GOOD EVENING EVERYONE !

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What technology is 80 years old in theory, 40 years old in practice, and looks brand new?

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THINGS PASS BY – MURRAY LEINSTER (1945)

Describes the process of feeding "magnetronic plastics—the stuff they make houses and ships of nowadays—into this moving arm. It makes drawings in the air following drawings it scans with photo-cells. But plastic comes out of the end of the drawing arm and hardens as it comes."

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RECENT ADVANCES IN ORTHOPEDICS

Robo
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Recent
implant
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3D
PRINTI
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Augme
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reality

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3D PRINTING

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3D PRINTING

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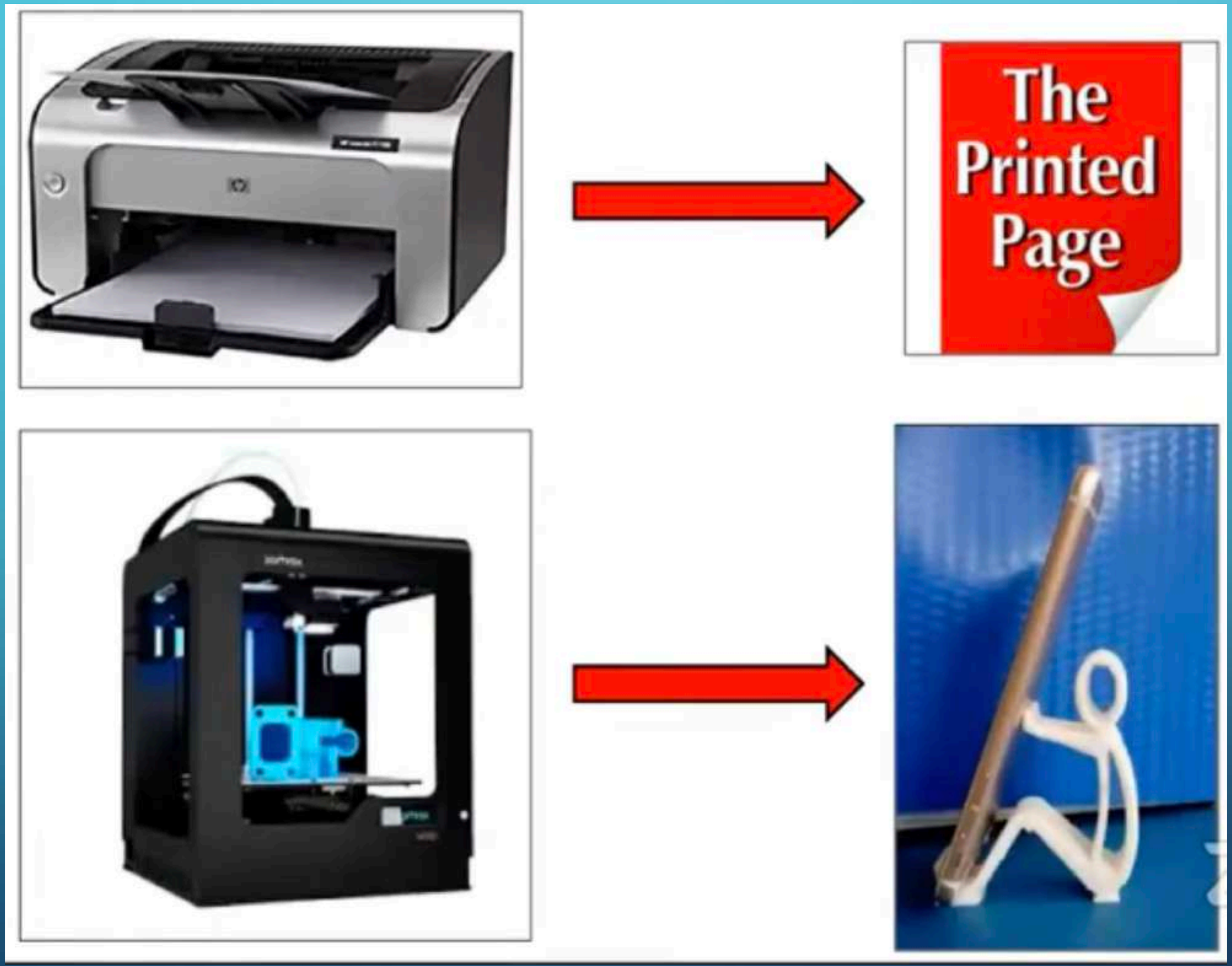
We've come a long way…….



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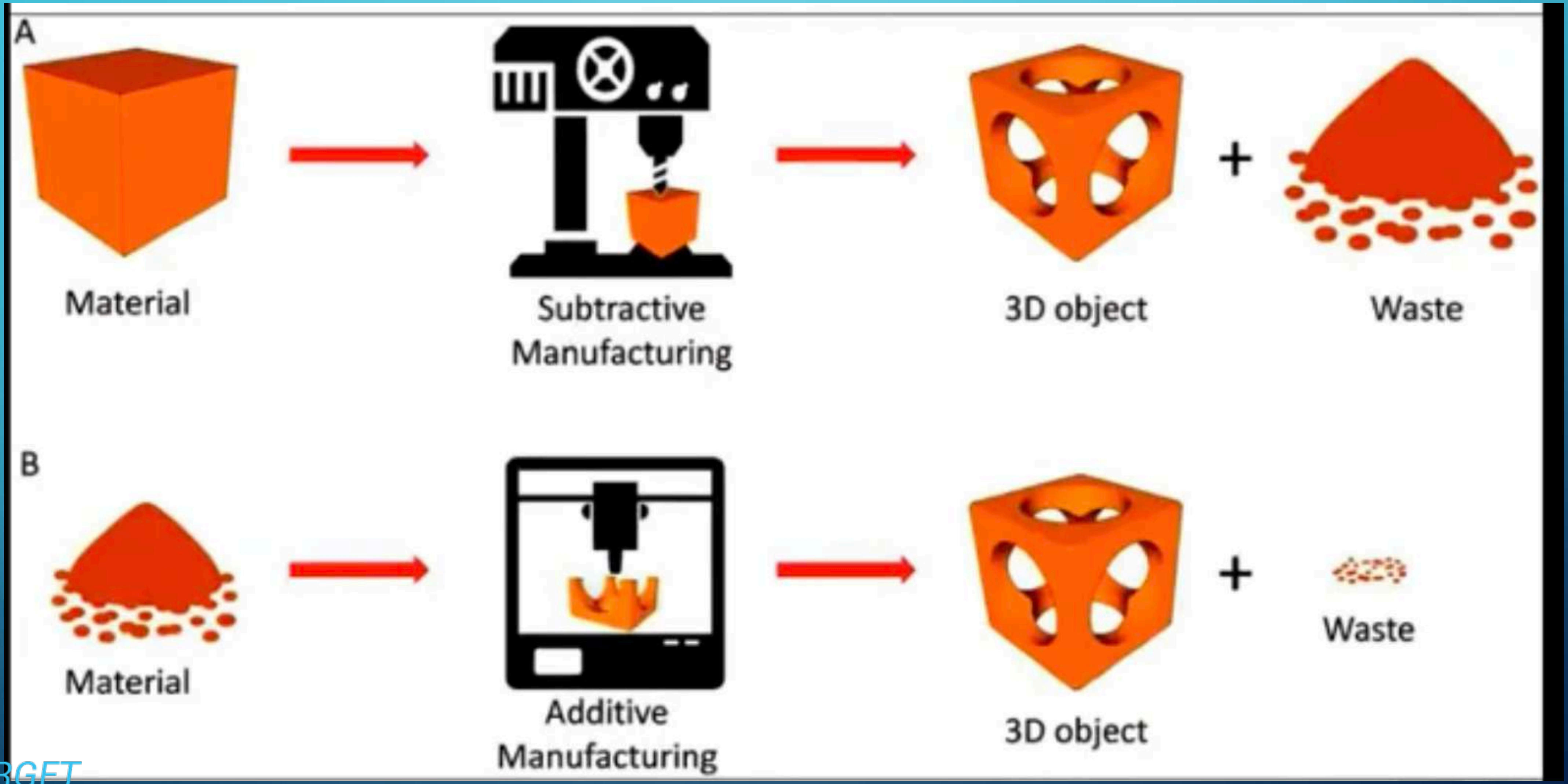
ADDITIVE MANUFACTURING & SUBSTRACTIVE MANUFACTURING



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TWO TYPES OF MANUFACTURING

Two main types of product manufacturing exist: additive and subtractive.

- **Additive manufacturing** fuses successive layers of solids, liquids, or powders to generate the finished product.
- **Subtractive manufacturing** - the beginning material is cut, milled, or molded from a base product to create the final structure

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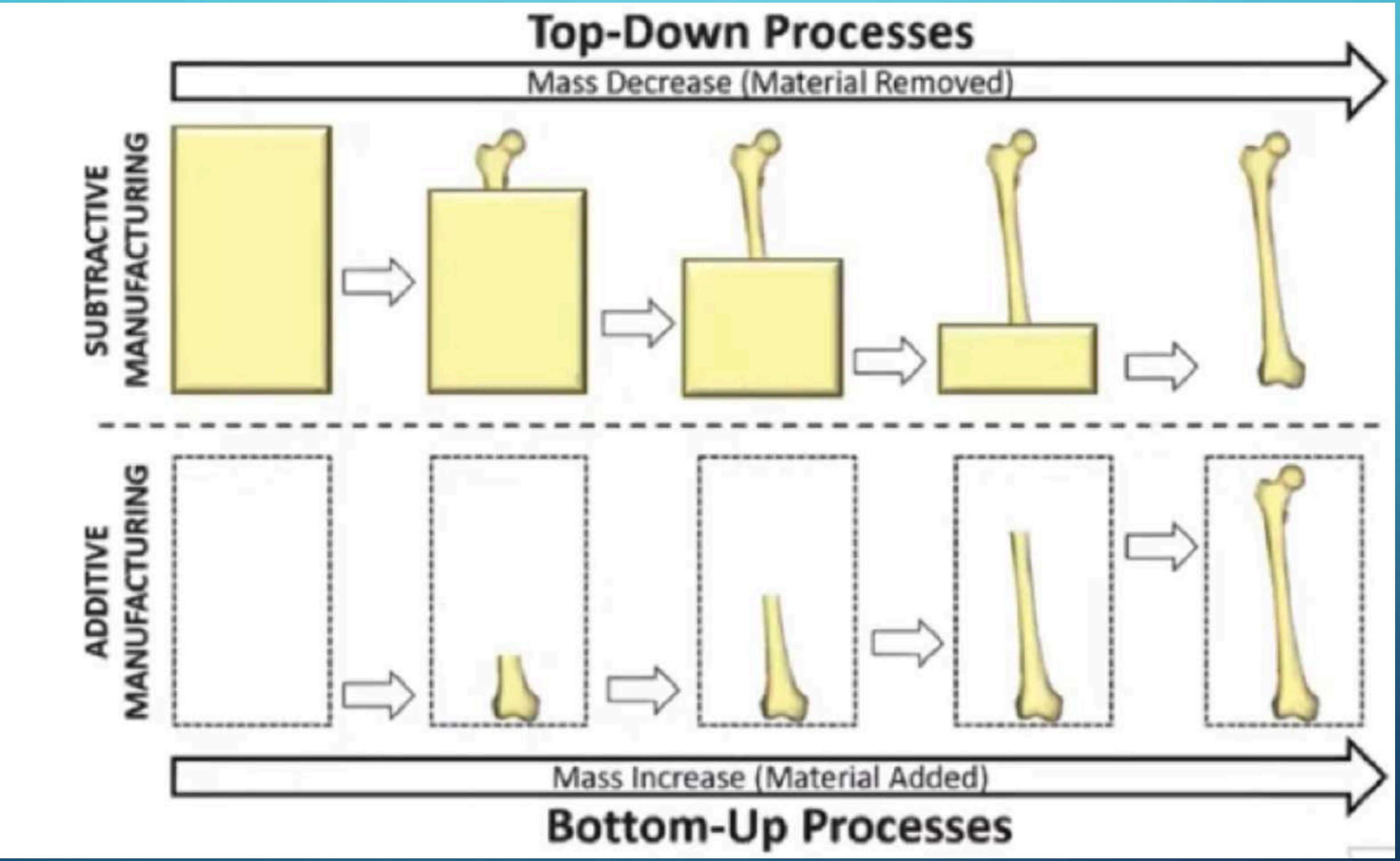
ADDITIVE MANUFACTURING IS THE CONCEPT OF 3D PRINTING



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3D PRINTING – INTRODUCTION

- Three-dimensional (3D) printing (additive manufacturing) has revolutionized the design theory and manufacturing processes behind a wide range of products in all major industries, providing substantial opportunity for easy prototyping, small production runs with opportunity for real-time refinement, and customizability.
- Creating geometrically complex and heavily detailed designs and even one-off manufacturing that would not be feasible with traditional production methods has been made possible with this powerful technology.

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VARIOUS METHODS OF 3D PRINTING EXIST, BUT EACH INVOLVES A COMMON STEPWISE PROCESS

1. Develop digital image (either through software or using patient imaging)
2. Refine the image (segmenting)
3. Translate refined image to STL file
4. 3D printer translates STL into G-Code for printing
5. Construct is printed using the G-Code parameter

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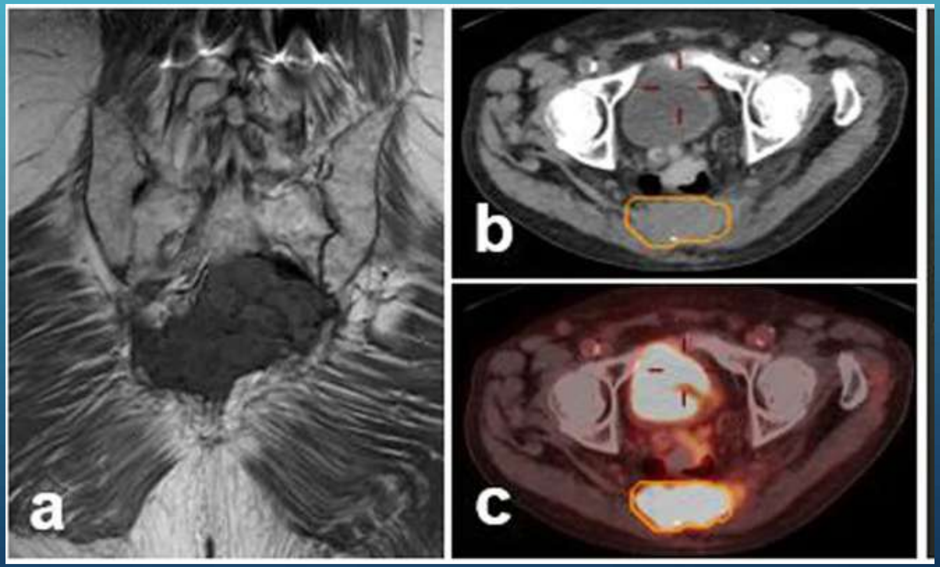
STEP 1

- First, a digital representation of the end product is generated through a de novo design or by processing cross-sectional imaging from CT and/or MRI scans saved in the digital imaging and communications in medicine format.



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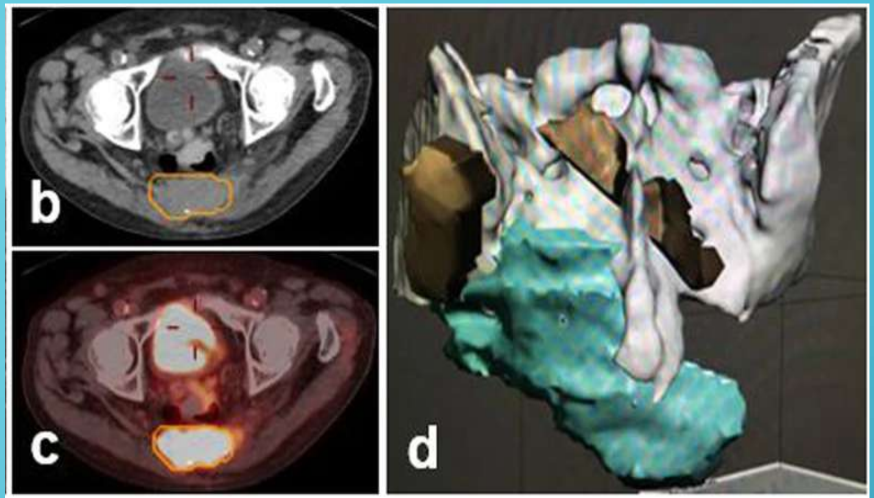
STEP 2



- This approach enables software to refine these images in the **segmentation** process to precisely define the shape of the object to be printed with regions of interest, which differentiate between tissues and surrounding anatomical structures.
- The contours of segmented regions of interest are computationally transformed into an **Standard Triangle Language file**

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STEP 3

- The next step translates the standard triangle language or additive manufacturing file into a code, typically the G-code, which enables the printer to transform the digitally supplied coordinates of the file into a sequence of two-dimensional cross-sections. These cross-sections are essential as they form the base of each layer, which the printer fuses together to create the final 3D object

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FINAL STEP OF 3D PRINTING

- Once the final product is ready for printing, several methods from which to choose are available, which include

- **Material extrusion or fused deposition modelling**
- **Material jetting**
- **Binder jetting**
- **Powder bed fusion**
- **Directed energy deposition**
- **Stereolithography,**
- **Sheet lamination**
- **Vat polymerization.**

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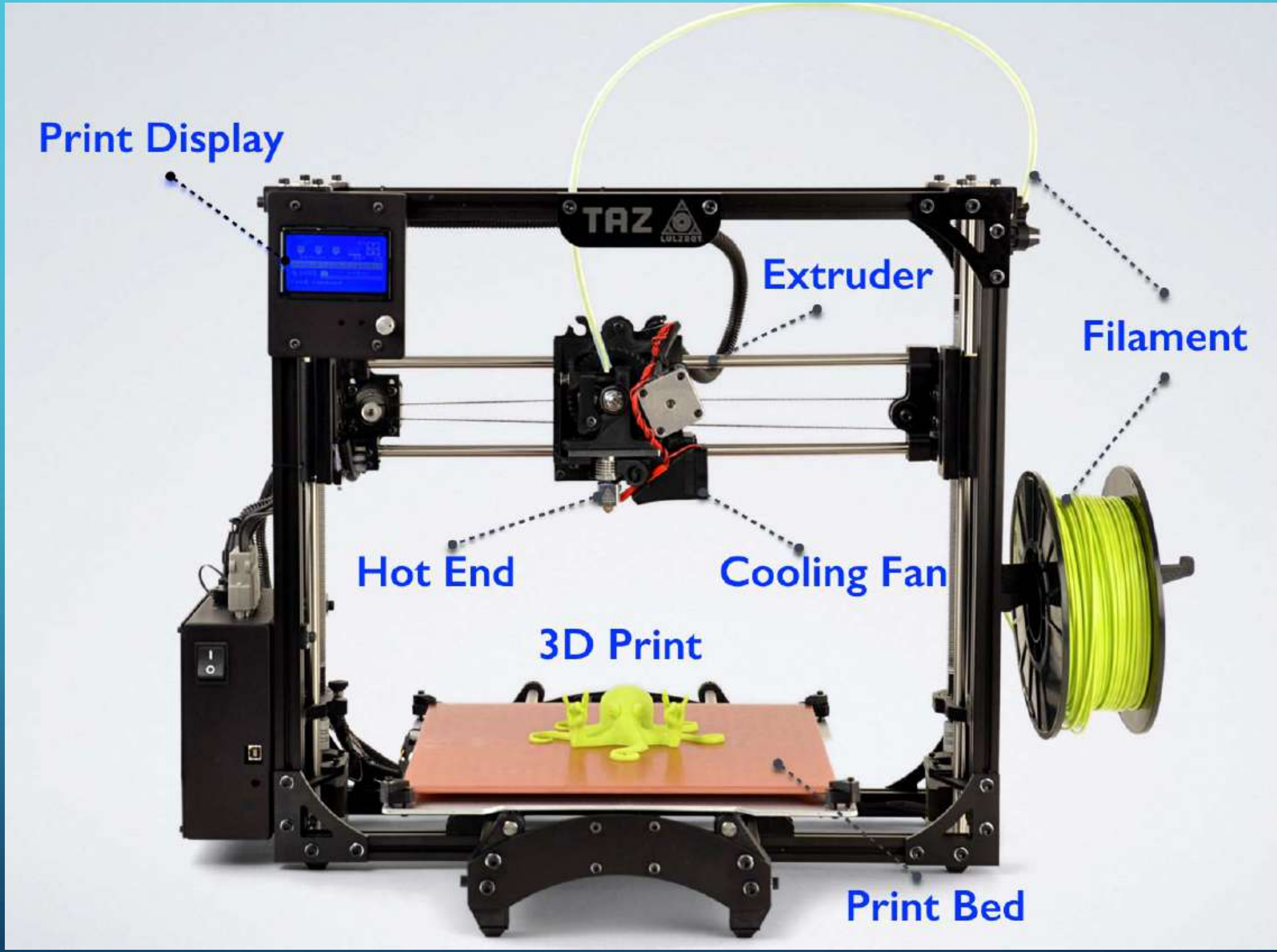
FDM Printers



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FDM

- Material extrusion, or fused deposition modeling, has become one of the most common printing methods and uses solid-based starting materials.

- In this process, tiny beads or streams of material exit an extruder in a heated liquid or semiliquid form that is rapidly cooled, forming a hardened layer

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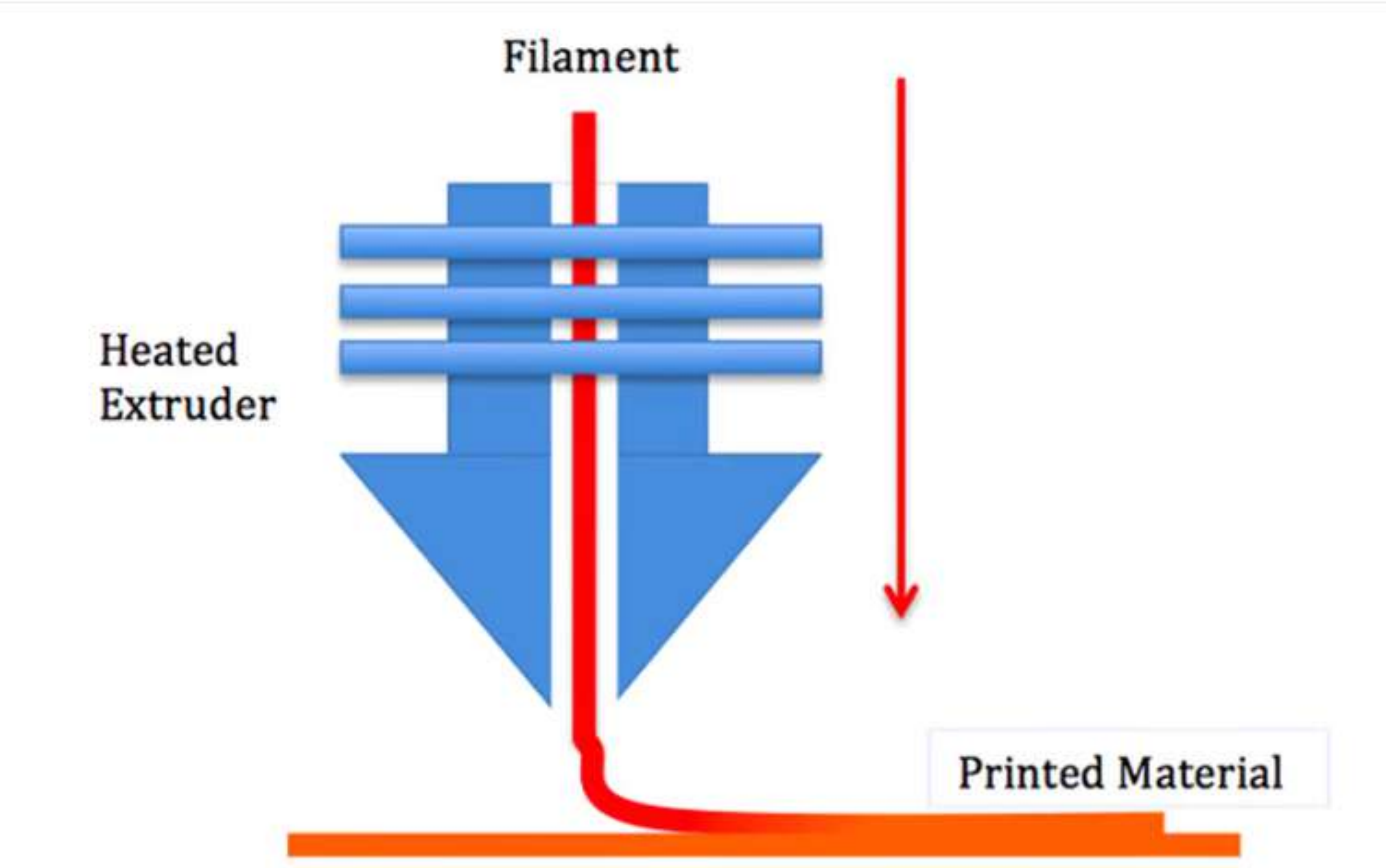
How it works ?



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POWDER BED FUSION

- For metal-based products, powder bed fusion-based methods have proven to be successful and are commonly used for orthopedic implants.
- A thin layer of powder is deposited on the building platform of the printer, where a thermal energy source, either laser or electron beam, fuses the appropriate region as indicated by the original design.
- This process is repeated for each layer or the slice of the structure until each has been fused properly, resulting in the desired final product

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POWDER BED FUSION

Steps of powde ... ed. A thermal energy source uses a beam of e ... tbed lowers, and a new layer of titanium powder is deposited. The process repeats until the object or objects are completely printed.

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Choose Software
Virtual Planning
Make STL File

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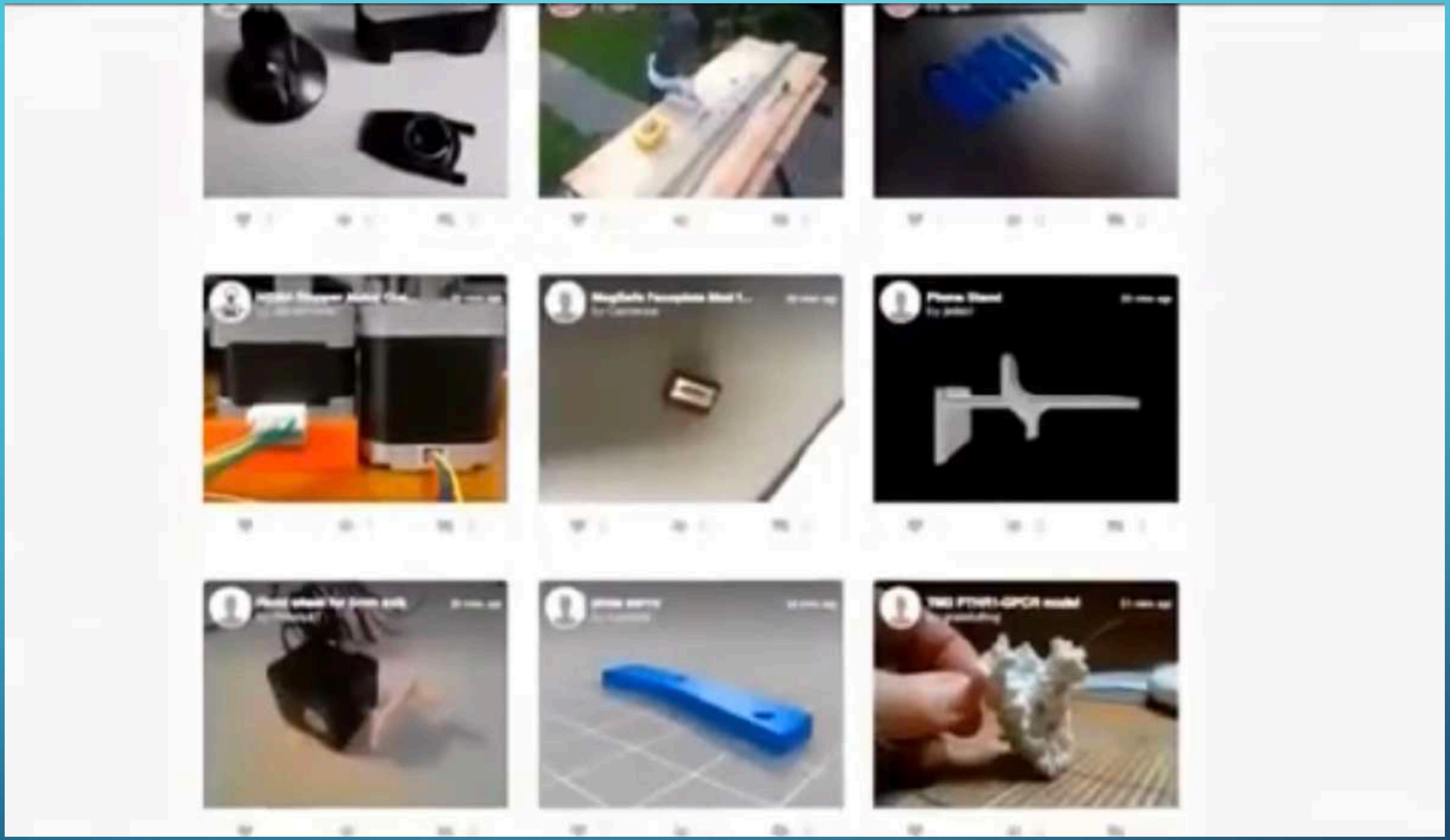
SOFTWARE AND VIRTUAL PLANNING / READYMADE TEMPLATES



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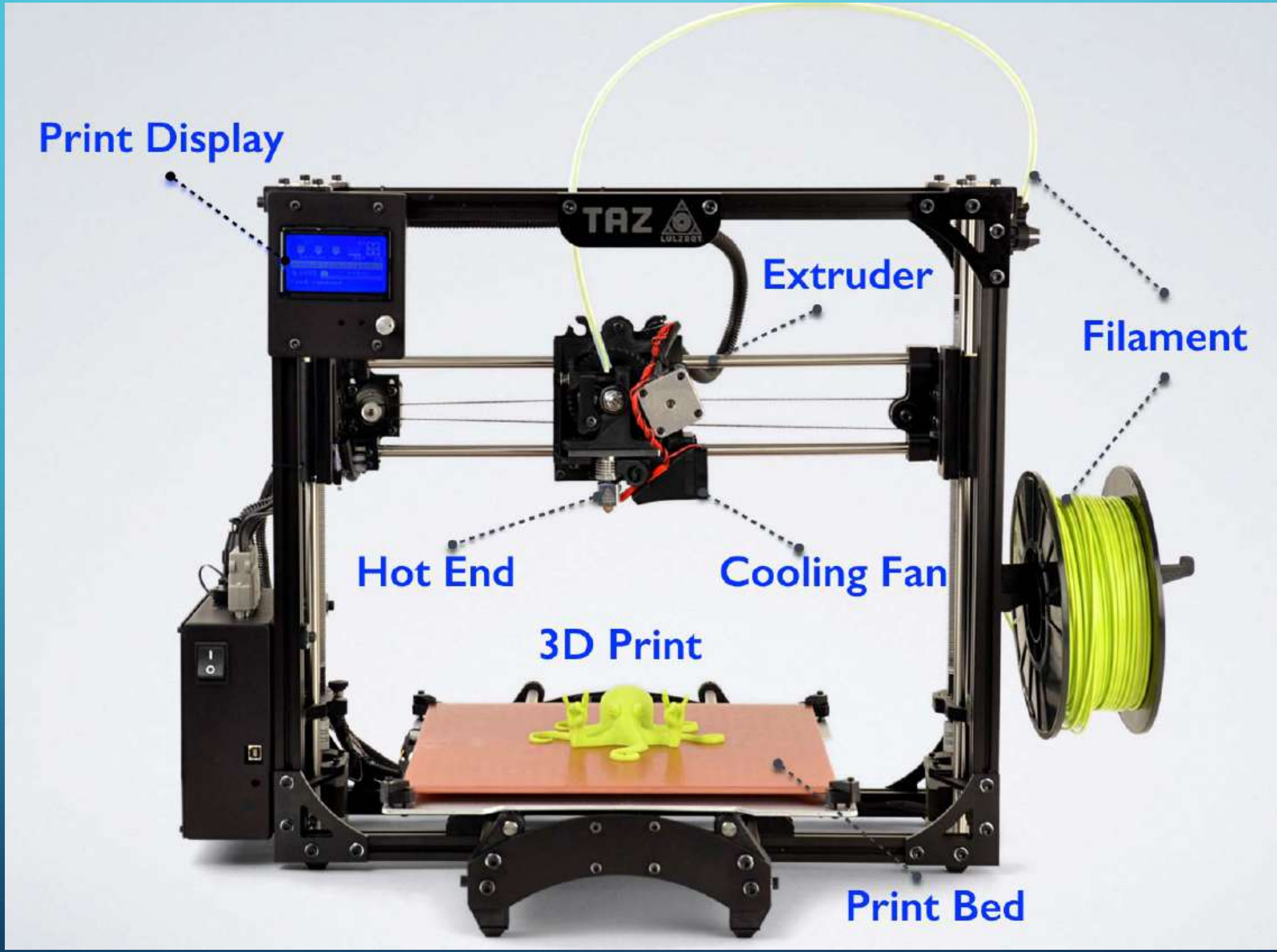
FDM Printers



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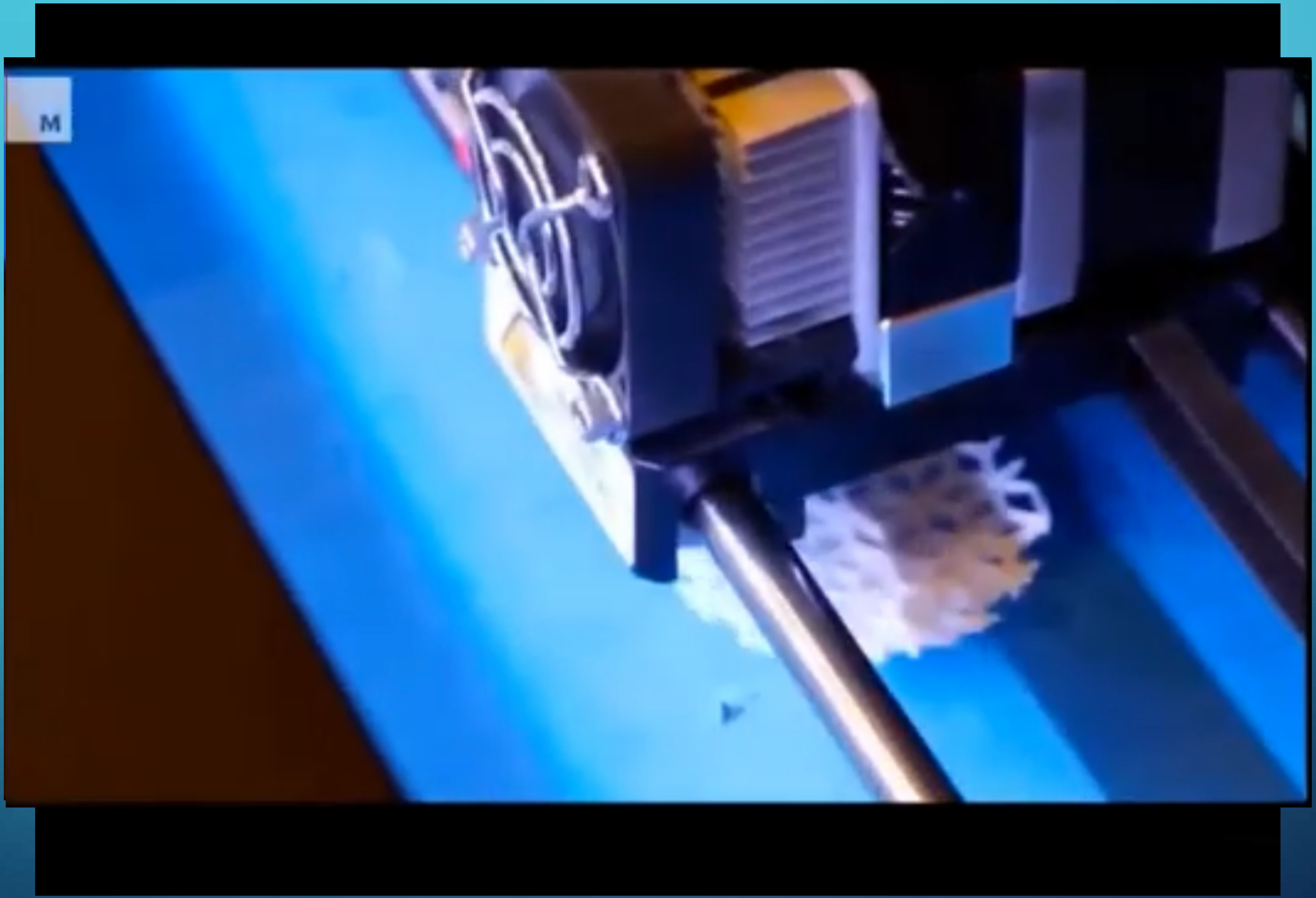

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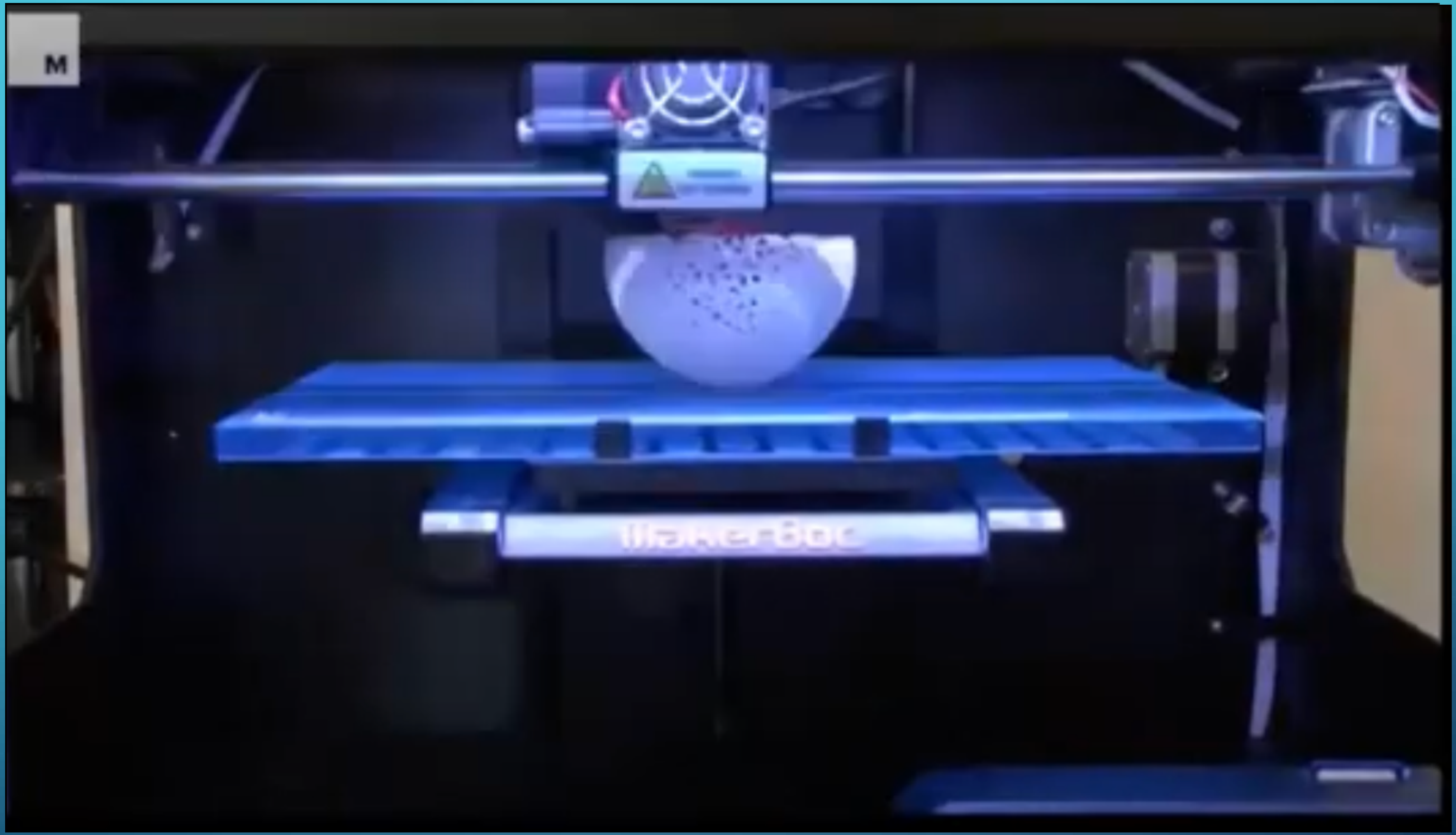

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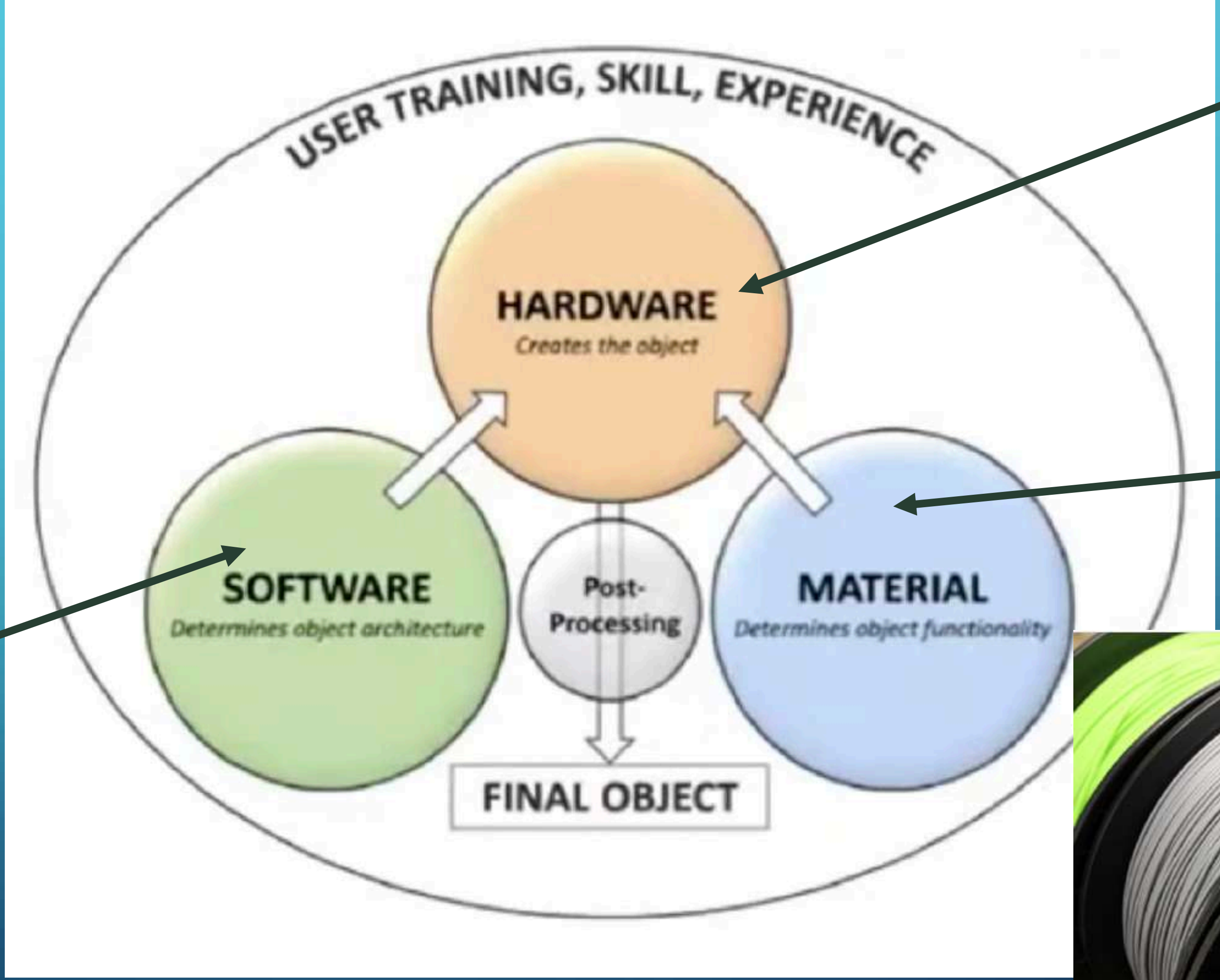
3D Printing triad

FDM printers



Filaments for FDM are PLA, PETG, and ABS

X-Ray CT scan – DICOM image

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3D PRINTING TECHNOLOGIES

FILAMENT	UV RESIN	HIGH POWER LASER
• FDM – PLA	• SLA • DLP	• SLS

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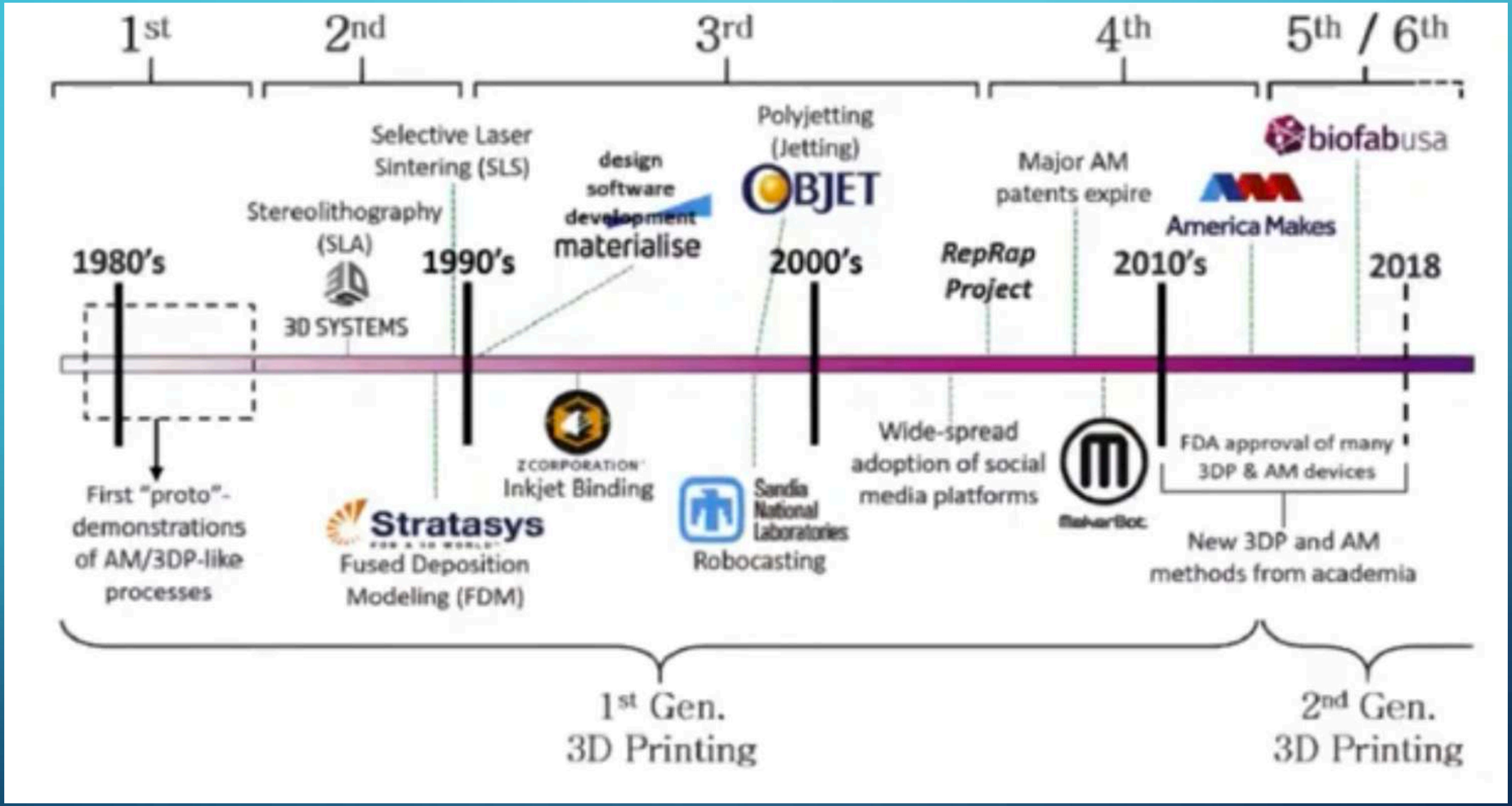

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IN 1983, Charles (Chuck) Hall, co-founder of 3D system invented the first 3D printing process and called it STEREOLITHOGRAPHY (SLA)

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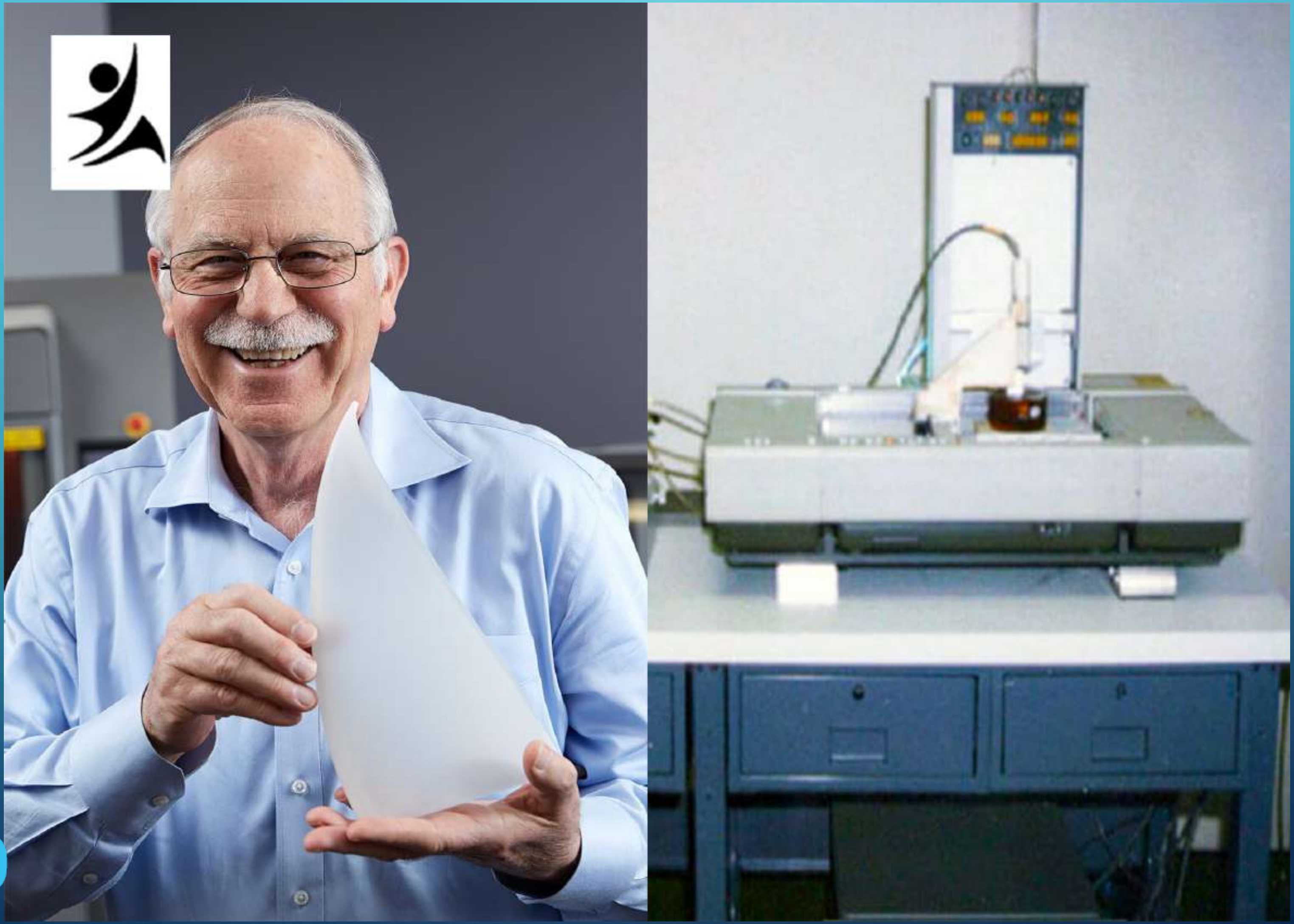
In a patent he defined Stereo lithography as 'a method and apparatus for making solid objects by successively "printing" thin layers of the ultraviolet curable material one on top of the other'



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VARIOUS APPLICATIONS OF 3D PRINTING – AN OVERVIEW

- ❑ SURGICAL PLANNING
  - CORRECTIVE OSTEOTOMIES
  - TRAUMA
  - TUMOURS
  - ARTHROPLASTY
- ❑ RESEARCH
- ❑ ACADEMICS AND DISPLAY
- ❑ DOCTOR PATIENT INTERACTION WITH 3D MODELS

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MODEL TO OBJECT

Computer assisted
Design (CAD)

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ANATOMIC MODELS

- Three-dimensional printed anatomic models are useful both for preoperative planning of complex cases and for teaching purposes

- Surgeons can see and feel what they will encounter in the operating room with an accurate representation of the anatomy in 3D space

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USES OF ANATOMIC MODELS

- SURGICAL PLANNING
- HARDWARE SELECTION
- PREBENDING OF SELECTED PLATES BEFORE SURGERY
- MIRROR IMAGING TECHNIQUE

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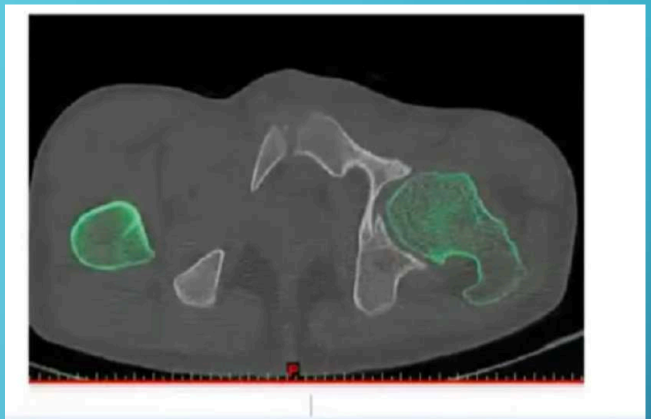
MIRROR IMAGING TECHNIQUE

- Three-dimensional printed anatomic models have been used in the mirror imaging technique

- In which models of the contralateral uninjured side are printed and used in preoperative planning.
- Surgeons can use the fractured/pathological 3D model to simulate their reduction technique and use the uninjured 3D model to optimize plate selection.

- This technique has been implemented for clavicle fractures, calcaneal fractures, pilon fractures, and ankle fractures with excellent results.



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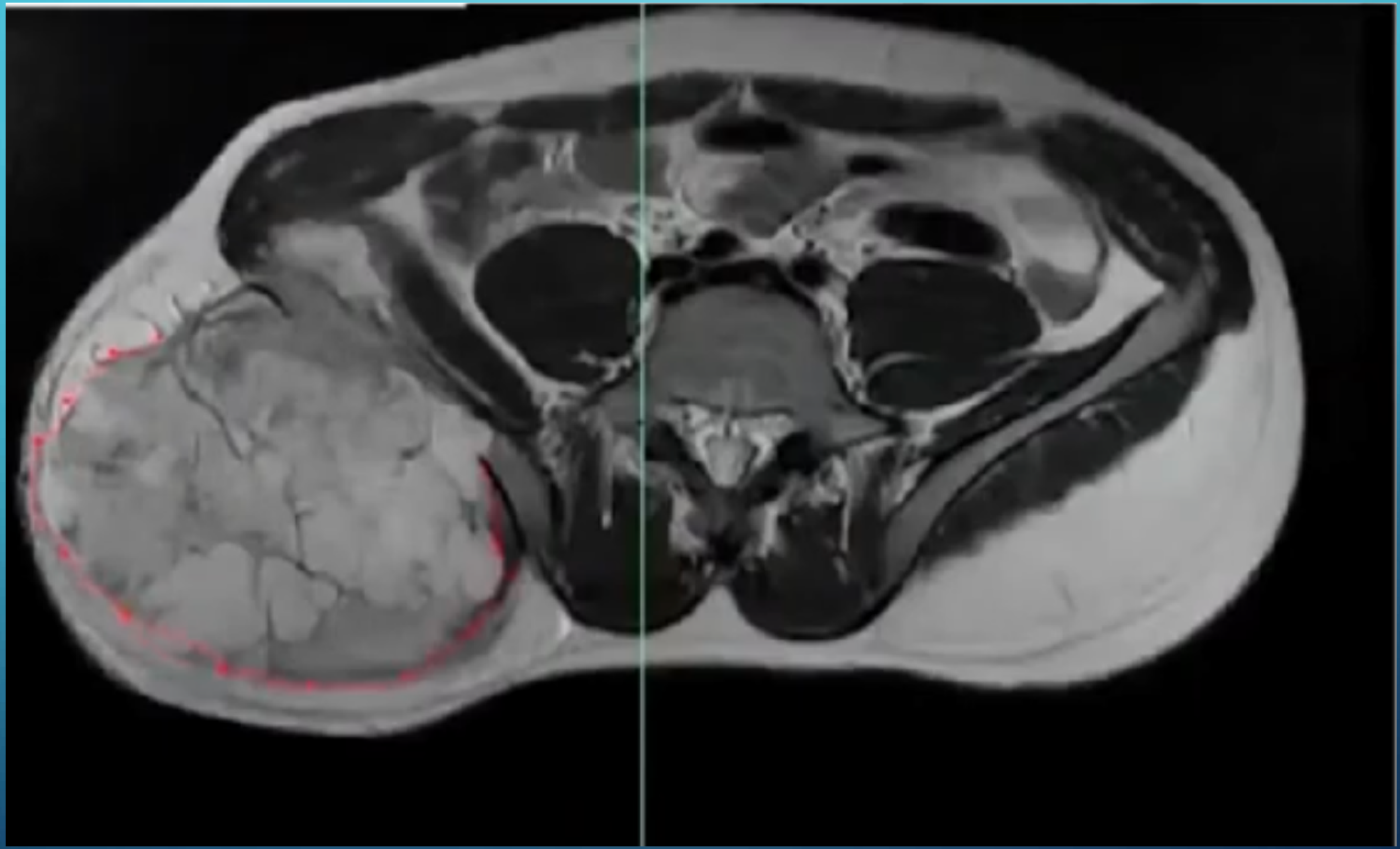
VIRTUAL PLANNING – CHONDROSARCOMA OF THE ILEUM



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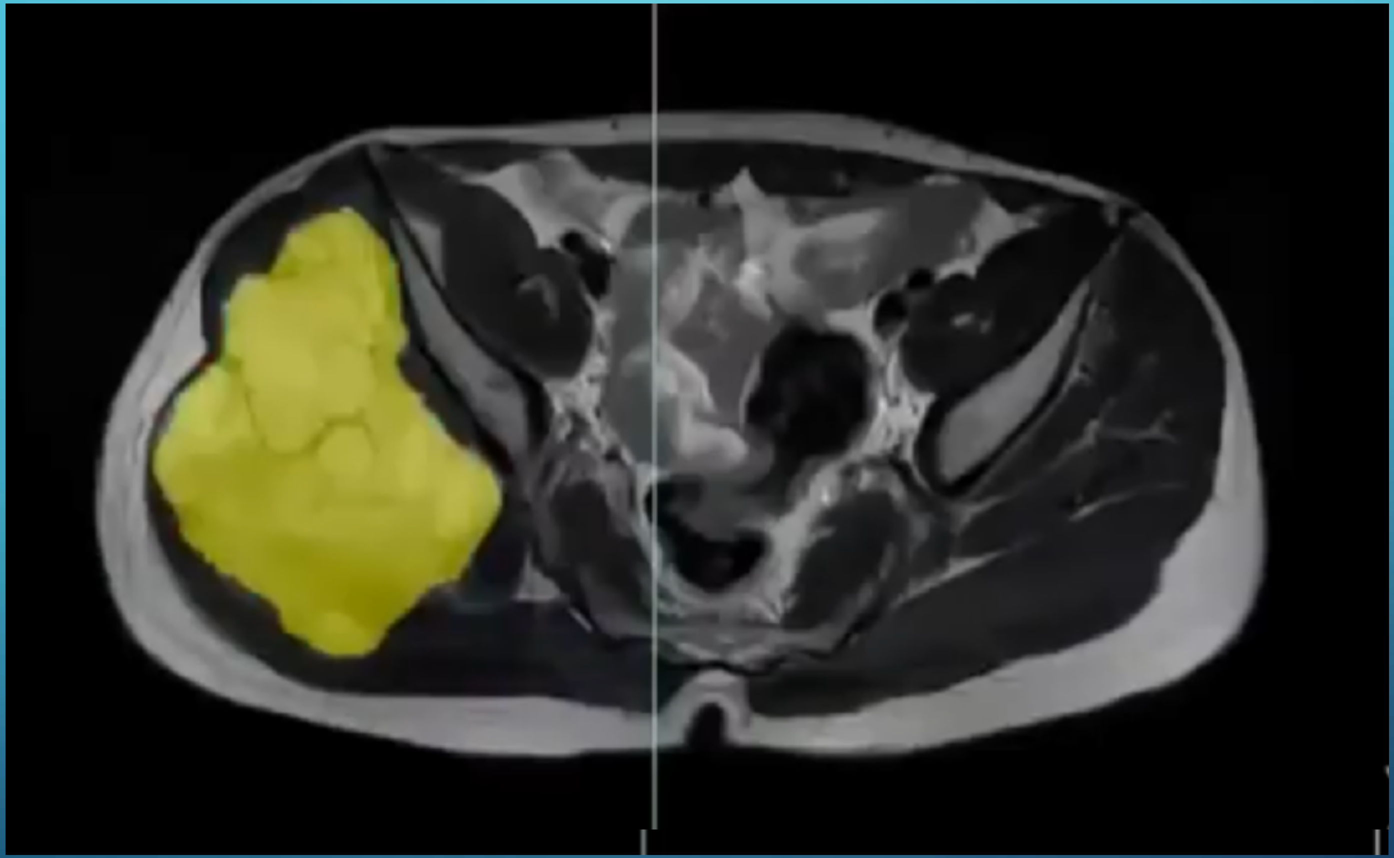
TUMOR MAPPING IN THE MRI SECTION – 3D IMAGING



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PLANNING OF THE RESECTION CUT DONE ON THE 3D MODEL

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PROSTHETICS AND ORTHOTICS

- Most braces and orthotics are available only in a limited number of sizes and are designed to fit a large fraction of the population.

- Although fully customizable prosthetics have proven to be effective, the manufacturing process is complex and adds to the overall cost and time required to make these prosthetics.

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3D PRINTING IN AFO'S

- 3D printing has revamped the design and production of ankle-foot orthoses (AFOs).

- Traditionally, AFOs are made from plaster castings of a patient's lower extremities, a labor-intensive and costly process that leads to problems with fit, comfort, and the overall design and appearance

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3D PRINTING IN AFO'S

- Three-dimensional printing has simplified the manufacturing process while facilitating a design that integrates the unique biomechanical metrics of each individual.

- AFO for plantar fasciitis – widely used

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NEW NON CUSTOM IMPLANTS

- Three-dimensional printing technology can be used to produce orthopedic implants that are not customized

- Several new implant types for hip and knee arthroplasty have entered the market as a result of the streamlined 3D printing production process

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NEW NON CUSTOM IMPLANTS

- Three-dimensional printed acetabular cups are thinner and less expensive than traditionally manufactured cups.
- A recently published study on a small group of patients who underwent revision of an acetabular defect with a 3D-printed acetabular cup reported improved stability, better hip scores, and decreased pain

Wan L, Wu G, Cao P, Li K, Li J, Zhang S: Curative effect and prognosis of 3D printing titanium alloy trabecular cup and pad in revision of acetabular defect of hip joint. Exp Ther Med 2019;18: 659-663.

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NEW NON CUSTOM IMPLANTS

- 3D printing has led to the development of porous metal implants for foot and ankle arthrodesis. These implants serve as an alternative to traditional plates, screws, and staples, providing sufficient structural support and improved surface for biological incorporation

- Innovative cage prototypes of interbody cages for spine surgery.

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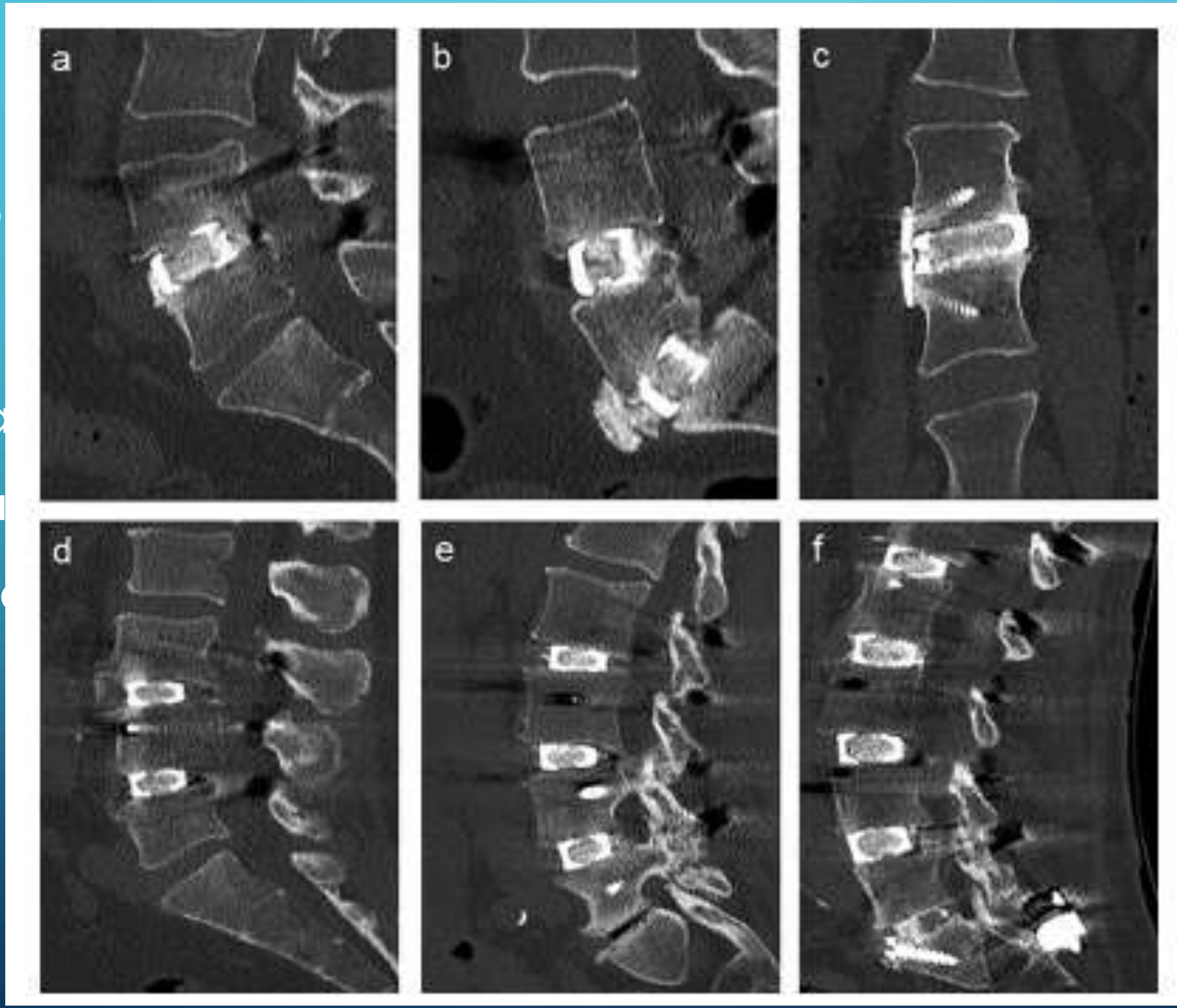
LUMBAR INTERBODY FUSION RATES WITH 3D-PRINTED LAMELLAR TITANIUM CAGES USING A SILICATE-SUBSTITUTED CALCIUM PHOSPHATE BONE GRAFT

- The aim of … of 3D-printed interverteb… …ic the compressive modulus of …
- After impla… …packed with bone graft, a pa… … 1 year in 93 patients un…



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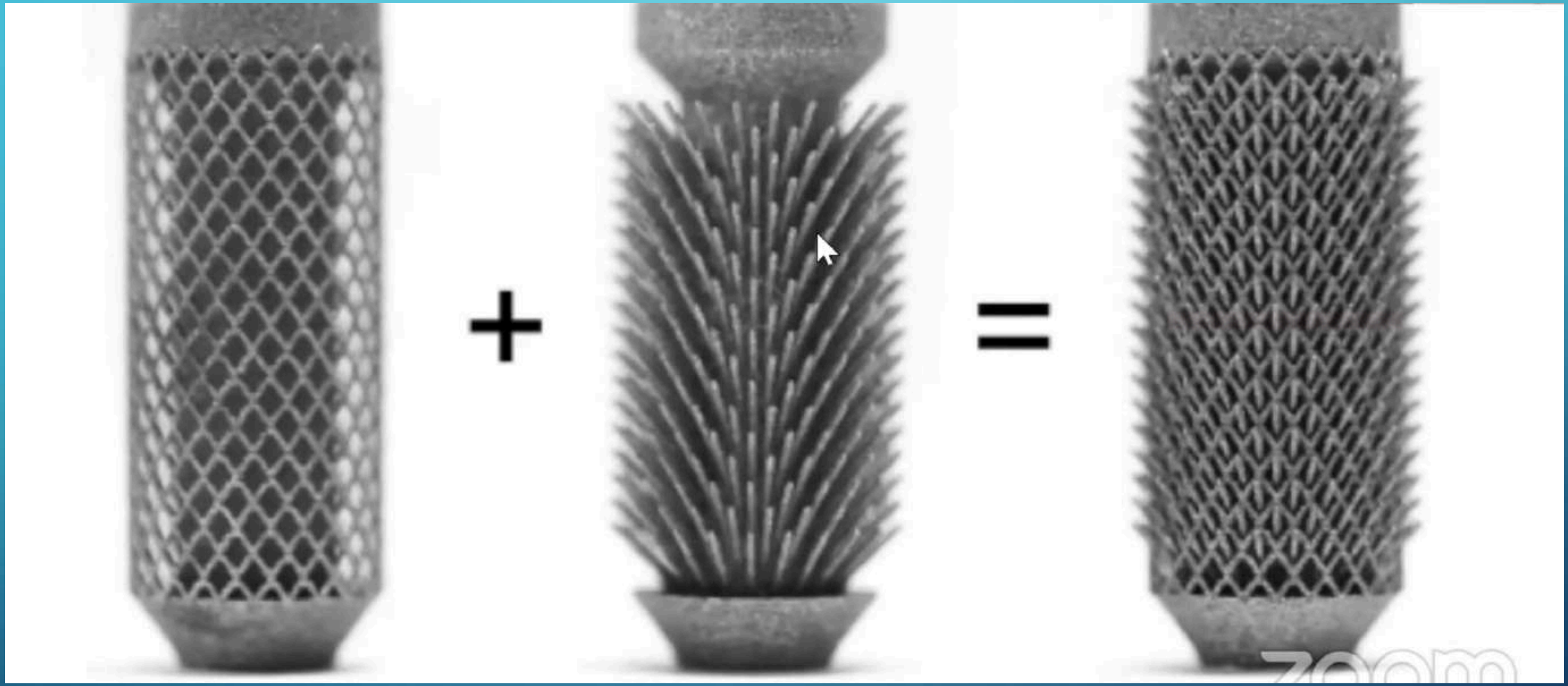
CUSTOMIZED IMPLANTS

REINVENTION OF THE SCREW



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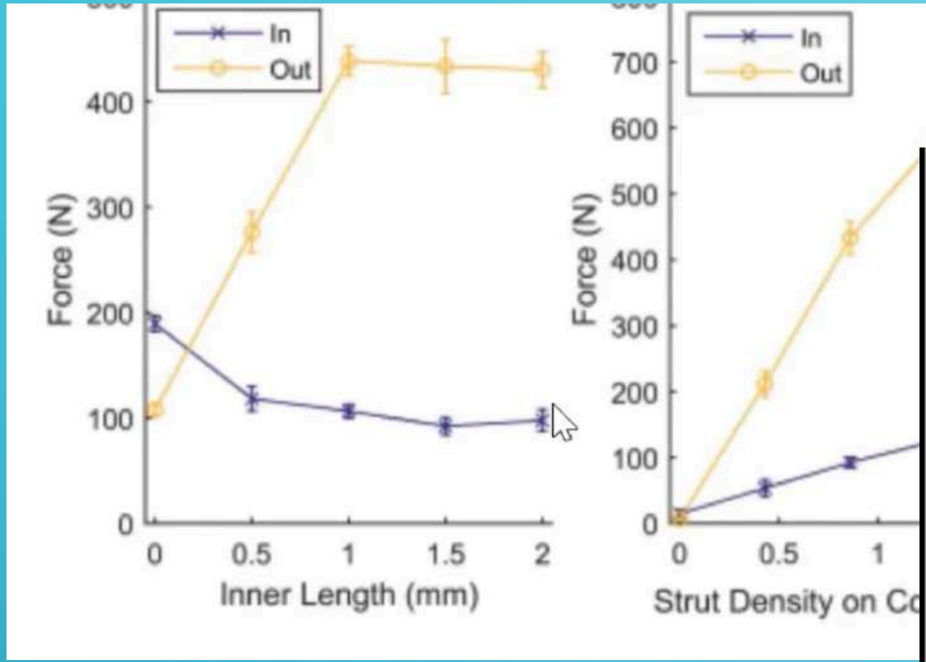

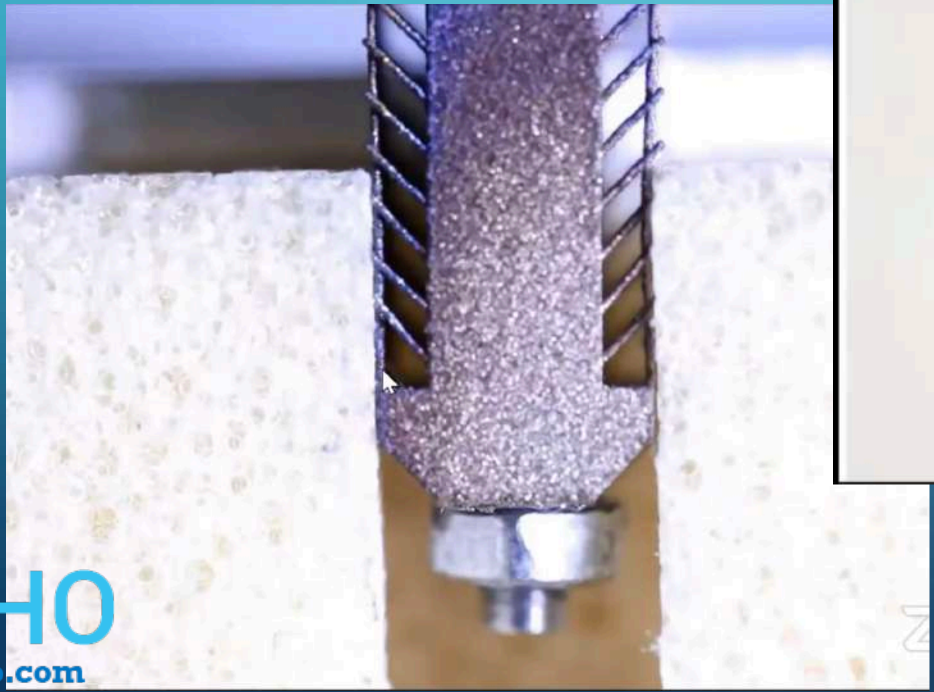

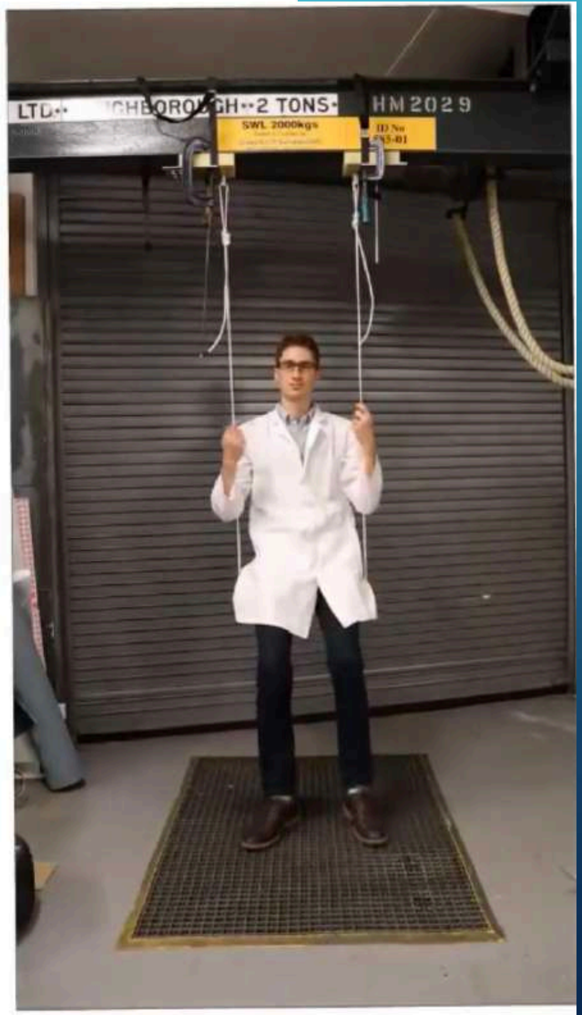

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PATIENT SPECIFIC INSTRUMENTATION

- Customized surgical guides for orthopedic surgery have been manufactured with the aid of 3D printing technology

- Three-dimensional printed patient-specific cutting jigs enable precise and accurate preoperative planning in complex cases of deformity

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PATIENT SPECIFIC INSTRUMENTATION

- Correcting angular and rotational deformity can be challenging and requires intense preoperative planning. Clinical outcomes often depend on the accuracy of correction

- Three dimensional printed cutting and locking guides allow for extensive preoperative planning to maximize intraoperative success. Improvements in accuracy have been noted in medial closing wedge distal femoral osteotomy for valgus knee malalignment and lateral compartment disease

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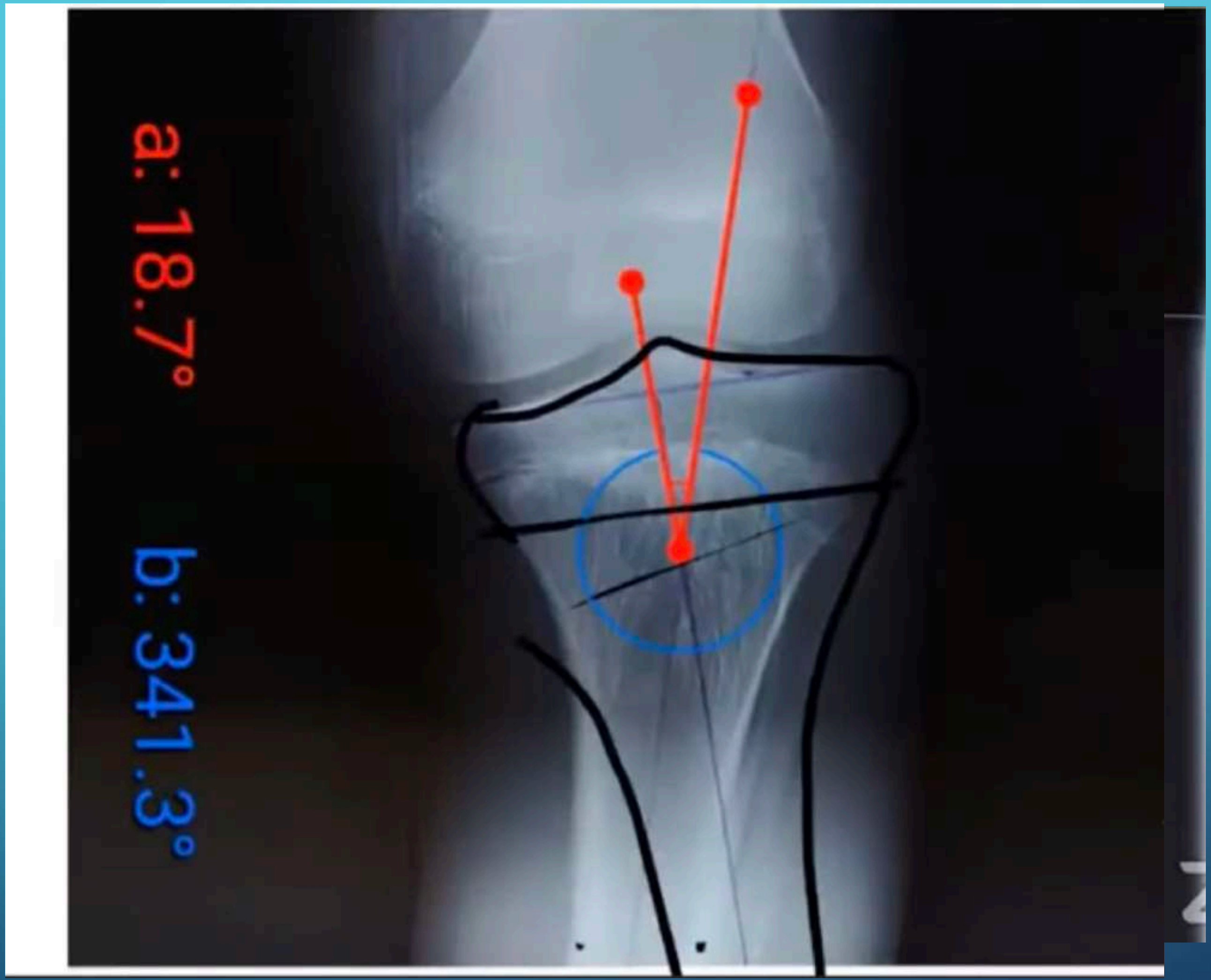
We use to plan for deformities using Scannograms and lines



mpossible to recreate intra-operatively…..

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APPLICATION OF VIRTUAL PLANNING AND PRINTING IN SURGICAL CORRECTION OF GENU VARUM DEFORMITY

A 14 year old girl presented with Varus deformity of left knee

NCCT (1mm cuts) of the left lower limb was obtained for virtual planning

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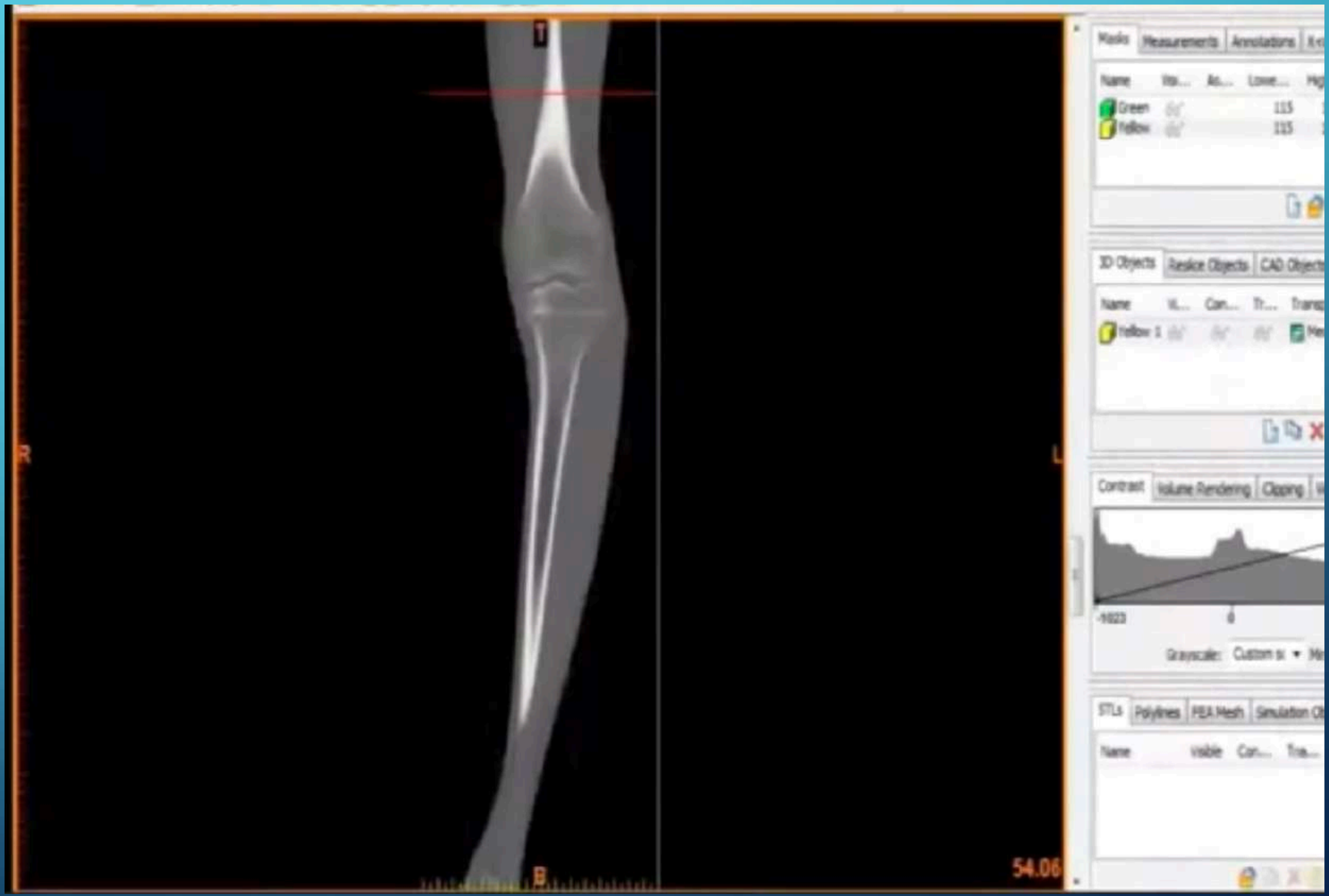
NCCT imported into the software

Coronal cut showing the Varus deformity



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THRESHOLDING

THRESHOLDING SEPARATES THE PART OF INTEREST (BONE) FROM REST OF PARTS (SOFT TISSUES) ON THE BASIS OF DENSITY AND GIVES A MASK TO IT (GREEN HERE)

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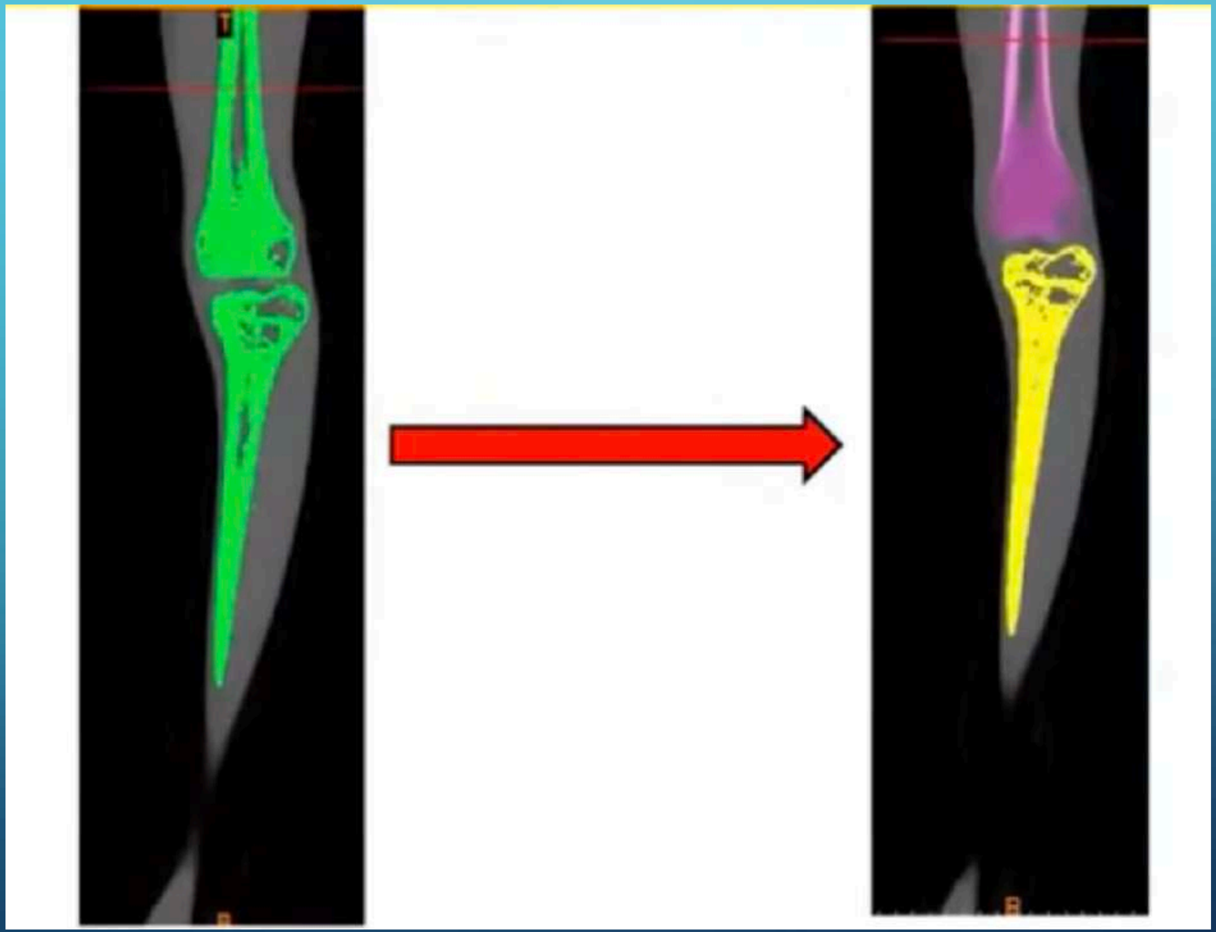
"SEGMENTATION" AND "REGION GROWING" IN SEPARATING VARIOUS PARTS (BONE HERE) IN A DESIRED MANNER



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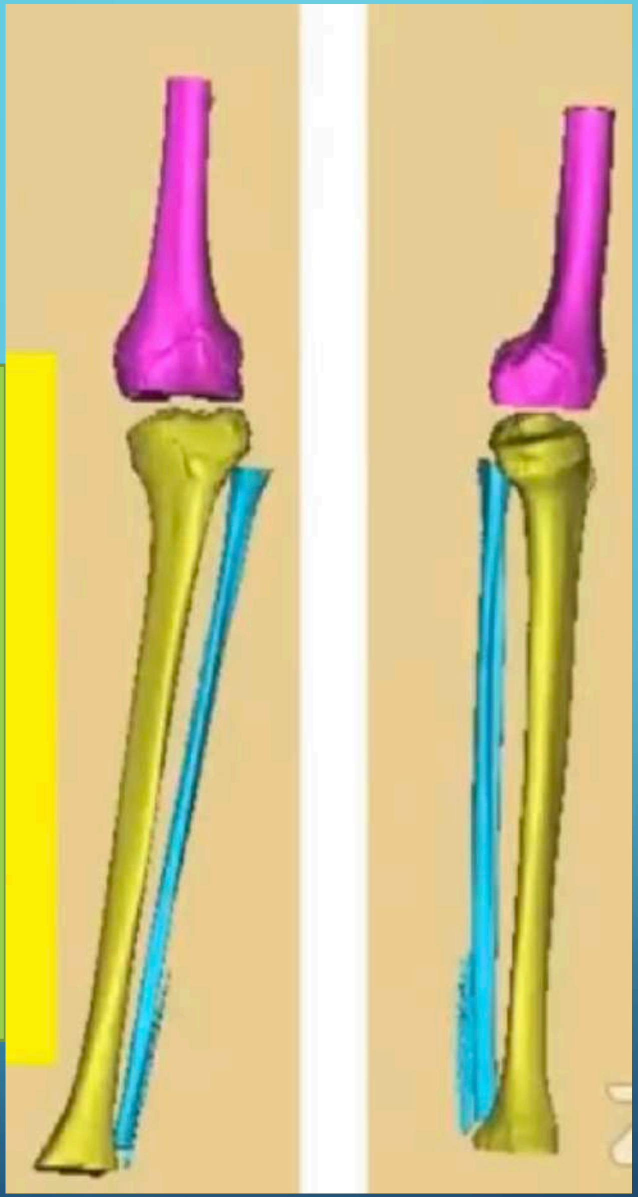
3D MODEL GENERATED USING "CALCULATE 3D" COMMAND AND EXPORTED AS STL FORMAT 3D OBJECT FILES



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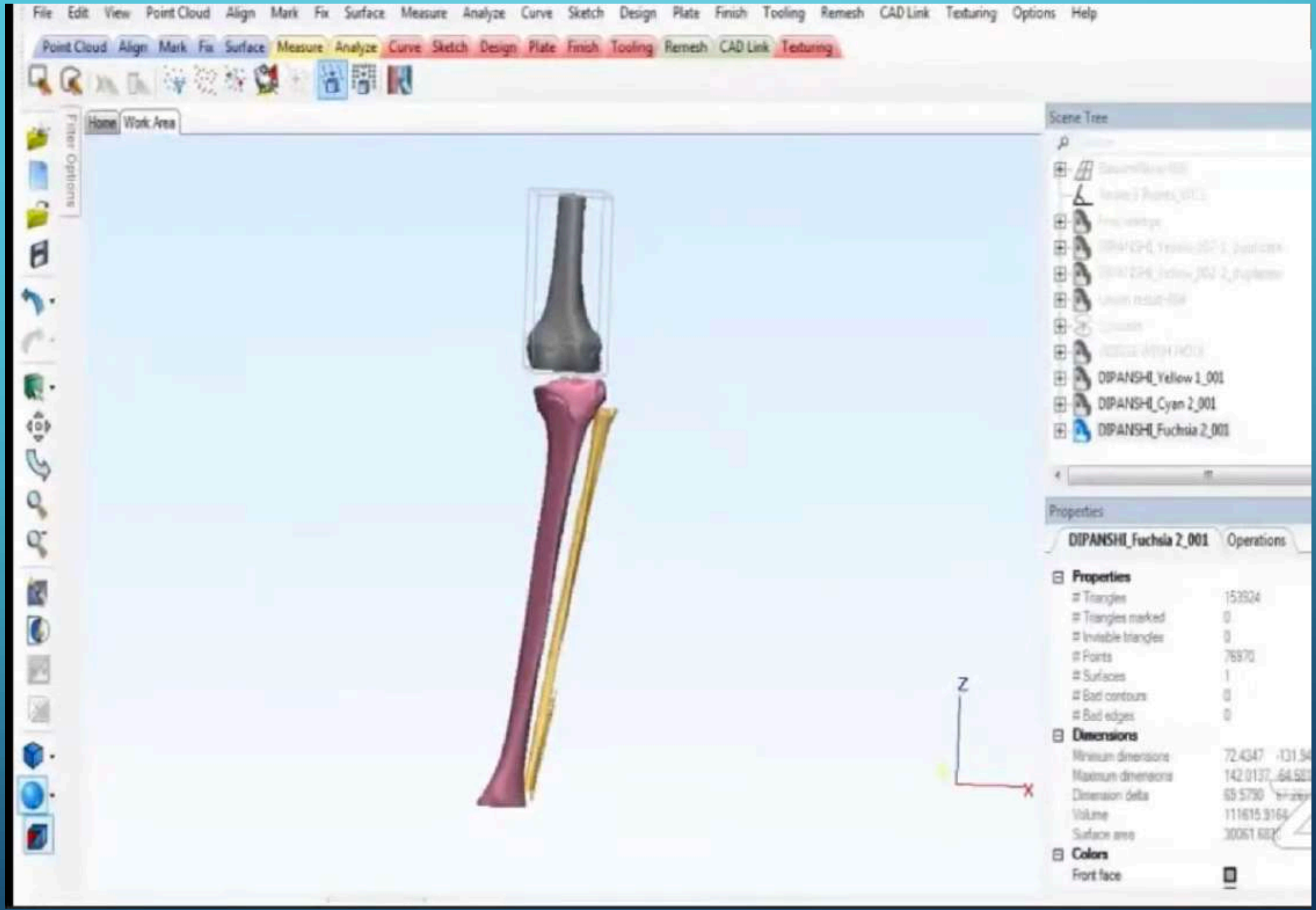
STL FILES IMPORTED IN 3-MATIC SOFTWARE FOR OSTEOTOMY PLANNING



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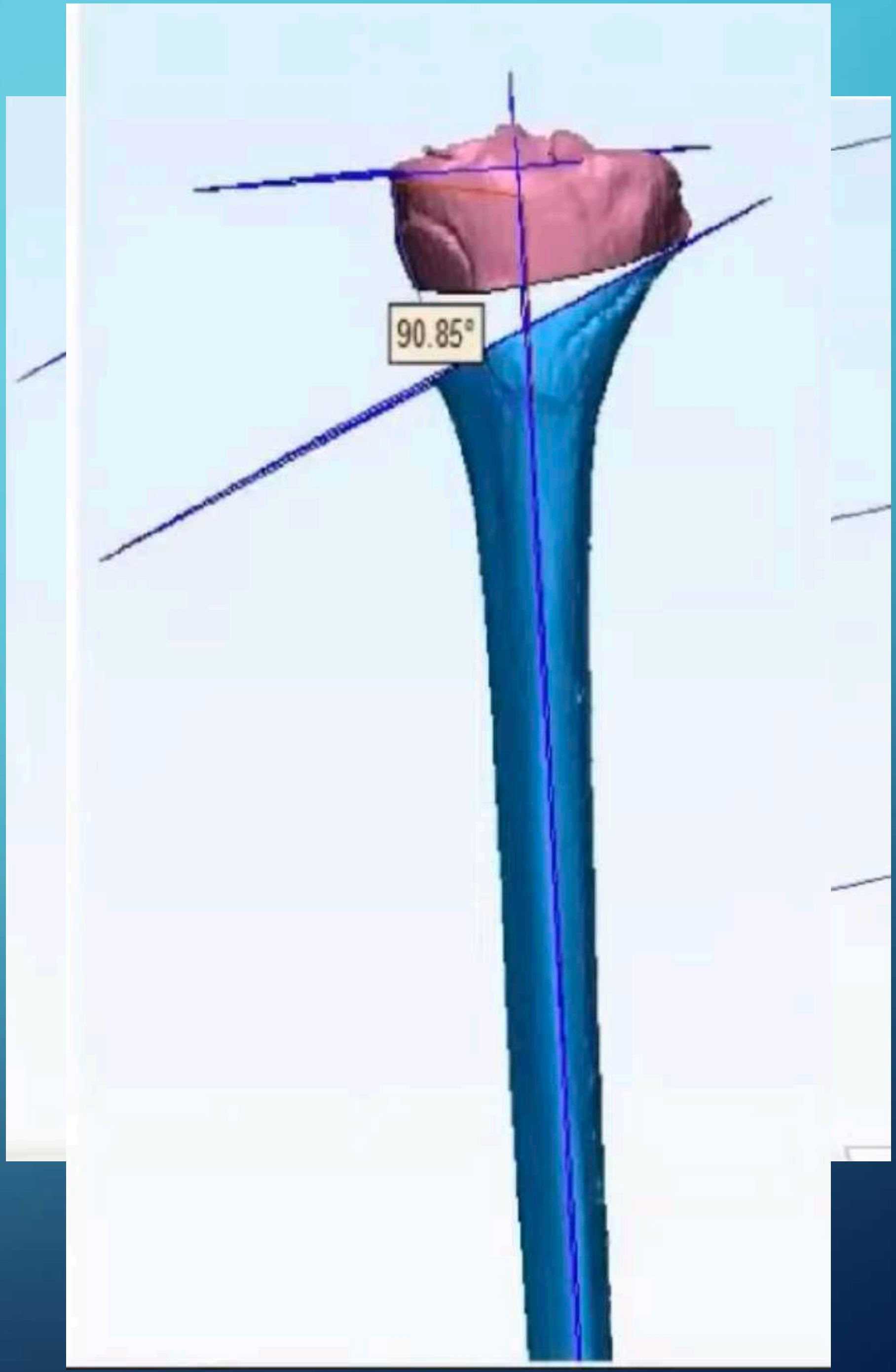
APPROPRIATE OSTEOTOMY PLANE DESIGNED TO CORRECT DEFORMITY USING "CREATE DATUM PLANE" COMMAND

FROM PLANNING WITH LINES IN X-RAY TO PLANNING WITH 3D DEFORMITY PLANES



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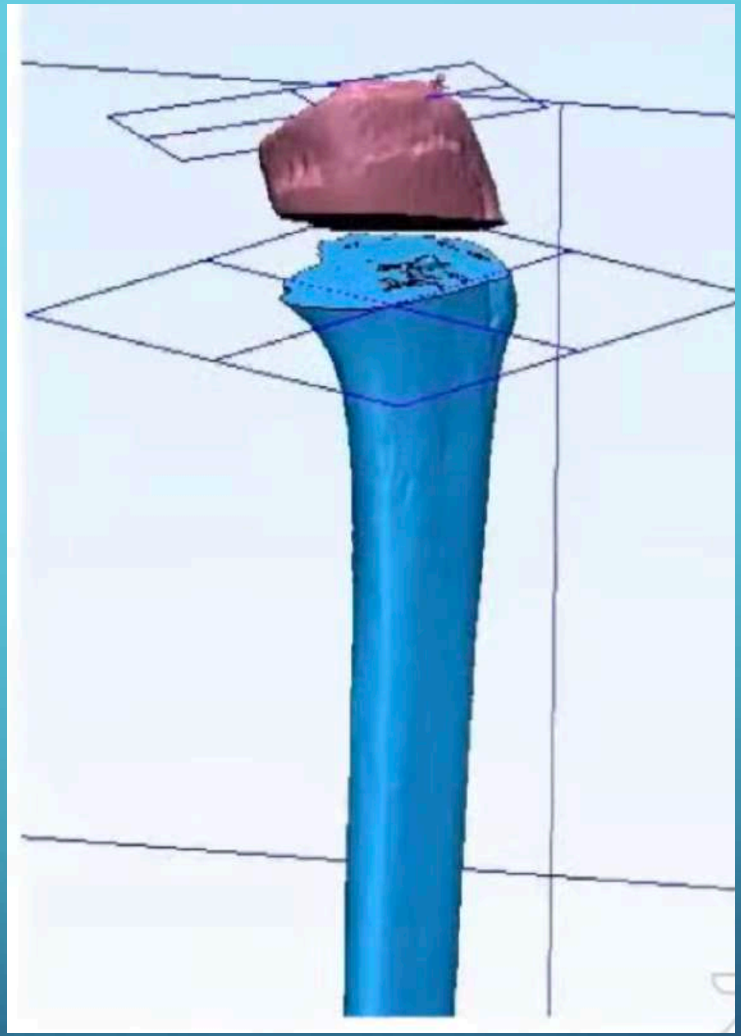
VIRTUAL OSTEOTOMY PERFORMED ALONG THE OSTEOTOMY PLAIN DESIGNED BEFORE FOLLOWED BY CORRECTION OF DEFORMITY USING “INTERACTIVE ROTATE” AND “INTERACTIVE TRANSLATE” FUNCTIONS

CORRECTION ALSO CONFIRMED BY MEASURING APPROPRIATE ANGLES



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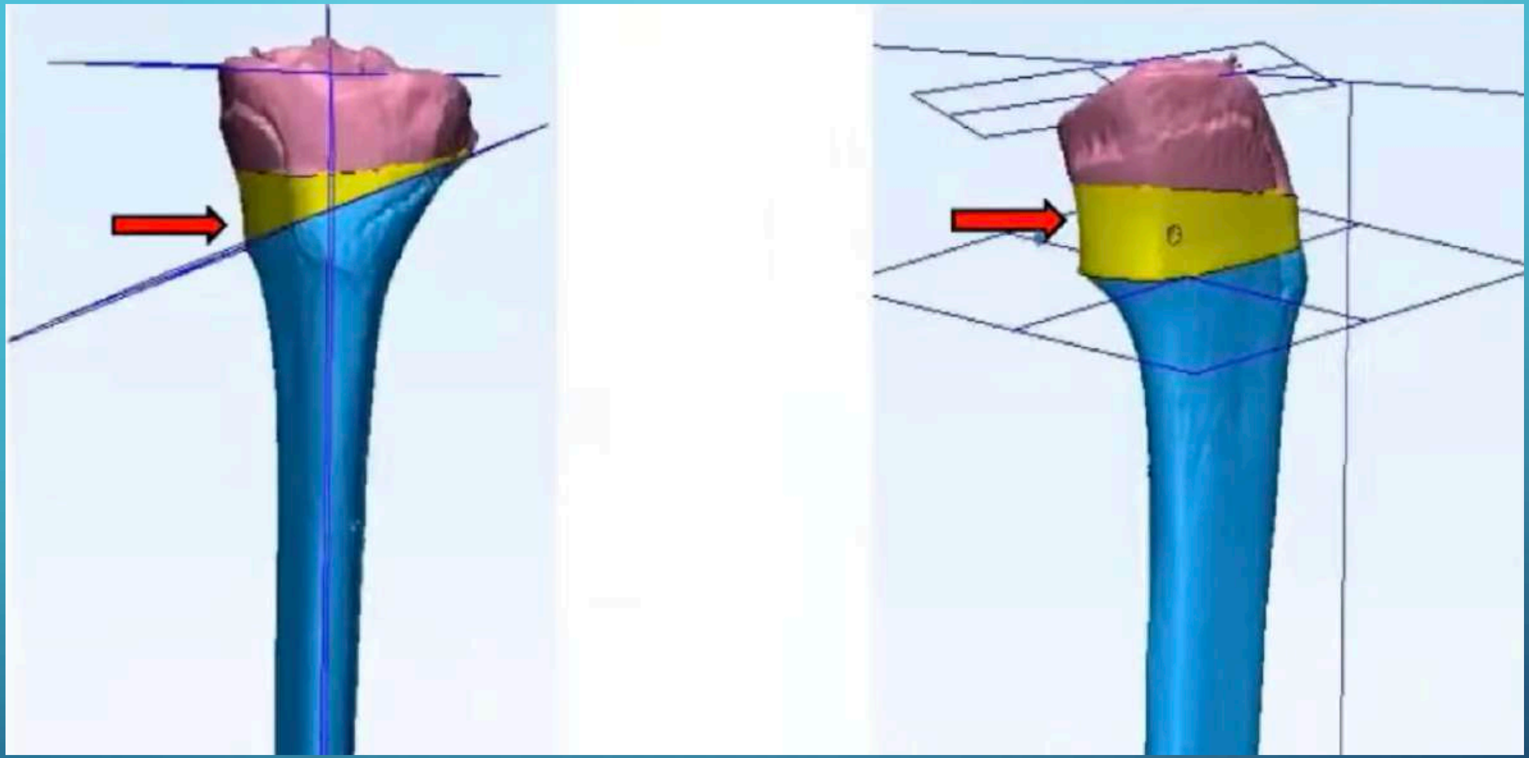
WEDGE DESIGNED TO FIT THE EMPTY VOLUME CREATED AFTER CORRECTION OF DEFORMITY



TRAPEZOIDAL DEFORMITY CORRECTION

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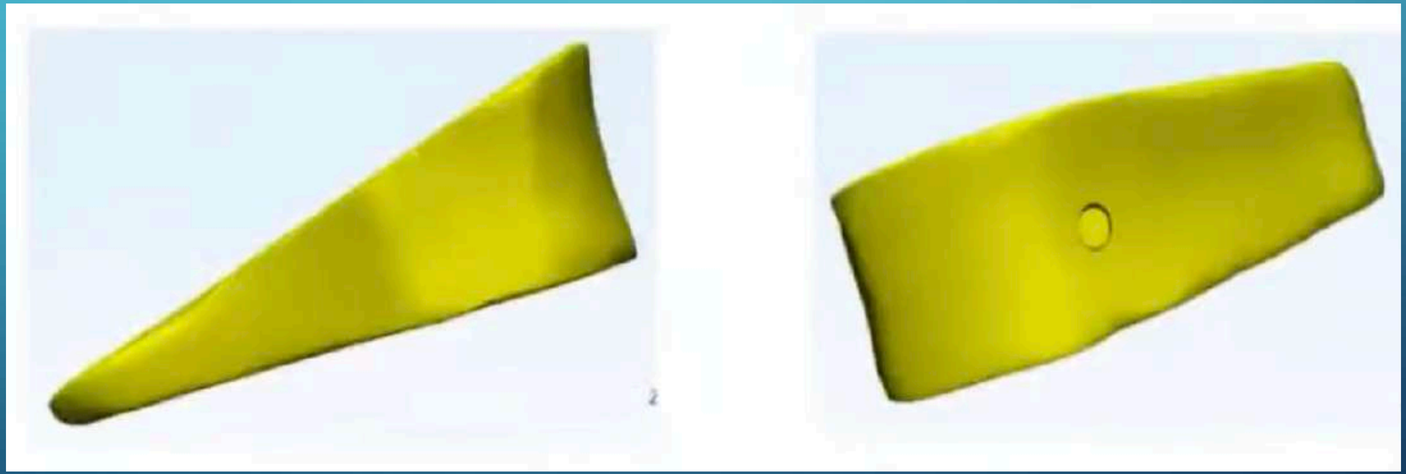
WEDGE EXPORTED AS STL FILE FOR 3D PRINTER

Measurements were done to determine the amount of opening required for correction in medial opening wedge osteotomy



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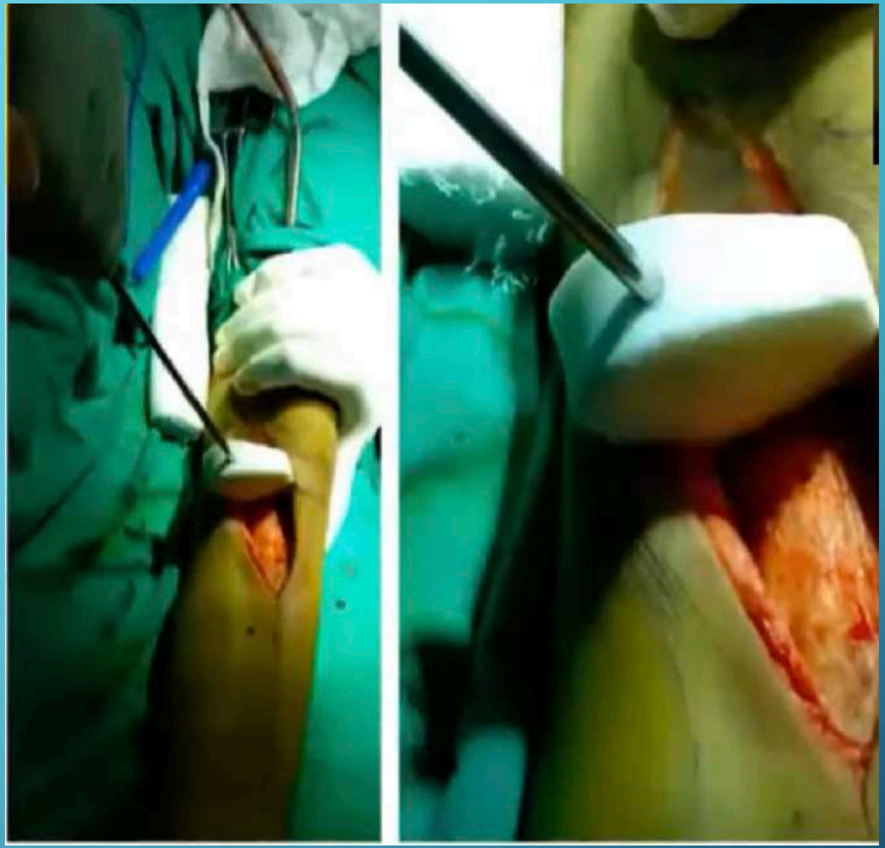
Intra-op pictures



3D Printed wedge being used as a customized chisel to create an appropriate space

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Case : 29y/M Post traumatic hip arthritis secondary to fracture Acetabulum

PROBLEMS :

1. Anatomy?
2. Fracture pattern ?
3. Bone loss ?
4. How to go about it ?

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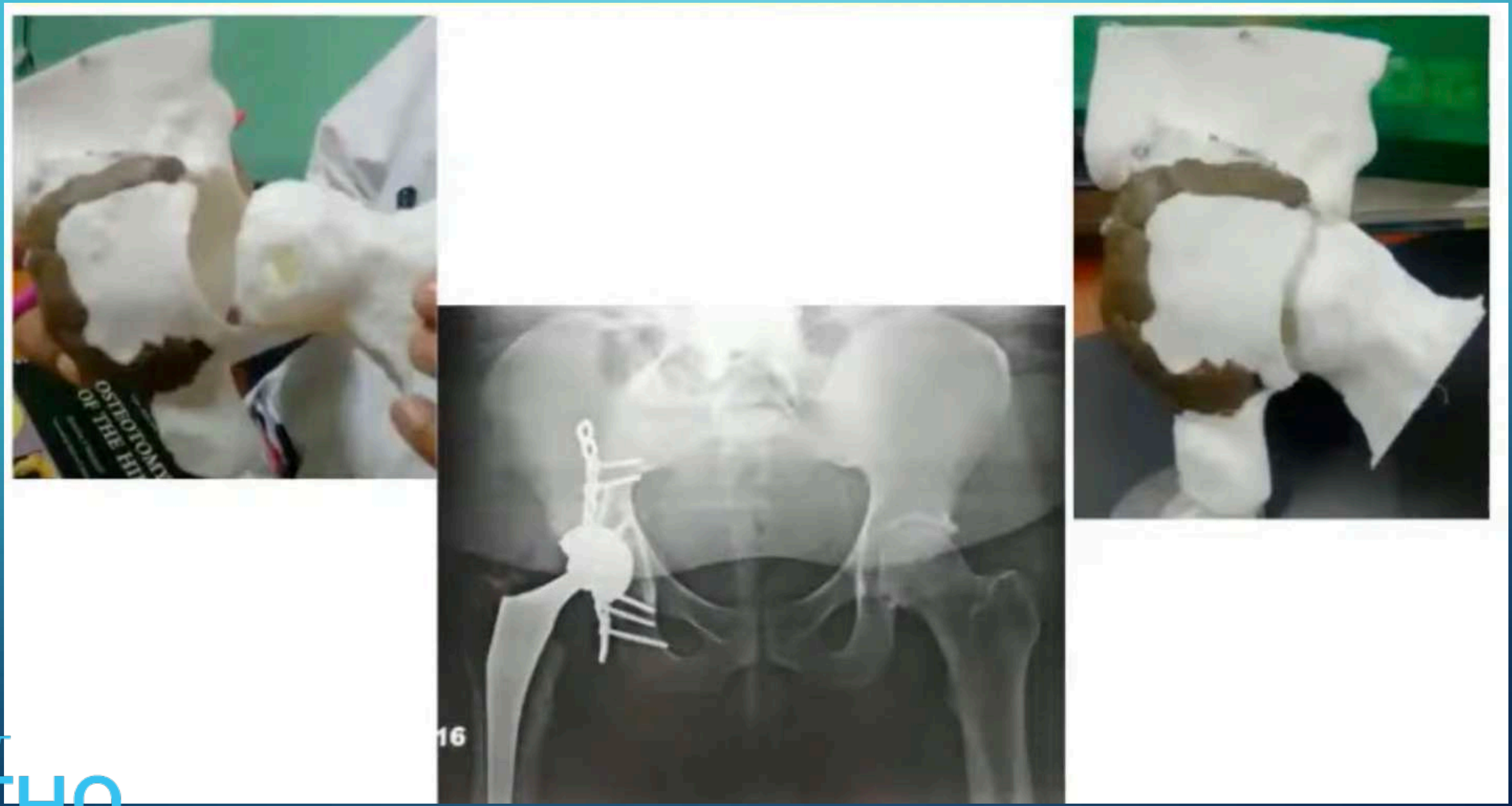
3D Model of the pelvis



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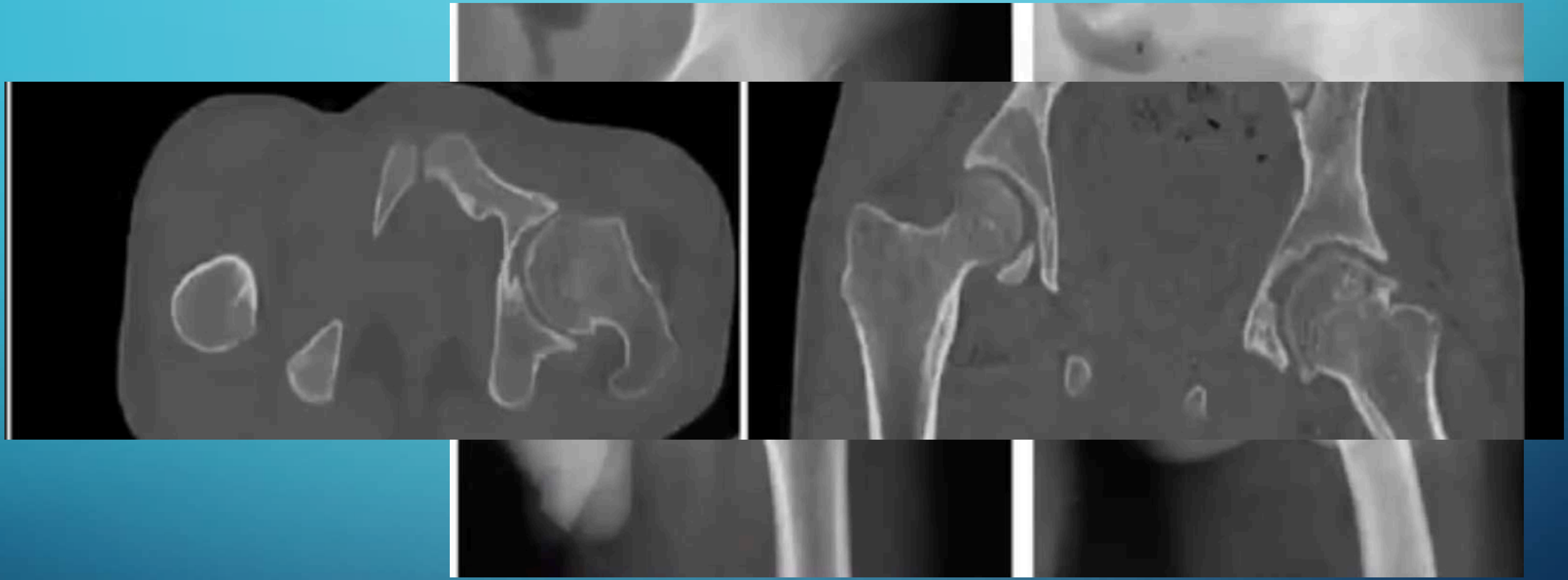
Pre-operative images



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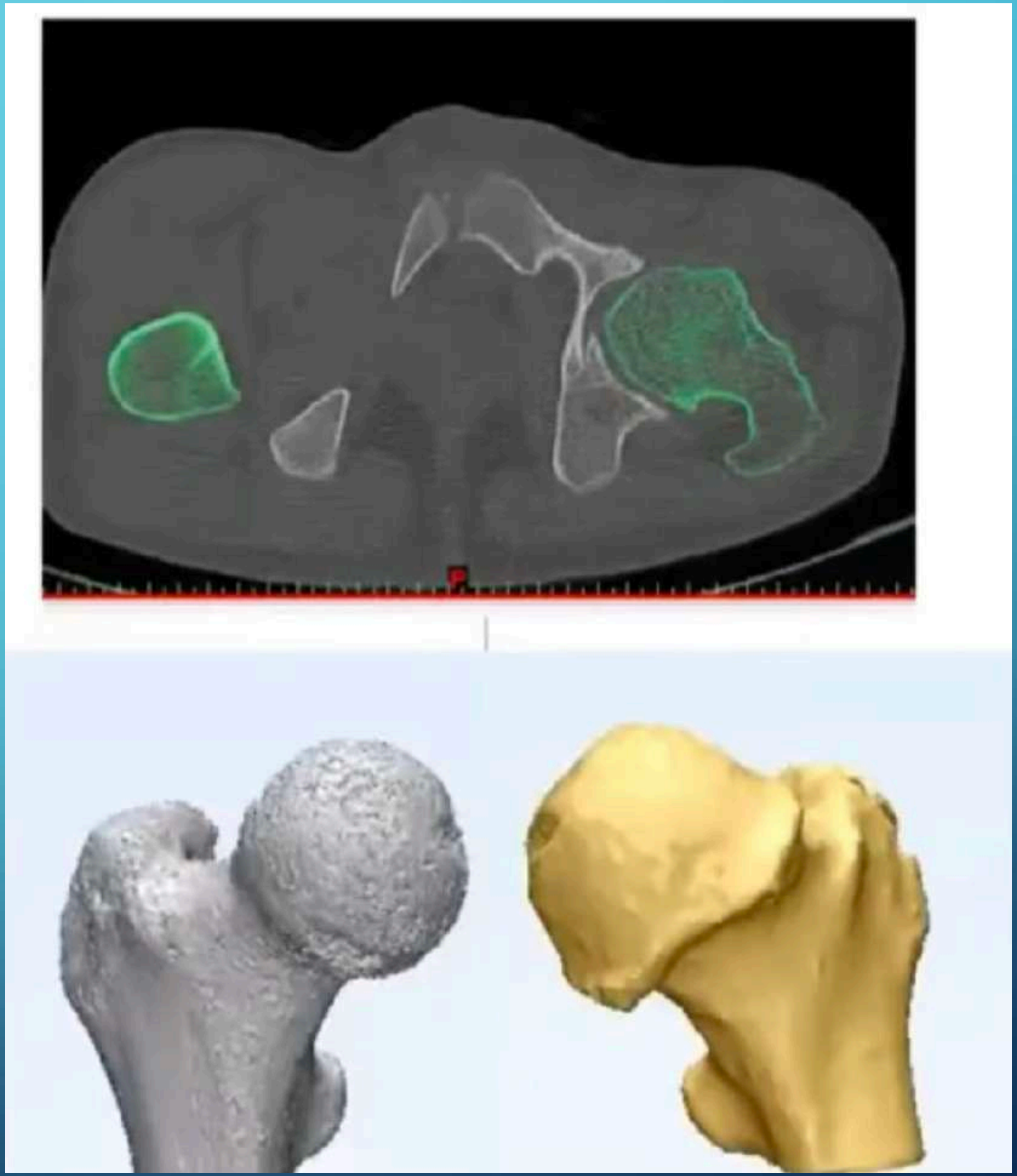
Thresholding & Segmentation done in NCCT DICOM images using software

Virtual 3D model of B/L Femur are generated in software and transferred to 3 matics software as STL files



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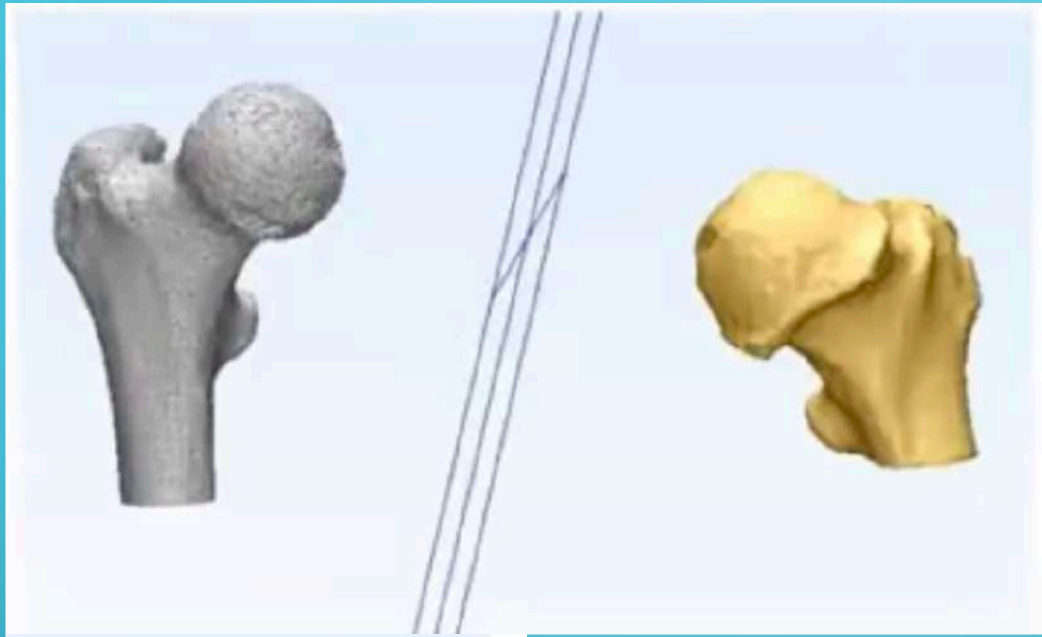

A mid plane is made between two femurs and contralateral normal femur of Right side is selected

A sphere is made fitting the dimensions as of femoral head

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Dimensions are measured and another sphere is made of radius 5mm bigger than previous sphere which is hollow with 5mm of thickness

Then it is trimmed in quarter

Trimmed sphere is attached with a cylinder to act as a handle giving a form of a jig

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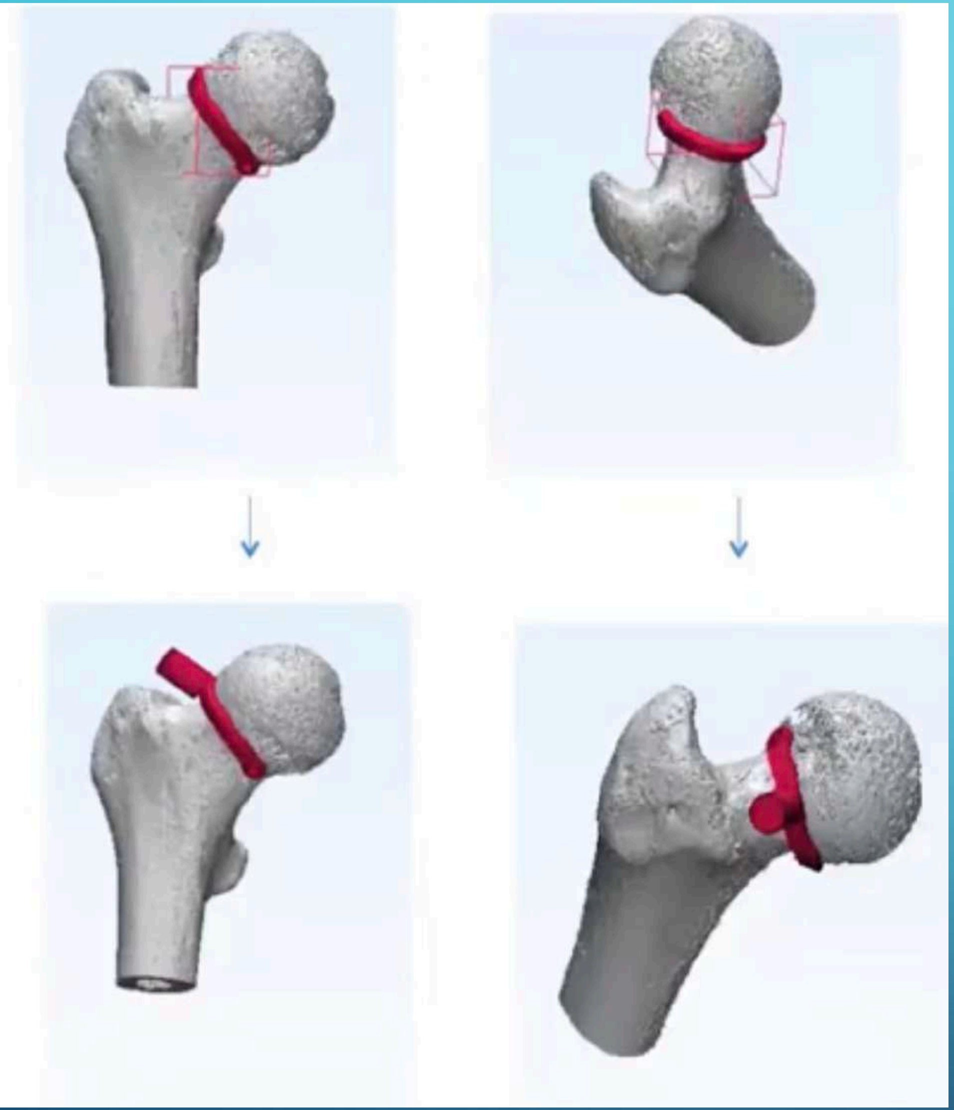

In a same manner a bent customized plate is made matching the contour of femoral neck

A cylinder is also attached to the neck giving it a form of jig

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Femoral head and neck jig is mirrored with respect to the mid plane made earlier

Femoral head and neck jig is placed over left femoral head to have an idea of amount of bone resection during cheilectomy

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These femoral head and neck jig are exported as STL files and converted into G-code
These G-code are then printed using a 3D printer

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ROLE OF 3D PRINTING IN ARTHROPLASTY SURGERIES

JOINT REPLACEMENT TODAY

- COSTLY PROCEDURE
- NO INCREASE IN PRODUCTIVITY SINCE JOHN CHARNLEY ERA
- BIG OP, LONG STAY, MORE PAY

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ROLE OF 3D PRINTING IN ARTHROPLASTY SURGERIES

POST THE 3D REVOLUTION	
	TECHNOLOGY WILL UPSKILL THE SURGEON
	SMALLER PRECISE PROCEDURES
	QUANTITY AND QUALITY WILL RISE
	PRICES WILL FALL

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LOW COST, NO INVENTORY, SUPPLY CHAIN DISRUPTED

SINGLE USE INSTRUMENTS – EFFICIENCY IN THEATRE

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DEVICES USED FOR DEVELOPING 3D HIP PROSTHESIS

1960 – STAINLESS STEEL FORGING
1970 – COBALT CHROME ALLOW CASTING
1980 – TITANIUM CNC MILLING
2010 – 3D PRINTED TITANIUM
2020 – SMART TITANIUM

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SEVERAL OPTIONS IN HIP PROSTHESIS –

FURLONG, 10A RATED STEM

EVOLUTION, SHORT STEM

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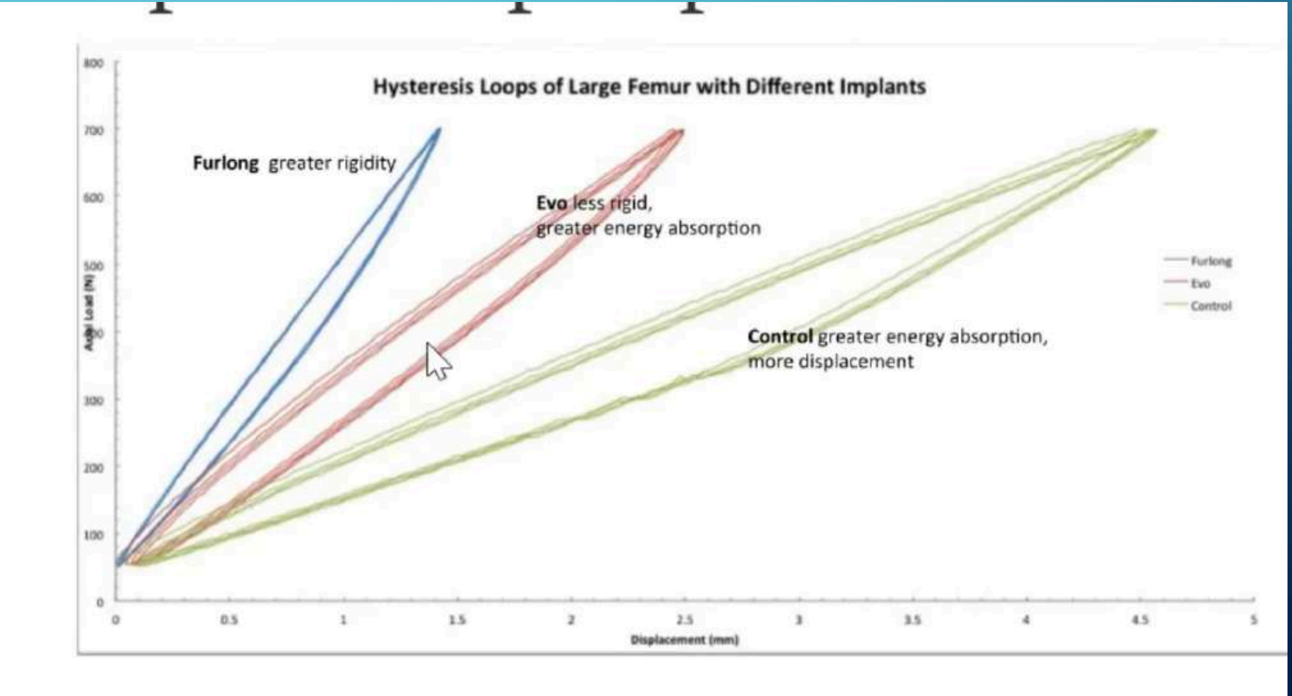
Shorter stems cause less stiffness



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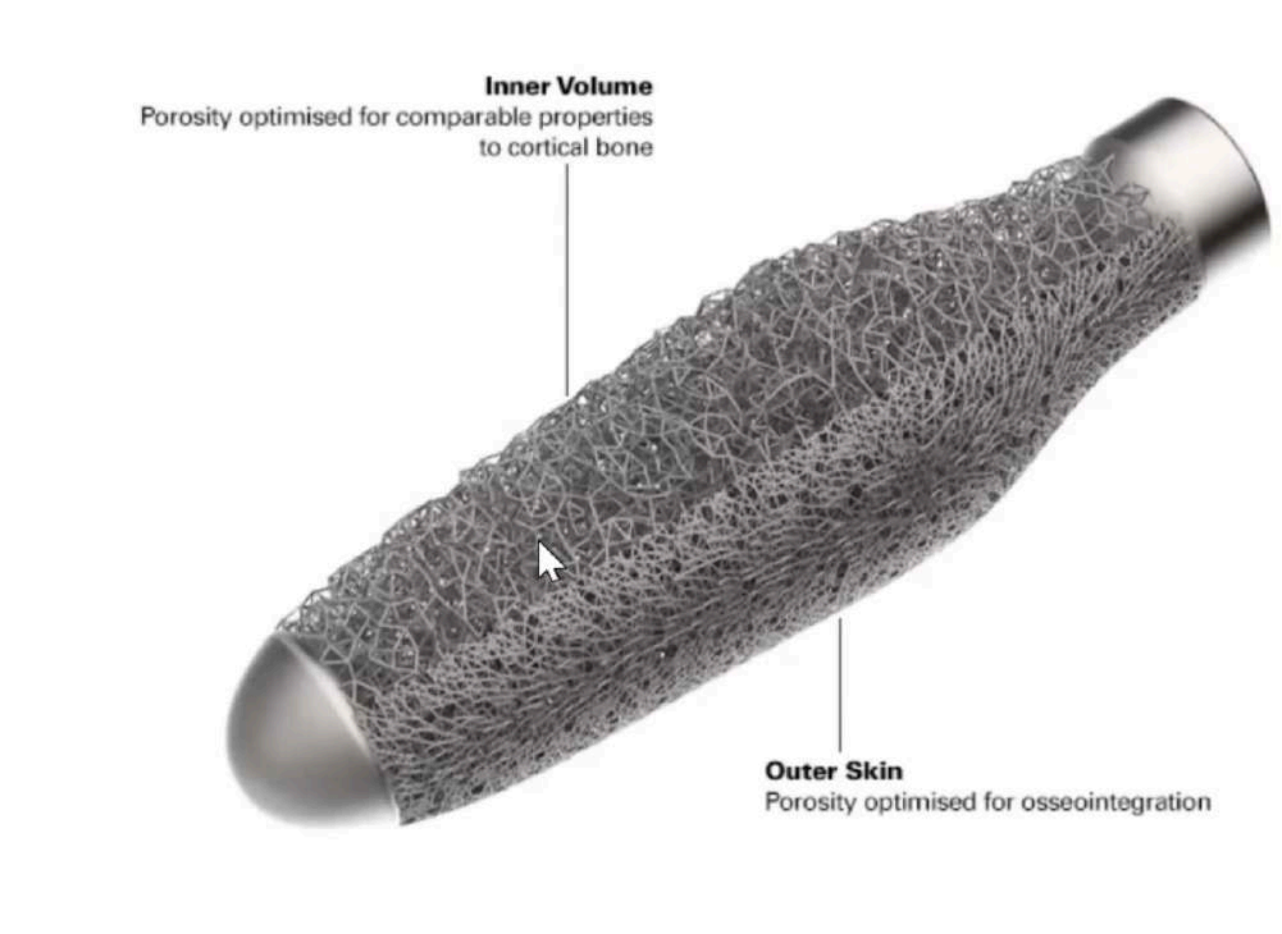
SMART TITANIUM



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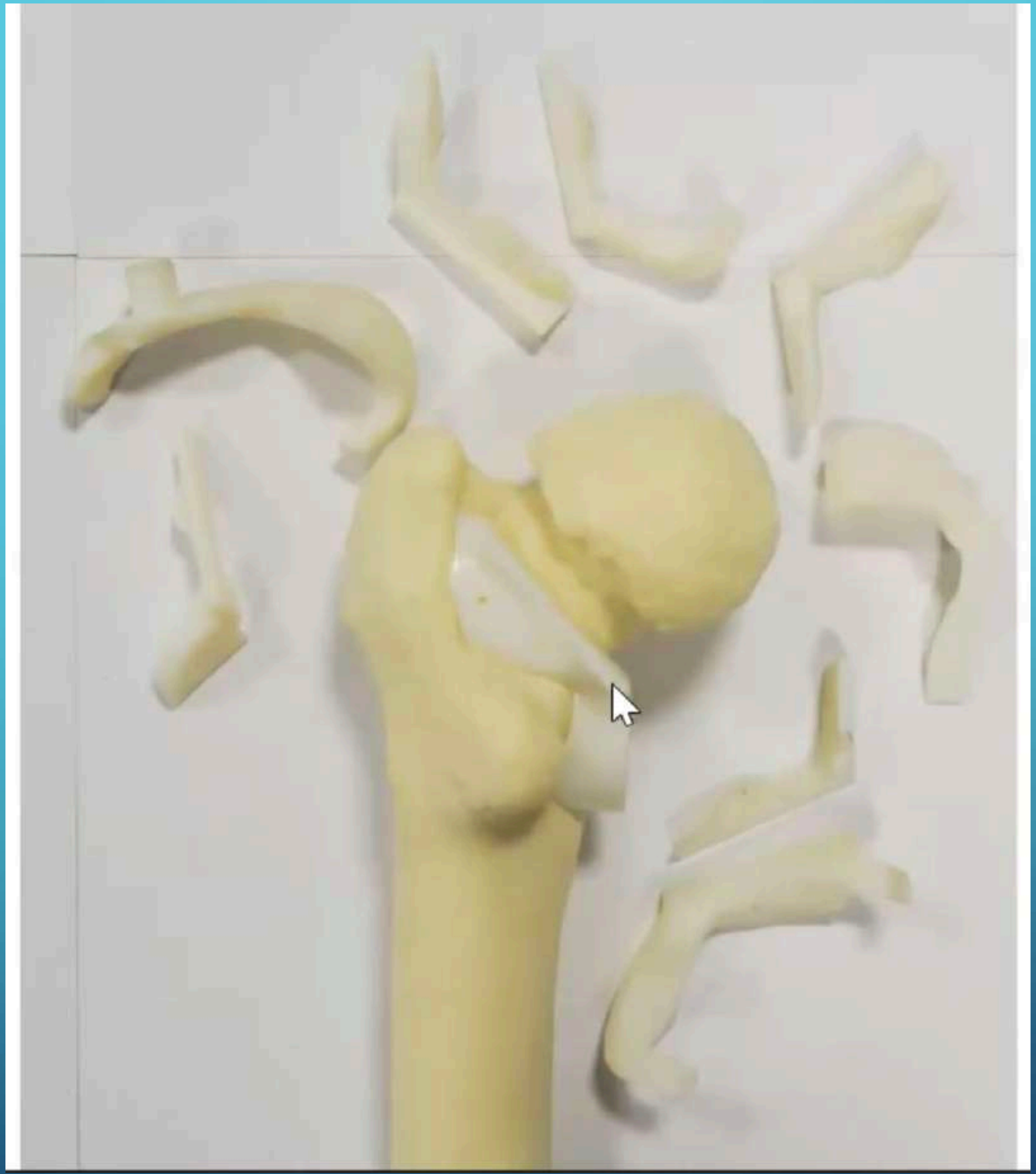

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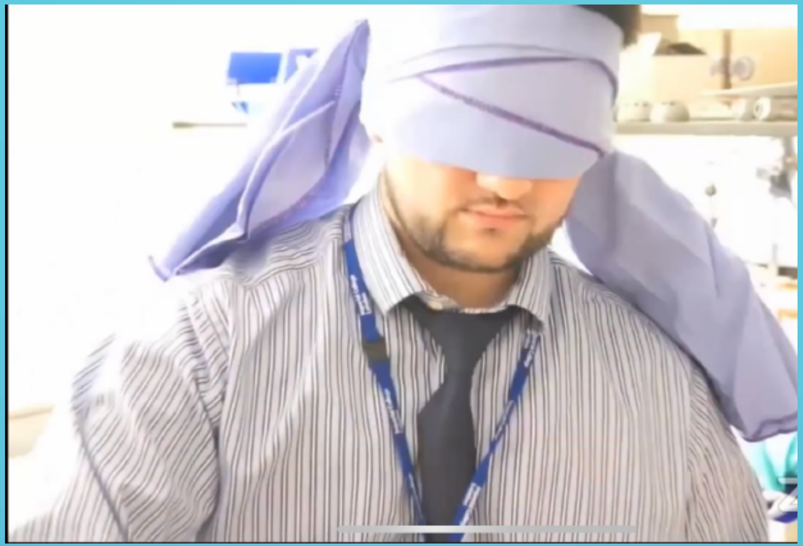

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PATIENT SPECIFIC CUSTOM IMPLANTS

- Although standard implants are made to fit most of the general population, a personalized fit is required in cases with variations in anatomy and cases in which no already produced implant would suffice (eg, severe bone loss for trauma, cancer, and infection)

- Custom implants are arguably the most ground-breaking aspect of 3D printing for orthopedic surgery; surgeons can now design and implant custom devices

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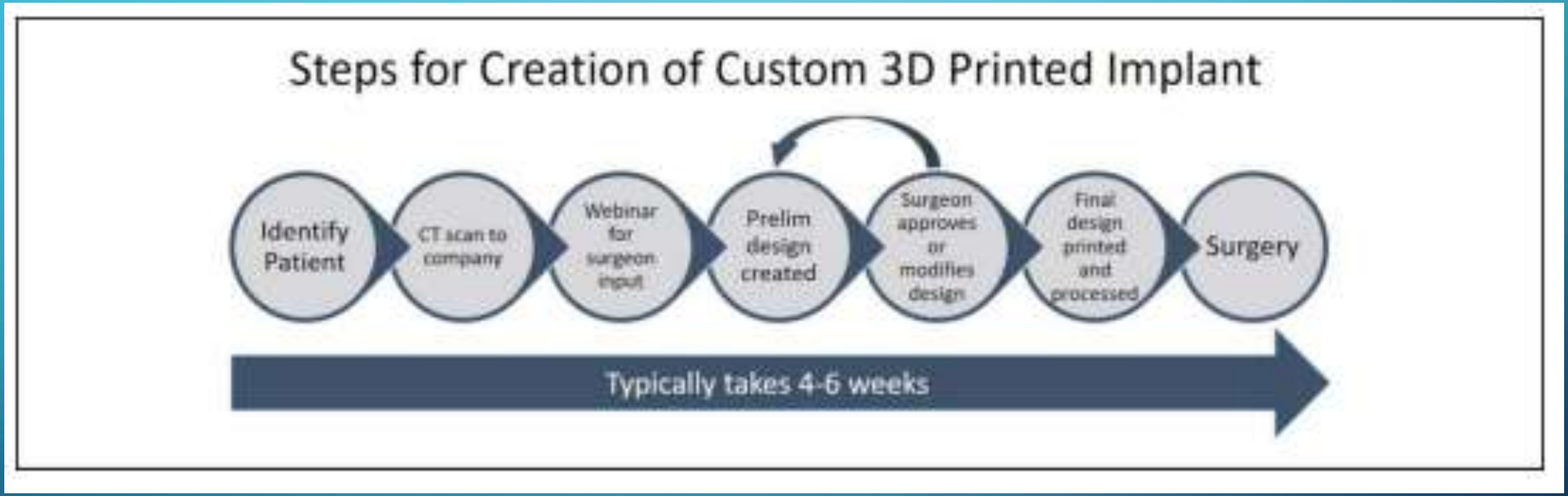
PATIENT SPECIFIC CUSTOM IMPLANTS



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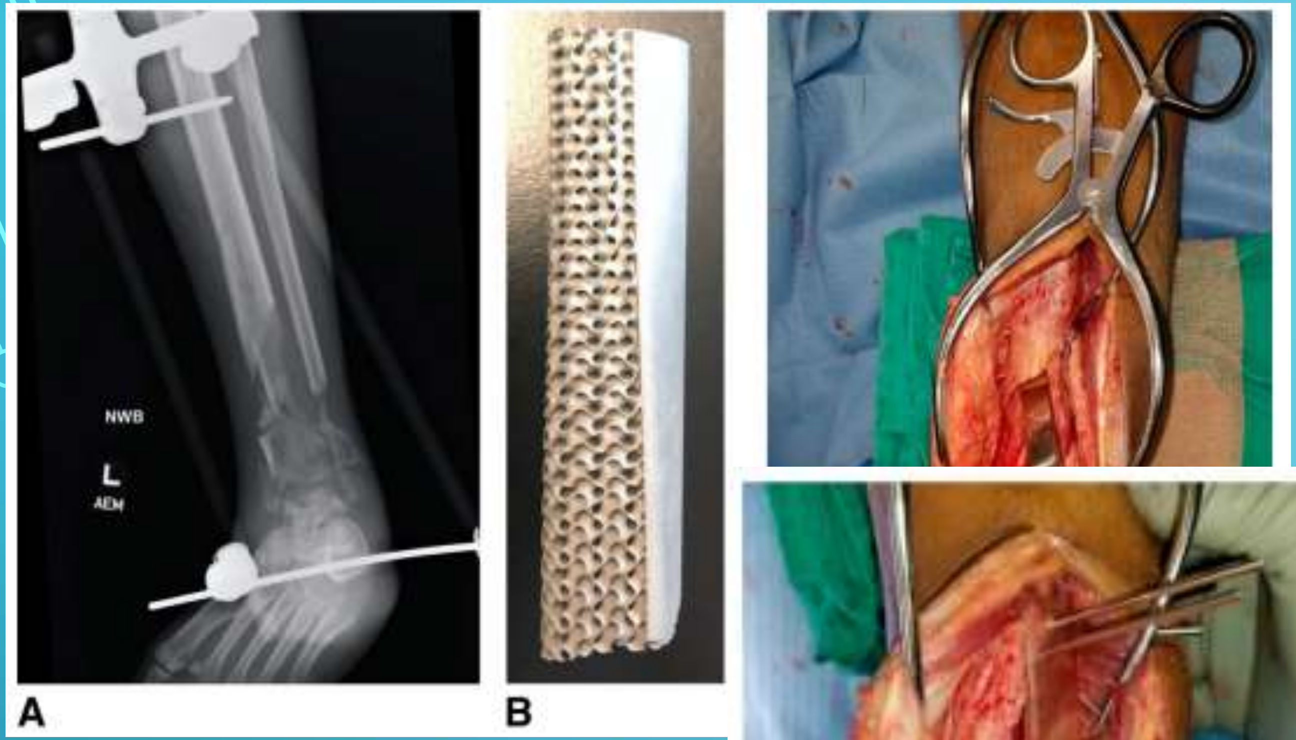

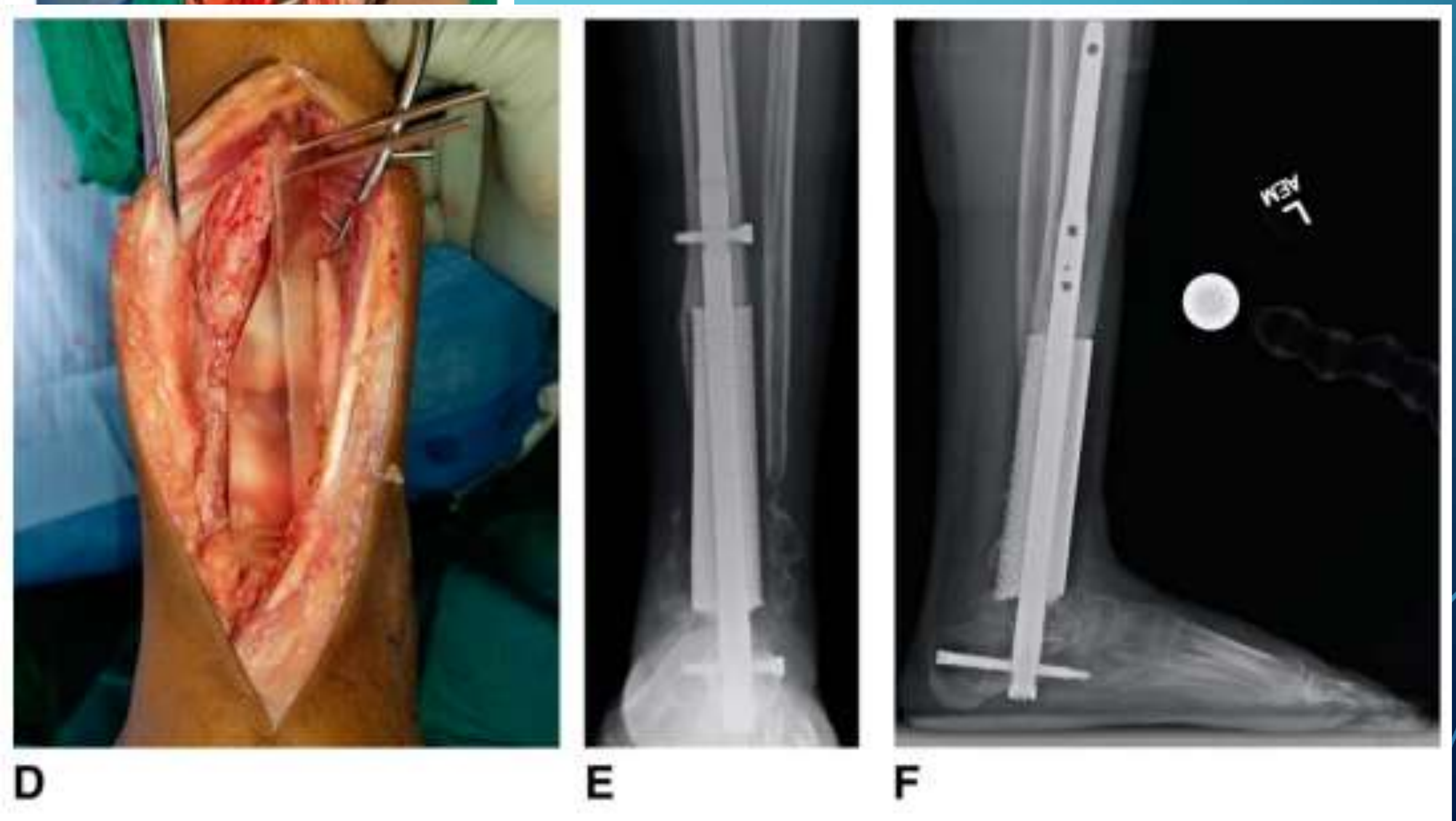

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3D BIOPRINTING

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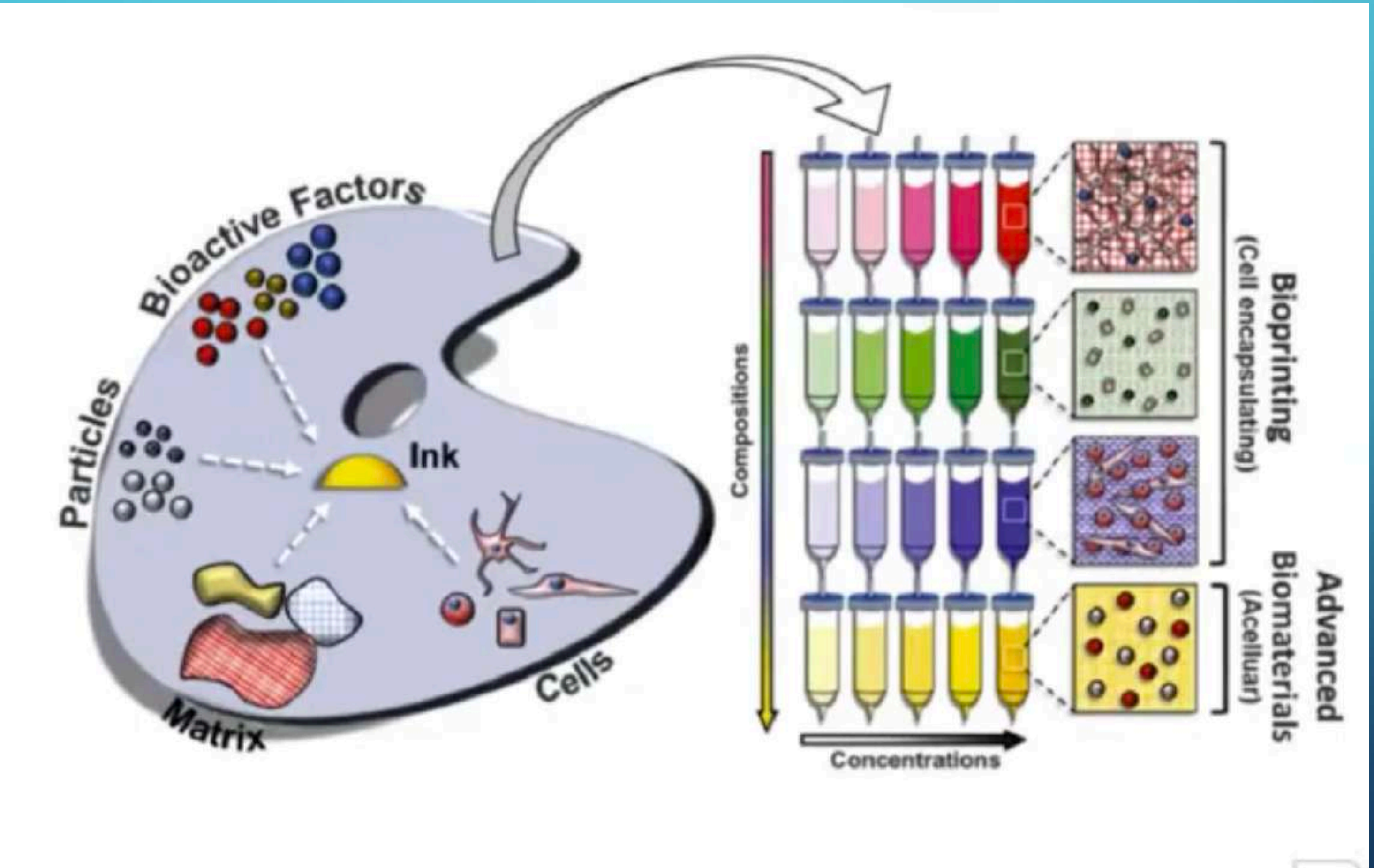
3D Bio printing



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3D Bio Printing

- 2003 – 3D Printing for producing a cellular construct was first introduced, when Thomas Boland of Clemson University patented the use of inkjet printing for cells
- Organs that have been successfully printed and implemented in a clinical setting are skin, blood vessel and bladder
- 2009: 3D Printed blood vessel (ORGANOVA)
- 2013: Human liver tissue (ORGANOVA). It is not suitable for transplantation, and has primarily been used for as a medium for drug testing
- 2016: 3D printed Kidney tissue (Harvard Jennifer Lewis's lab)

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3D BIOPRINTING

- Known officially as 3D bioprinting, this process distributes cells, biomaterials, and supporting biological factors in a layer-by-layer fashion to form living tissues and organ analogs
- To make this possible, the medium for printing is composed of inert material that can support live cells.
- Examples include hydrogels, microcarriers, tissue spheroids, cell pellet, tissue strands, and decellularized matrix components

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CARTILAGE BIOPRINTING

- Most restorative techniques create a form of functional cartilage; however, it is not the same as healthy articular cartilage at a molecular level

- Three-dimensional bioprinting presents an alternative solution as the ability to print native cartilage would be groundbreaking in the management of cartilage defects and arthritis

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THREE-DIMENSIONAL BIOPRINTING OF MULTILAYERED CONSTRUCTS CONTAINING HUMAN MESENCHYMAL STROMAL CELLS FOR OSTEOCHONDRAL TISSUE REGENERATION IN THE RABBIT KNEE JOINT - **SHIM ET AL**

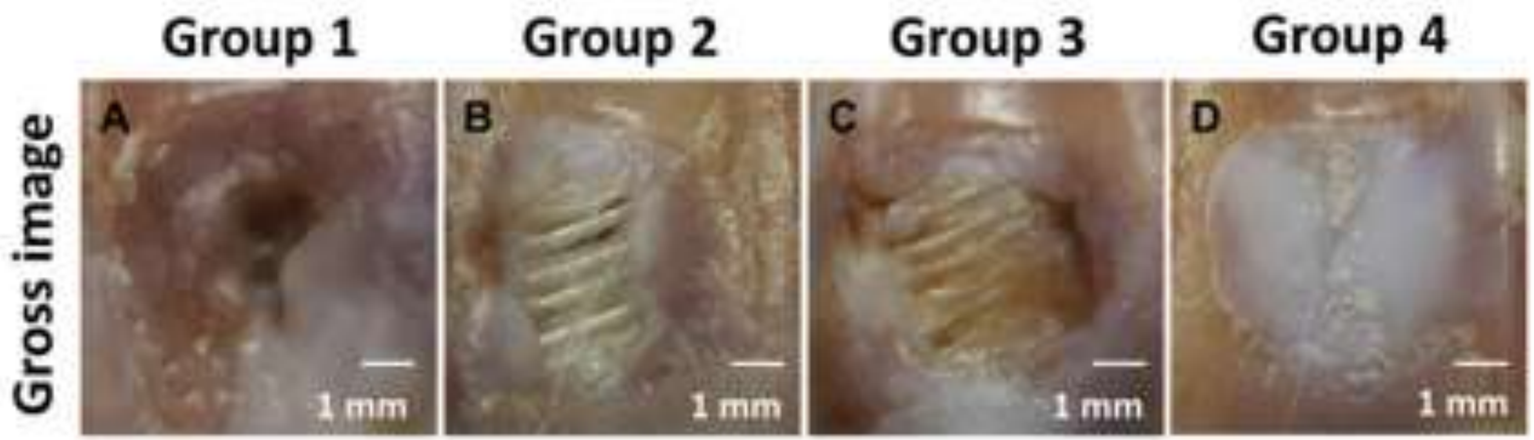

Figure 5. Gross morphology of bone regeneration in the four groups (A–D) at 8 weeks after implantation.

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BONE BIOPRINTING

- Scaffolds are an essential technology for both bone tissue engineering and regenerative medicine as they provide the substrate where cells can attach, proliferate, and differentiate into bone. Important characteristics to consider are biocompatibility, biodegradability, microstructure, and osteoconductivity

- With the advent of 3D printing, it has become easier to control the microstructure, which is critical to cell viability and osseous ingrowth. Furthermore, the material of the scaffold is integral to maintaining cell viability and facilitating osteogenic differentiation

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MATERIALS USED

- **Calcium phosphate** is one of the most commonly used materials for 3D-printed bone scaffolds and has gained attention for its superior biodegradability

- **HA** did not demonstrate any biodegradation.

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ISSUES FACED

- These 3D products still face many challenges: growing the correct number of functioning cells, reaching the appropriate cell density, and retaining viability throughout the printing process, but its future potential could revolutionize regenerative medicine

- The bioprinting process is a threat to the viability of the cells because they must endure the pressure and shear stress of the printing process and then manage to migrate and proliferate appropriately while receiving sufficient blood supply

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FOUR DIMENSIONAL PRINTING

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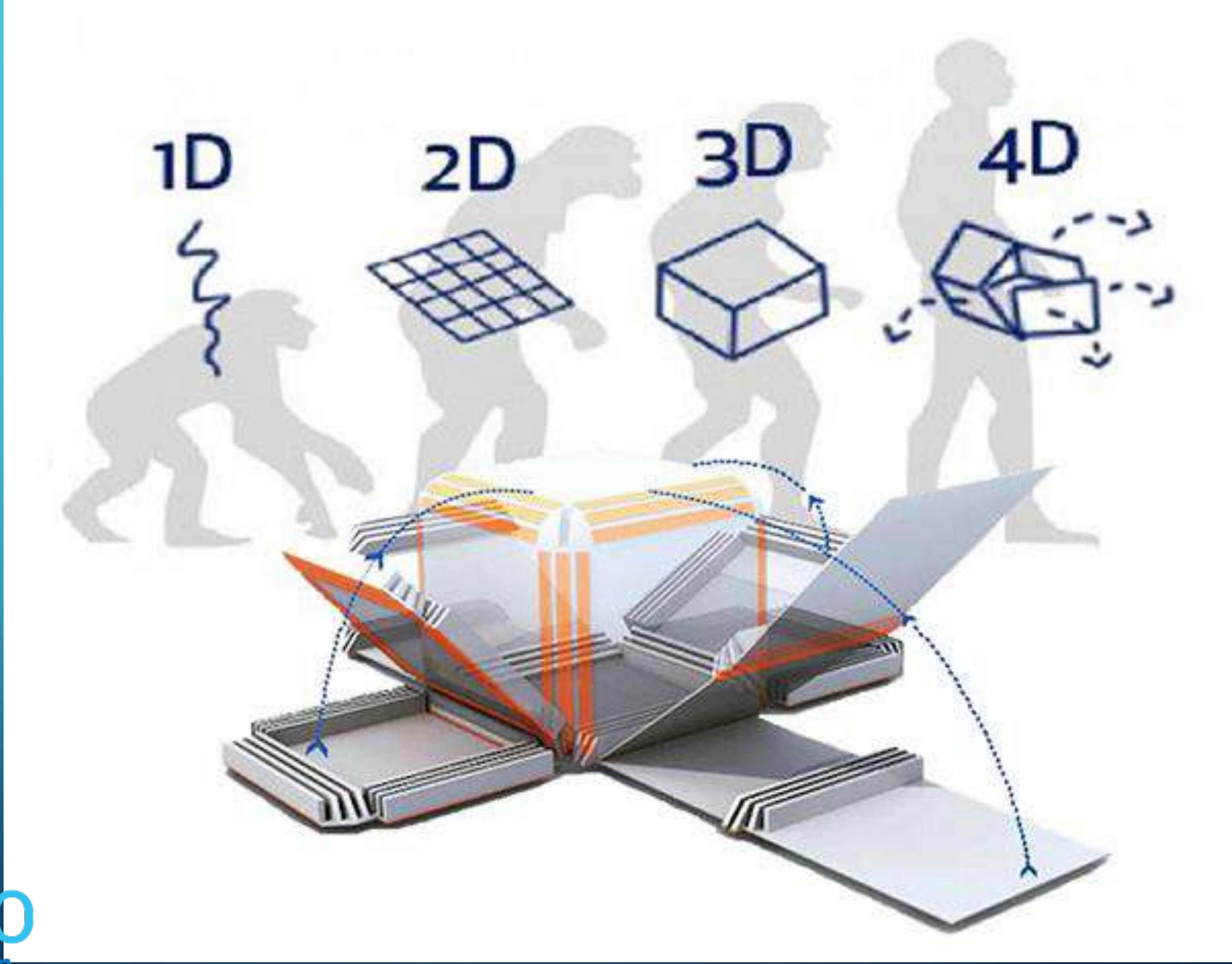

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4D PRINTING

- Four-dimensional (4D) printing uses the same set of technologies as 3D printing but adds in one more dimension by allowing the printed part to change shape over time in response to a specific environment

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4D PRINTING

- Four-dimensional printed objects can self repair or self-assemble by changing or reshaping their parts in response to varying environmental conditions (eg, temperature, pH, magnetic field, and solvent interaction).

- For example, photo thermal-responsive shape memory bone tissue engineering scaffolds were constructed and exposed to near-infrared radiation before implantation so that they could be easily molded and configured into a bony defect. After implantation, the temperature rapidly decreased to 37 degrees Celsius, at which temperature the scaffold displayed mechanical properties analogous to those of cancellous bone

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THANK YOU !!

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