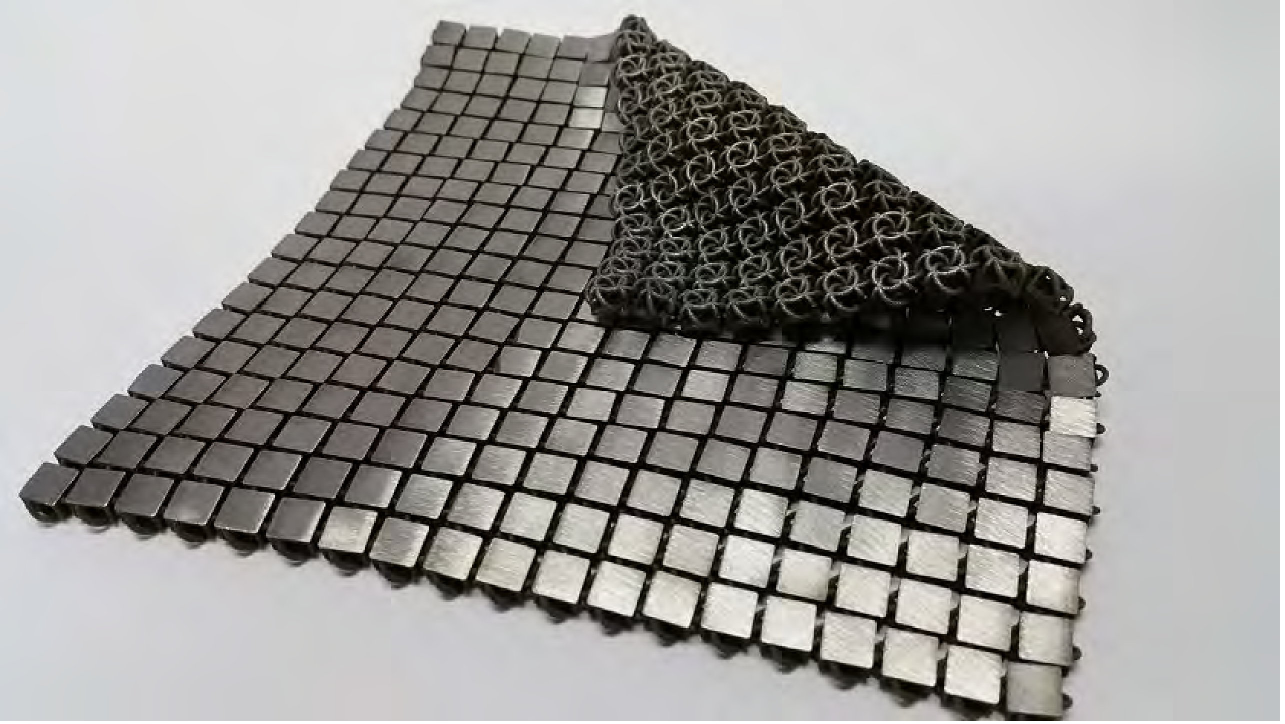

3D printing technologies
Powder solidification
Liquid solidification
Extrusion based systems
Drop on solid deposition
object built by liquid binding of powdered material
Selective laser sintering or melting
object built by solidification of powdered material by high energy beam
Drop on drop deposition
object built by droplet solidification
Stereolithography
object built by solidification of photosensitive liquid
solid
semisolid
Fused deposition modeling
object built by melted material solidification
Pressure assisted syringe
object built by semisolid material solidification

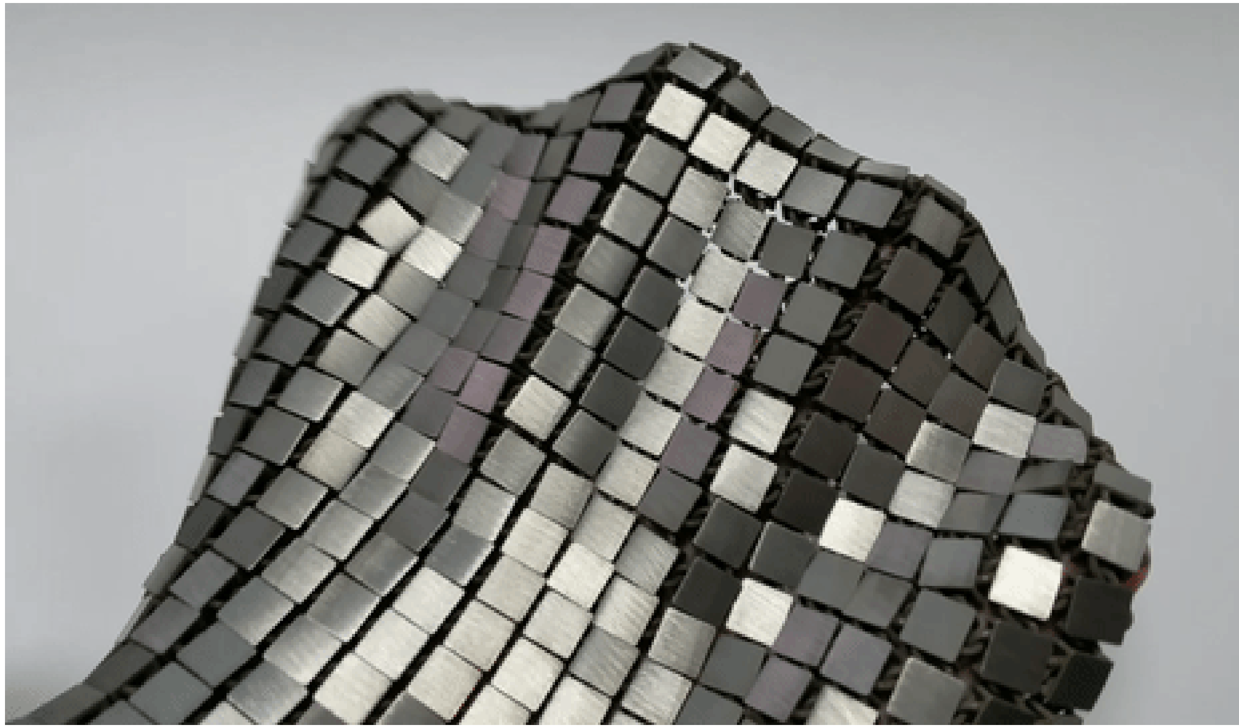
Rapid prototyping methods with red arrows indicating the directions of motion (x, y, and z axes).



The metal textile is 3D printed in one piece yet can be easily folded and flexed.

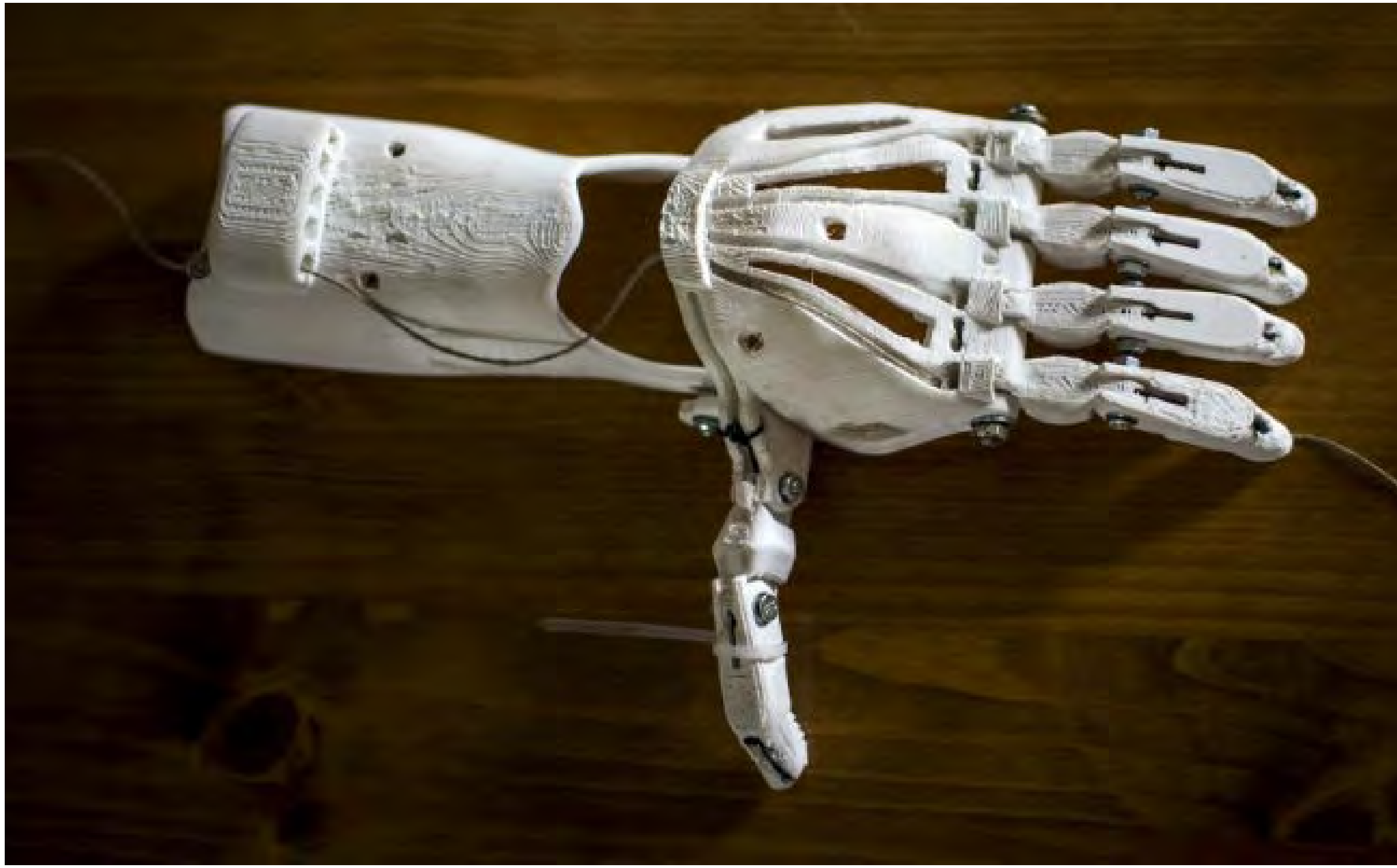
Eventually, the researchers expect that such materials could be used as deployable shields to protect spacecrafts from meteorites, as insulation, or possibly for new kinds of spacesuits.





3D printing of 1) medical devices,
2) medications and 3) human tissue is quickly becoming a promising reality.

The FDA has reviewed more than 100 devices currently on the market that were manufactured on 3D printers.



- ❖ Knee replacements
- ❖ Parts for a Prosthetic Hand ---------→
- ❖ Implants designed to fit like a missing puzzle piece into a patient's skull for facial reconstruction
- ❖ The first drug produced on a 3D printer, which is used to treat seizures.
- ❖ **Near Future:** Burn patients will be treated with their own new skin cells that are 3D printed directly onto their burn wounds.
- ❖ **Future:** Develop replacement organs.

LIVING SKIN WITH BLOOD VESSELS CAN NOW BE 3D PRINTED

Researchers at Rensselaer Polytechnic Institute have developed a way to 3D print living skin, complete with blood vessels.

They are now able to turn two types of living human cells into “bio-inks” and print them into a skin-like structure.

They add these key items:

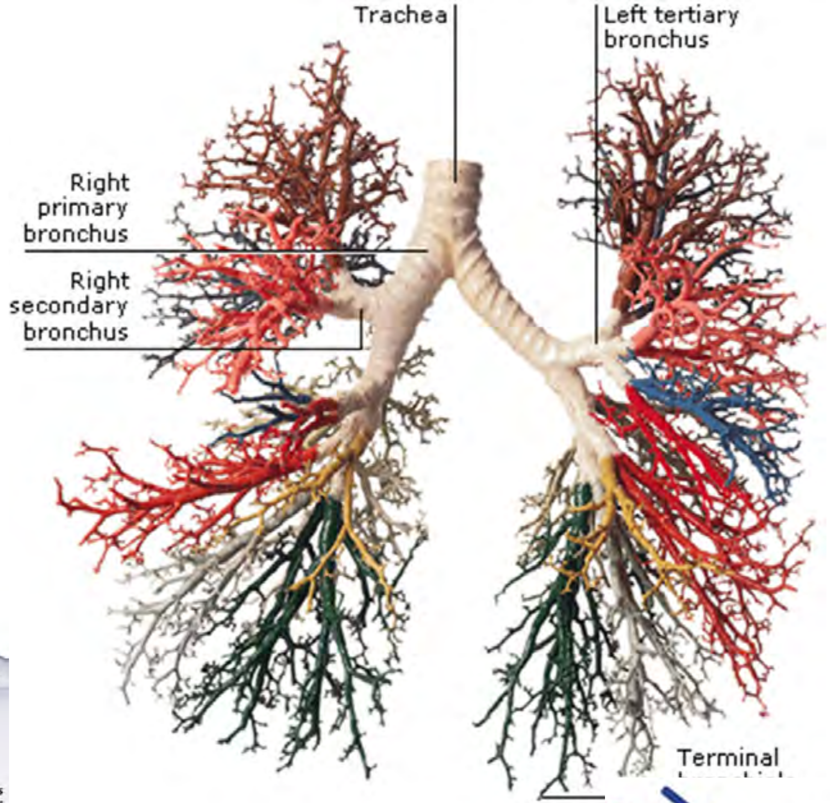
- ❖ Human endothelial cells (which line the inside of blood vessels)
- ❖ Human pericyte cells (which wrap around the endothelial cells)
- ❖ Animal collagen
- ❖ Other structural cells typically found in a skin graft

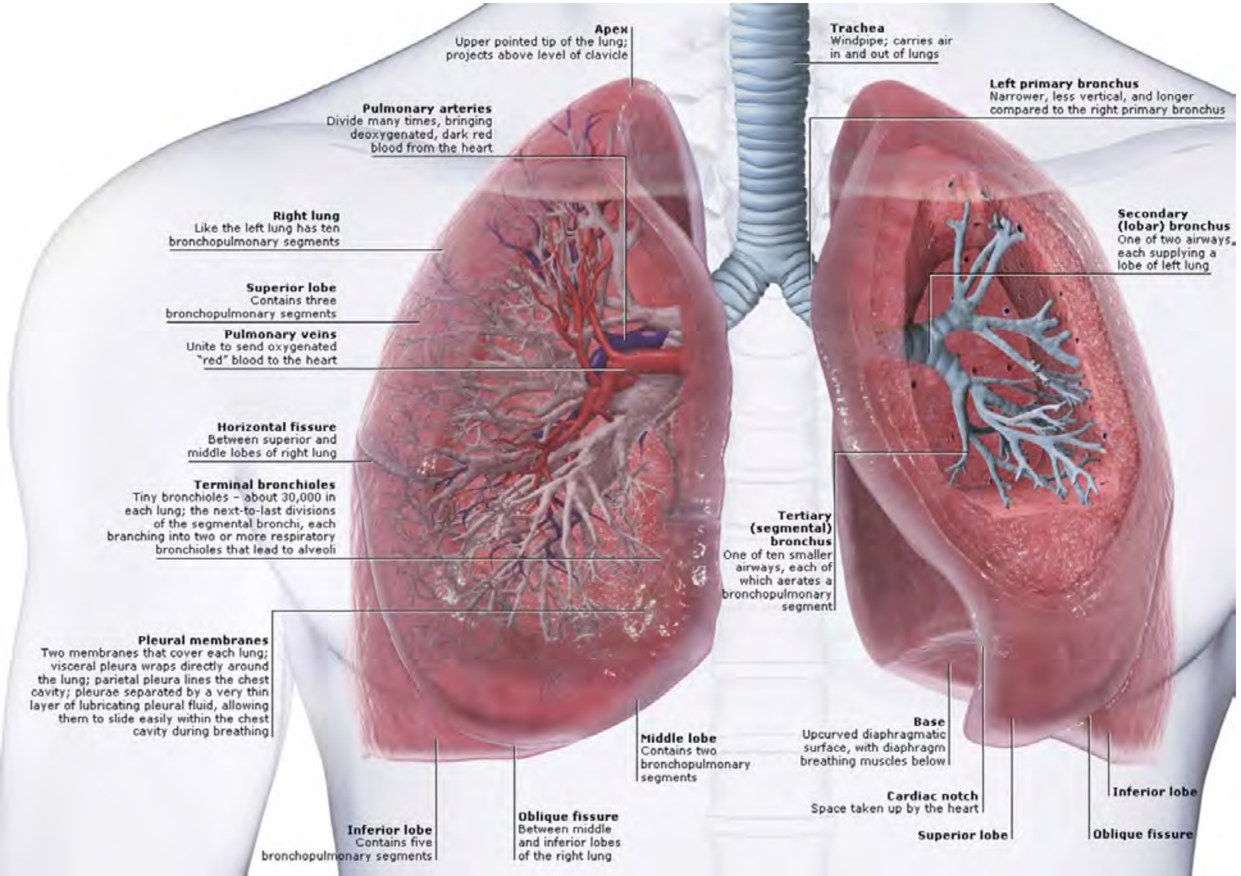
Then the cells start communicating with each other and form a blood vessel network within a few weeks.

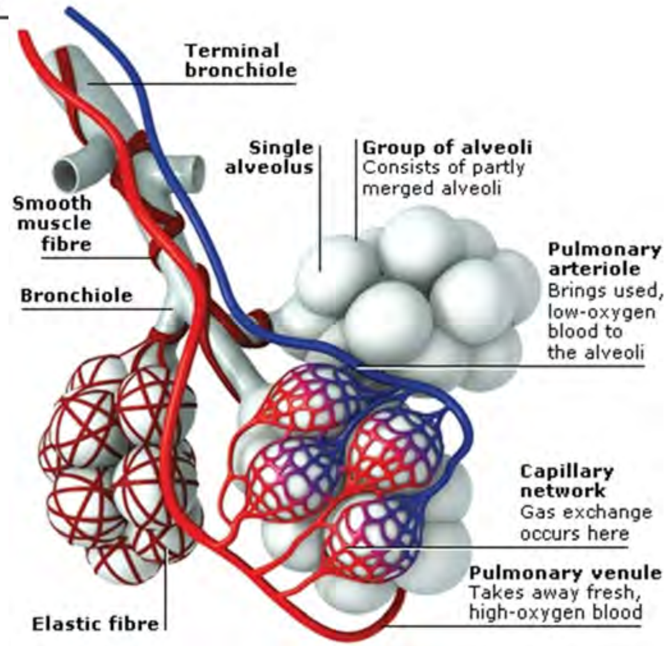
ALVEOLI - The lungs' microscopic air sacs, alveoli, are elastic, thin-walled structures arranged in clumps at the ends of respiratory bronchioles.

Around the alveoli are networks of capillaries. Oxygen passes from the air in the alveoli into the blood by diffusion through the alveolar and capillary walls

Carbon dioxide diffuses from blood into the alveoli. There are more than 300 million alveoli in both lungs





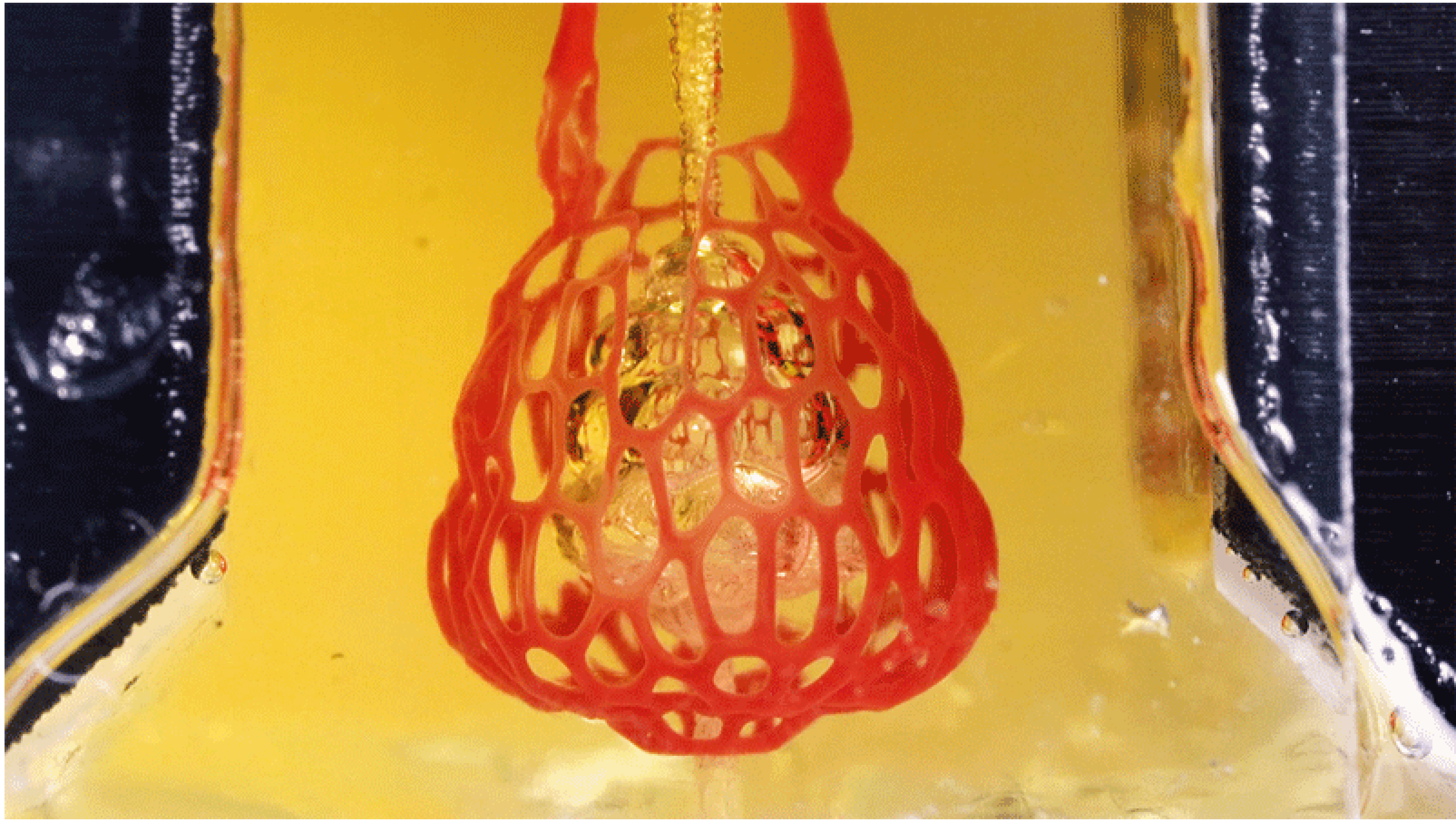


CREATING BODY TISSUE WITH SMALL, WORKING BLOOD VESSELS INSIDE

The Miller Lab is developing the bioengineering, 3D-printing technology, cell culturing, and analysis tools that make these designs possible.

They developed a new 3D-printing process with live cells called SLATE (stereolithography apparatus for tissue engineering).

The SLATE printer can embed live cells into soft gels containing very small, intricate blood vessels down to 300 microns in diameter. Hydrogels printed in only minutes by SLATE can function as lung-like networks with entangled air / blood networks



https://www.youtube.com/watch?v=GqJYMgAcc0Q&feature=youtu.be

A University of Toronto team is at work on a handheld 3D skin printer, weighing less than a kilogram, that could provide a revolutionary change to the field.

The technology they are using now is a tape dispenser which dispenses a tissue tape

“The handheld unit has onboard syringe pumps, and parts of the printer are manufactured with sterilized plastics and surgical steel.

A stepper motor drives the printer at a controlled speed.

The consumable is the printer itself, which is a micro-fluidic device.”

The portability of the printer means treating more patients in more places as well, with minimal operator training required.

Rady Children's Hospital is one of the first hospitals in California to open a laboratory dedicated to 3D technologies. This facility allows surgeons to print 3D anatomical models with a complicated operation.

This allows them to better prepare their operation and understand each step of it.

Matthew is a patient who suffered from heart disease and was able to have a successful operation, thanks in particular to a 3D replica of his heart:

https://www.youtube.com/watch?v=nbT9na7Fhes&feature=emb_logo

5 minutes

The 3D printer NextDent 5100 developed by 3D Systems has become a real work tool for dentist Michael Scherer.

Thanks to this solution, he can create dental parts quickly and accurately.

A patient who has an appointment in the morning can leave with his dental prosthesis in the afternoon which saves a lot of time for the dental professionals and the patients!

https://www.youtube.com/watch?v=9MfyJ5aiAQE&feature=emb_logo

2 minutes

Castable Ceramics dental laboratory shows how they are making state-of-the-art 3d printed dentures using the Carbon 3d printer and liquid programmable resins.

https://www.youtube.com/watch?v=PMZtnWnn_6k 5 min

Intra-oral mapping (scanning) based on different non-contact optical principles and technologies is now possible without the negative aspects of dental impressions such as discomfort for the patient, imprecision, and lab work.

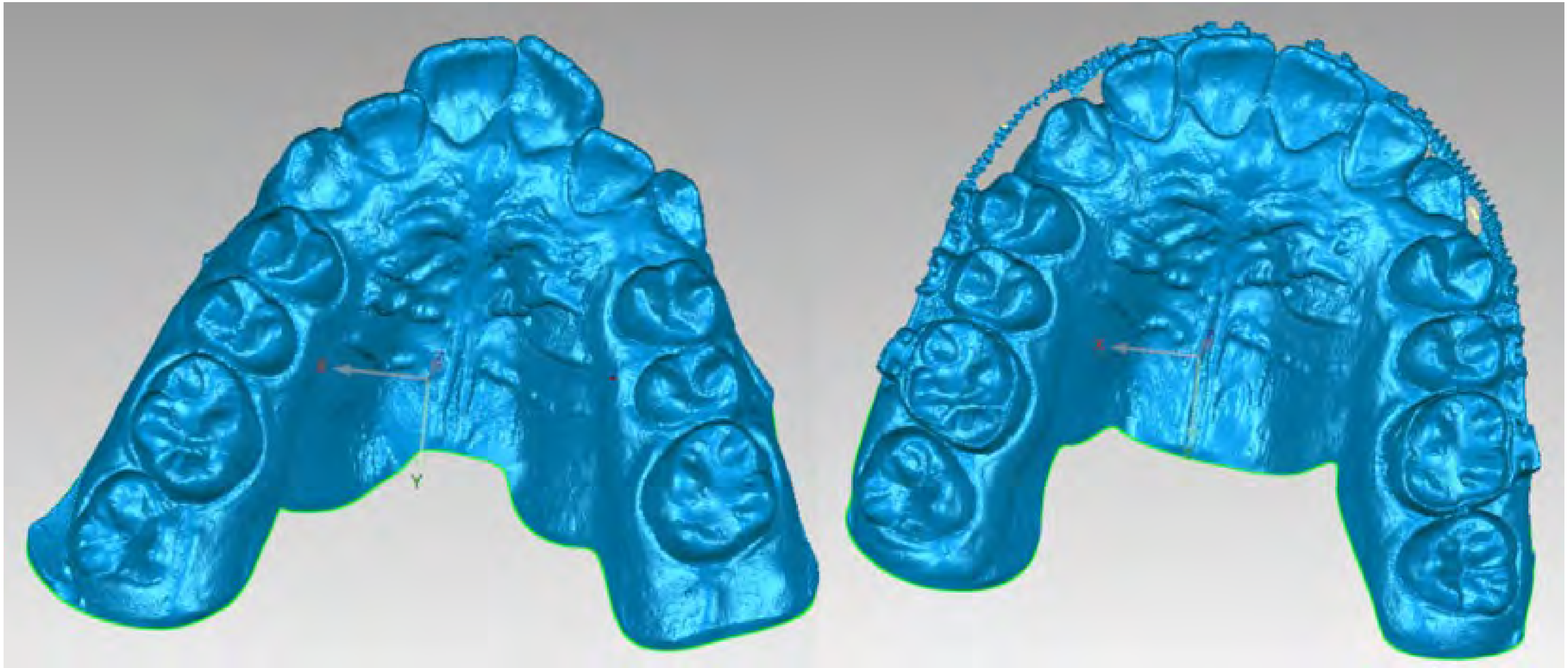
They can be used to make a large range of dental restorations, implants, study models, and orthodontic appliances such as customized indirect brackets, arch wires, expanders, aligners, retainers, etc.

The highly-accurate open file formats are incorporated in the patient electronic health record which can be remotely stored, accessed, and managed through a secure, cloud-based digital hub from basically anywhere.

Figure 4.

3D digital models of the upper dental arch.

The software is an aid in the CAD/CAM process, able to repair errors in the mesh prior to 3D printing, edit the models, and design appliances.



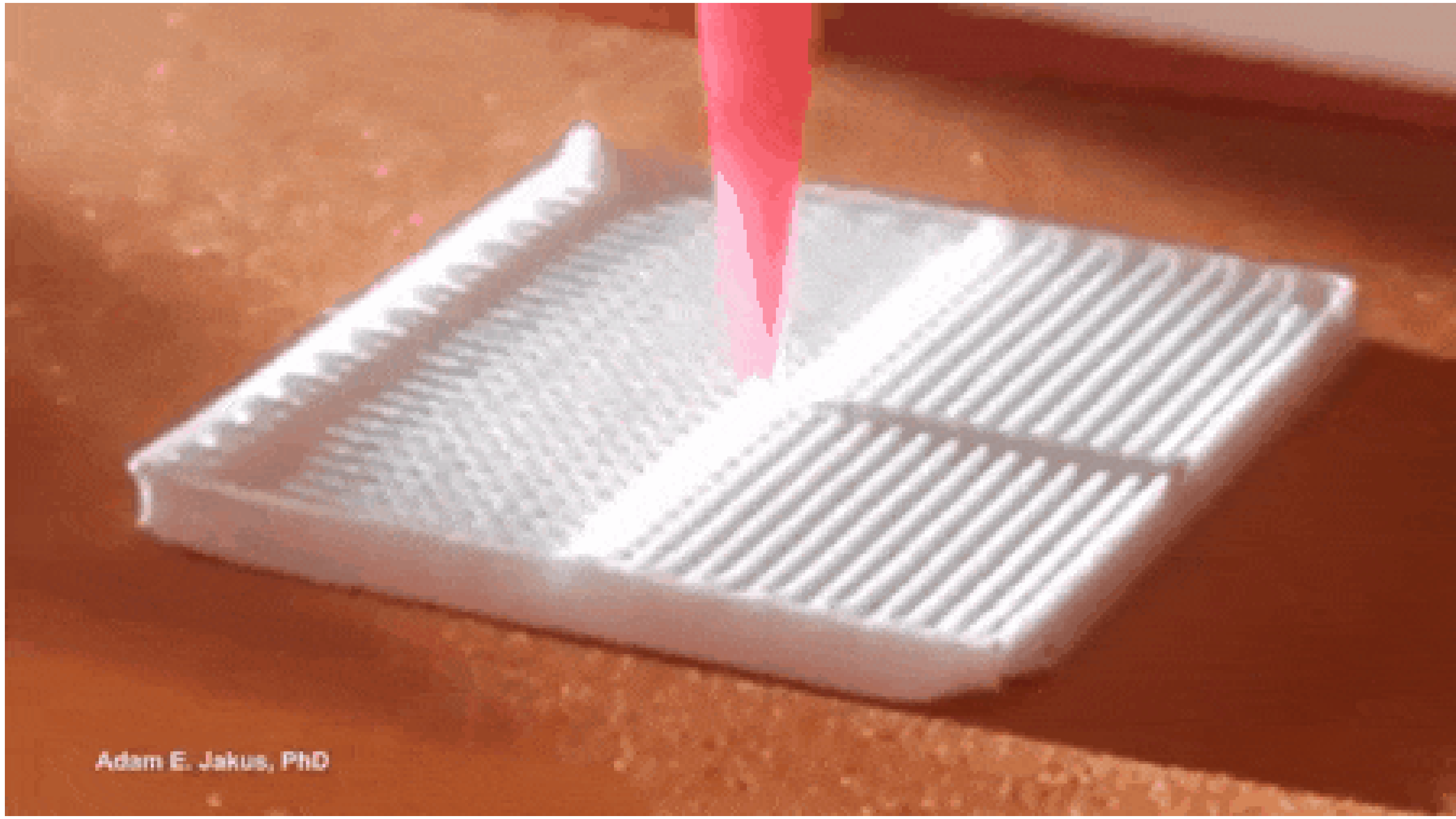
3D-PRINTED HYPERELASTIC BONE WILL CHANGE MEDICINE

HEALING BROKEN BONES JUST GOT A WHOLE LOT EASIER.

A bizarre new substance scientists nicknamed “hyper-elastic” bone has been developed by researchers at Northwestern University.

They figured out how to patch the gap between shards of bone using a substance they call hyper-elastic bone — or HB for short.

The squishy material gets 3D-printed into the right shape, then compressed and wedged into the space, where it will expand to fill in the nooks and crannies in the broken bone.

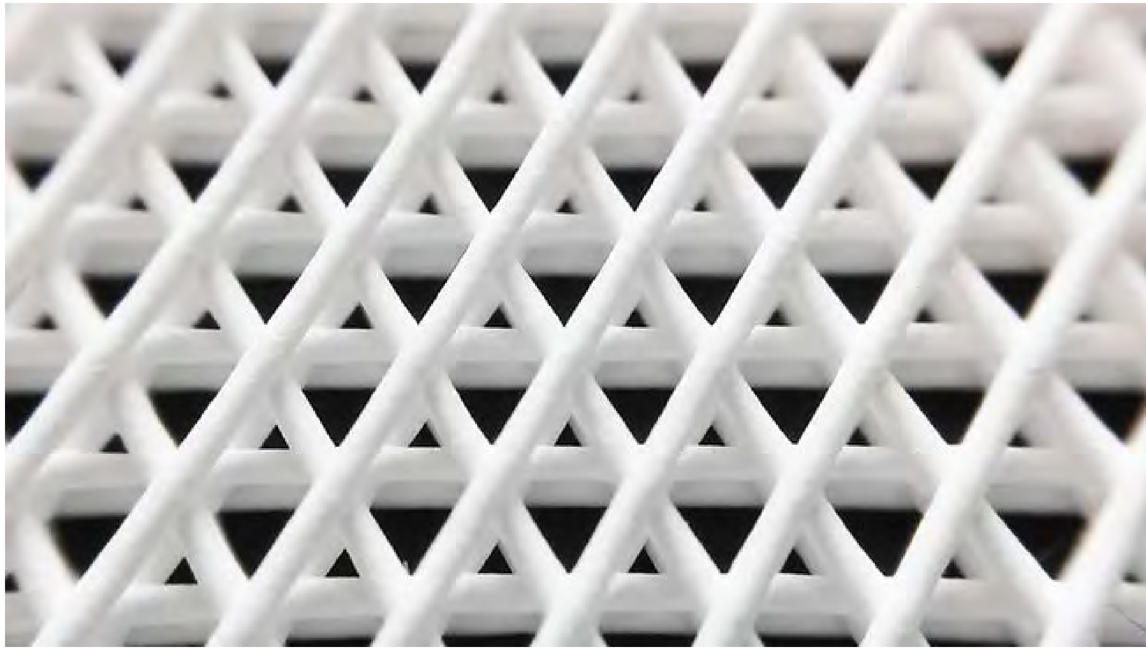


The material is created out of the same stuff bone is made of a mineral called **hydroxyapatite**, mixed together with binding agents that give the otherwise brittle substance bendable properties and unprecedented strength.

Because it's both biodegradable and, importantly, *biocompatible*, it integrates itself into the body, making it easier for blood vessels to pass through and cells to grow.

They tested it by seeding it with stem cells — cells that have the potential to specialize into any kind of tissue.

What they found was remarkable: The stem cells planted on the HB not only multiplied but began to *make bone*, mining minerals from the HB itself as a resource. And the immune system, as far as their experiments have shown, doesn't freak out when HB enters its turf.



This is a close-up of a small region of the first several top layers of a 3D-printed sheet of hyper-elastic bone.

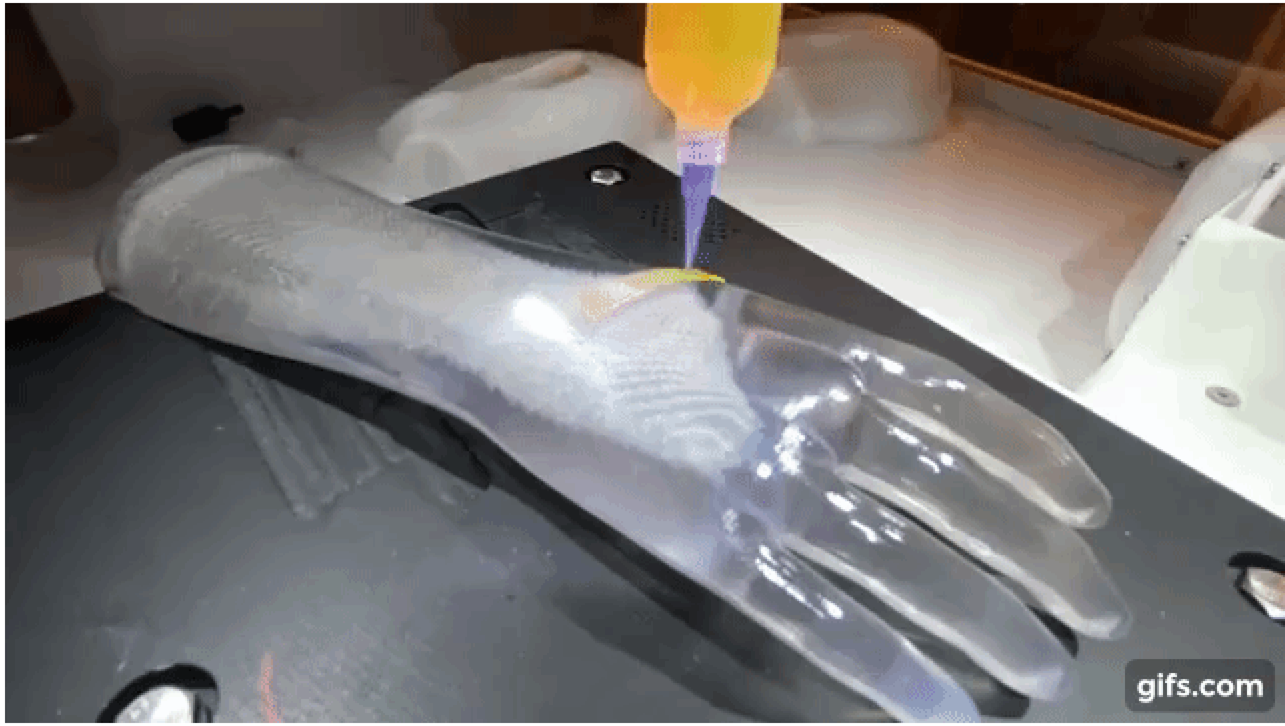
3D.FAB BIOPRINT "LIVING BANDAGE" WITHIN REGENERATIVE MEDICINE RESEARCH PROJECT

3D.FAB, a French additive manufacturing platform, is developing a "living bandage" using 3D bioprinting and direct additive manufacturing called "STRESSKIN".

The 3D printed bandage is from a cell-based bio-ink.

Using a Bio-Assembly Bot, a 6-axis robotic arm for bio-fabrication, this material is deposited onto the patient's skin, forming an autograft that will create new skin in approximately two weeks.

This approach is said to overcome other 3D printed skin solutions which have been proven to be too fragile to be sutured.



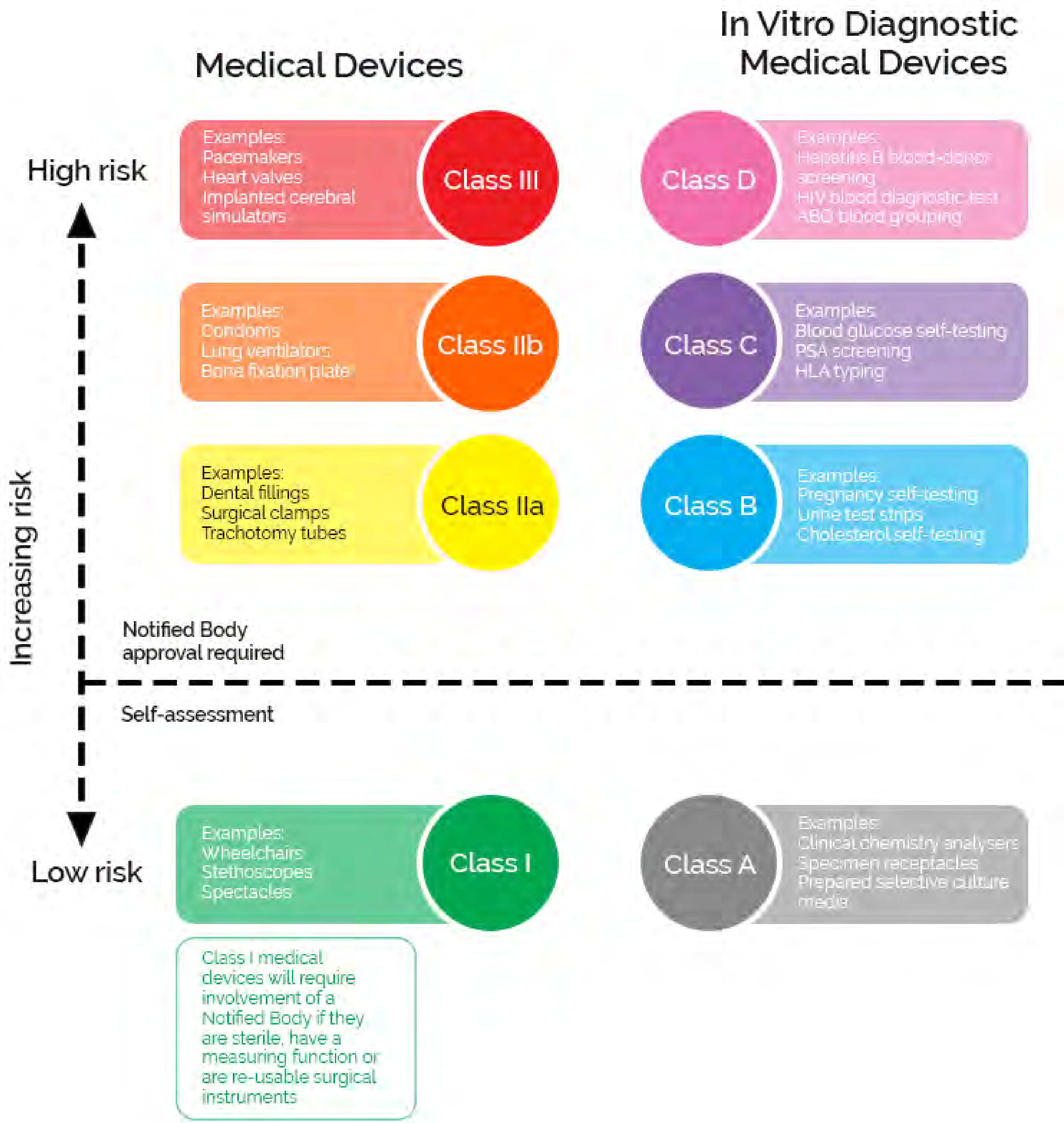
.8 minute https://www.youtube.com/watch?v=mDlz9ILoskU&feature=emb_logo

There are three classes of medical devices:

Class I: Low-risk devices, like bandages and gloves.

Class II: Intermediate risk devices, like pregnancy kits and X-ray machines.

Class III: High-risk devices, like implants (e.g. spinal, orthopedic) and pacemakers.



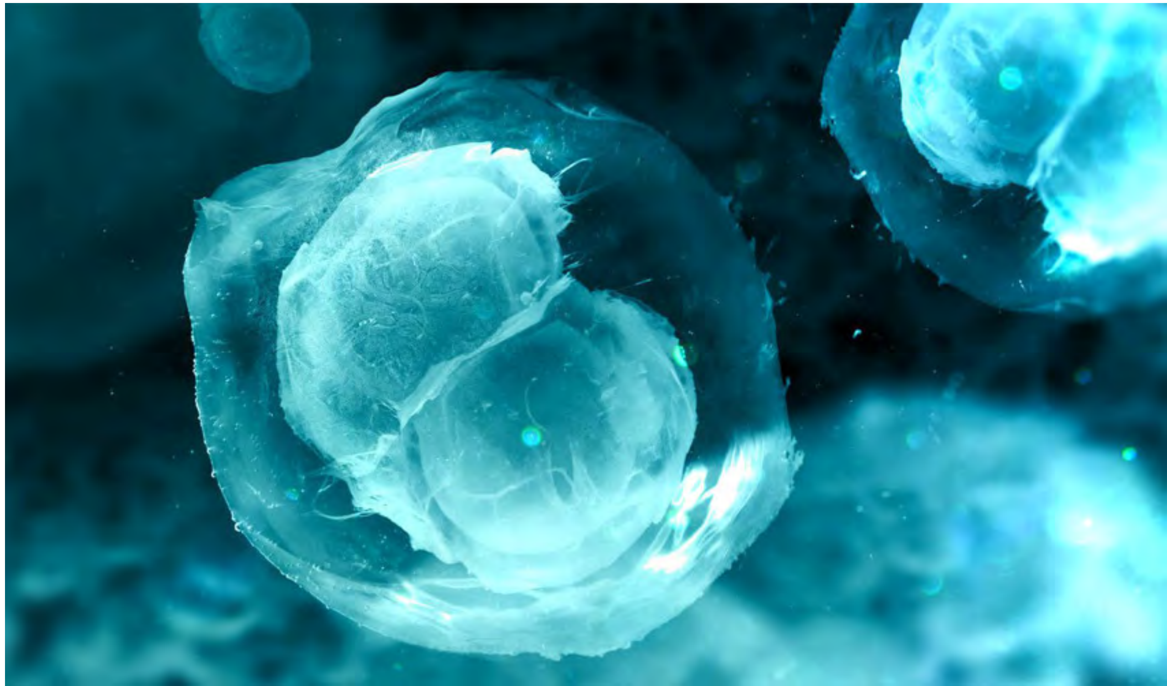
Bioprinted ovary to restore fertility and hormone production

The objective of the researchers is to use the structural proteins of the human or a pig's ovary to develop a bioprinted scaffold which can then be used in the creation of a biological scaffold.

This could allow eggs and hormone-producing cells to develop.

The structural proteins from a pig ovary are the same type of proteins found in humans, giving us an abundant source for a more complex bio-ink for 3D printing an ovary for human use.

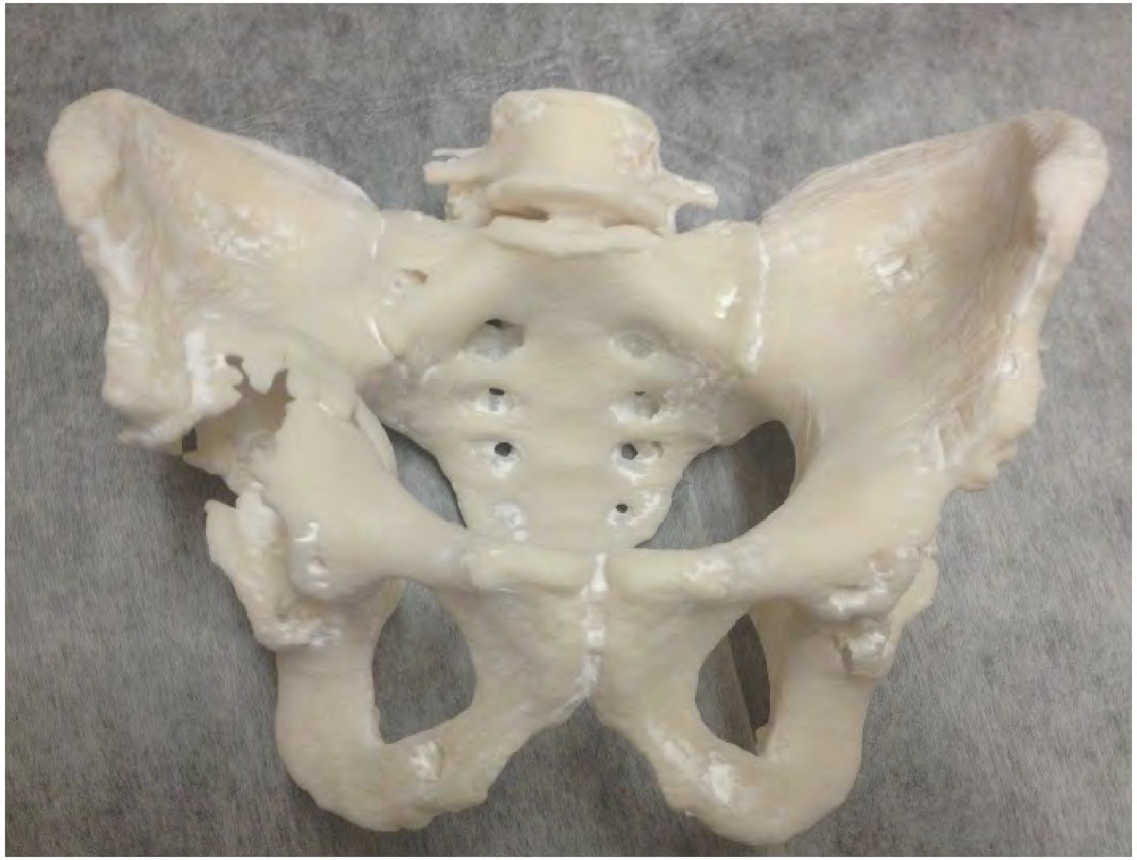
Once implanted, the artificial ovary would be able to respond to natural ovulation signals, allowing pregnancy to occur.






The Radiology Departments conducts a CT scan of the persons pelvis which creates a life-sized 3D image of it. This provides the surgeon with a visual and tactile appreciation of the actual pelvis itself.

Afterwards, the digital images are converted into a DICOM file (digital imaging and communications in medicine) image files. A computerized bone modelling is done and then the process continues until a stereolithography (STL) image is created which is used to create the 3D model. For this type of model, a fine Nylon powder was used which provides good part definition.



A 3D printed anatomical model assisted in recent successful surgery on eighteen-year-old Moises Campos.

In order to help surgeons better prepare for the complex operation, the Children's Hospital of Orange County (CHOC) recently teamed up with Dinsmore Inc., a 3D printing company from Irvine, California, to 3D print a full-scale model of Campos' tibia based off his CT scan, using the Stereolithography (SLA) process.

https://www.youtube.com/watch?v=fDSlp2yq_CI 2 min

Australian Man Gets World's First 3D Printed Tibia Replacement

Reuben Lichter became the first person in the world to have a 3D-printed tibia transplanted into his leg.

A scaffold to form the bone shape was initially modeled at Queensland University of Technology.

Biomedical engineers designed it to promote bone growth around it and then slowly dissolve over time.

To have the body successfully grow around the scaffold, the team introduced tissue and blood vessels from both of Lichter's legs to the scaffold. The surgery itself happened over five operations at Brisbane's Princess Alexandra Hospital.

FOSSILABS CREATES PEEK IMPLANTS TO PROMOTE BONE GROWTH

High-performance thermoplastics such as **PEEK** have gained a lot of attention in the last few years in the 3D printing sector. It stands for **Poly Ether Ether Ketone.**

In the medical sector, it’s their biocompatible properties that are of particular interest for implants.

It has developed a proprietary process to offer a first-of-its-kind 3D printed PEEK porous medical implant with defined areas of full porosity and advanced water attracting properties to promote osseointegration (growth into bone). In other words, unlike other 3D printed PEEK implants, the entire piece has porous structures instead of only surface porosity or windows within defined layers.

FUTURE OF GLOBAL HEALTHCARE

$8.7 TRILLION

Global healthcare spend projected by 2020[2]

11.5%

Percent of total population over 65 years of age.[3]

HOSPITALS IN THE US WITH A CENTRALIZED 3D PRINTING FACILITY

Using Materialise Mimics technology

OVERALL 3D PRINTING/AM GROWTH[4]

21% Compound annual growth rate (CAGR) of AM industry in 2017

$7.3 BILLION 2017 AM market size

11% Approximate revenues from medical/dental pieces

97% AM professionals who expect an increase in Medical AM/3DP applications[5]

THE DIRECT METAL LASER SINTERING PROCESS (DMLS) IS A GREAT EXAMPLE OF BEING ABLE TO MAKE AN ACETABULAR CUP OUT OF TITANIUM POWDER, FOR A HIP REPLACEMENT OPERATION.

IT IS MUCH CHEAPER THAN MACHINING ONE.

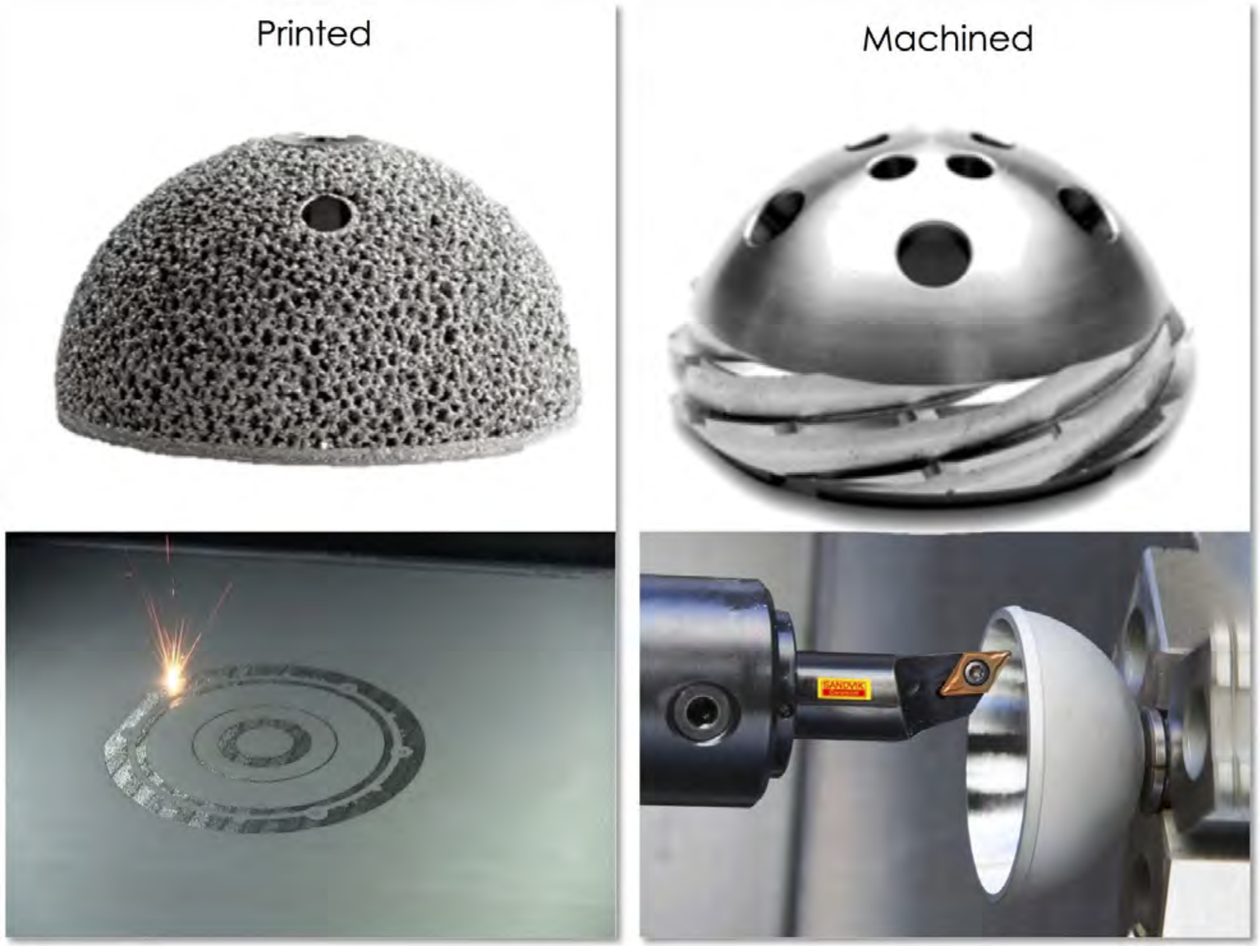
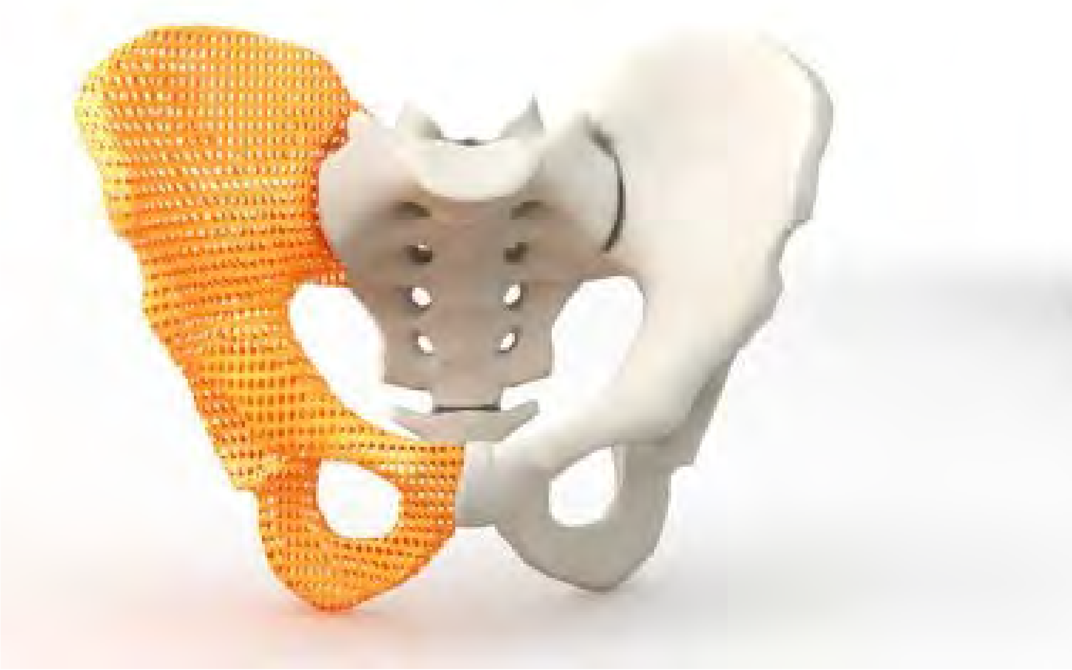


Photo credits: Makernest, Sandvik, Okuma

3D printed titanium hip cups developed by 3D Systems Medical Device and Manufacturing team.



The Fraunhofer Institute in Germany developed a way to create ceramic and metal suspensions that utilize a thermoplastic binder and can precisely control the viscosity of the suspension, which is key to allowing the material to print correctly.

The method can be used to print ceramic, glass, plastic and metal.

This material flexibility combined with the geometrical freedom that 3D printing allows, could truly revolutionize medical device design.

BioNEEK knee brace exploits INTAMSYS 3D printing and ultra-light and very strong PEEK material for improved endurance and mobility

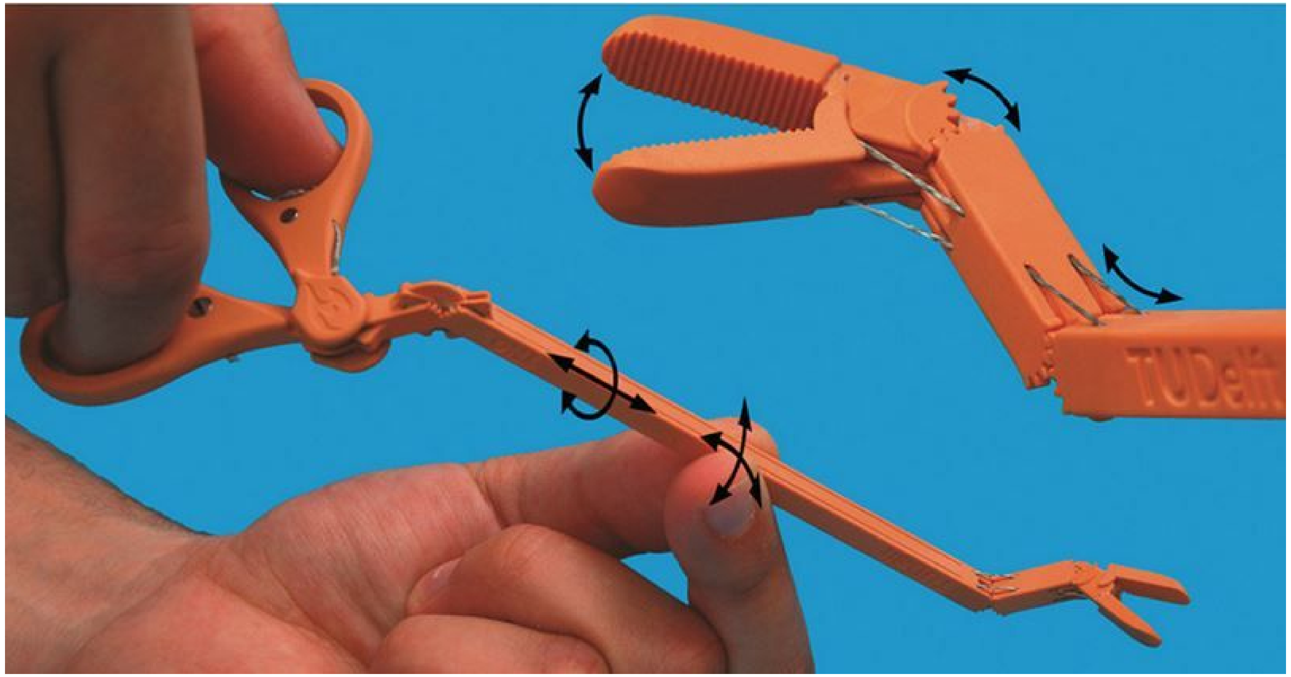
Shanghai-based INTAMSYS is known for being one of the **3D printing world's leading** suppliers of PEEK materials (Poly Ether Ether Ketone) and the technology required to effectively print with them.

PEEK is a high-performance FDM filament that is often used for medical applications, and INTAMSYS's own products were recently used by China's Sichuan Ju An Hui Science and Technology to build an advanced medical device known as **BioNEEK**.

This passive bionic exoskeleton brace is intended to provide support for people with a broad range of knee problems, as well as improving their mobility and preventing any further damage.

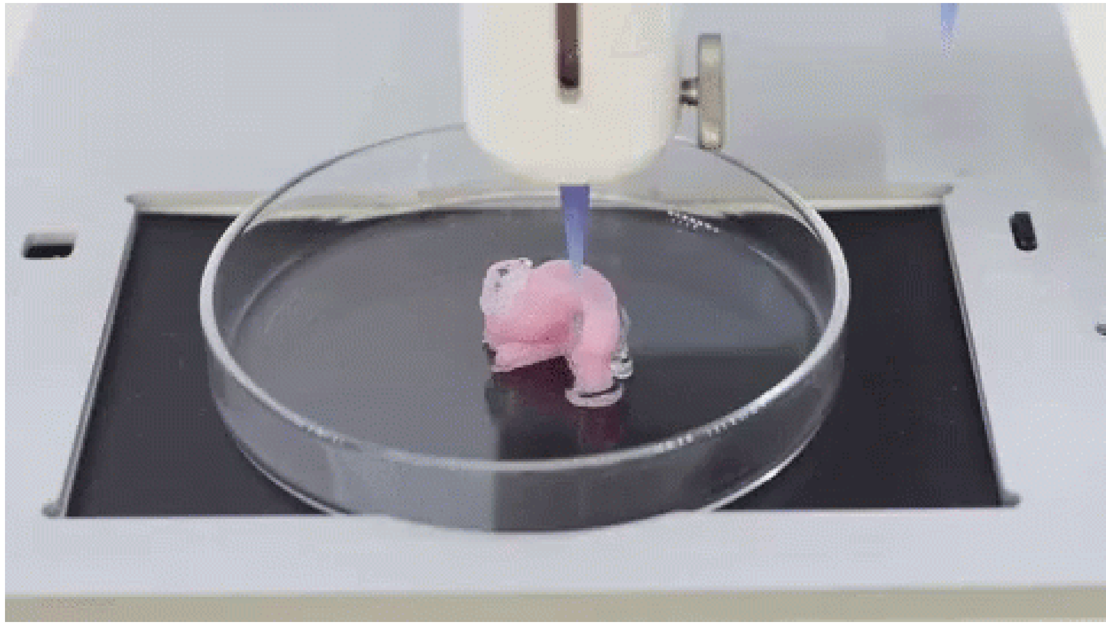
The **DragonFlex**, is a steerable medical instrument for keyhole (very small) operations, using parts made with 3D printing.

Modeled after the **EndoWrist**, a surgical tool that is engineered to act similar to the human wrist and be able to be used through small incisions, the aim of the design was to demonstrate a design of a structurally simple handheld steerable laparoscopic grasping forceps free from cable fatigue, while attaining sufficient bending stiffness for surgery.



Bioprinting is the 3D printing of biological tissue and organs through the layering of living cells, usually stem cells of the person the organ is being made for.

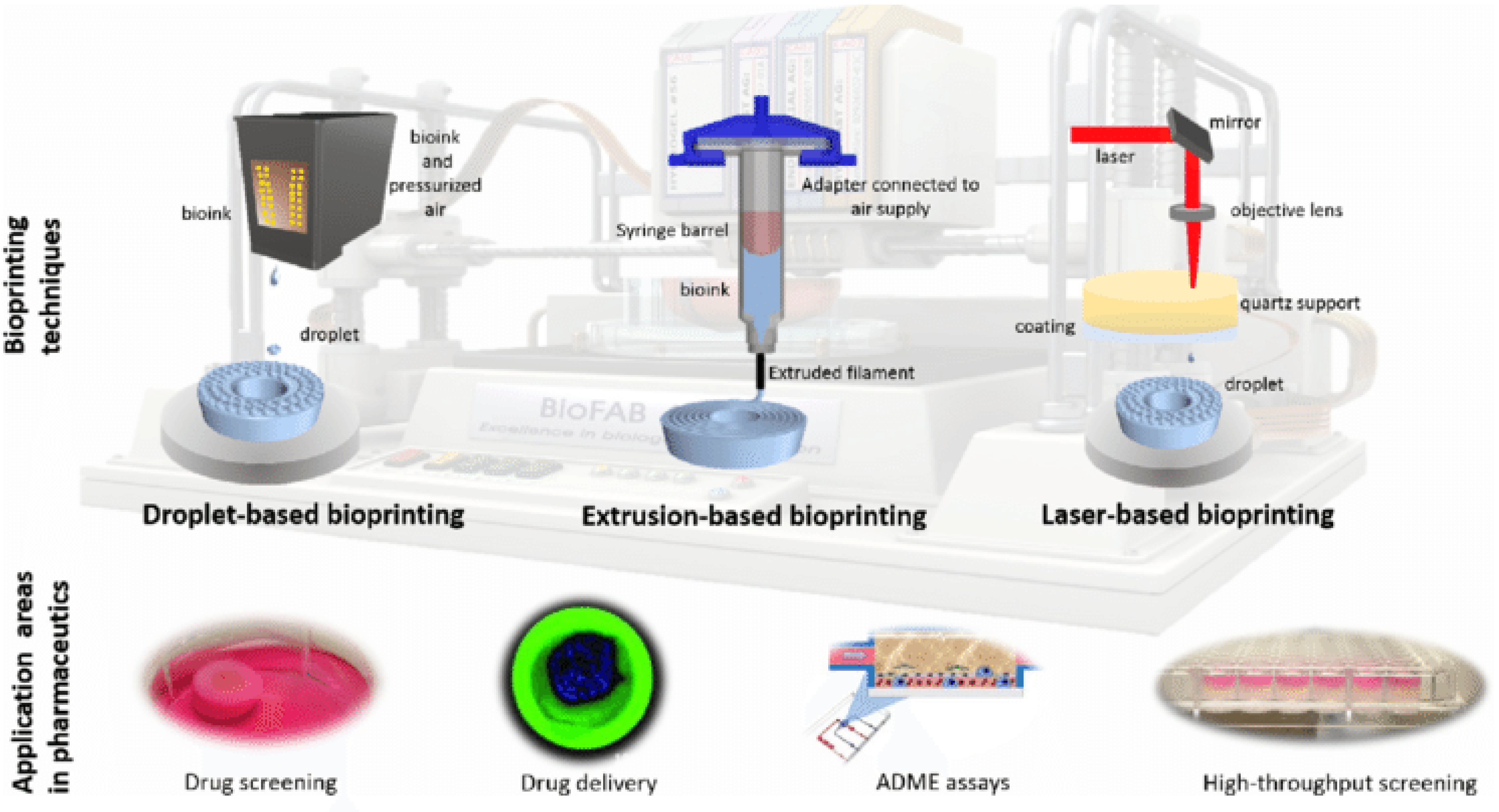
Bioprinting begins with creating a 3D scan of the part design based on the fundamental composition of the target tissue or organ.



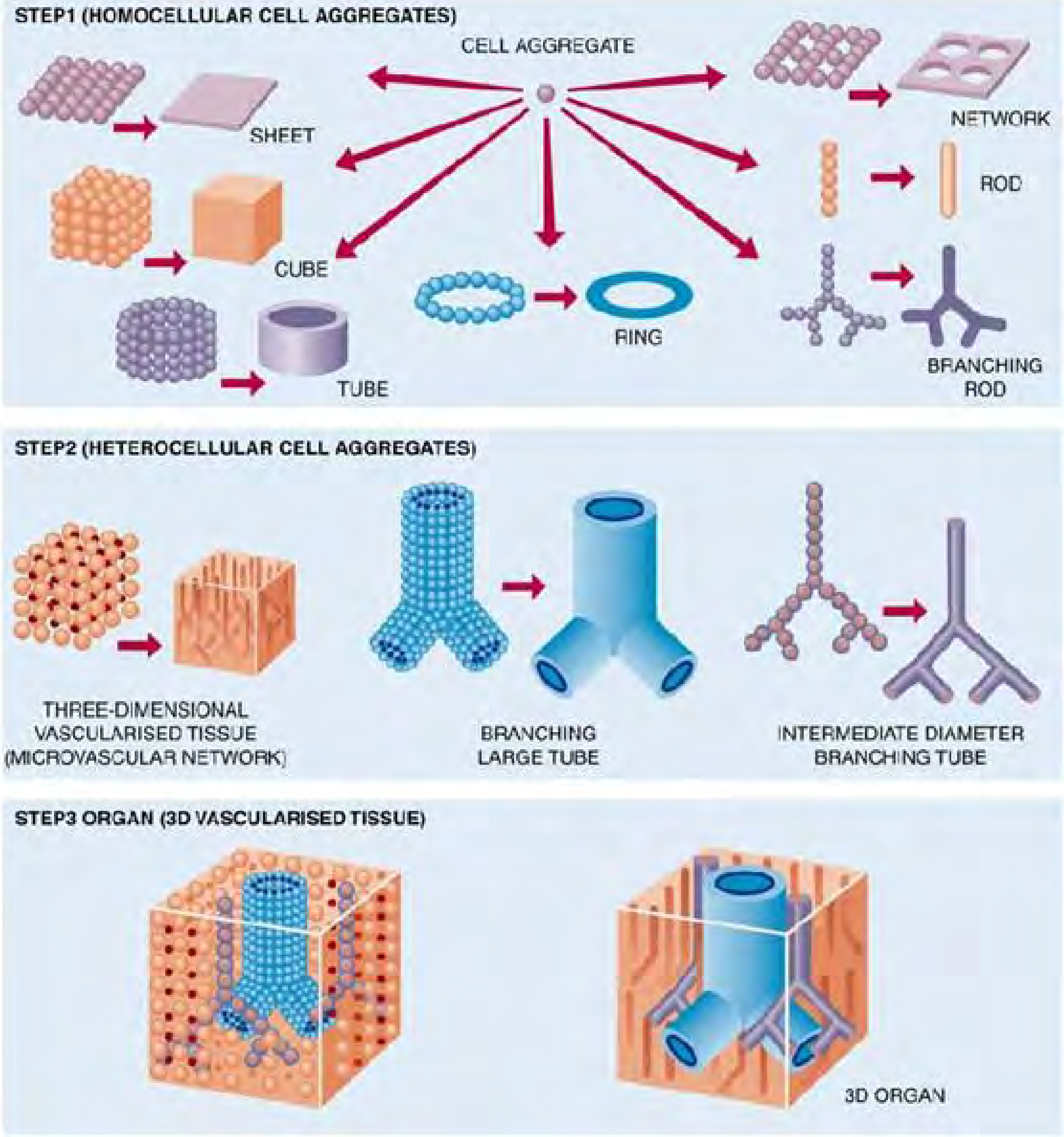
In a laboratory environment, a bioprinter then uses that design and deposits thin layers of bio-ink cells using a bio-print head, which moves either left and right or up and down in the required configuration.

They also dispense a dissolvable hydrogel to support and protect cells as tissues are constructed vertically, to act as fillers to fill empty spaces within the tissues.

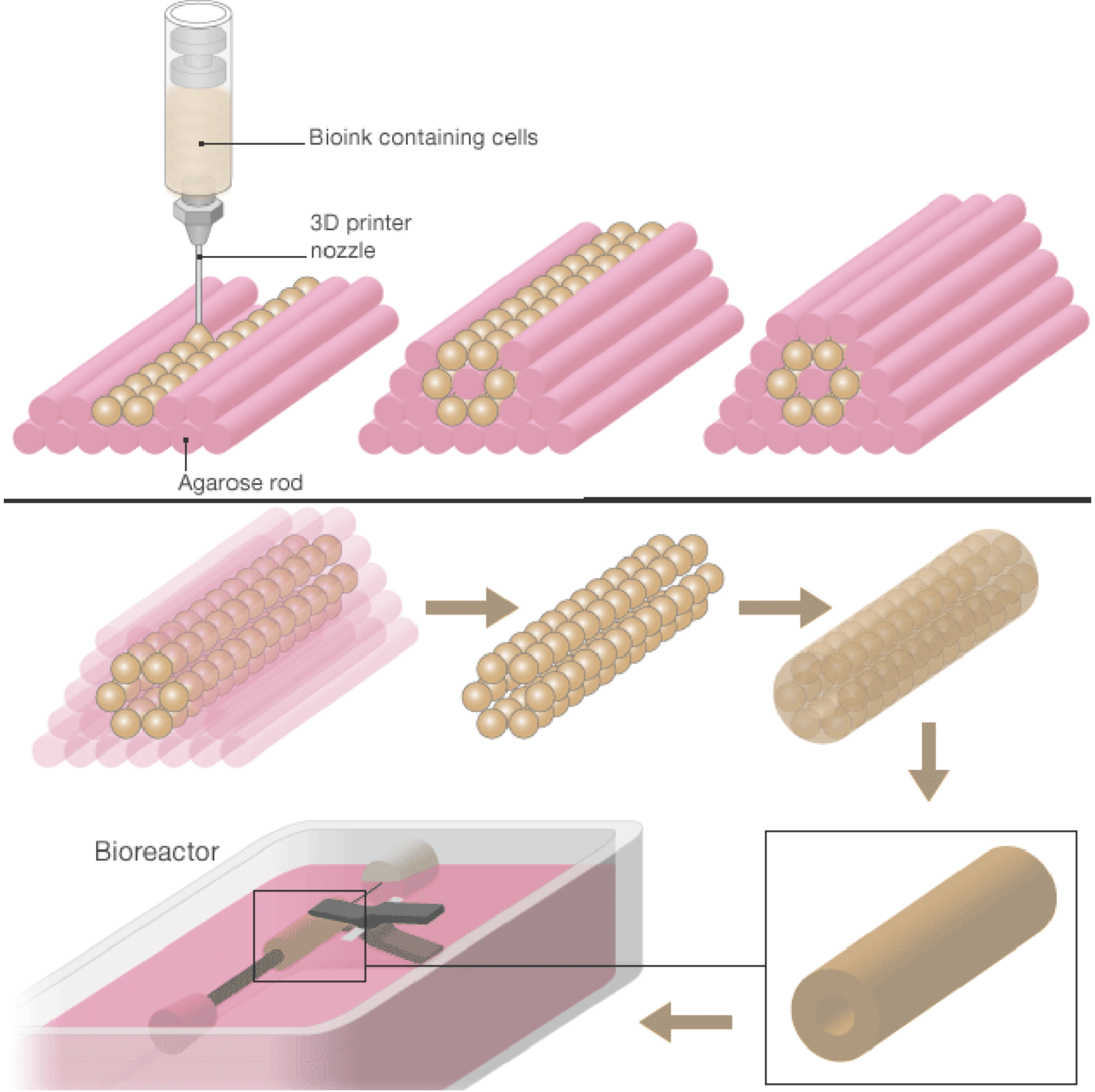
Other uses for bioprinting include transplants, surgical therapy, tissue engineering and reconstructive surgery.



Bioprinting techniques
bioink
bioink and pressurized air
droplet
Syringe barrel
bioink
Adapter connected to air supply
Extruded filament
BioFAB
mirror
laser
objective lens
quartz support
coating
droplet
Droplet-based bioprinting
Extrusion-based bioprinting
Laser-based bioprinting
Application areas in pharmaceutics
Drug screening
Drug delivery
ADME assays
High-throughput screening

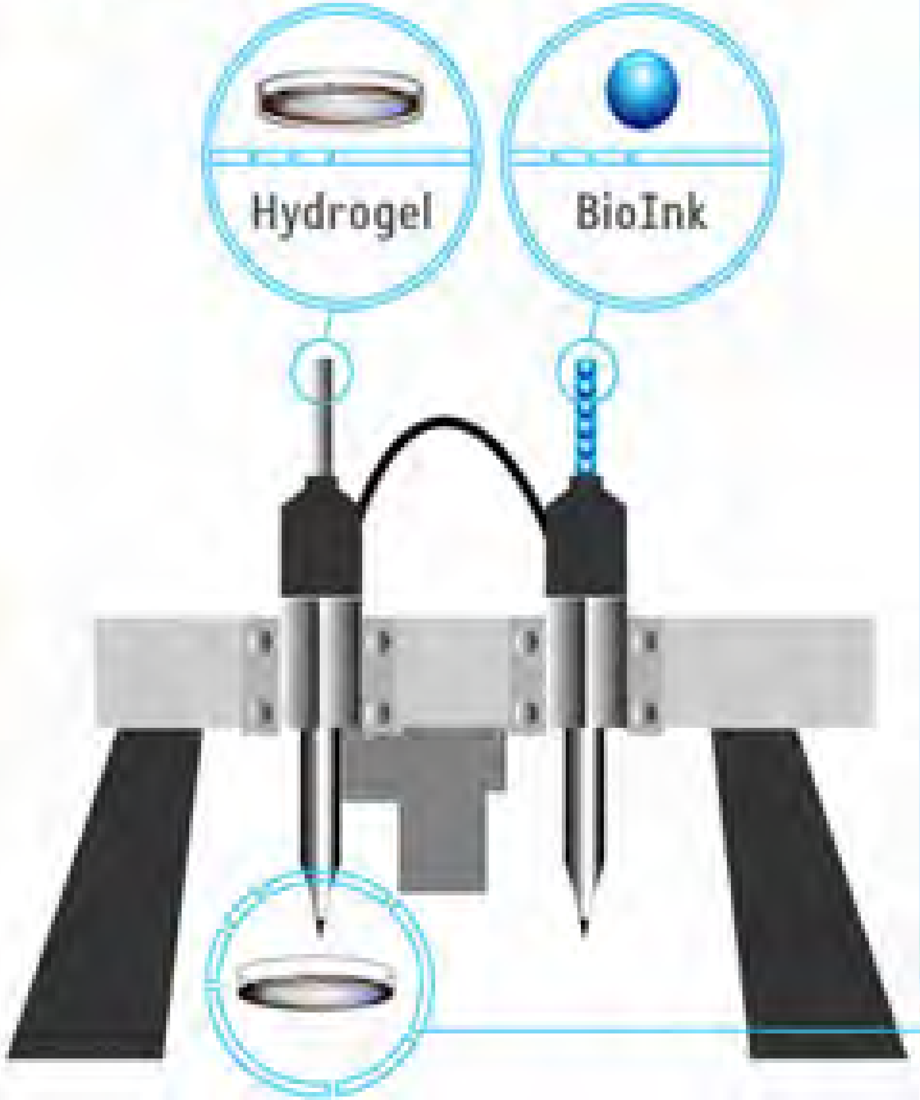


STEP1 (HOMOCELLULAR CELL AGGREGATES)
CELL AGGREGATE
SHEET
NETWORK
ROD
CUBE
RING
TUBE
BRANCHING ROD
STEP2 (HETEROCELLULAR CELL AGGREGATES)
THREE-DIMENSIONAL VASCULARISED TISSUE (MICROVASCULAR NETWORK)
BRANCHING LARGE TUBE
INTERMEDIATE DIAMETER BRANCHING TUBE
STEP3 ORGAN (3D VASCULARISED TISSUE)
3D ORGAN


Bioink containing cells
3D printer nozzle
Agarose rod
Bioreactor

Printing Process

NovoGen MMX bioprinter



NovoGen MMX bioprinter is used to:

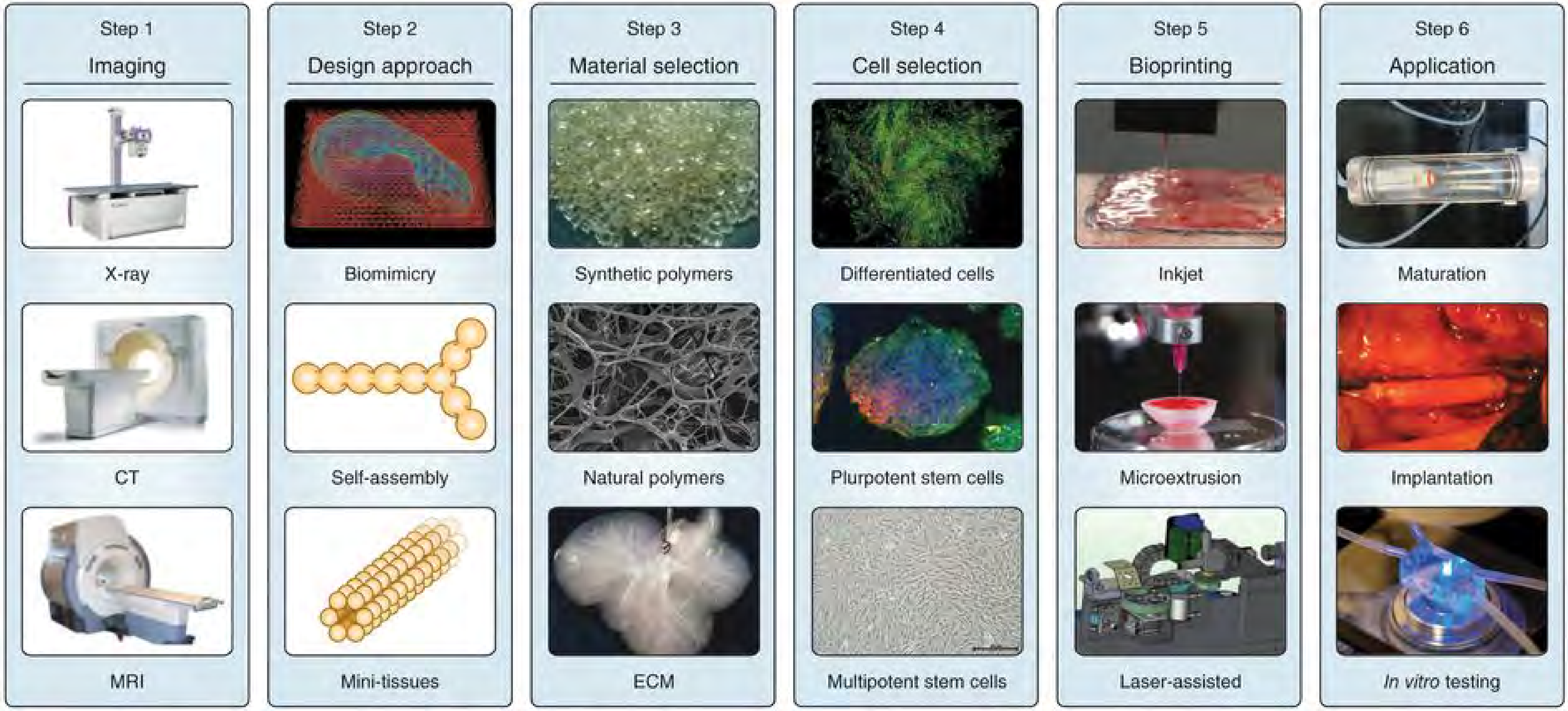
print a layer of hydrogel (an inert water based gel), which functions as a space holder for the printed tissue

deposit bioink spheroids into the layer of hydrogel

Hydrogel/spheroid print process is repeated

As layers are built upon, the spheroids naturally fuse together

BIOPRINTING: PROCESS FLOW



ECM stands for extra-cellular matrix

Artificial Arms for Disabled

Richard Van As, a South African carpenter, assembles a Robohand and fits it to Liam Dippenaar.

Liam was born without fingers on his right hand.

Makerbot provided them with the 3D printing technology that they used to print the parts for the Robohand.

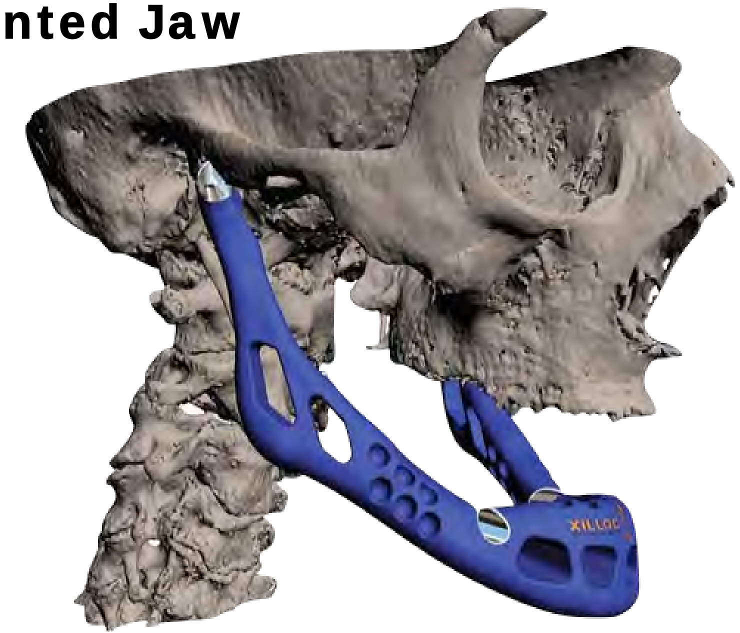
https://www.youtube.com/watch?v=S6bqKOUrk28
2 min

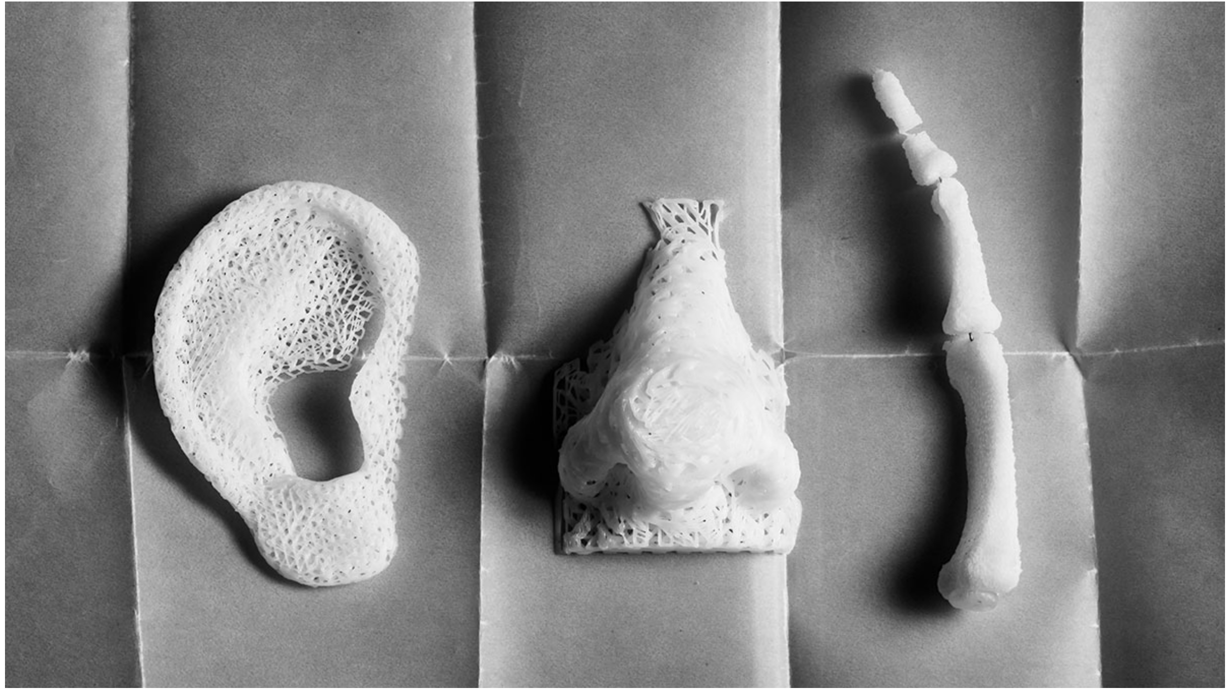
7 YEAR OLD GIRL GETS 3D PRINTED "ROBOHAND"

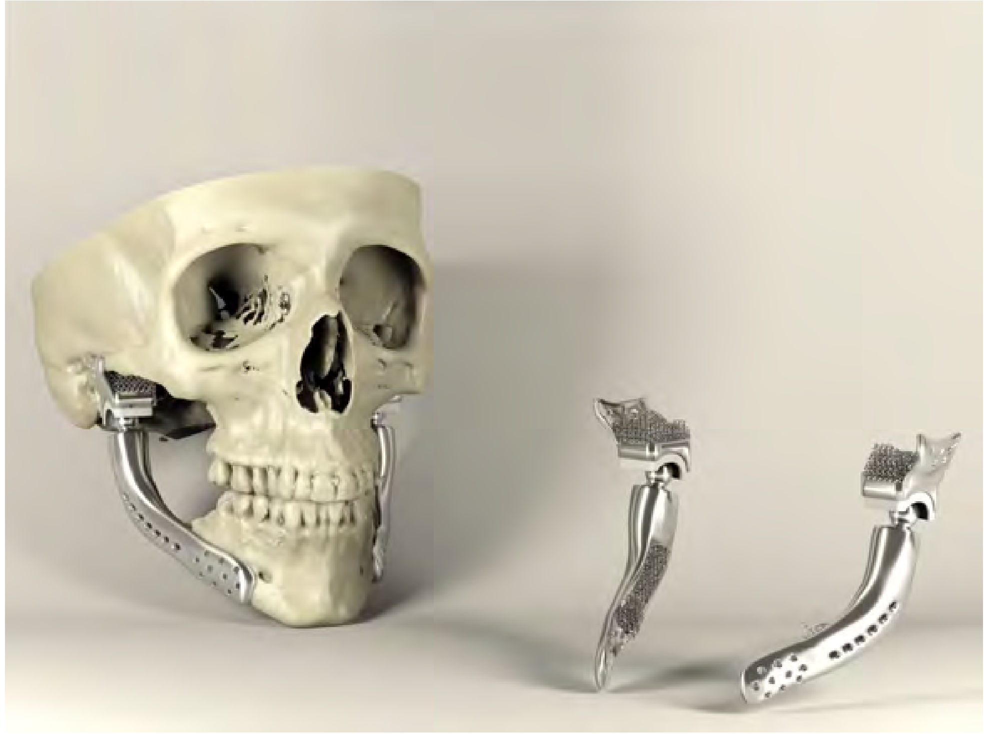
https://www.youtube.com/watch?v=uJJhEhk9ypU 1.3 min

Physicians can use 3D printing to make hearing aids, artificial teeth, and bone grafts.

3D printed Jaw







•**Medical 3D printing** is used to produce plastic casts, light and custom-made to perfectly fit the patient.

•In 2013, Jake Evill, a UK designer, produced the first 3D printed cast, called the **Cortex exoskeletal cast** and is based on the X-ray and 3D scan of a patient, used to generate a **3D model of a customized cast**.

•This cast provides a highly localized support system on the trauma zone.

The **3D printed cast** is also ventilated, very light, hygienic, and recyclable. It can even be used in the shower!

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STUDIO FATHOM PUTS A SOCIAL MEDIA SPIN ON THE 3D PRINTED CAST WITH THE #CAST

The #CAST is a 3D printed broken arm cast that can be uniquely customized for the individual user with messages aggregated from their friends and family on social media through a #CAST mobile app.

The # symbol when used before a person's name on Twitter and other Social Media, is called a Hashtag.

The cast is created with a basic 3D CAD program using a 3D scan taken of a broken arm by a doctor.

Once they reach the maximum number of characters the design is quickly generated and sent to be 3D printed using the Selective Laser Sintering (SLS) 3D printing process out of a medical grade, breathable nylon material.

THIS COMPANY LETS YOU HOLD AND TOUCH YOUR UNBORN BABY

A Russian company, Embryo 3D, has developed a way to 3D print your unborn child.

They use pre-natal ultrasound images taken by medical professionals to produce high-quality 3D prints made from plastic and heavy-duty plaster.

https://www.youtube.com/watch?time_continue=165&v=5tob6B4DWBo&feature=emb_logo

Go to 1:51

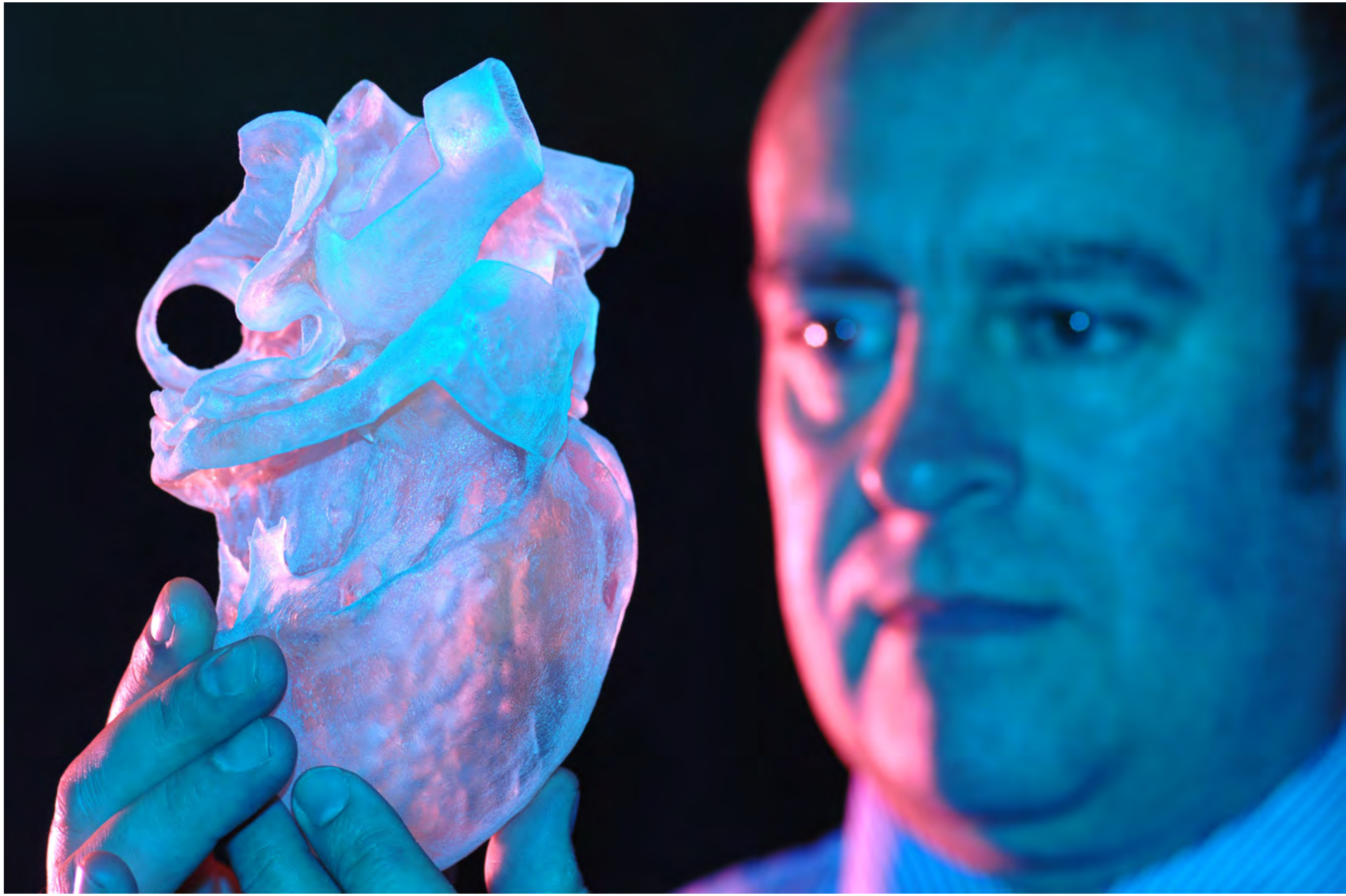
Figure 3 The NIH 3D print exchange is a free online resource for sharing medical and scientific 3D print files and tutorials.[12]

The NIH (National Institute of Health) has a NIH Print Exchange website with existing files for making 3D medical models and is a site where new ones can be sent to share with others. The website is https://3dprint.nih.gov/

Examples at the site are 3D models you can download and has collections on 3D designs for 1) Prosthetics, 2) Neuroscience, 3) A Heart library, and 4) Molecule of the month.

Medical researchers at the University of Sydney and the Harvard Medical Institute have come up with a **heart patch that seeks to literally repair damaged hearts with 3D printed cells.**

After successfully testing the product on rats, they are attempting to develop artificial cardiac tissues that mimic the biological and mechanical properties of an actual human heart.



3D PRINTING OF MEDICATIONS

To make tablets, the printing process mode of action is similar to desktop inkjet printers and is called **drop on solid deposition – DOS** or powder bed jetting.

Droplets of ink sprayed from a print head, bind the layer of free powder bed while unbound powder particles act as a support material preventing from collapsing of overhang or porous structures.

After each step the formed object is lowered and a layer of free powder is applied by roller or powder jetting system and the process is continued until the part is done.

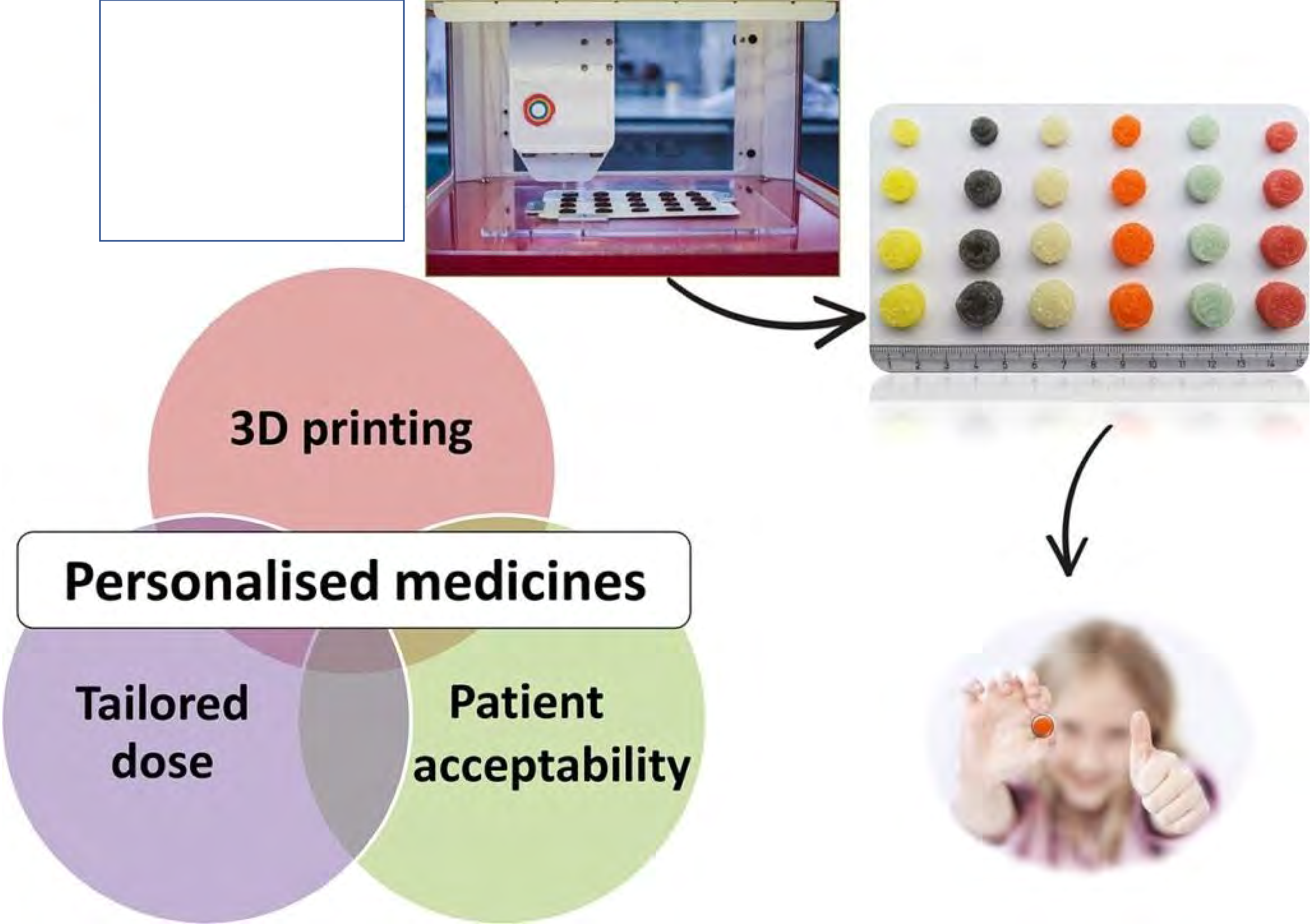
https://www.youtube.com/watch?v=krukI6Pn9lk&feature=emb_logo 1.5 min

FabRx Ltd., in collaboration with University College London (UCL) School of Pharmacy, is evaluating 3D printing to produce Printlets™ (3D printed tablets).

Their aim is to make healthcare personal by producing personalized medicines using 3D printing, tailoring the dose, shape and size for each individual patient.

The US Food and Drug Administration has approved the first 3D printed pharmaceutical drug which is carefully printed to more effectively treat epileptic seizures.
https://www.youtube.com/watch?v=RFgthQ_RcvU 2.2 min

How SLS is used to 3D print personalized Medicine – FabRx Customer Story
https://www.youtube.com/watch?v=ePVFasXDi68 4.3 min


3D printing
Personalised medicines
Tailored dose
Patient acceptability

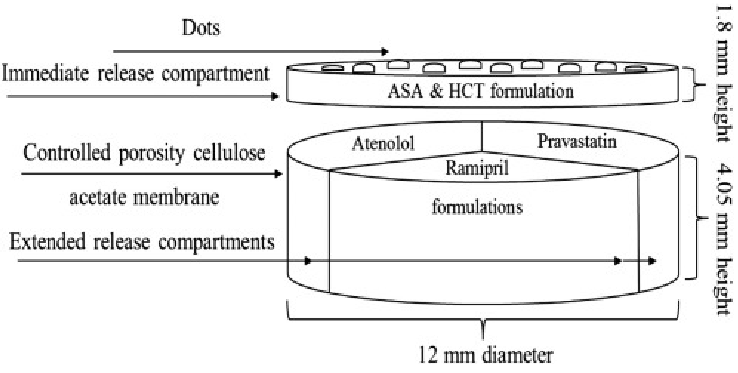
THE POLYPILL WITH 5 DRUGS IN IT

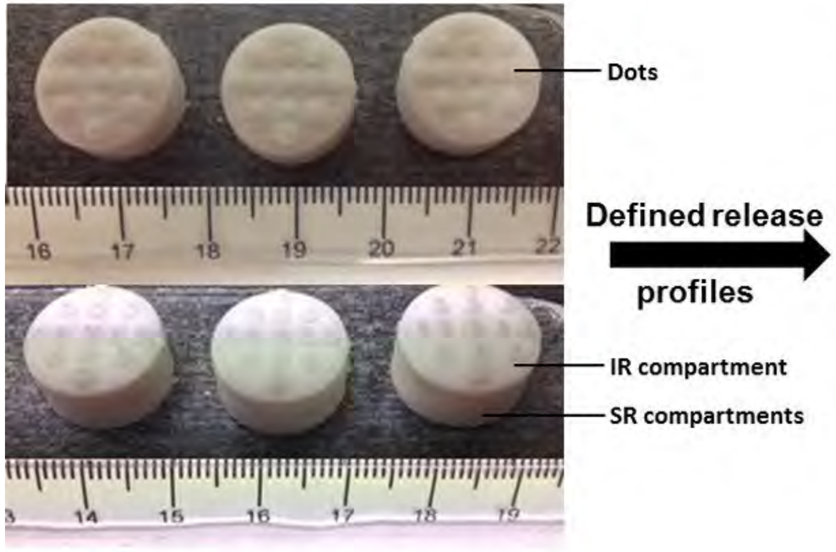
A company has used three-dimensional (3D) extrusion printing to manufacture a multi-active solid dosage form, called polypill.

This contains five compartmentalized drugs with two independently controlled and well-defined release profiles.

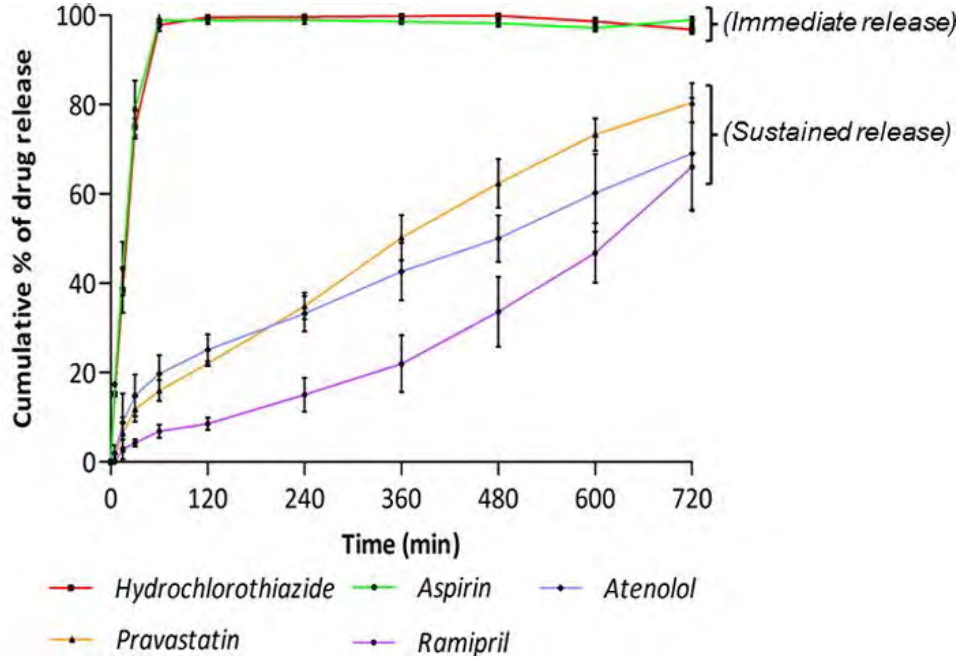
The polypill here represents a cardiovascular treatment regime with the incorporation of an immediate release compartment with aspirin and hydrochlorothiazide and three sustained release compartments containing pravastatin, atenolol, and ramipril.

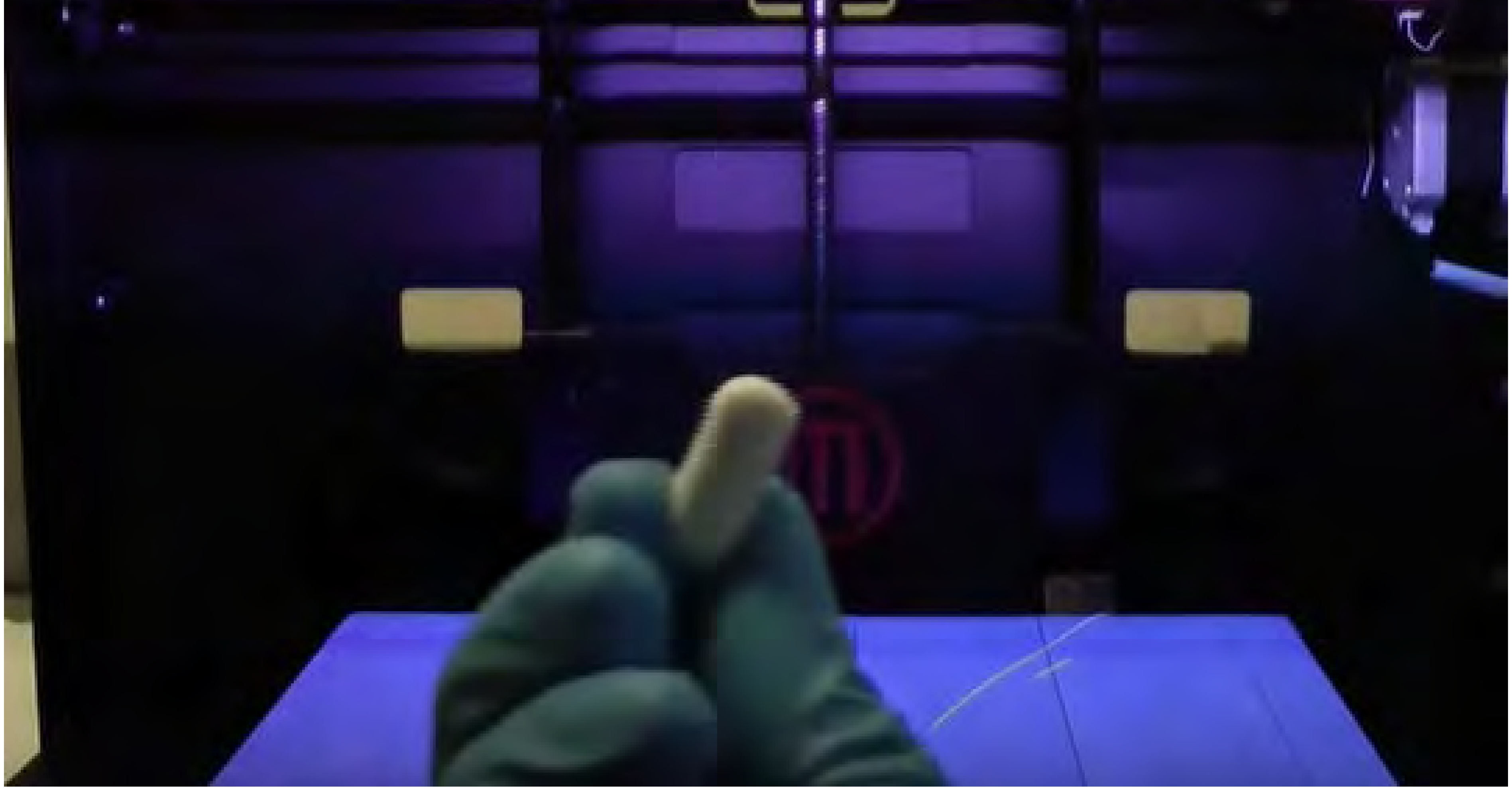
Another Polypill containing three different medications has already been created to treat patients with hypertension and diabetes.





Multi-active tablet (Polypill)





3D printing of a Theophylline tablet which is used to treat lung diseases such as asthma and COPD (bronchitis, emphysema).

It must be **used** regularly to prevent wheezing and shortness of breath. This medication belongs to a class of drugs known as xanthines.

https://www.youtube.com/watch?v=FGpbiJxkkak 2 min

3D printers help researchers test new drugs' impact on organs more efficiently

https://www.youtube.com/watch?v=pJqdCS3Zbbs 2.3 min

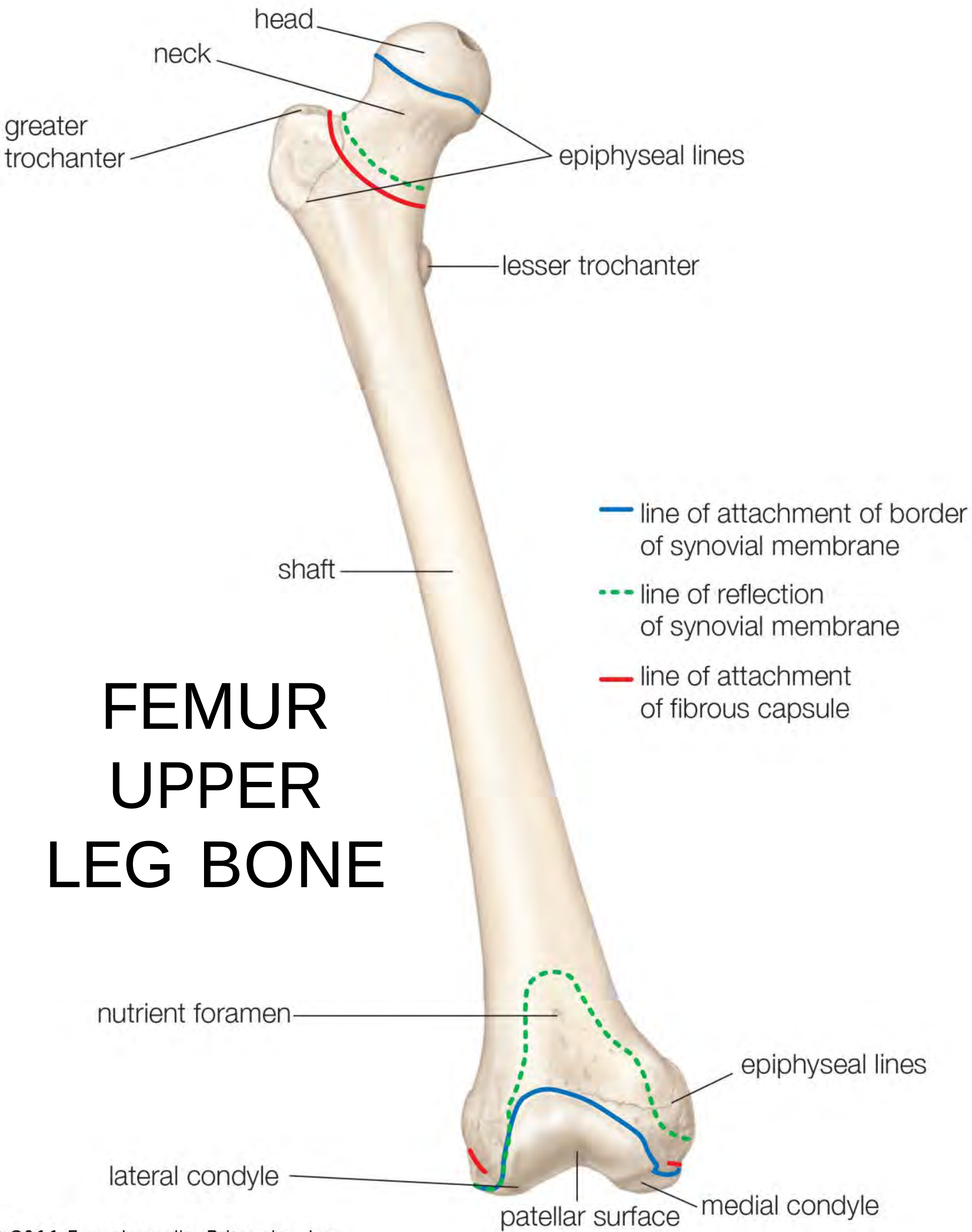
3D-printed scaffold enables controlled release of biomolecules into the body

Tissue development is guided by gradients of biomolecules that direct the growth, migration, and differentiation of cells.

Biomedical engineers are interested in recreating these developmental gradients in adults to aid the growth of new tissue in areas that have sustained damage.

Now, researchers are one step closer to this goal thanks to the creation of new 3D-printed scaffolds that enable researchers to release biomolecules into the body with exceptional control.

https://www.youtube.com/watch?v=gXaagHdaVhE 2 min



FEMUR UPPER LEG BONE

TIBIA LOWER LEG BONE

MODERN AESTHETIC DESIGNS FOR PROSTHESES
(MANY CAN BE 3D PRINTED)

UNYQ 3D PRINTED PROSTHETIC COVERS

UNYQ is an industry-leading company with global reach, currently producing medical wears.

They create, innovative, mass customized products, re-imagining orthopedic devices using **3D printing** to create products that heal or reflect who a person is.

Their products are both aesthetically beautiful yet practical and functional.

Their product line is a range of Prosthetic Wears for upper and lower limb amputees.

http://unyq.com/en-us/prosthetic-covers/about/

Jonathan Butcher, at Cornell University has printed a heart valve that will soon be tested in sheep.

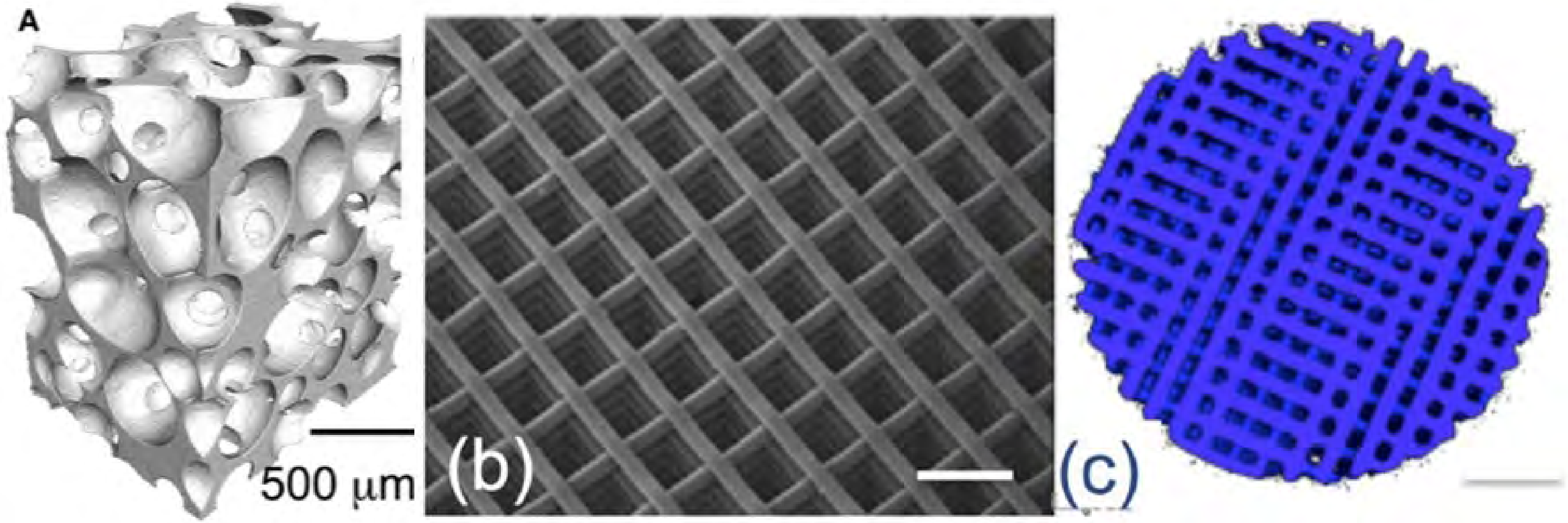
With a dual-syringe machine, he was able to print a combination of alginate, smooth muscle cells, and valve interstitial cells, to control the valve’s stiffness.

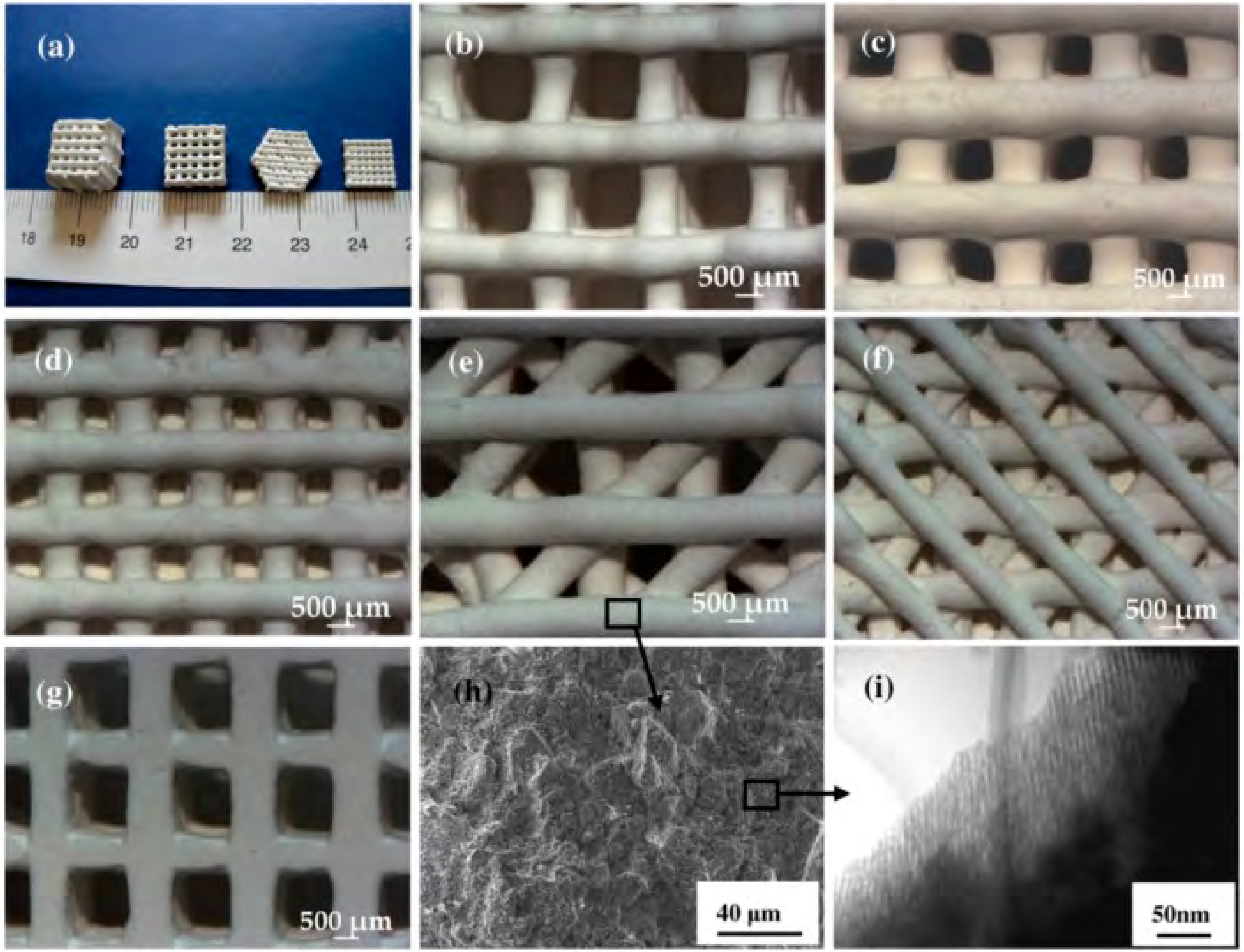
3D PRINTING OF CERAMIC CUSTOM SCAFFOLDS AND BIO-ACTIVE GLASS FOR MEDICAL USES

Researchers are now combining advanced materials like bioactive glasses and 3D printing techniques to create custom scaffolds and implants, the form of foams that dissolve in the body and are replaced with new tissues.

Surgeons often require scaffolds for bone grafts that have precise pore architectures and can be load bearing.

3D printing can produce bioactive glass structures with finely controlled pore structures and increased mechanical strength.





The representation of 3D printed bioactive glass (MBG) scaffolds and their pore shapes and microstructure.

3D cell printing with the use of biomaterials and polymerization techniques, precise copies of human tissues can now be done.

A 3D printing Biopen device called Biosphere has recently been developed by researchers in Australia.

The technology is essentially a device filled with stem cell ‘ink’ that allows surgeons to repair damaged bone and cartilage by drawing new cells directly into any damaged areas of bone during surgery.

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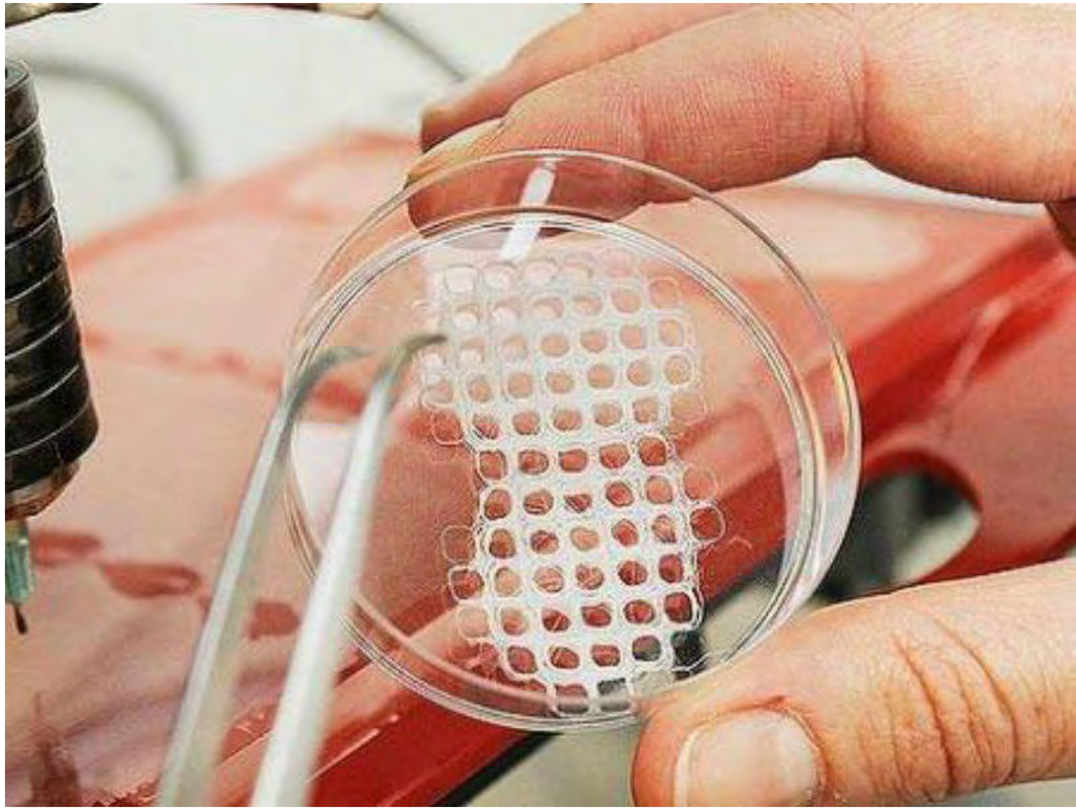
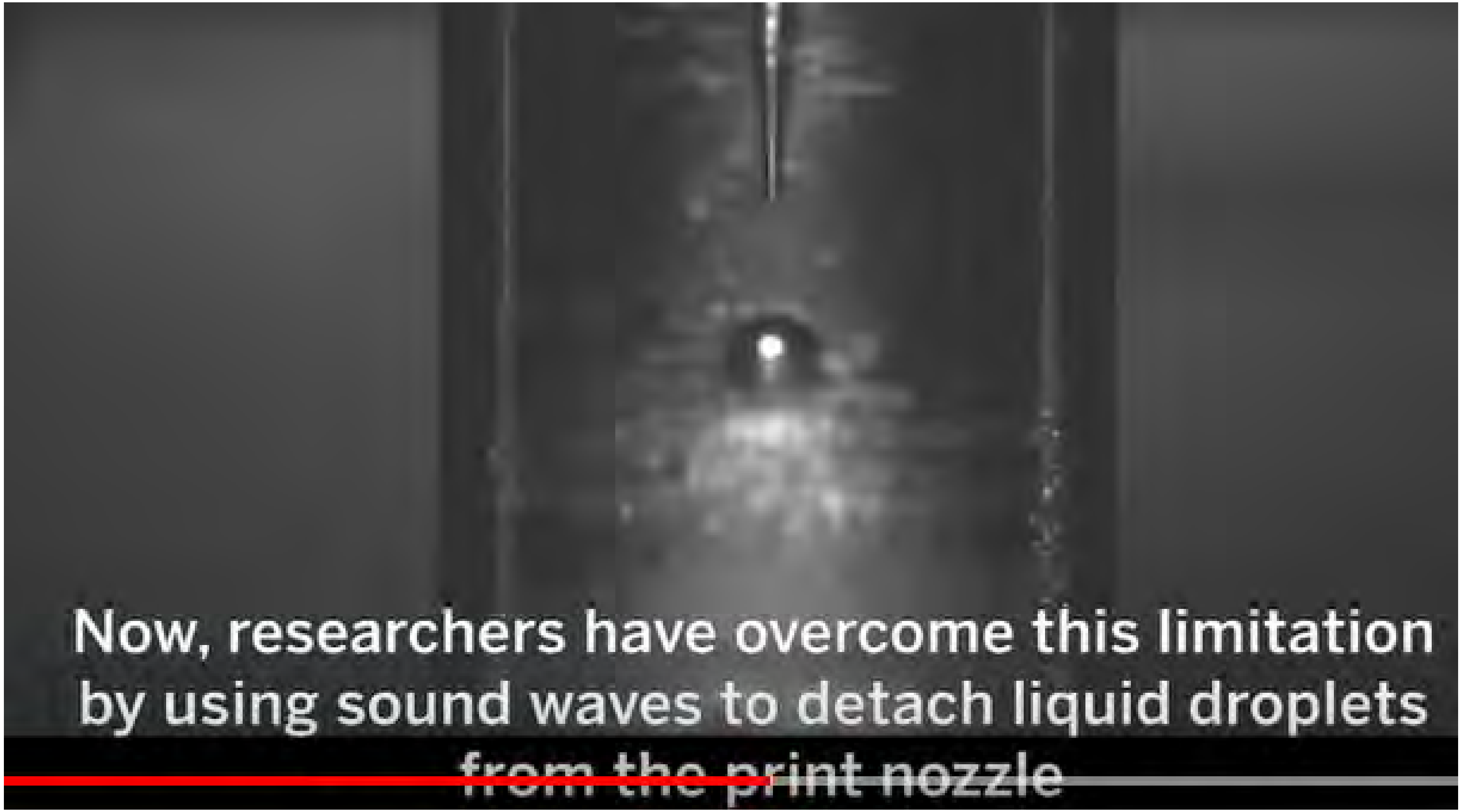


Image Credit: Open Biomedical Initiative

The Ultimate List of What We Can 3D Print in Healthcare

https://www.youtube.com/watch?v=9XYLRaVqzNY 3 min



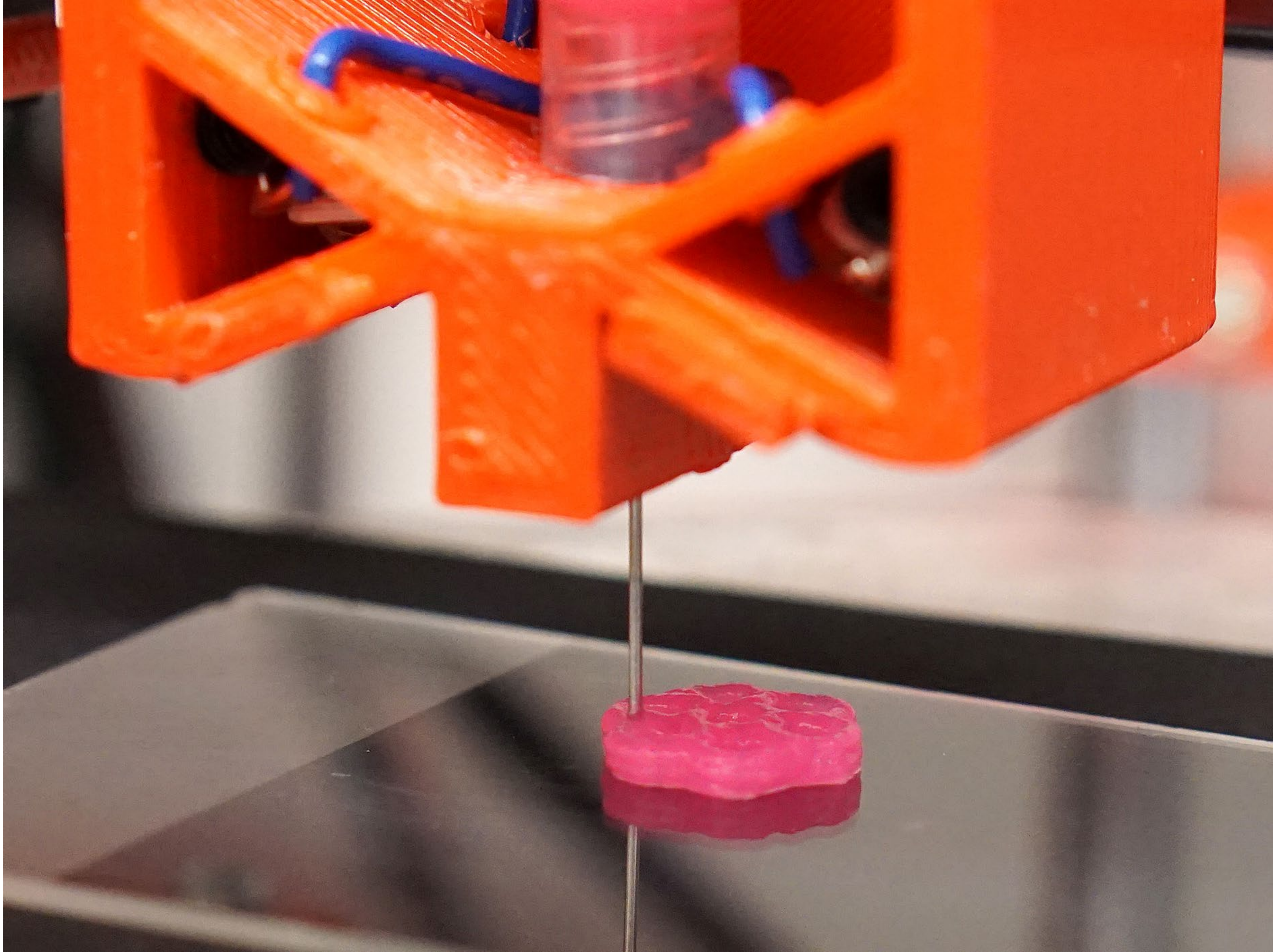
Printing with sound, new Harvard tech opens door to 3D printing cosmetics, food, and drugs

https://www.youtube.com/watch?v=8pJ8FOKwZ-s 1.7 min

LIVING INK

A 3D printer can be modified to print living cells encapsulated in a photosensitive hydrogel ink [pink].

Photo: Jun Li and Feng Cheng/Zhang Lab



3D PRINTED BLADDERS

After more than 16 years, a 3D bioprinted bladder, created by Dr. Anthony Atala at Boston Children's Hospital, is still sustaining the life of a patient.

The 3D bioprinted organ was made to replace patient Luke Massella's defective bladder in 2004.

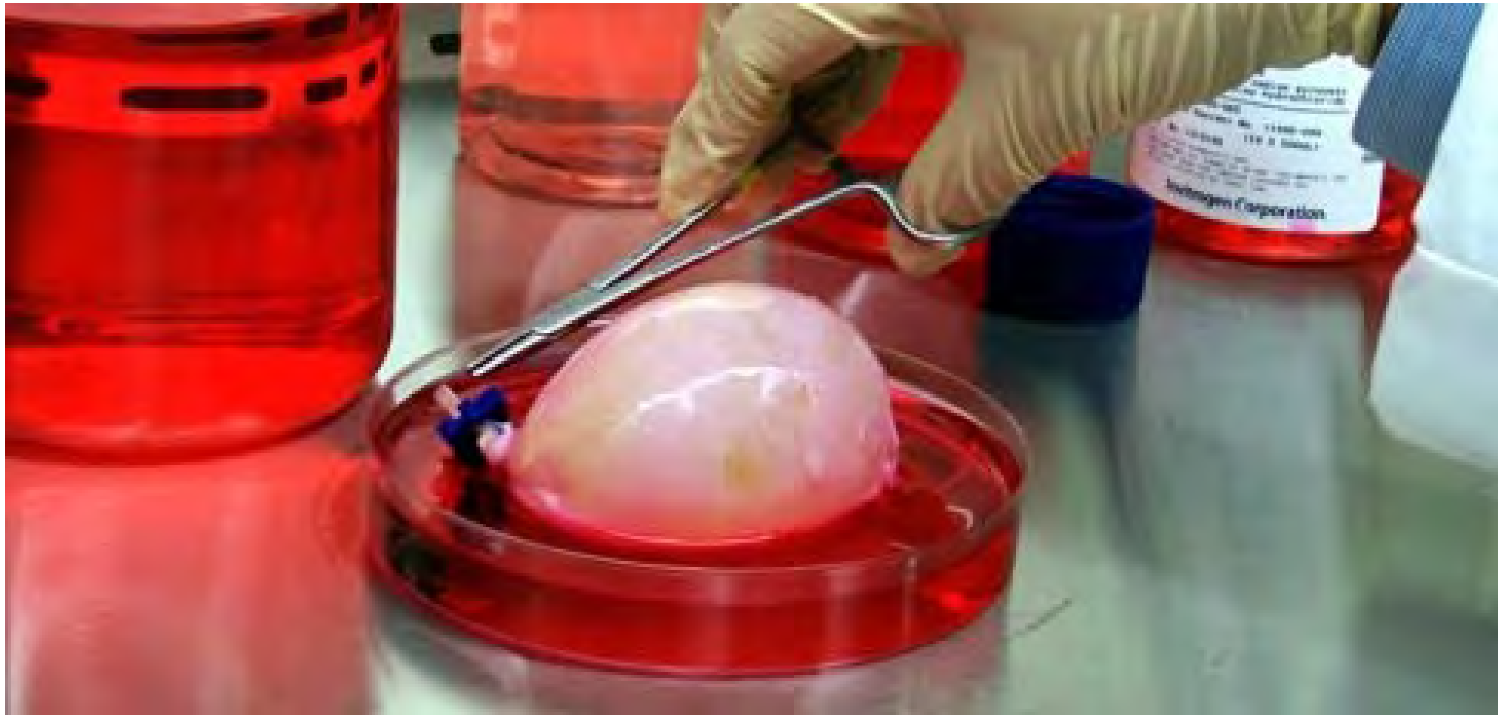
Since then, Massella has not required any further surgery.

The bladder was made using a sample of Massella's bladder tissue, and modified inkjet printer, used to build a scaffold/host for the cells.

Incubated in lab conditions, the new bladder was grown in 2 months, and then successfully transplanted into the patient.

Massella is 1 of 10 people with a bioprinted bladder grown from their own cells.

According to Dr. Atala, flat structures like skin are easiest to print, whereas tubular structures like blood vessels and hollow non-tubular organs like bladders are more complex.

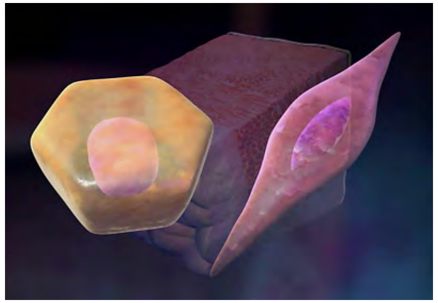


A researcher dips a bladder-shaped mold, seeded with human bladder cells, into a growth solution. (Brian Walker / AP)

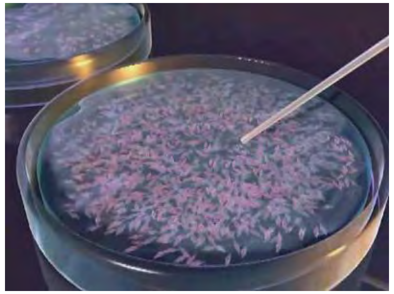
https://www.youtube.com/watch?v=bX3C201O4MA start at 12:28

NEO-BLADDER – A COMMERCIAL SYNTHETIC BLADDER

A surgeon takes a small, full-thickness biopsy from the patient's bladder.



urothelial and smooth muscle cells that are capable of regeneration are isolated.

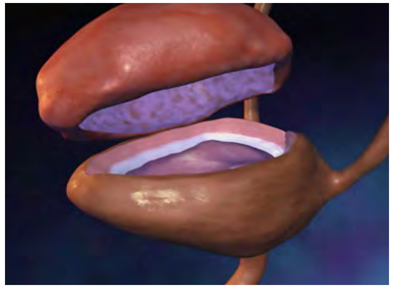


The isolated cells are cultured separately until there are a sufficient quantity.

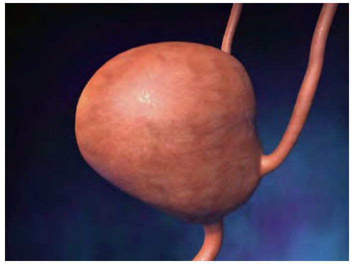
The cultured cells are properly seeded onto a biodegradable scaffold shaped like a bladder.

The cells attach and grow properly throughout the scaffold.

After about 8 weeks, the neo-bladder construction is returned to the surgeon for implantation



The neo-bladder construct is implanted by the surgeon using standard surgical techniques.



The body uses the neo-bladder construct, regenerate and integrate new tissue, restoring the bladder's functionality.

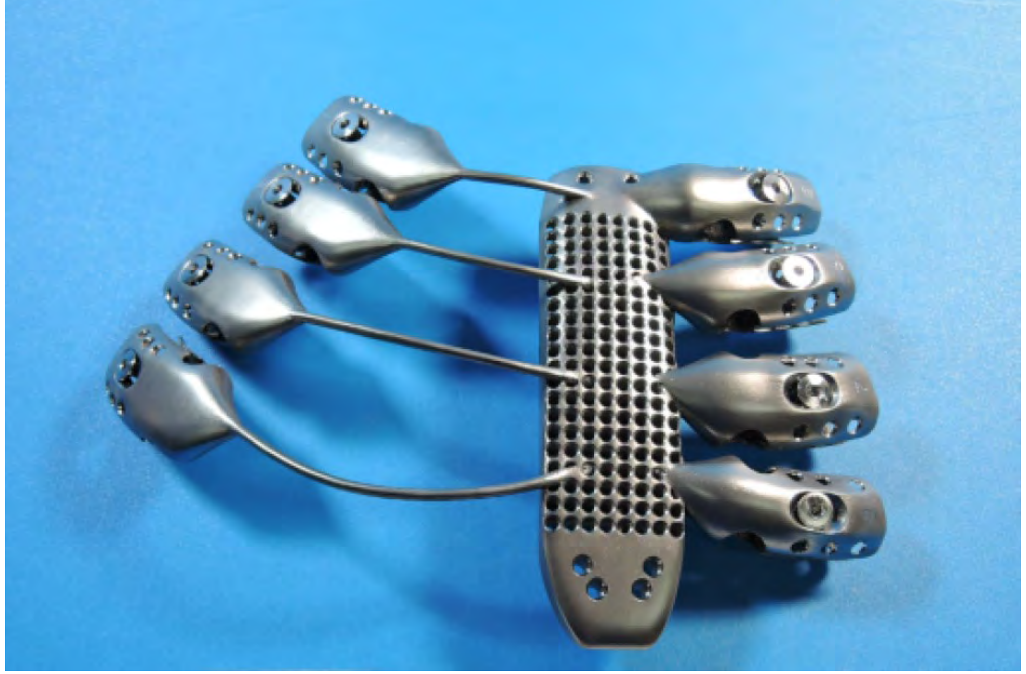
The biodegradable scaffold dissolves and is eliminated from the body, leaving a functioning bladder made only of the patient's own newly regenerated tissue.

WORLD-FIRST OPERATION IMPLANTS 3D-PRINTED TITANIUM RIBCAGE AND STERNUM

A Spanish cancer patient is the first person in the world to receive a titanium 3D-printed sternum and rib cage, designed and manufactured by an Australian company.

Anatomics, the company who made the implant, used an electrum beam metal printer to create the part.

The implant has a titanium plate that is over the sternum and the mimicked parts of the ribs are screwed into the bones of the rib cage, securing the implant with the bone.



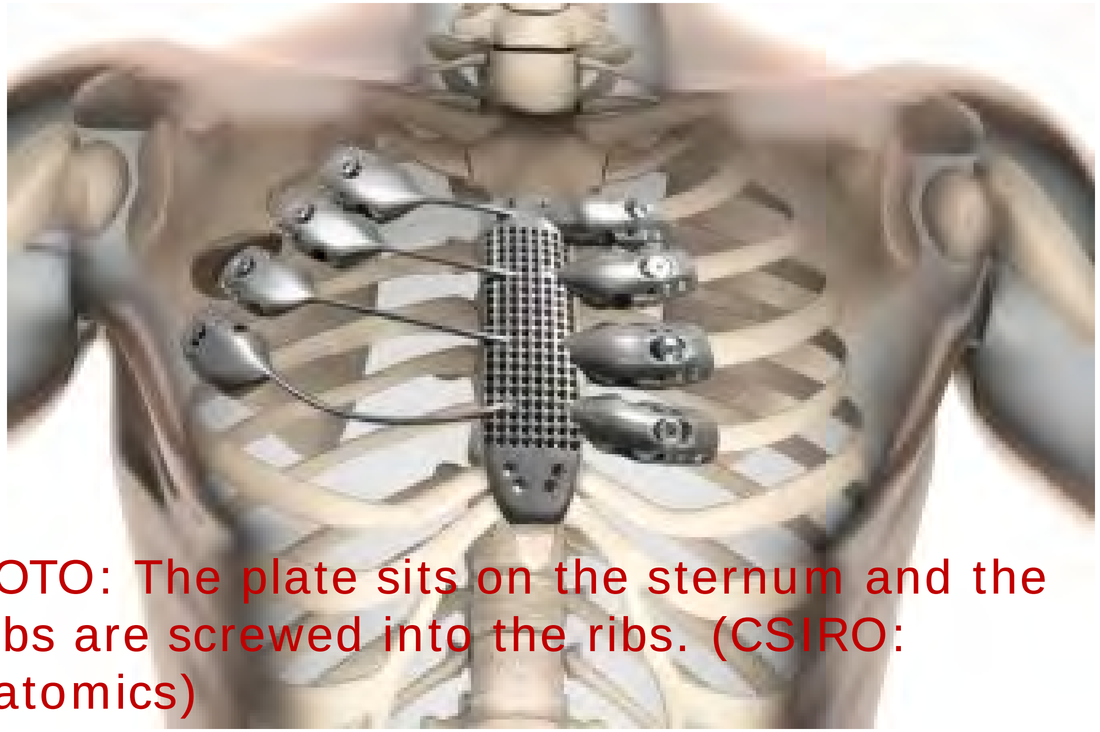


PHOTO: The plate sits on the sternum and the limbs are screwed into the ribs. (CSIRO: Anatomics)

As a new process, 3D printed parts can be fiber-reinforced to make them stronger and the placement of the fibers and types can be changed, depending on what the part needs for strength.

These are the 4 types of fiber reinforcement used by the Markforged Co.

COMPOSITES DESIGN GUIDE

Markforged

Diving Deep into Fiber Reinforcement

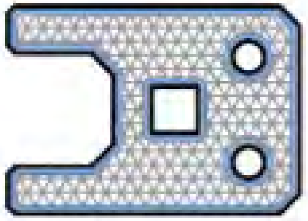
Types of fiber

	Carbon Fiber	Fiberglass	HSHT Fiberglass	Kevlar®
Properties	High strength-to-weight ratio, stiff	Sturdy, cost-effective	Sturdy, high heat deflection	Tough, impact-resistant
Ideal loading type	Constant loading	Intermittent loading	Constant loading at high temperatures	Impact loading
Failure behavior	Stiff until fracture	Bends until fracture	High energy absorption until fracture	Bends until deformation
Characteristics and advantages	Metal stiffness and strength, lightweight	Economical starting point, general-use fiber	Keeps strength at high temperatures	High deflection and impact resistance

Types of fiber fill

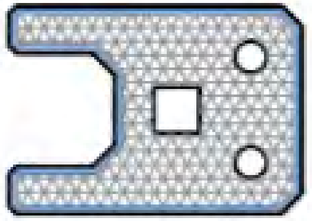
Concentric Fill

Concentric Fill lays fiber around the perimeter of a wall. This fill type mainly helps resist bending about the Z axis and strengthens the walls against deformation. You can specify how many fiber shells you want by changing the number of **CONCENTRIC FIBER RINGS**. You can edit the start point of the fiber by changing the **START ROTATION PERCENT** setting when viewing a 2D layer slice or group in **INTERNAL VIEW.**



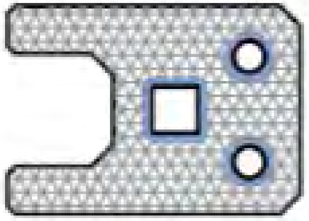
All walls

This type lays down fiber to reinforce both the outer shell and the inner holes, providing the reinforcement properties of both.



Outer shell only

This type only reinforces the outer walls of a part. This can be used to reinforce the part for bending or impact loads applied to the sides of the part.

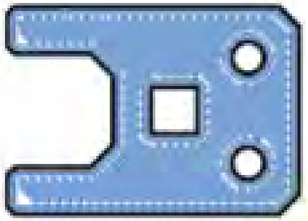


Inner holes only

This type only reinforces the inside walls of a part. This can be used to strengthen bolt holes or cavities to improve load distribution when compressive or out-of axis torsional forces are applied to inner holes.

Isotropic fill

Isotropic fill is routes fiber back and forth in a zig-zag pattern to simulate the individual unidirectional layers of a traditional laminated composite. By default, subsequent Isotropic Fiber layers rotate the fibers by 45° to achieve unidirectional strength within a fiber group, but the **FIBER ANGLE** can be changed if needed. Layers of Isotropic Fill Fiber resist bending in the XY plane. In addition to the isotropic fill pattern, this option by default traces concentric rings around all walls to improve wall strength.



TODDLER GETS SYNTHETIC WINDPIPE

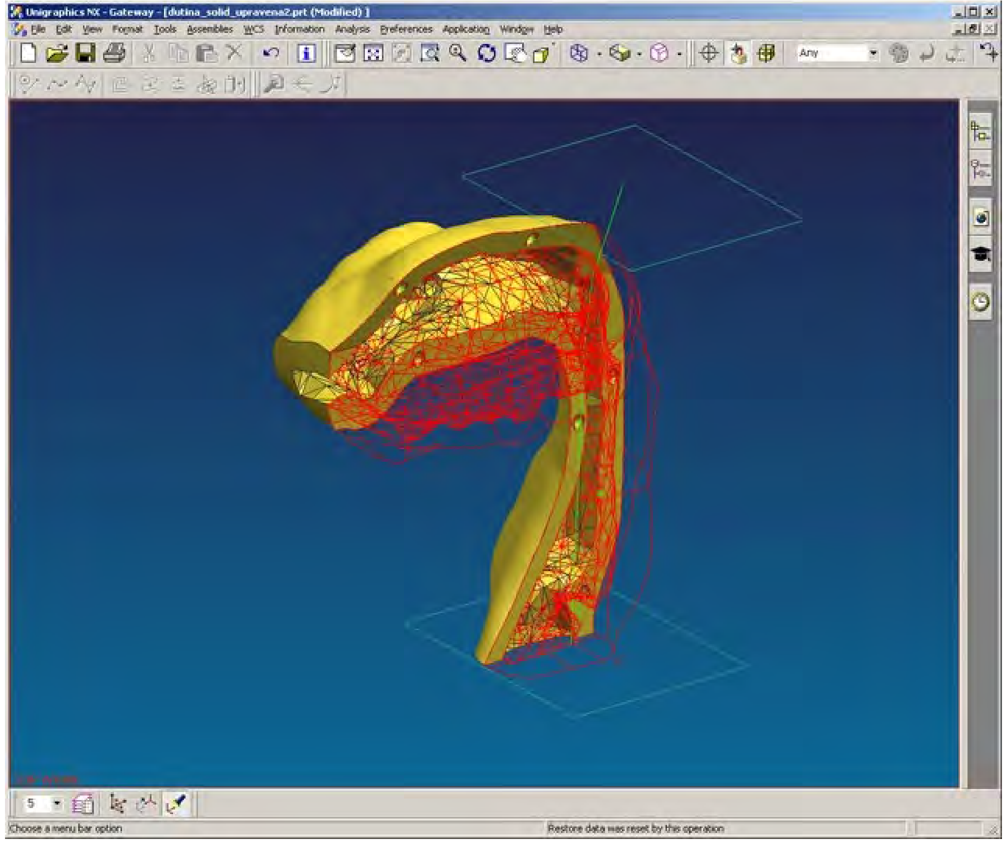
Doctors culture a custom-made trachea from plastic fibers and human cells, and successfully implant it into a child who was born without the organ.

HANNAH WARREN AND HER PARENTS

Hannah Warren, a 2.5-year-old girl born without a windpipe, has received a bioengineered replacement made with her own stem cells

The scaffold and bioreactor in which the synthetic trachea was cultured with stem cells taken from bone marrow was custom-made for the patient.

Although she will need a new wind pipe every few years as she grows, the researchers behind the procedure have tried to limit such replacements by including biodegradable plastic fibers to allow the trachea to stretch.

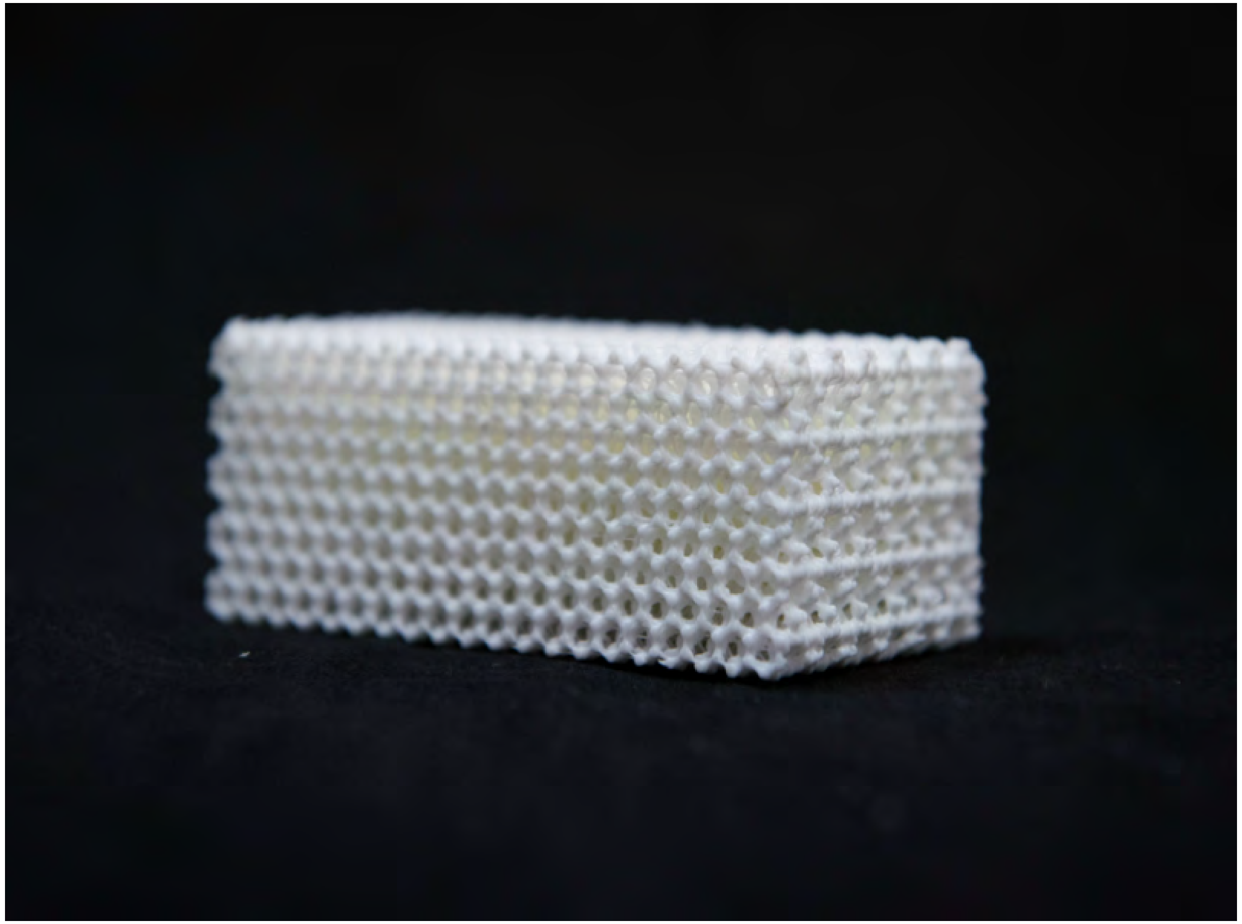


CAD model of the experimental set-up component for experimental analyses of the acoustic field inside a human vocal tract.

The computer model of the acoustic cavity was created by 3D reconstruction of magnetic resonance (MR) images, and other construction features have been added.

Rapid Prototyping (RP) model of the human vocal tract produced for experimental purposes

3D-PRINTED BONE IMPLANT MADE WITH A SHAPE MEMORY PLASTIC THAT DISSOLVES IN THE BODY



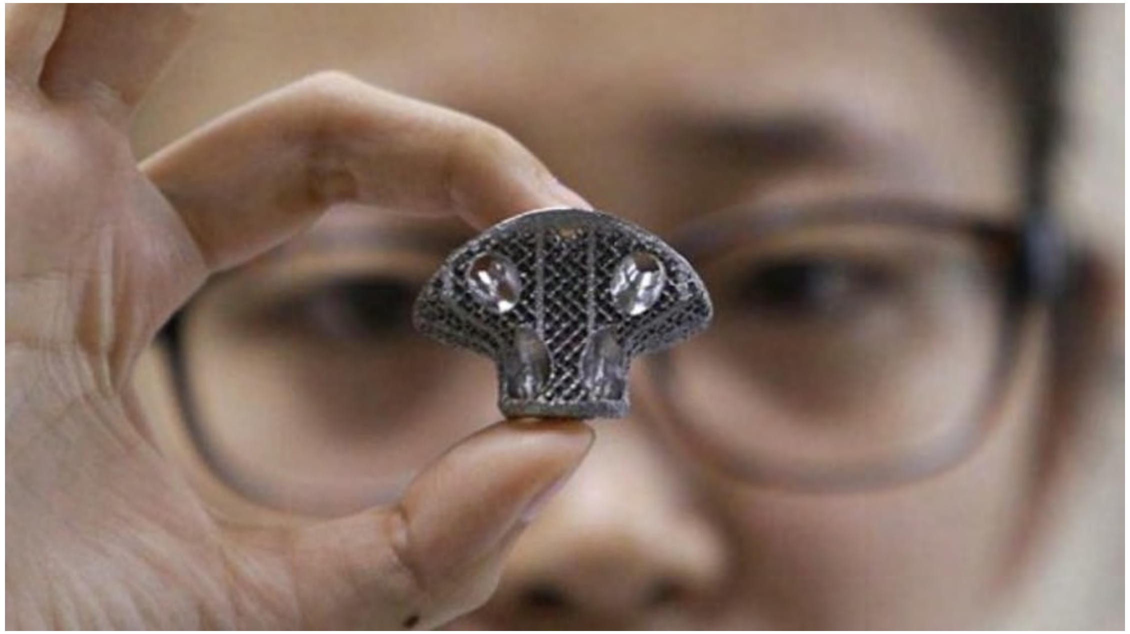
Scientists have developed a new type of 3D-printed polymeric bone implant with increased survival rate in the body, as well as the ability to organically degrade and thus subsequently be replaced by natural bone tissues.

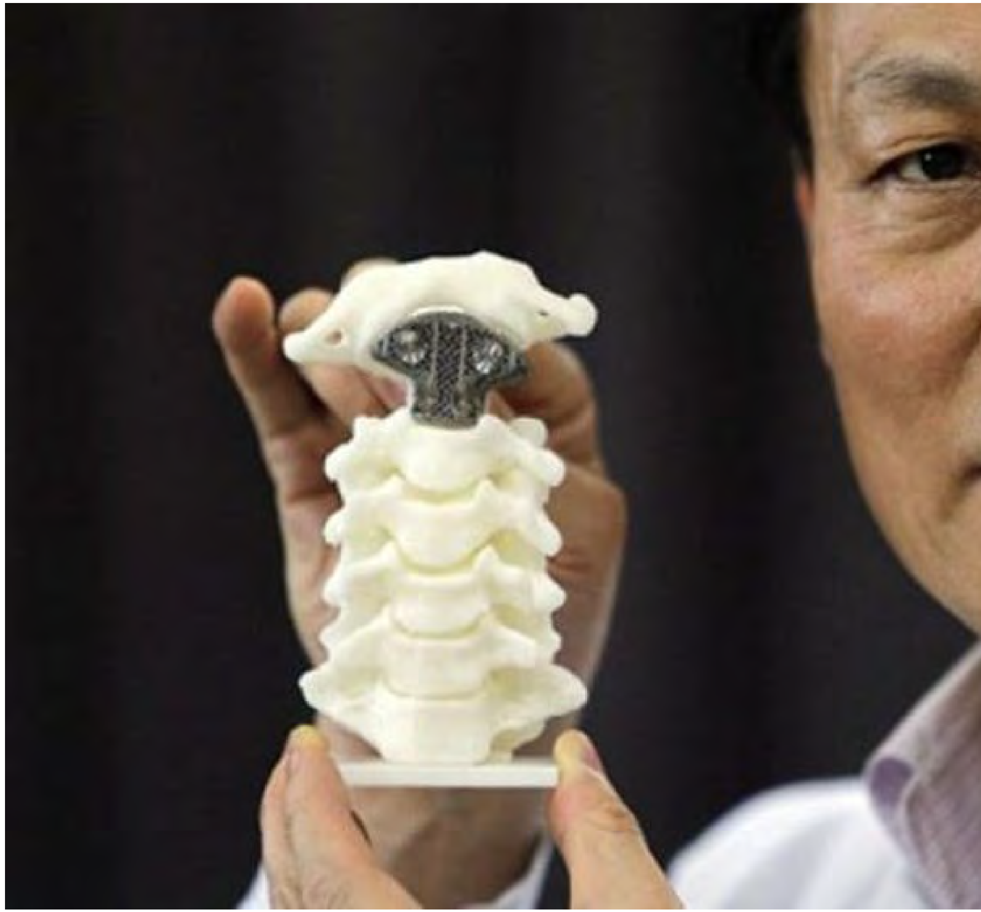
It was made with a shape memory polymer and was compressed twice in a protective, biodegradable covering, heated during the surgery and eventually become securely fixed into the renovated area of bone tissue.

3D PRINTER MAKES NEW BONE FOR 12-YEAR-OLD BOY

In China, doctors operating on the boy removed a tumor and then discovered they would need to replace the boy’s second vertebrae, so they turned to a 3D printer to create a replica which they made out of **Titanium**.

It was designed with small pores and holes to allow the boy’s body to grow into it naturally.



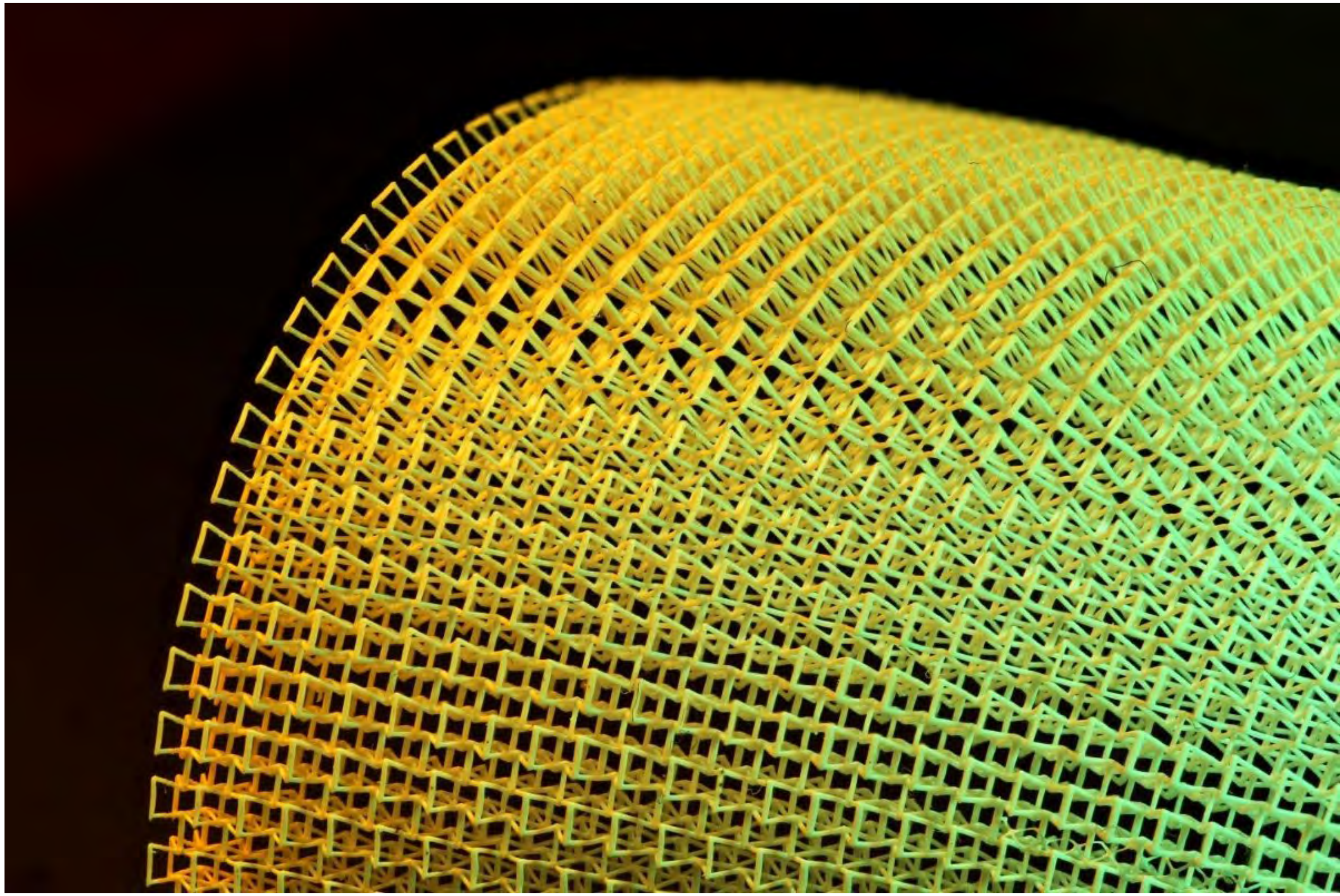


3D PRINTED PIEZOELECTRIC MATERIALS LINE UP FOR MEDICAL APPLICATIONS

If you’ve ever owned a quartz watch, received an ultrasound exam in a doctor’s office, used a candle or grill lighter and heard “the click”, you have used Piezoelectric materials.

Researchers have developed a method for 3D printing piezoelectric materials.

These new, 3D printed piezoelectric materials are tunable - the new method allows users to create and program voltages in the material, to be magnified, reversed or suppressed in any direction.



The printed flexible sheet of piezoelectric material. (Courtesy: Virginia Tech)

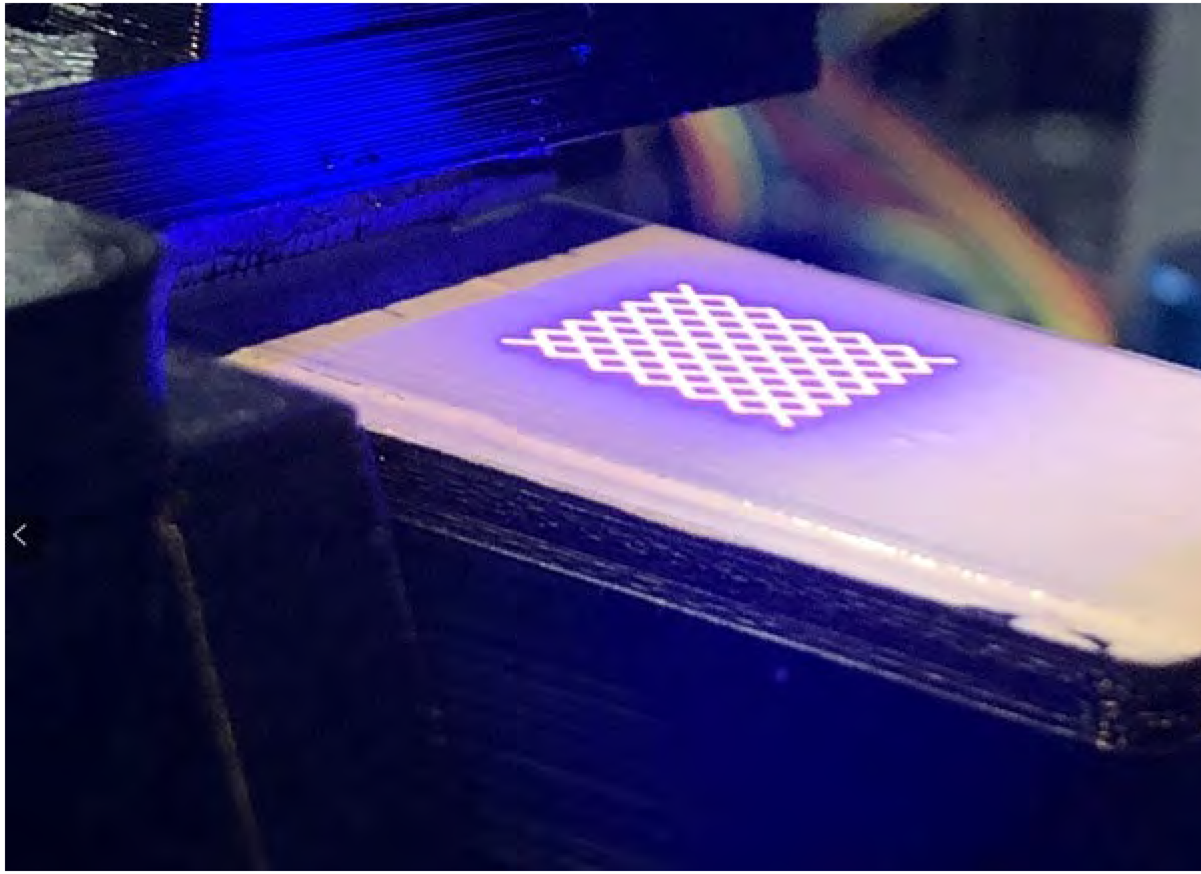
The tunability of 3D printed piezoelectric materials allows them to be used in intelligent materials and devices, particularly in medicine.

- ❖ Adaptable stents in blood vessels will regulate and sense blood pressure changes.

- ❖ Self-sensing synthetic skin will record and detect pressure, pulse, joint movement, voice, breathing rate and motion.

- ❖ Wearables will sense dynamic pressure changes in the hands and feet

- ❖ Ultrasound transducers will help medical personnel visualize tissues in different ways.

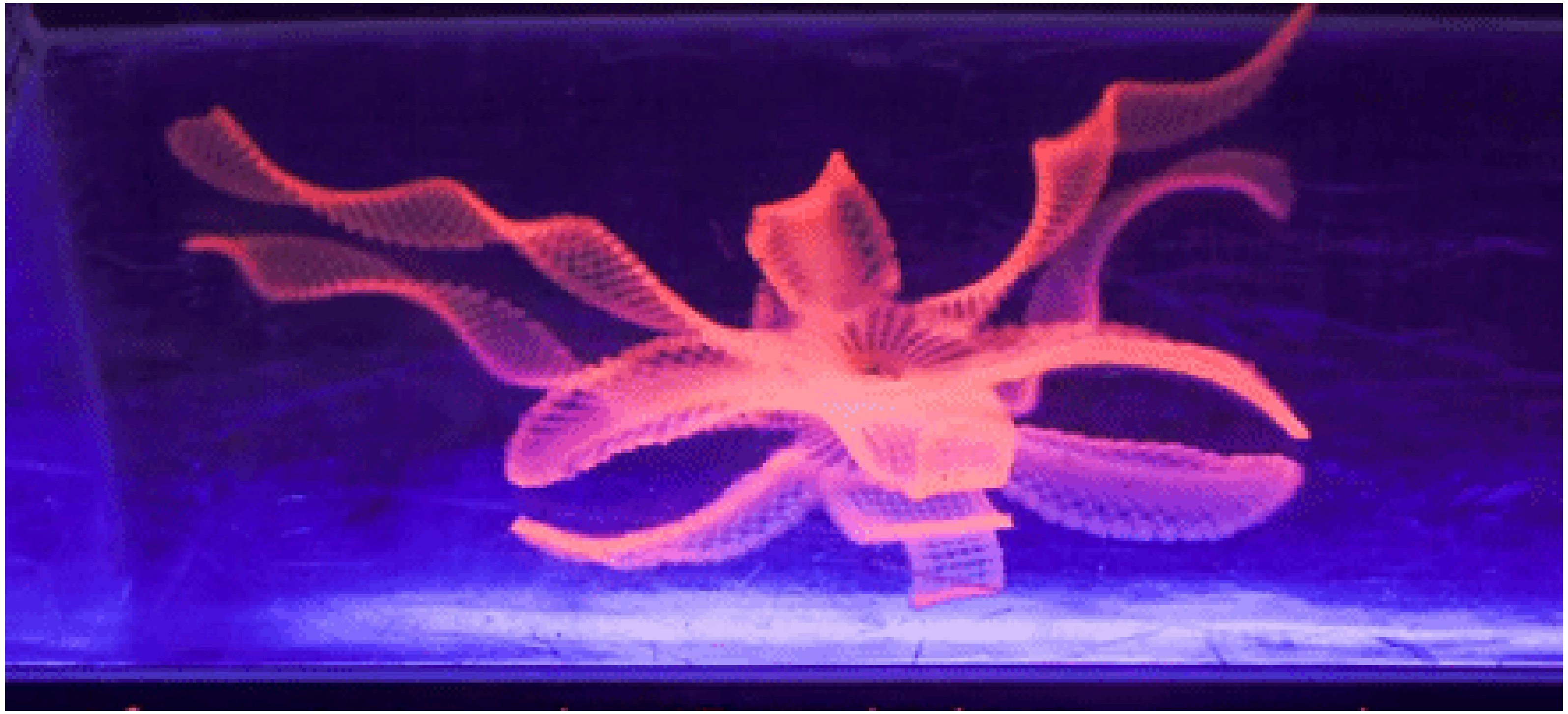


Printing stage for 3D printed piezoelectric materials. (Courtesy: Xiaoyu (Rayne) Zheng)

APPLICATIONS FOR 4D PRINTING OF PARTS

4D Printing uses the same process as 3D printing but with Smart and sensitive materials made of special plastic, ceramic, or metal that change shape or other ways, when the part is exposed **to heat, cold, moisture, light, or other environmental changes.**

This orchid-shaped structure is printed with a hydrogel composite ink containing aligned cellulose fibrils that allow it to change shape when put in water.



https://www.youtube.com/watch?time_continue=3&v=7Q_Fu1KlVac&feature=emb_logo 1.1 min

4D PRINTING ADDS BREATHING SPACE

Trachea-broncho-malacia is a disease in children that causes the windpipe to collapse during breathing.

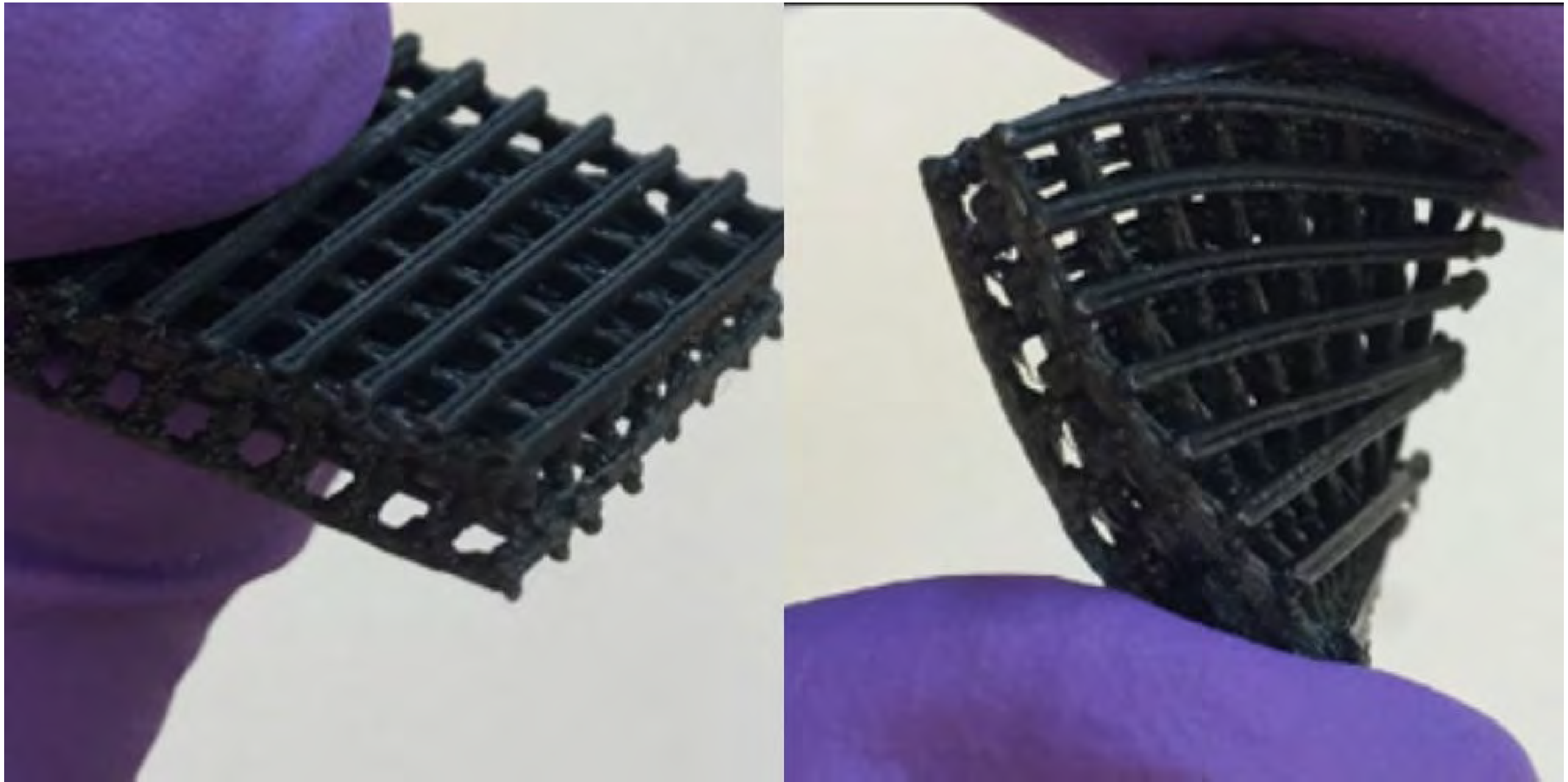
The new “4D biomaterial” part changes shape as the infant grows and it eventually disappears through bio-degradation when no longer needed.

This procedure has saved the lives of babies suffering from severe breathing problems.

3 boys have benefited from the technology at CS Mott Children’s Hospital, part of the University of Michigan.

New 3D bio-printing research shows that combining materials could be the secret to 3D printing bones and organs.

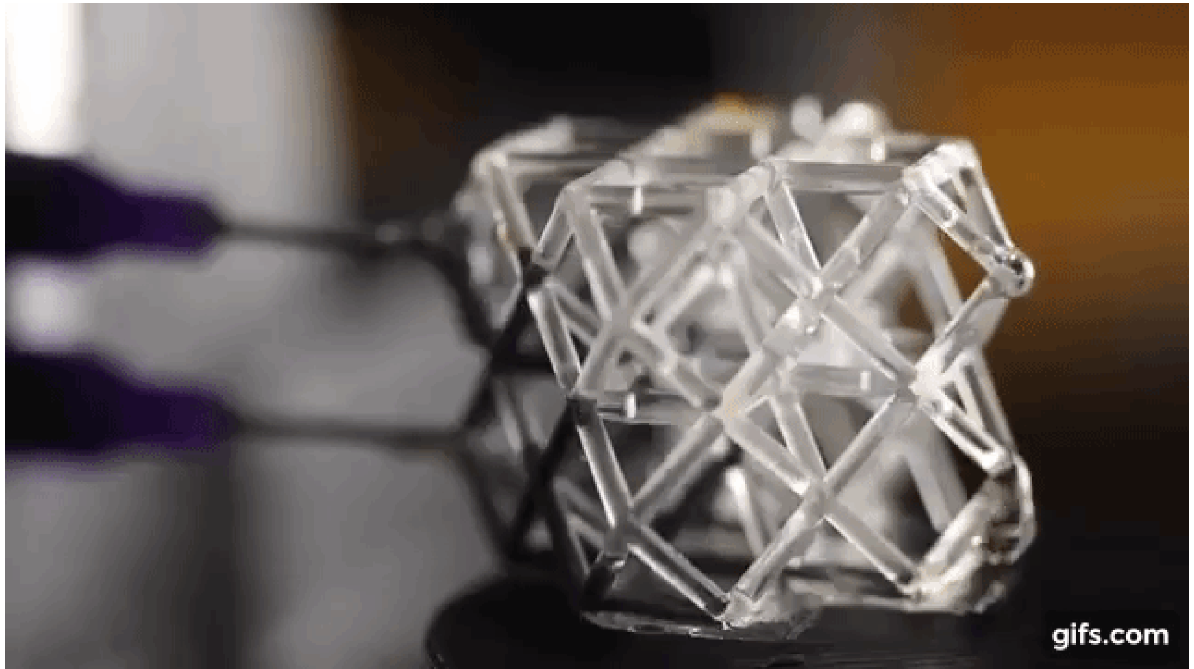
Research at Case Western Reserve University describes research into the strength and bio-compatibility of a 3D printable material made from a mix of Thermo-plastic Urethane, Poly-Lactic Acid plastic, and graphene oxide.



After optimization, experimental lattices were 3D printed using a new type of 3D printing called Micro-stereolithography. With microscale precision, it enabled the design and creation of thin tubular walls that hold injected fluid.

It is filled with a fluid that has a very fine magnetic powder in it. Its change from flexible to rigid is almost instantaneous – it stiffens up when a magnetic field is applied.

This unique class is the next step forward in metamaterials that can be tuned “on-the-fly” to achieve desired properties and applied to make intuitive objects: e.g. armor that responds on impact; car seats that reduce whiplash; and **next generation neck braces**.

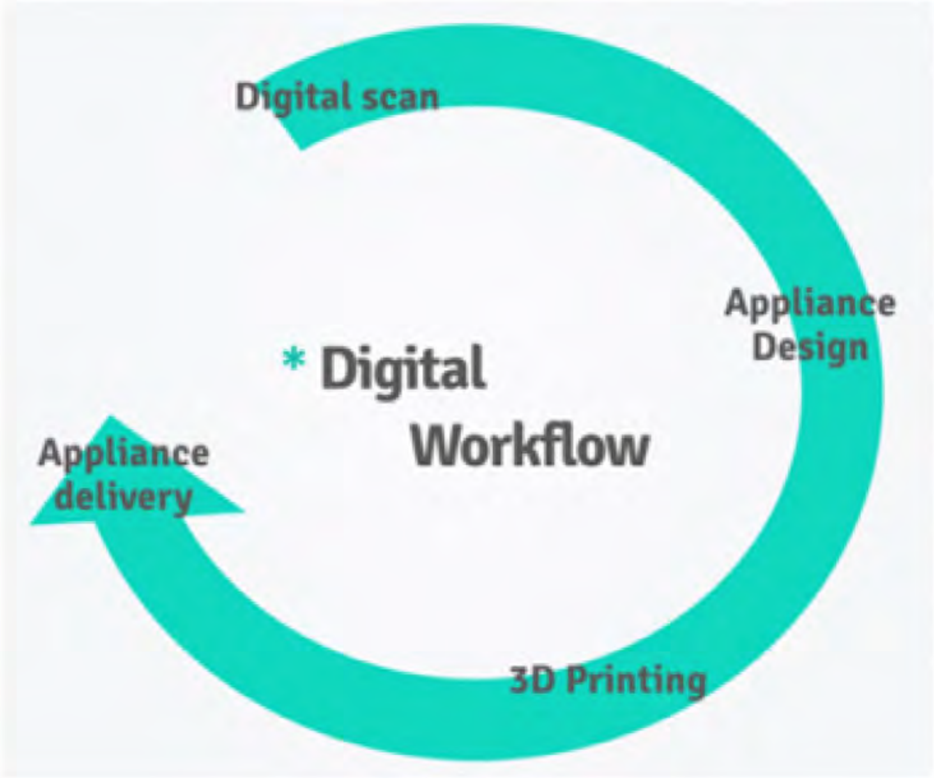


The picture to the right shows what happens when the magnetic field is removed from the part

The 4D printing in healthcare market is projected to reach 31.63 million dollars by 2026 from 8.54 million dollars in 2021

The market for 4D printing in healthcare is primarily driven by technological advancements in 3D printing technology, such as the development of smart, programmable materials.

There is a growing demand for 4D-printed organs, medical implants, and the wide range of applications of 4D printing technology in **dentistry**.



3D PRINTING OF A PERSON !!

https://www.youtube.com/watch?v=NMeODpNg_k8


THE END