Future of Fracture Fixation: A Generative Design Approach to Surgical Implants

Sanjeevan Kanagalingam | Peter Champneys

Doctoral Researcher | Technical Specialist

AUTODESK. UNIVERSITY

Agenda

ADDITIVE MANUFACTURING

An overview of additive manufacturing, specifically how it is changing the way we design products for the medical industry.

GENERATIVE DESIGN

We’ll talk about some of the challenges and opportunities around additive manufacturing. And how we can use generative design as a design tool for additive.

DATA DRIVEN DESIGN PROCESS FOR MEDICAL IMPLANTS

Walkthrough of the process used to create patient specific implants using a data capture, generative design and additive manufacturing workflow.

Peter Champneys

Autodesk – Technical Consultant

Peter is a technical consultant working out of the Autodesk technology center in Birmingham UK. He is a specialist in additive manufacturing and generative design, and works alongside Autodesk customers to help them implement emerging MAKE processes into their day to day workflows.

Sanjeevan Kanagalingam

University of Birmingham – Doctoral Researcher

Sanjeevan has a Masters in mechanical engineering, currently pursuing a doctorate with the biomedical engineering group at University of Birmingham. His areas of interest are around the design and application of additive manufacturing in the medical industry, with a particular focus on patient-specific implants.

UNIVERSITY OF BIRMINGHAM

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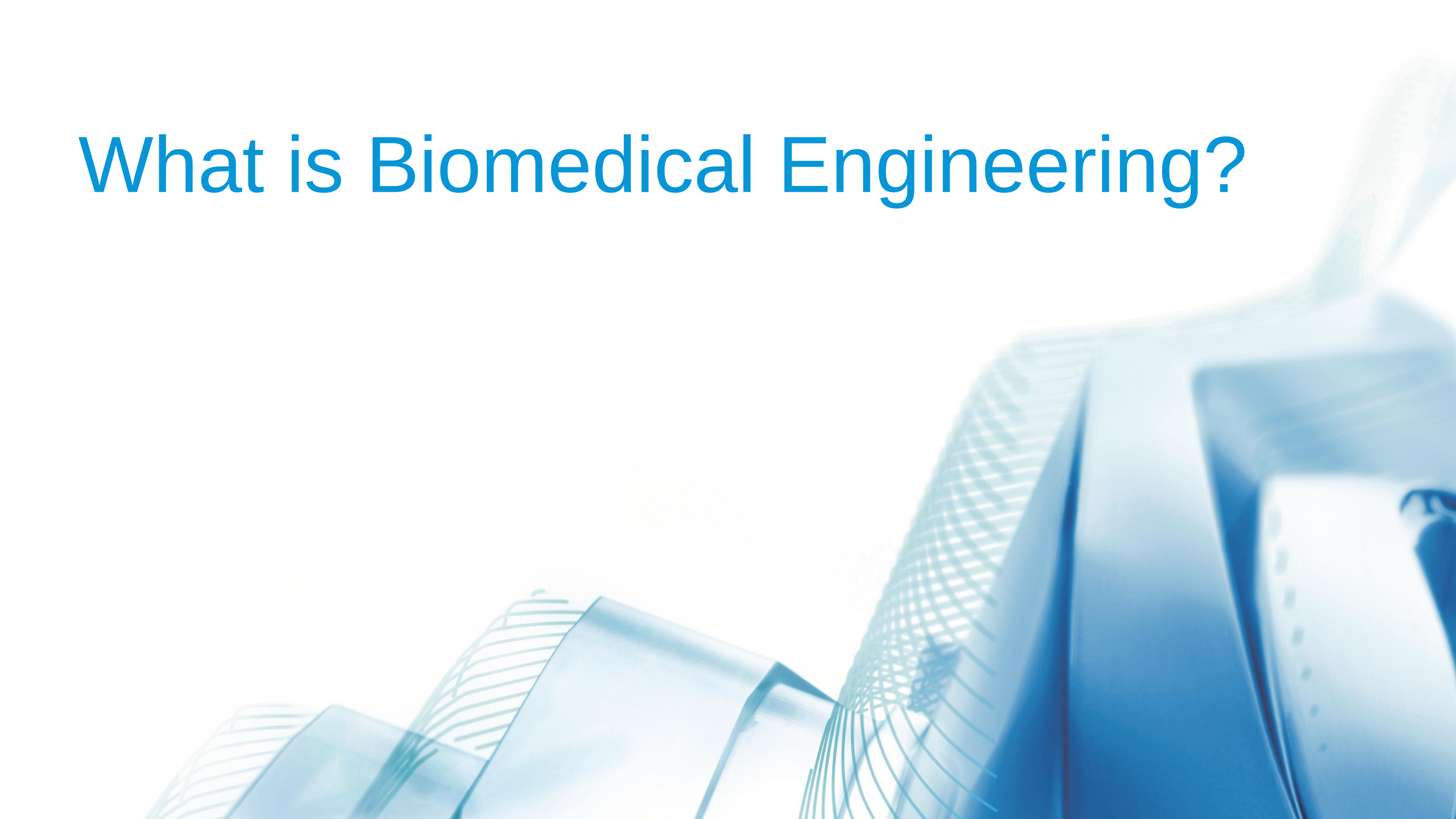
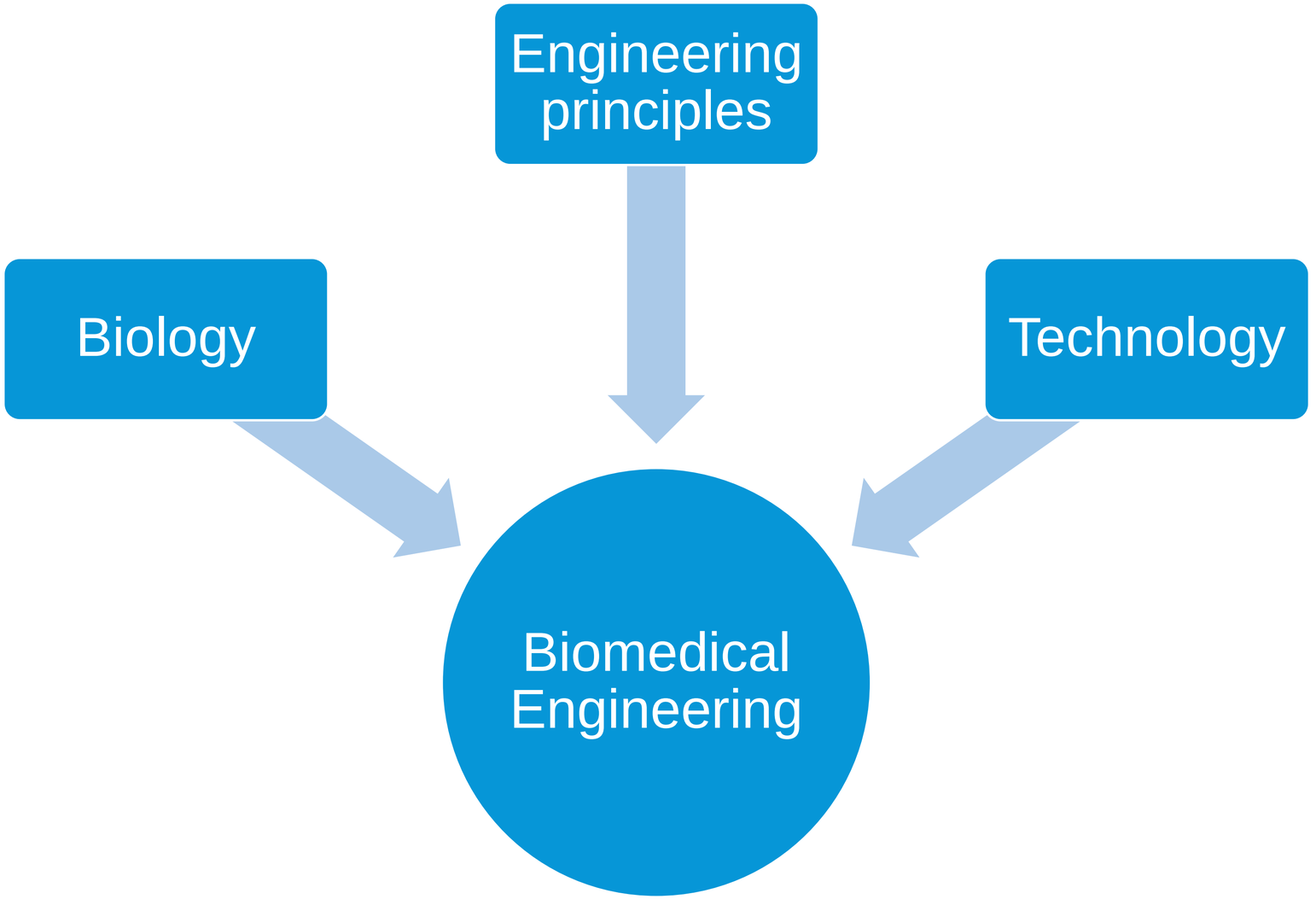
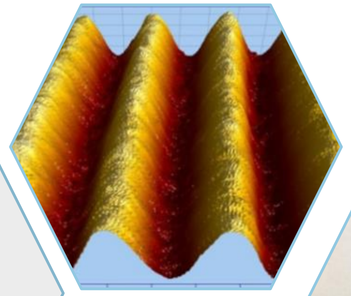
What is Biomedical Engineering?



Biomedical Engineering

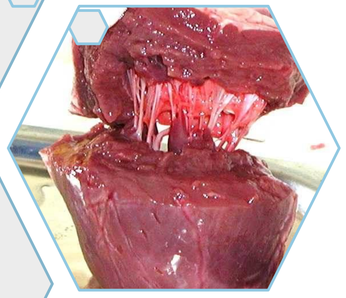


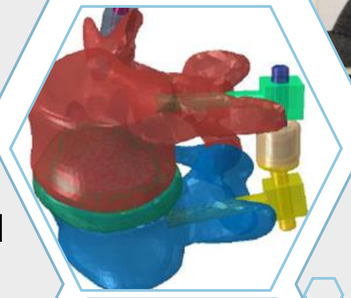
Biomedical Engineering Research at University of Birmingham



Design

Biomaterials





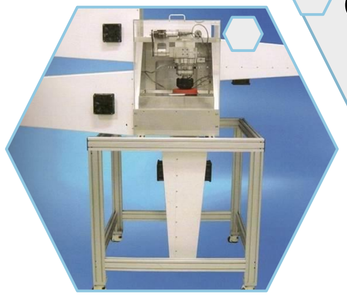
Medical Devices

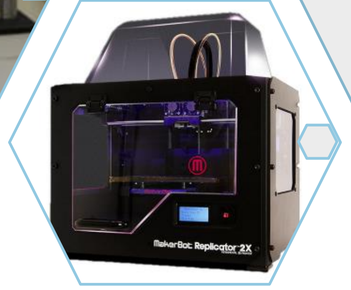
Translational Medicine

Computational Modelling

Mechanical Testing

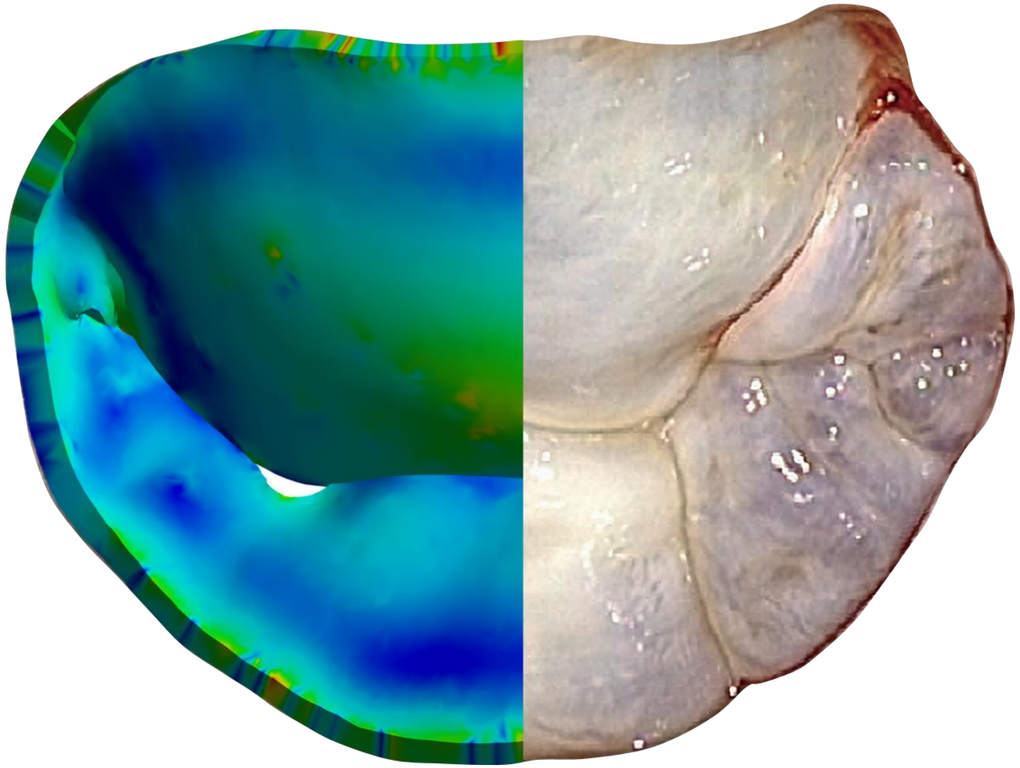
Industrial Collaboration

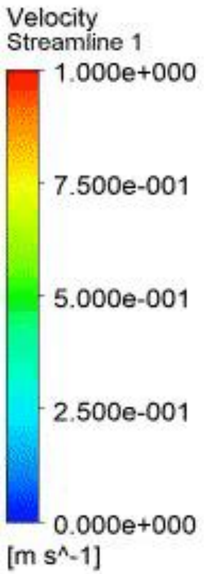


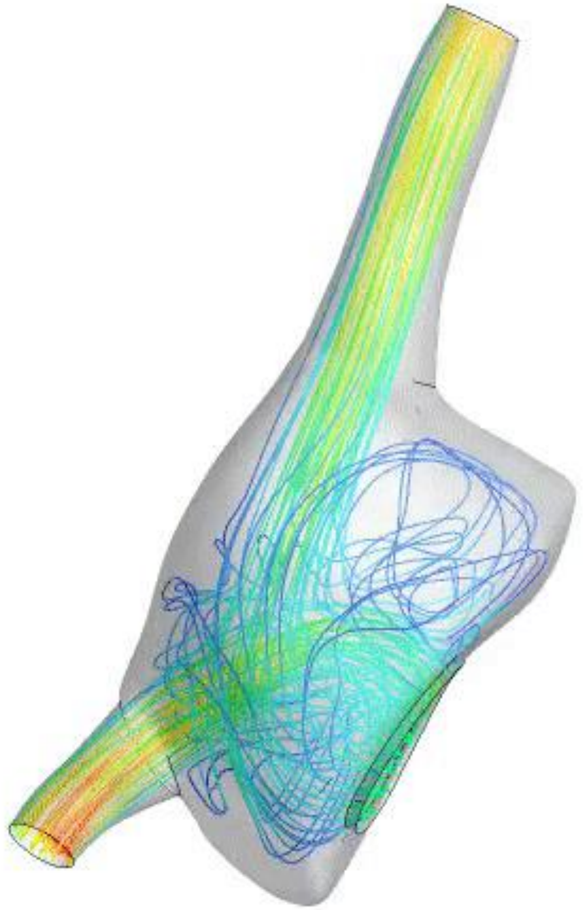


Additive Manufacture

Cardiovascular Research







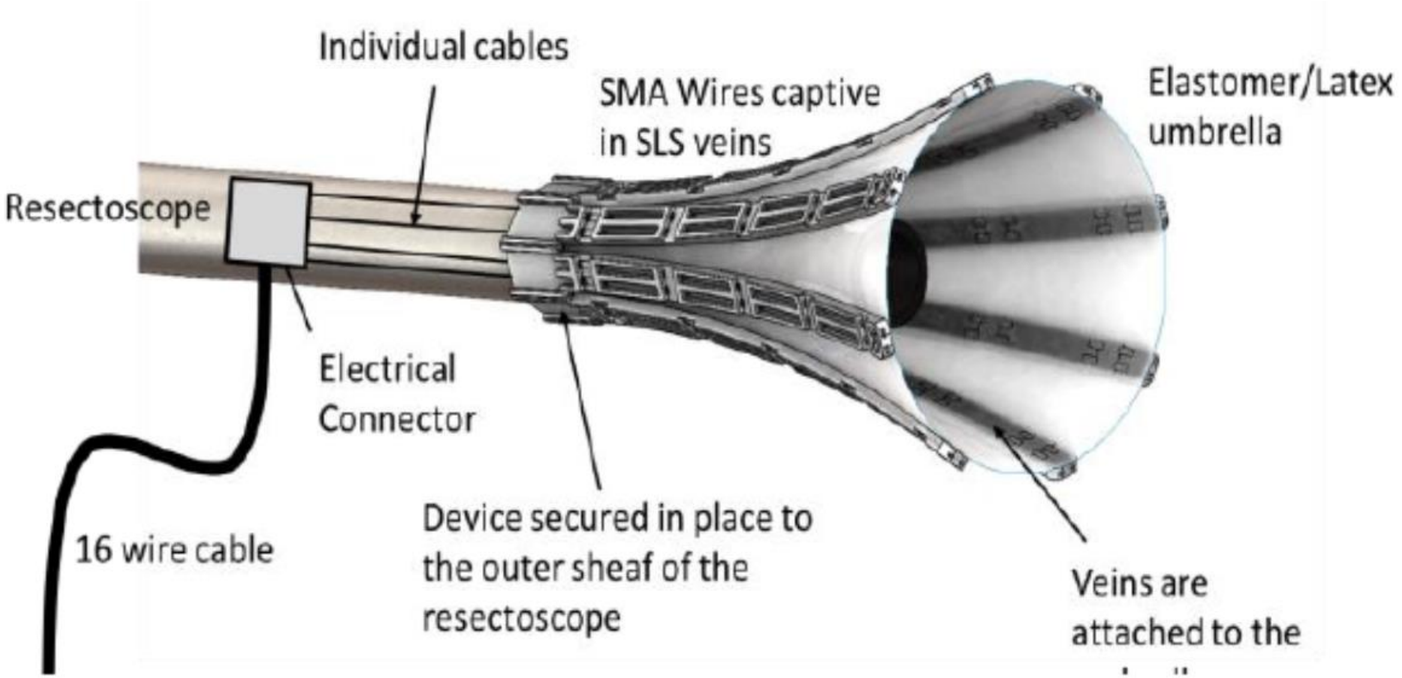
Understanding Heart Valves

Image courtesy of Diana Oliveira

Predicting Heart Blood Flow

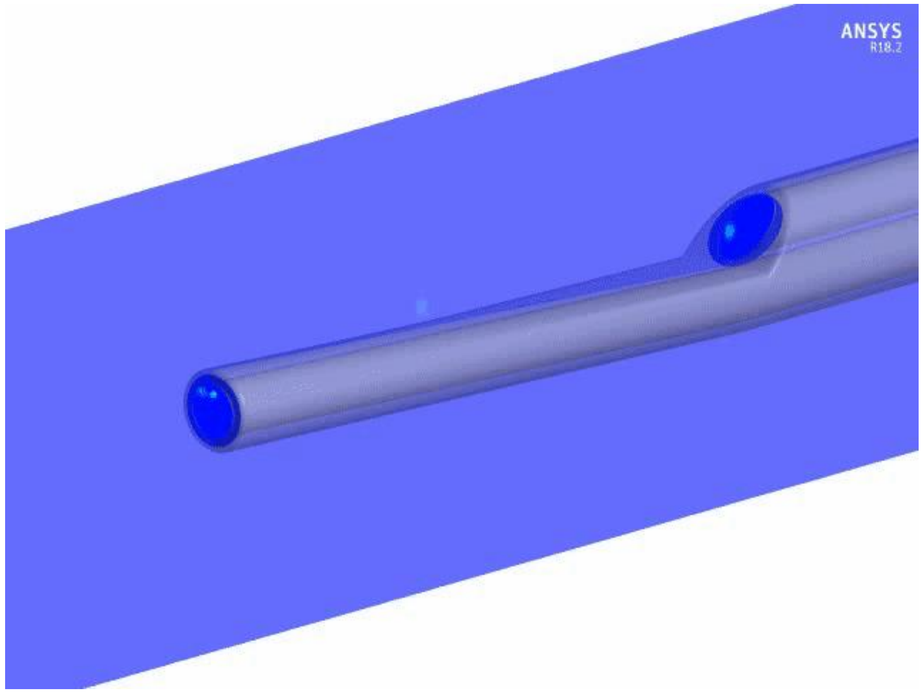
Image courtesy of Diana Oliveira

Medical Devices



Novel Tumour Surgical Device

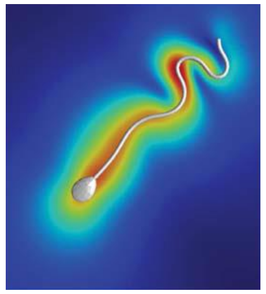
Image courtesy of Cambridge Mechatronics Ltd

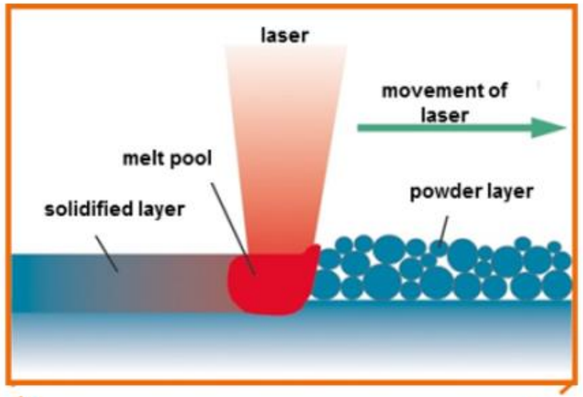


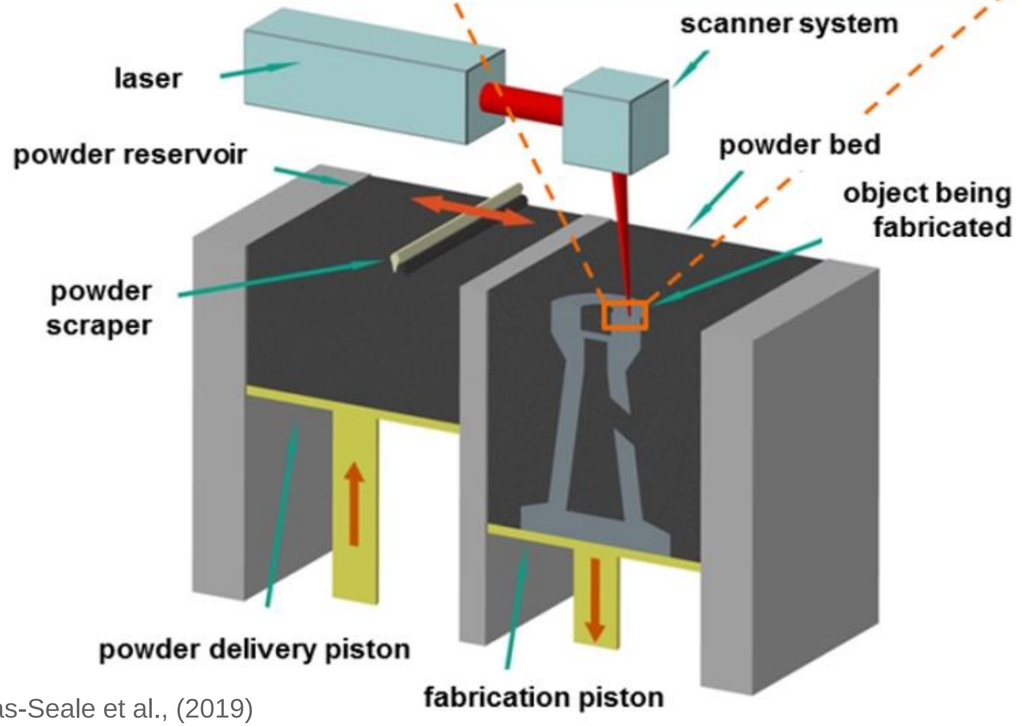
Analysing Dialysis Catheters

Image courtesy of David Owen

Design the Future:
Developmental Biology and Additive Manufacture







Images Courtesy of L.E.J. Thomas-Seale et al., (2019)

Design the Future

MECHANICAL ENGINEERING | RESEARCH ARTICLE

The analogies between human development and additive manufacture: Expanding the definition of design

Authors
L. E. J. Thomas-Seale, J. C. Kirkman-Brown, S. Kanagalingam, M. M. Attallah,D. M. Espino & D. E. T. Shepherd

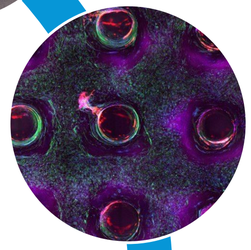
(Published 2019)

Additive Manufacturing in Medicine

AM in Medicine

Additive Manufacture

Anatomic Models



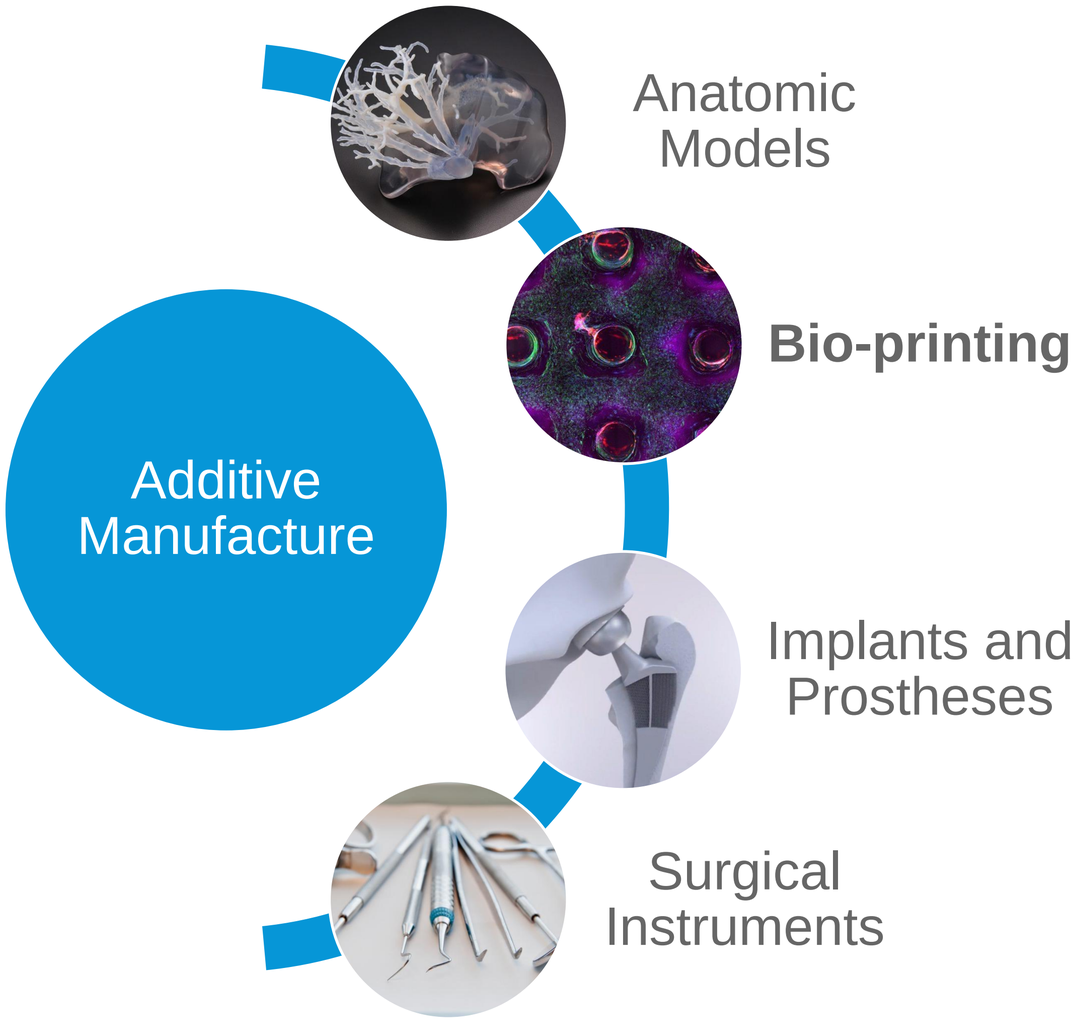
Bio-printing

Implants and Prostheses

Surgical Instruments

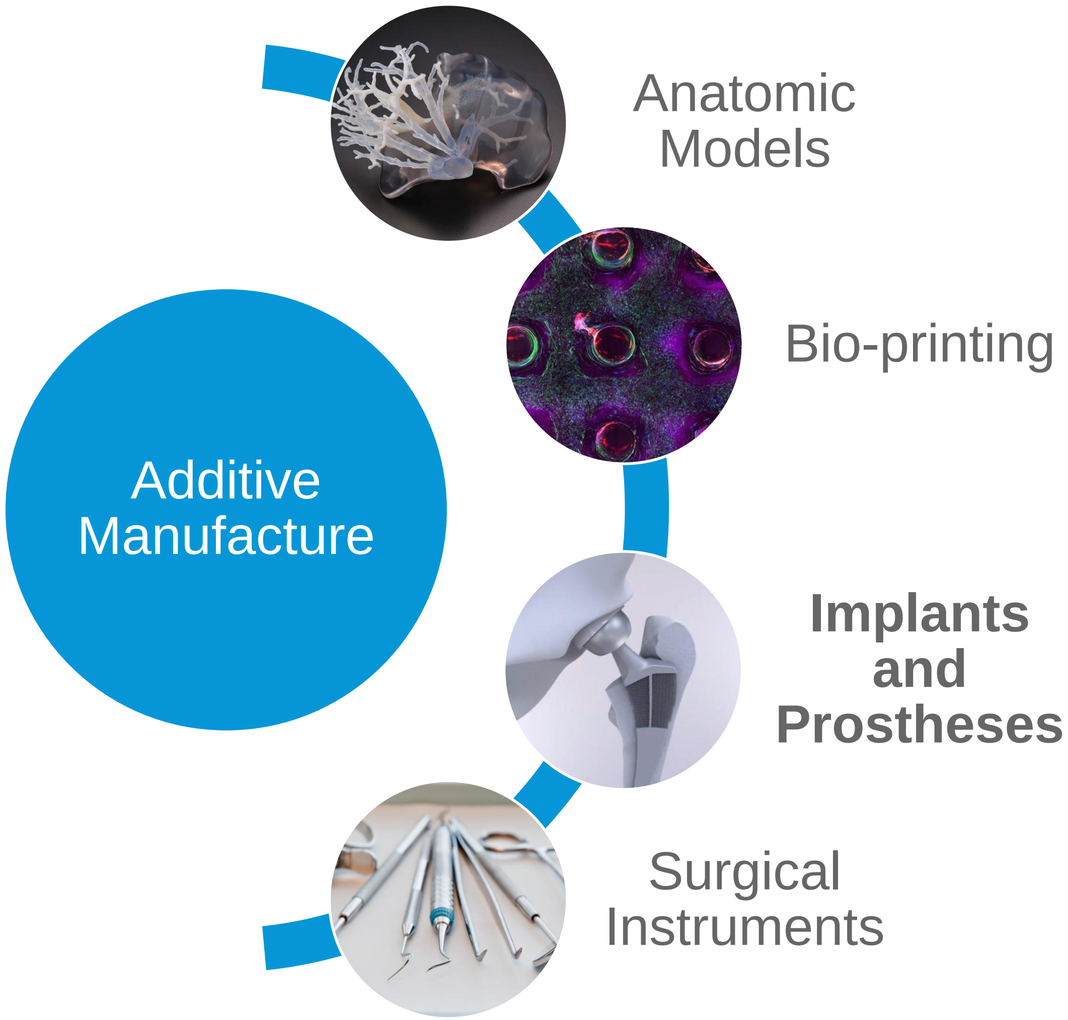
Source: Stratasys
https://3dprintingindustry.com/

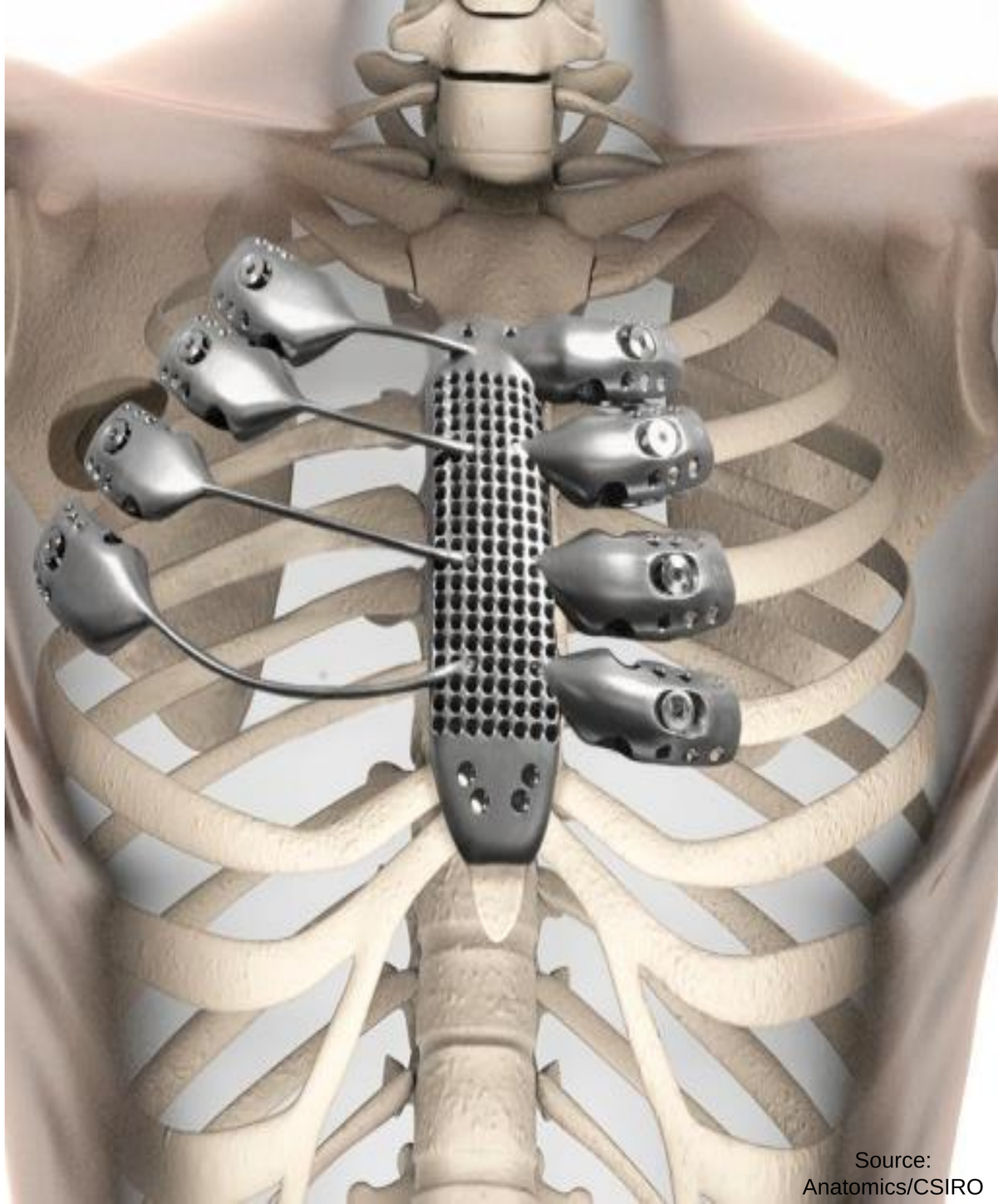
AM in Medicine



Source: BLOOMBERG
https://3dprint.com/

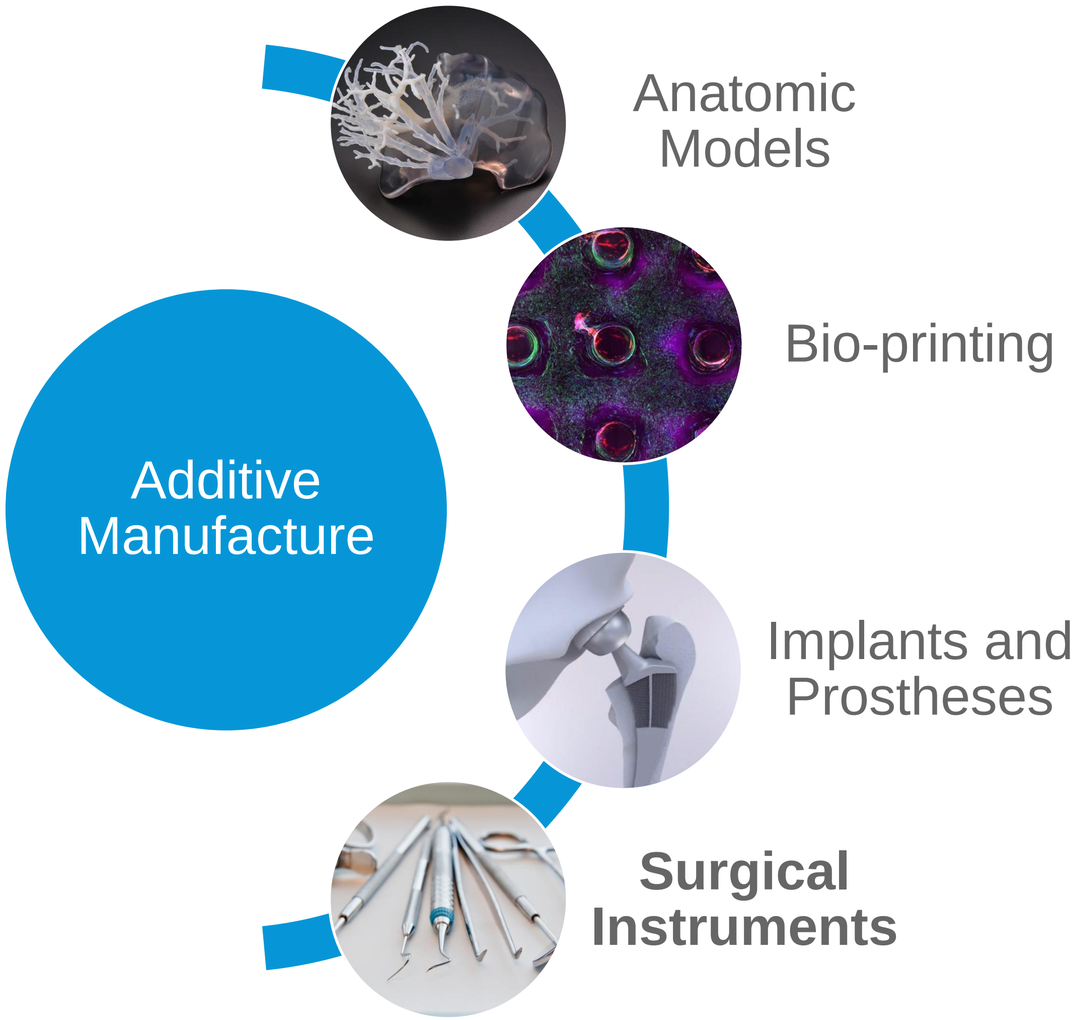
AM in Medicine





Source: Anatomics/CSIRO

AM in Medicine



Source: Think3D

Design for Additive Manufacture

Additive Manufacturing Processes

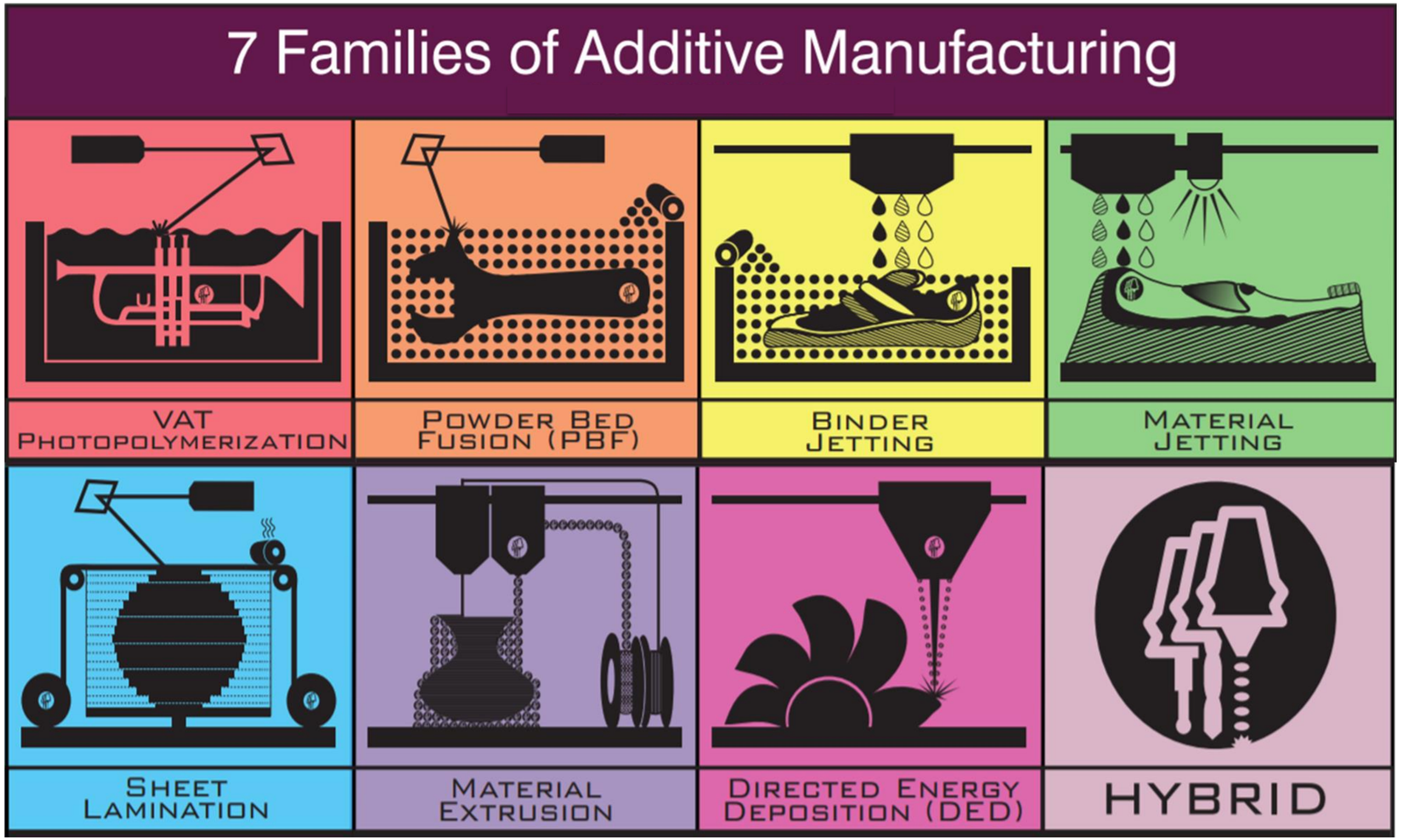
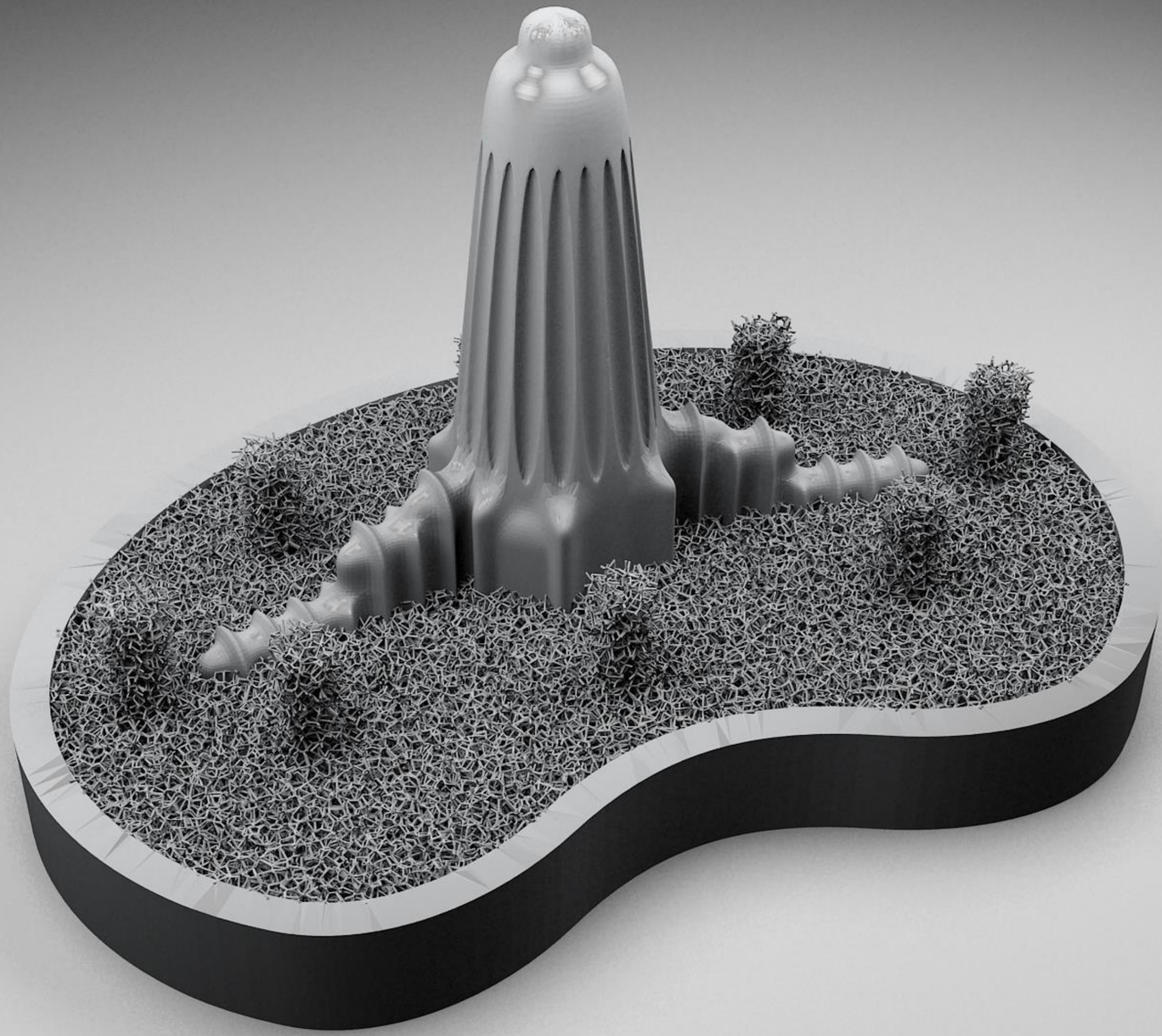


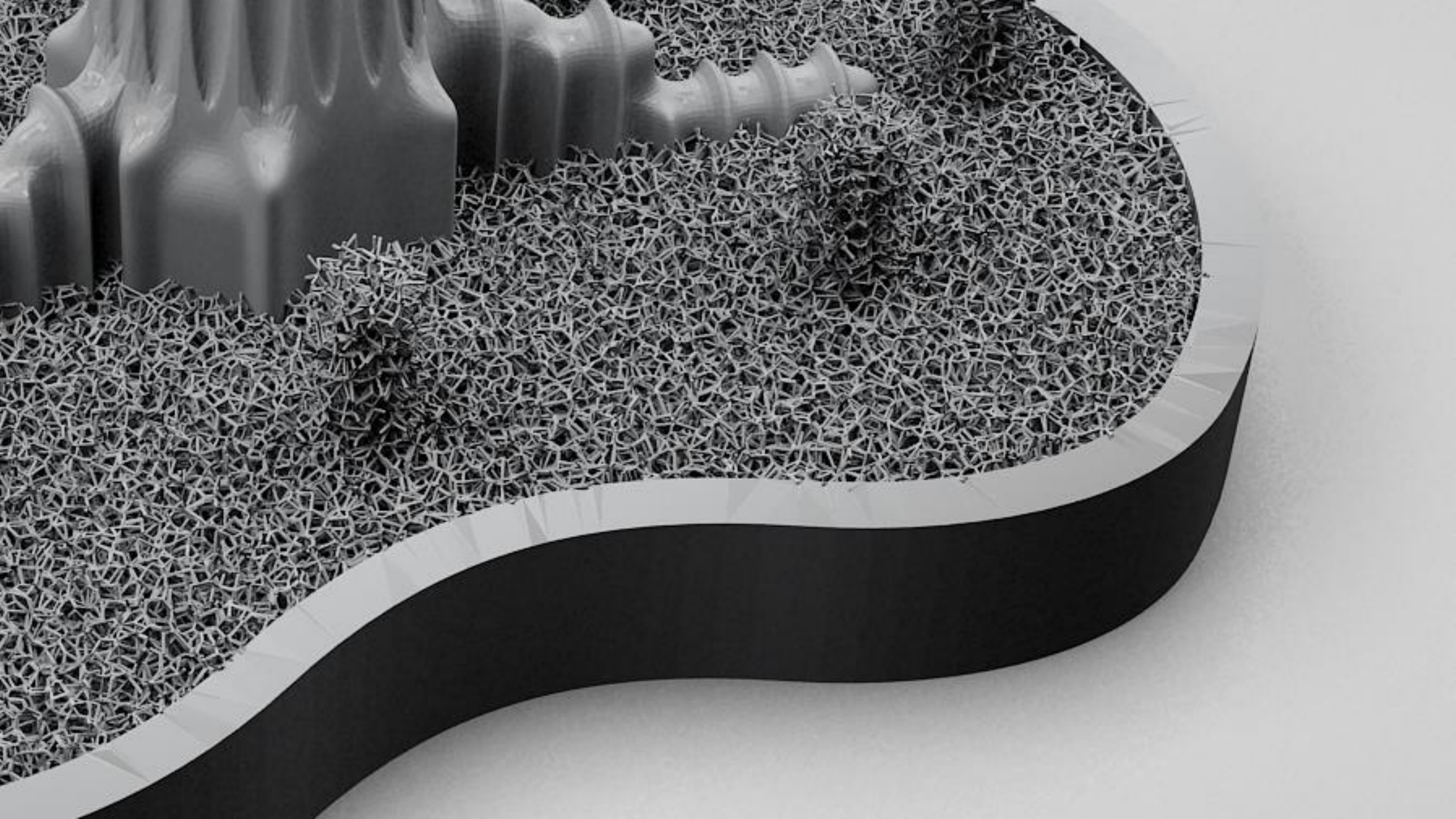
Image courtesy of HMT
http://www.hybridmanutech.com/

Advantages of Additive Manufacturing

- Part Complexity
  - COMBINE MANY PARTS TO ONE
  - NO ADDED COST
  - INTERNAL STRUCTURES
- Low Production Volume
  - COST
  - LEAD TIME

Source:Stratasys
https://www.medgadget.com





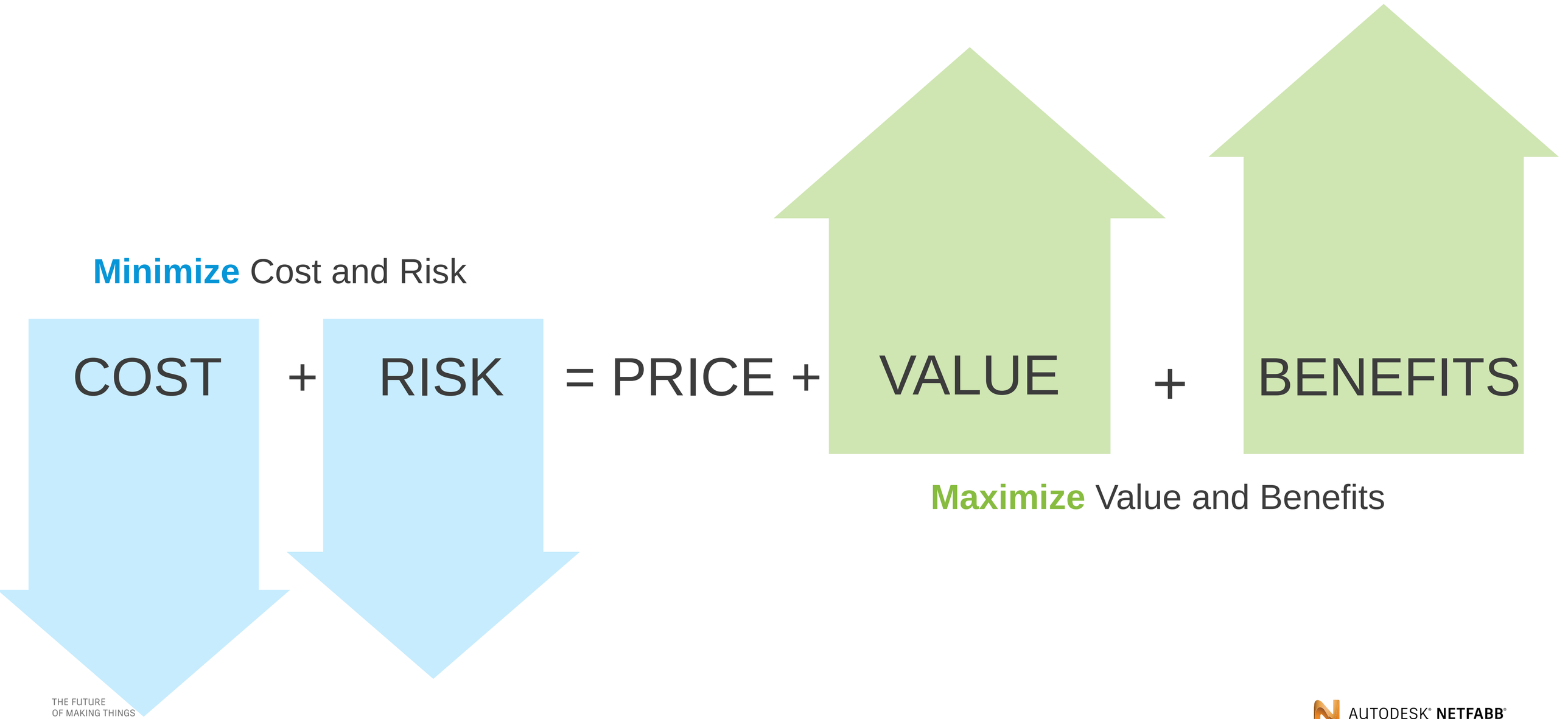
Traditional Manufacturing Approach

Increased Cost and Risk

Maximize Value and Benefits

The Right Equation for Additive Manufacturing

Minimize Cost and Risk



Maximize Value and Benefits

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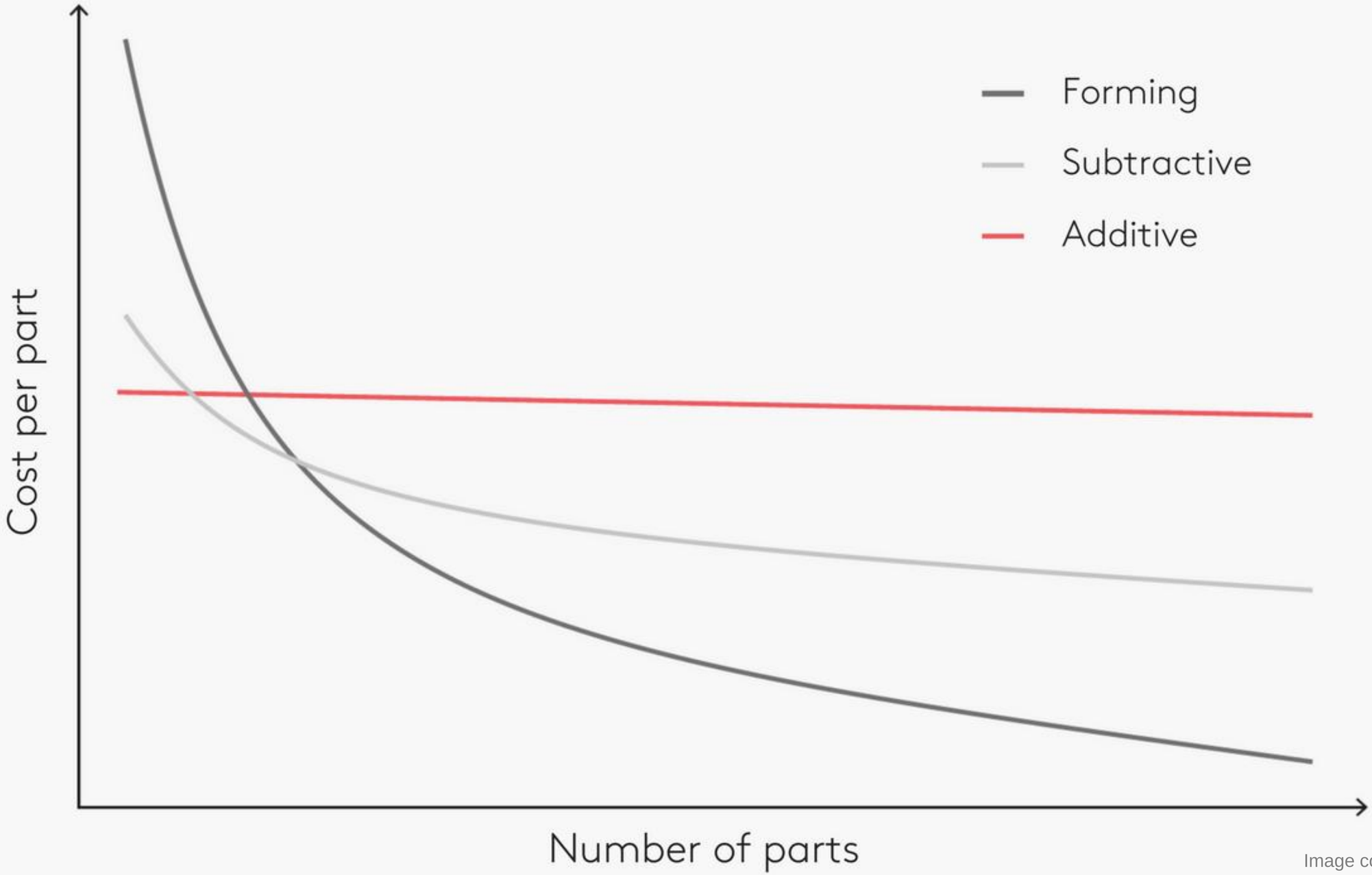
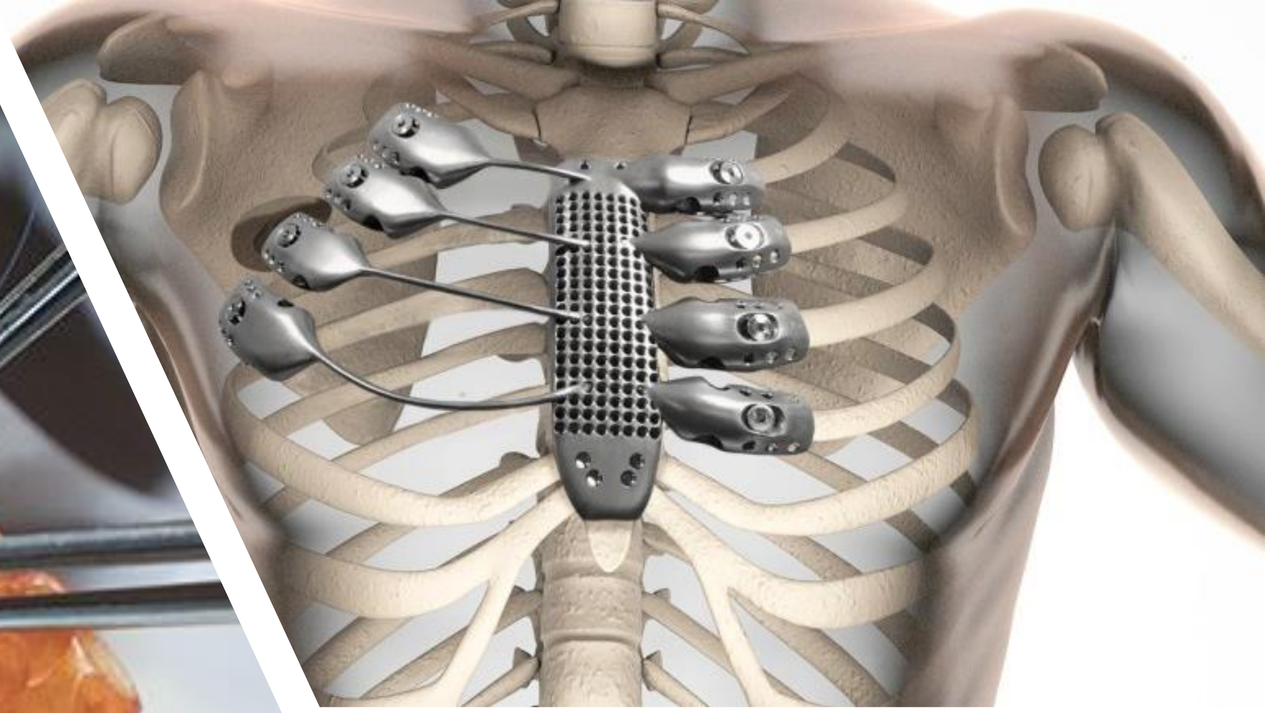
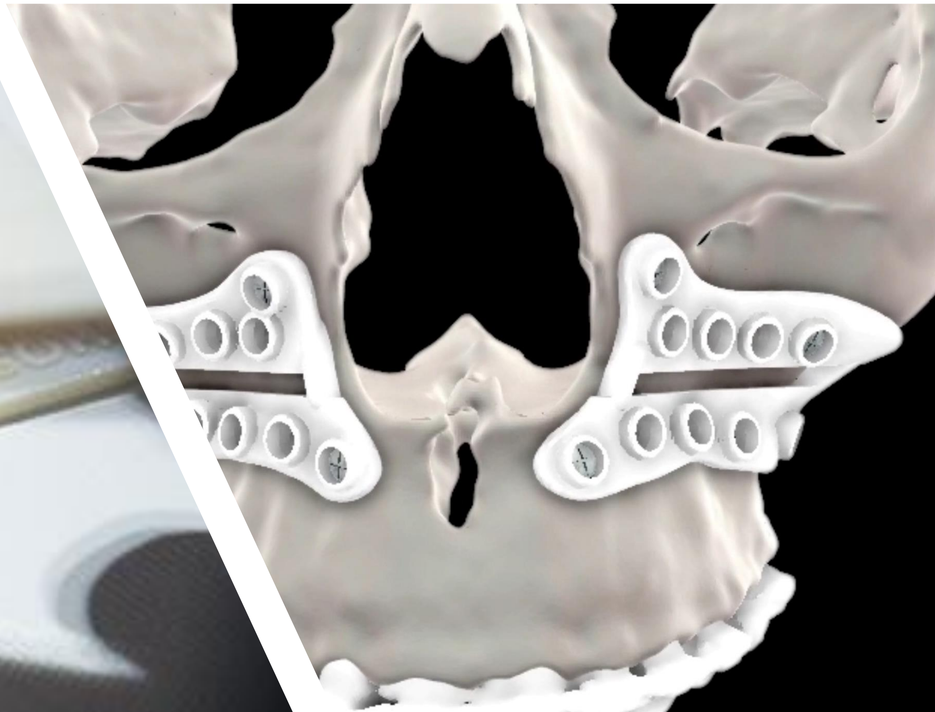


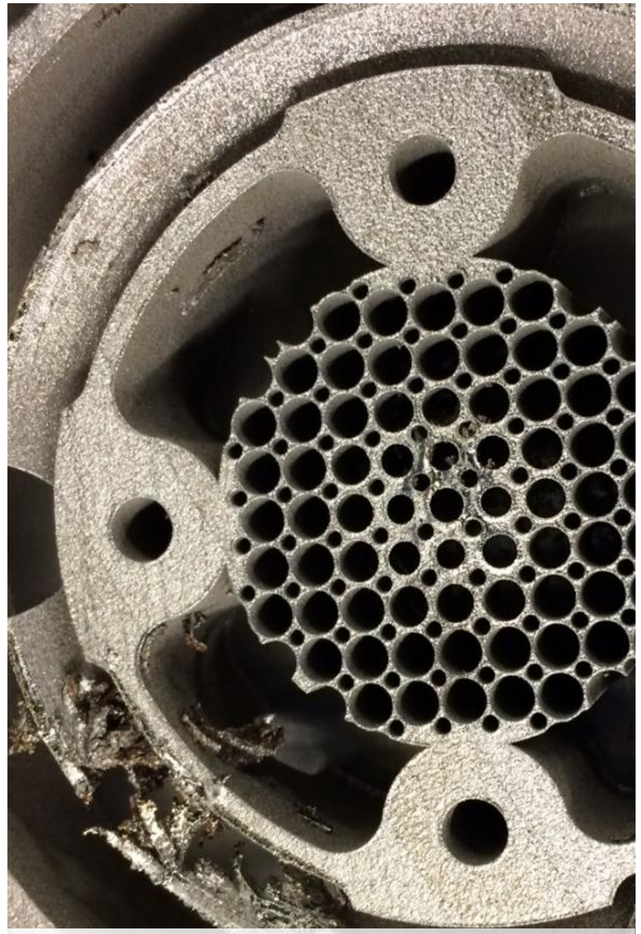
Image courtesy of 3D Hubs





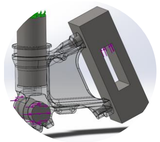
Challenges in Additive Manufacturing

DESIGNING COMPLEX, ORGANIC FORMS

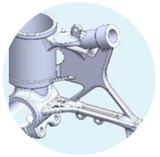


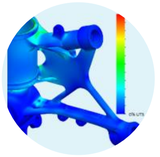
PART DISTORTION AND PRINT FAILURES

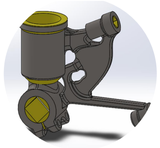
Additive Manufacturing Workflow



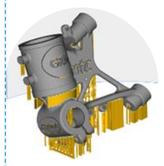
Problem Definition

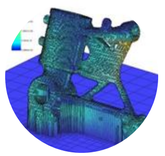






Design for Additive Manufacturing





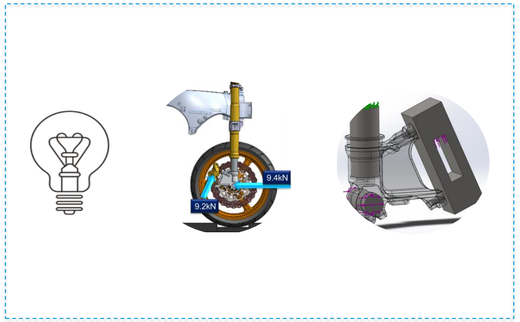
Build Preparation

Printing

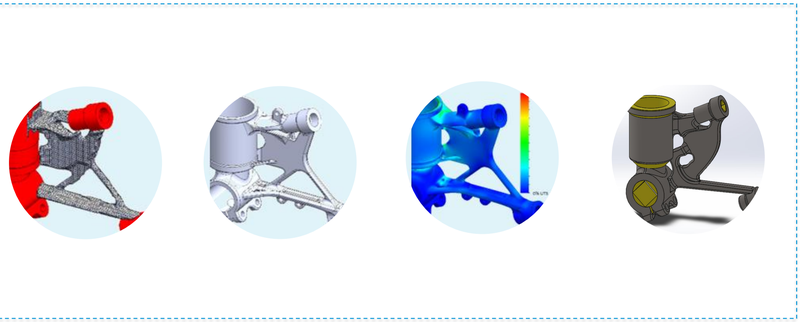
Post-Processing

Images courtesy of the MTC

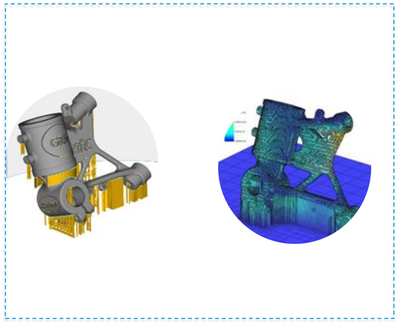
Additive Manufacturing Workflow



Problem Definition



Design for Additive Manufacturing



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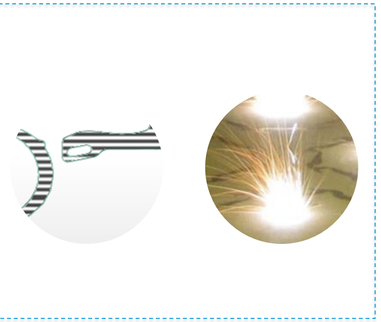


Printing

Post-Processing

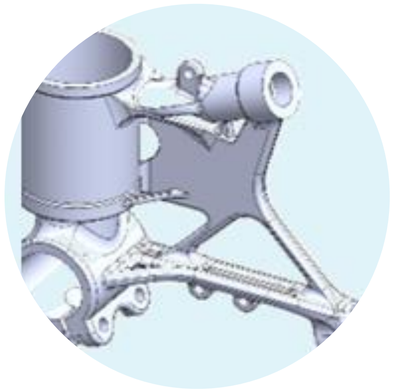
Design for Opportunity

Risk Mitigation

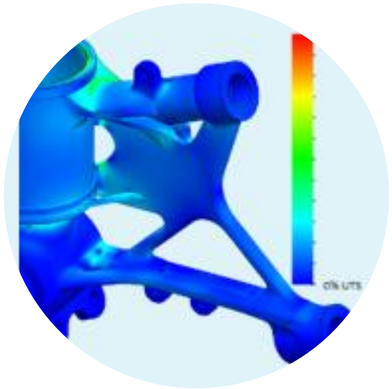
Images courtesy of the MTC

Design for Additive Manufacturing

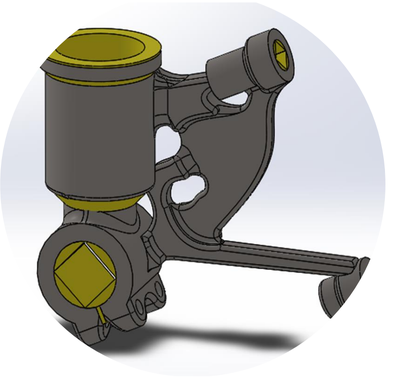
Concept Generation



Remodeling



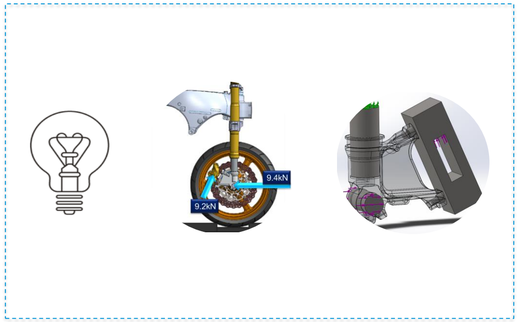
Validation



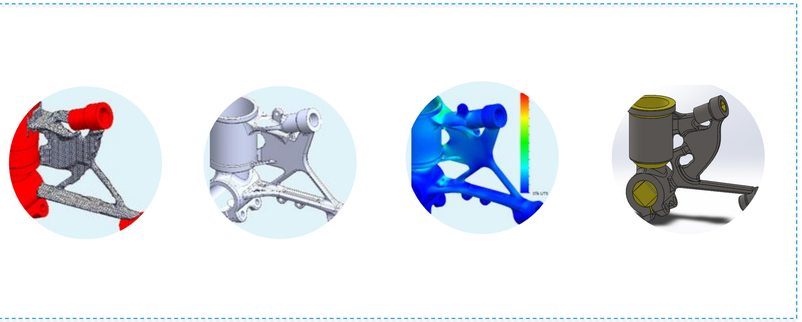
Design for Manufacture

Images courtesy of the MTC

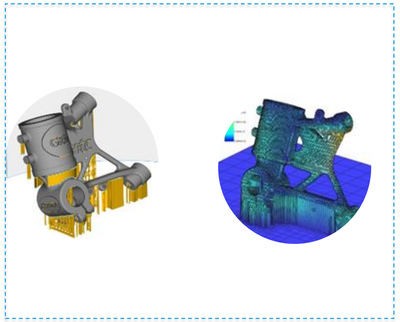
Additive Manufacturing Workflow



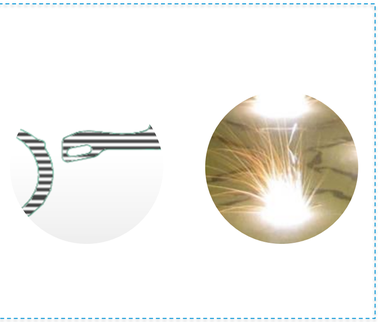
Problem Definition



Design for Additive Manufacturing



Build Preparation



Printing

Post-Processing

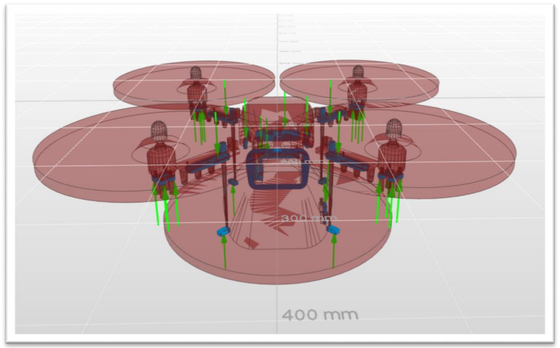
Design for Opportunity

Risk Mitigation

Images courtesy of the MTC

Generative Design as a Design Tool for Additive Manufacturing

Generative Design Workflow



Define

Generate

Explore

AUTODESK.

Generative Design Workflow

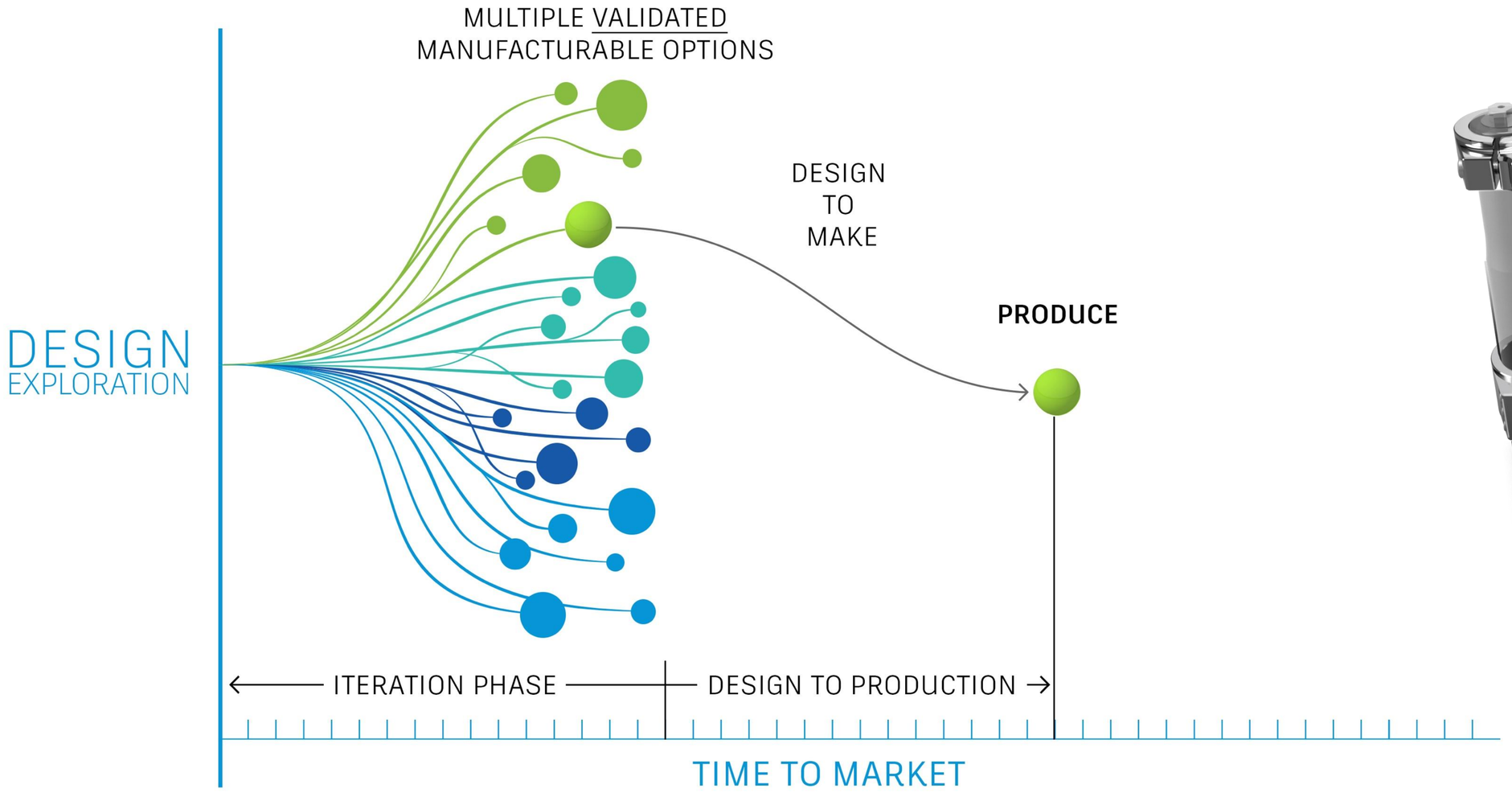
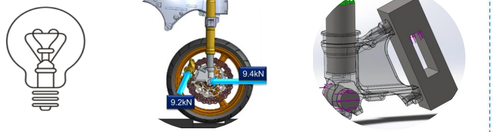


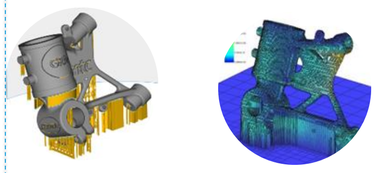
Image courtesy of MJK

Additive Manufacturing Workflow



Problem Definition

Generative Design



Build Preparation

Printing

Post-Processing

Design for Opportunity

Risk Mitigation

Images courtesy of the MTC

Generative Design Case Study

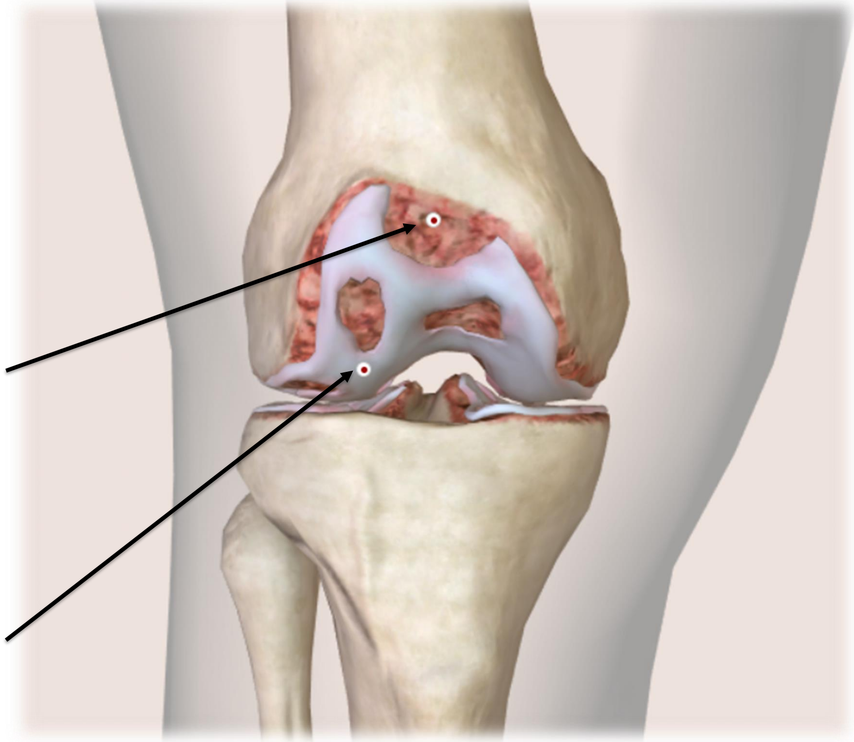
Osteoarthritis (OA)

- OA affects 27 million Americans and 240 million people globally
- Annual cost per patient ~ $15K
- Causes and risk factors
  - Aging
  - Genetics
  - Infection
  - Obesity
  - Overuse
  - Trauma

Source: BioDigital
https://www.biodigital.com/

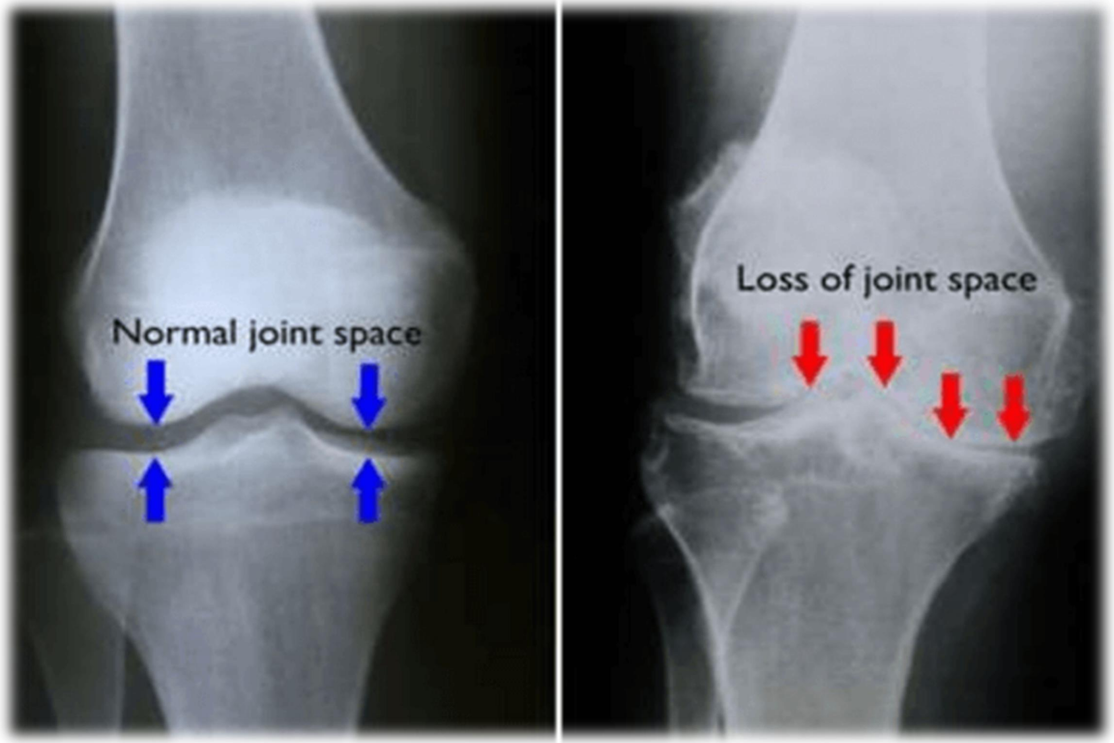
Knee Osteoarthritis

DAMAGED CARTILAGE AND BONE



Source: BioDigital
https://www.biodigital.com/

UNEVEN WEIGHT DISTRIBUTION



Source: American Association of Orthopaedic Surgeons
https://orthoinfo.aaos.org/

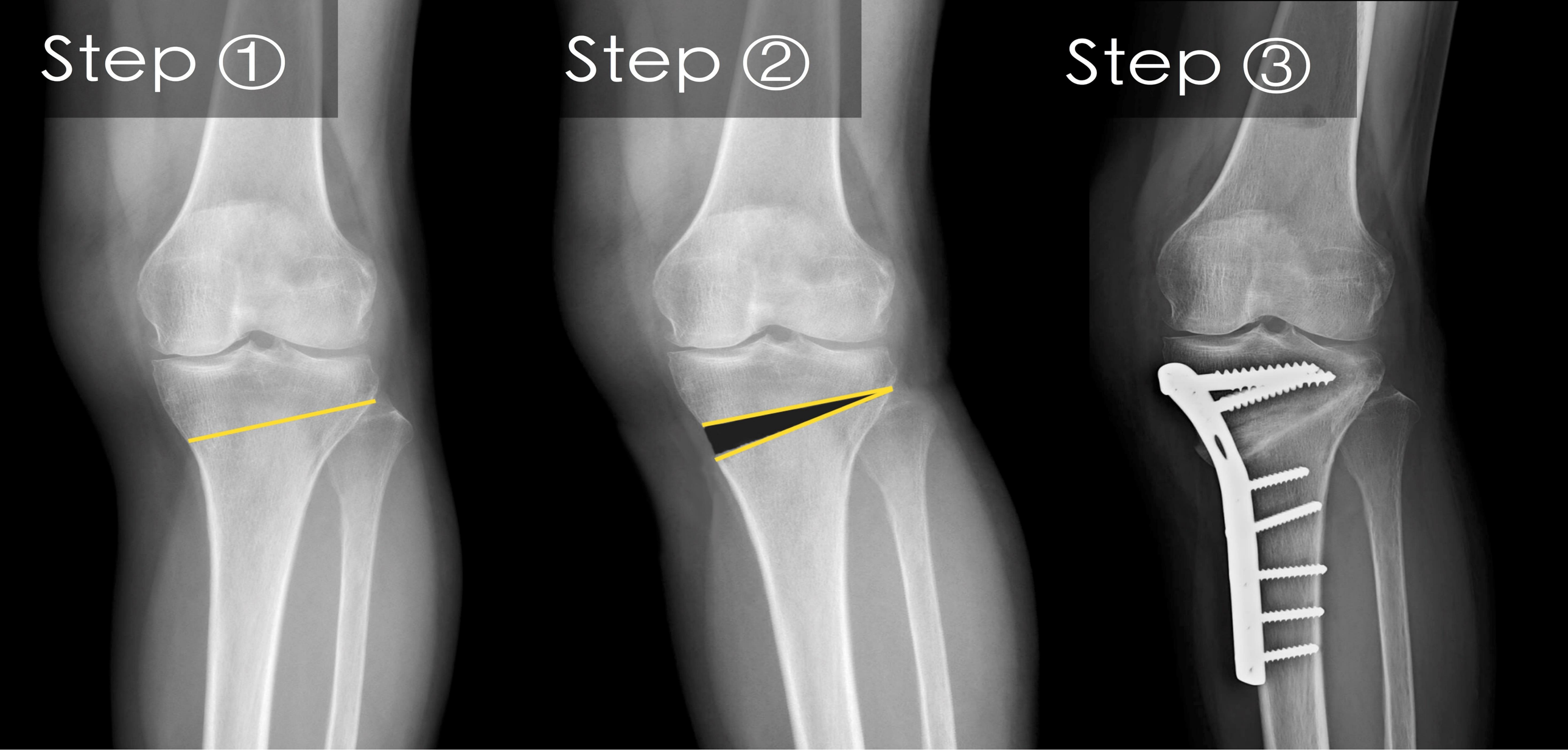


Image courtesy of Taipei Veterans General Hospital

High Tibial Osteotomy (HTO)

High Tibial Osteotomy (HTO)

- HTO realigns the knee joint with an induced fracture (open wedge)
- The open wedge redistributes weight-bearing loads at the knee, relieving pain and preventing further damage to the joint.
- HTO is a preventive measure for osteoarthritis and/or delays the need for a knee replacement.

Image courtesy of DePuy Synthes

Clinical Problem

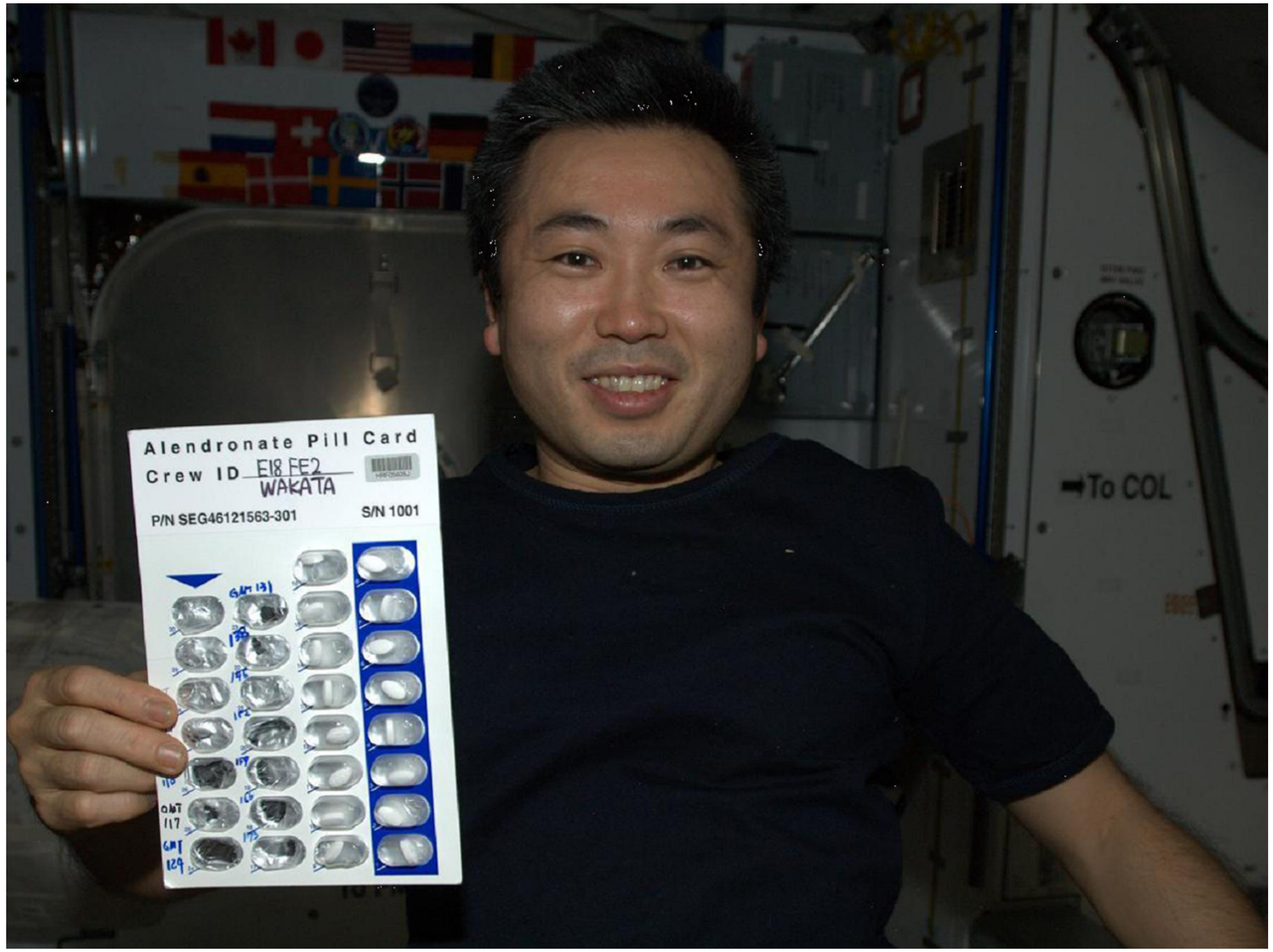
Bone Remodelling

- Bone is a living material, actively constructed and remodelled throughout life
- Remodelling is triggered by mechanical stimuli (force or pressure)
- Absence of mechanical stimuli leads to loss of bone density in critical areas of the skeleton

Microgravity Affects Bone Density

Source: NASA

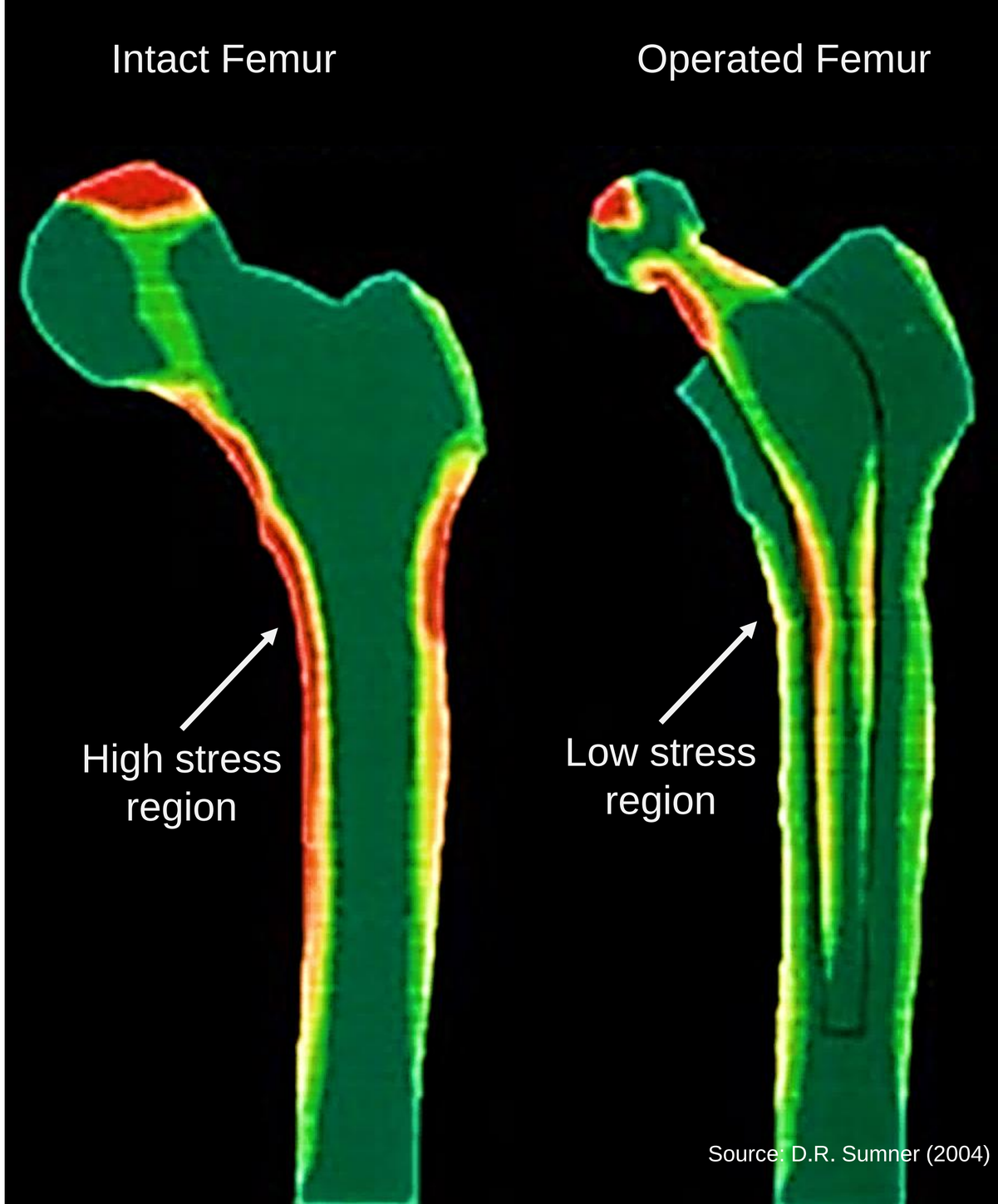
Calcium Supplementation for Astronauts



Source: European Space Agency

1. Stress Shielding

- Metal implants are 10 times stiffer compared to Bone (20 GPa)
  - Stainless steel - 200 Gpa
  - Titanium – 120 Gpa
- Physiological load on a bone is shielded by the implant
- Stress shielding affects the natural remodelling process and thus bone resorption and loss in bone density



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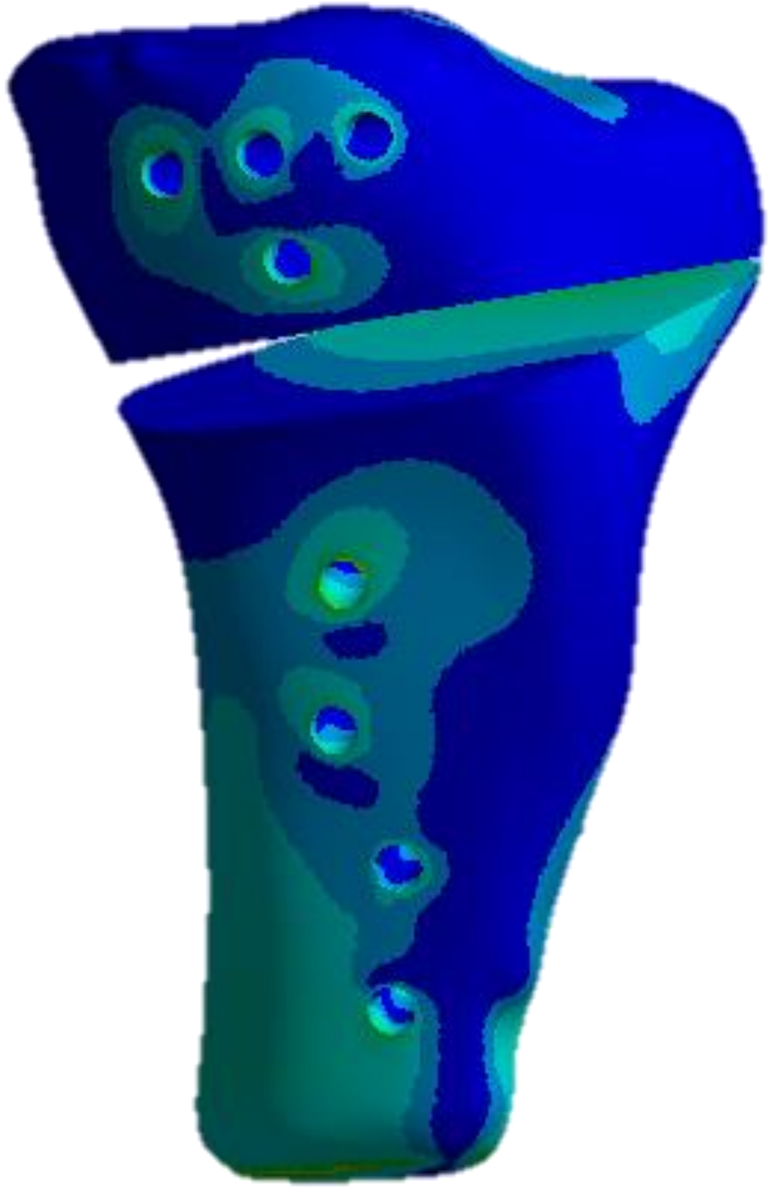

2. Relative Motion

- Stiff implants induce minimal movement around the open wedge (absolute stability)
- Absolute stability impedes the reconstruction of bone around the open wedge
- Relative motion (1mm) between the bone and implant is necessary to provide optimal conditions for biological healing to take place

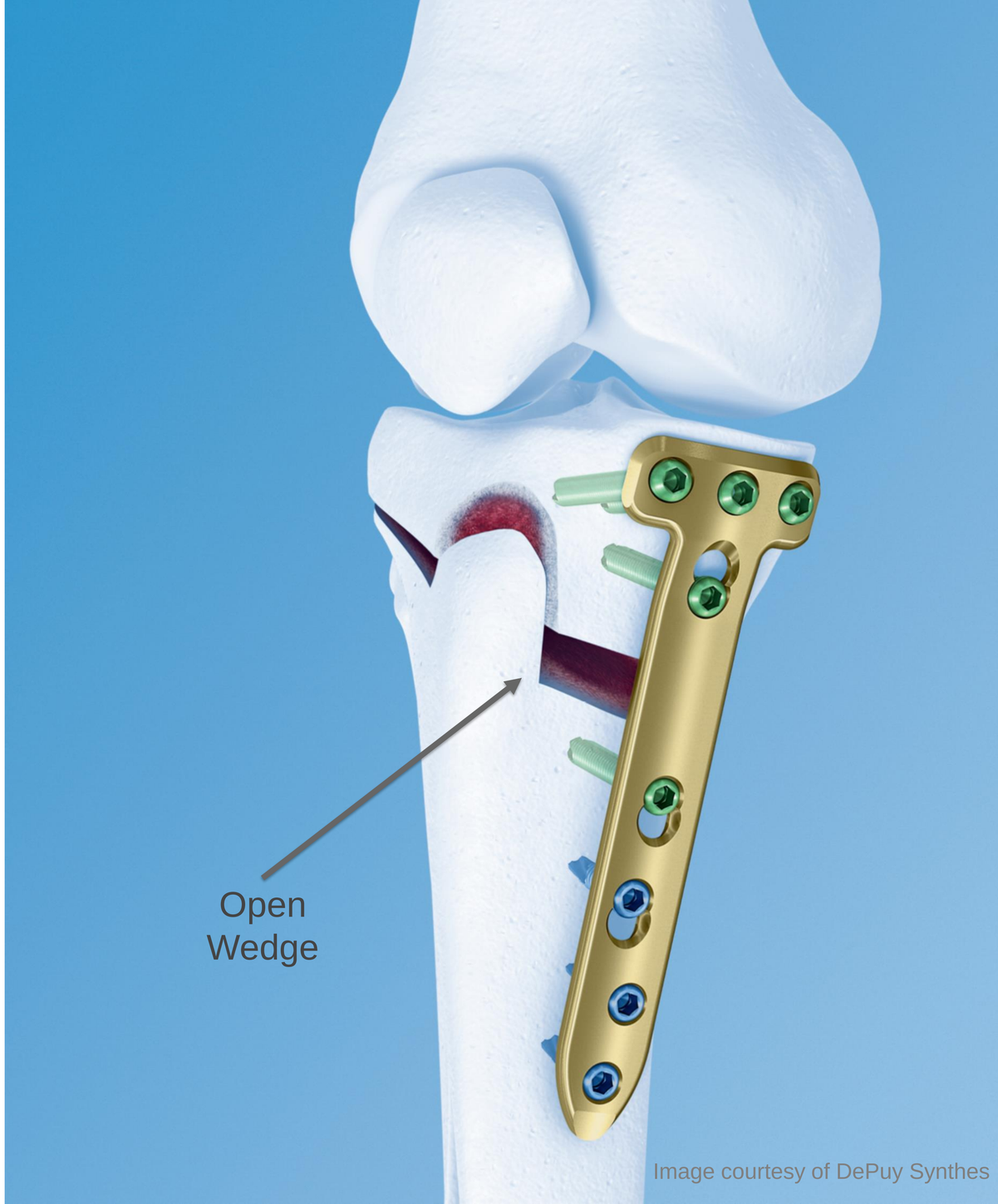

Image courtesy of DePuy Synthes

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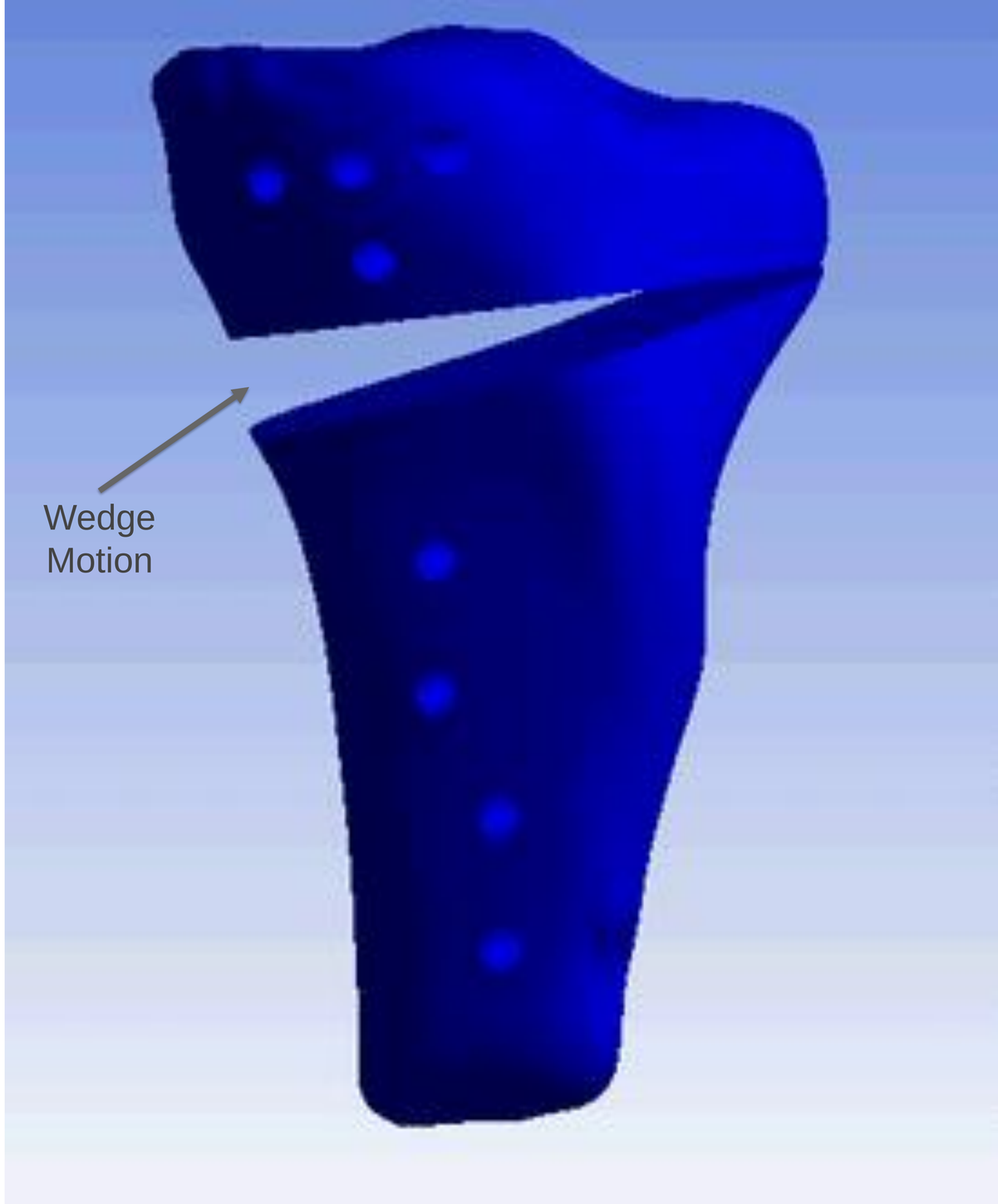


High stiffness of implants induce stress shielding and inhibit biological healing of the bone

Ideal Implant for HTO?

1. Reduced stiffness to minimise stress shielding
2. Allow 1mm wedge motion for optimal healing
3. Low profile to avoid implant prominence
4. Support physiological loading

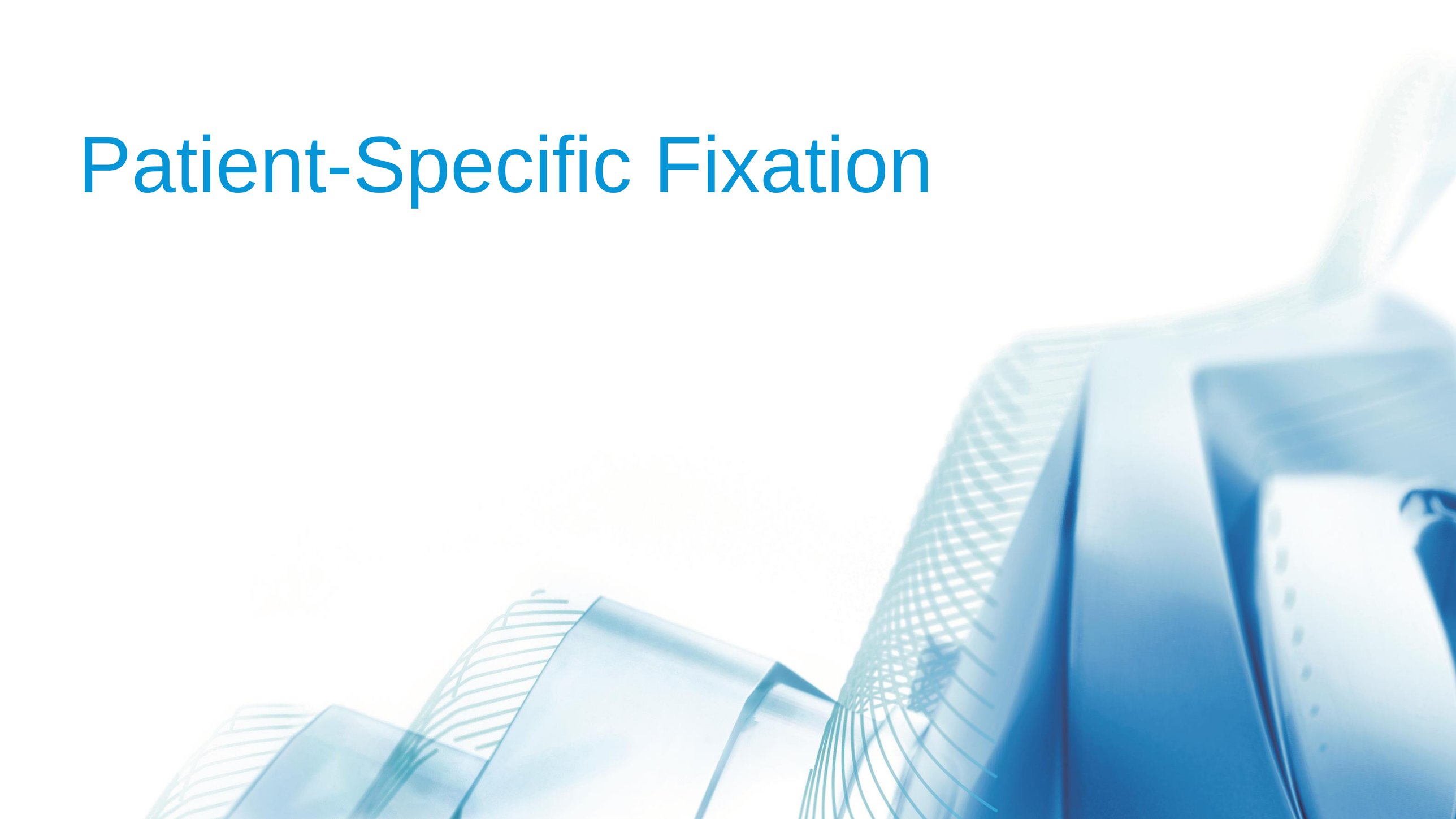
Image courtesy of DePuy Synthes

Source: NEWCLIP

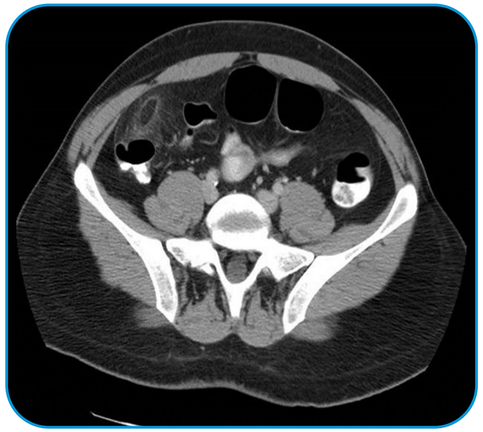
Source: Arthrex

ONE-SIZE-FITS-ALL

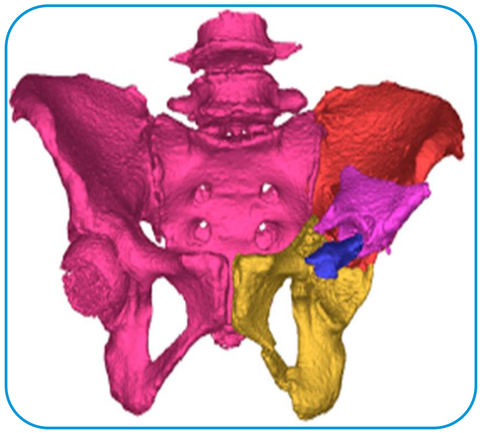
Patient-Specific Fixation



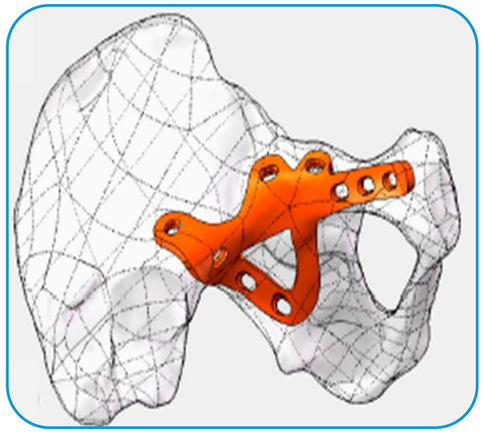
Standard Patient-Specific Fixation



CT/MRI Image



3D Model

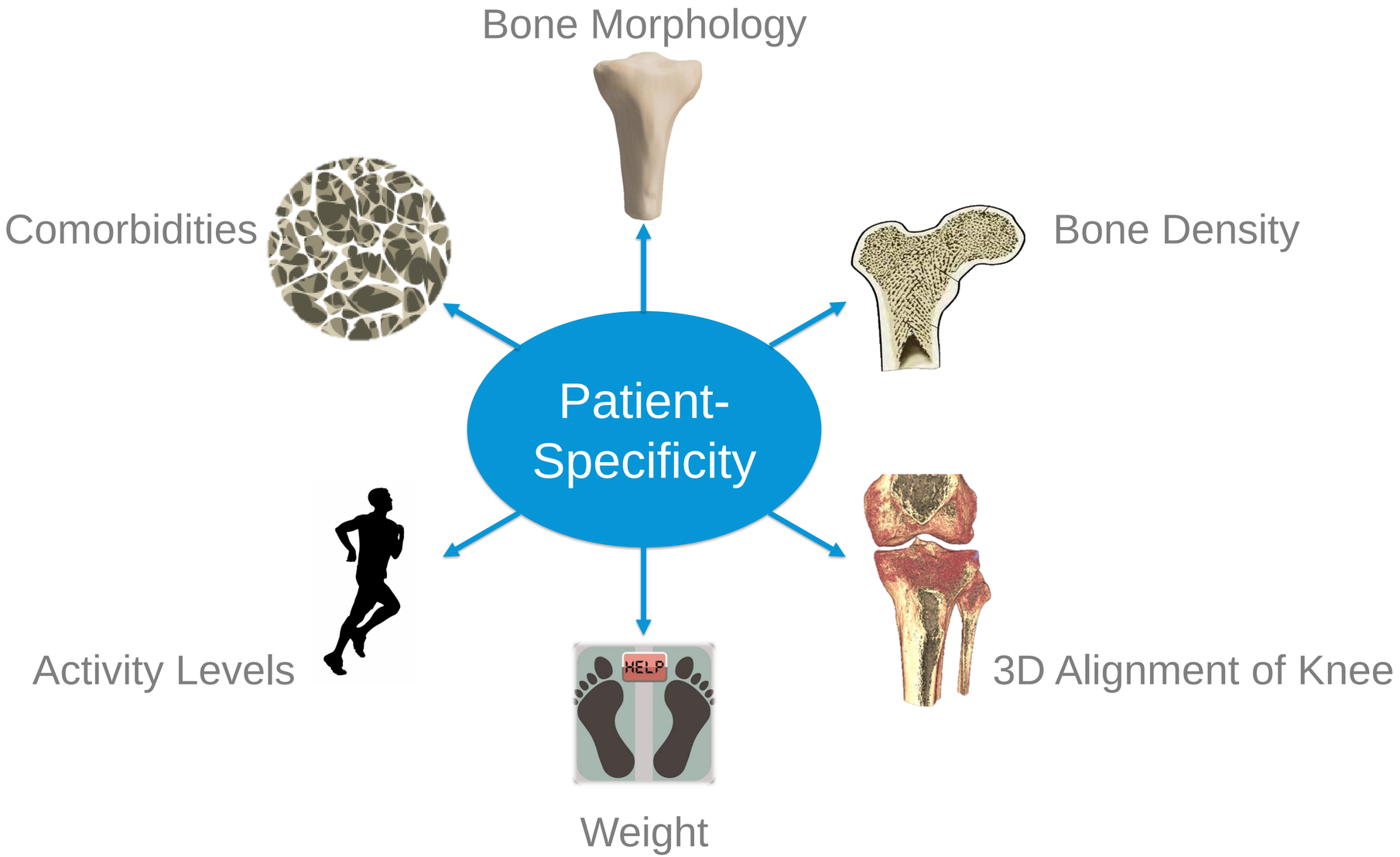


Patient-Specific Design

Manufacture

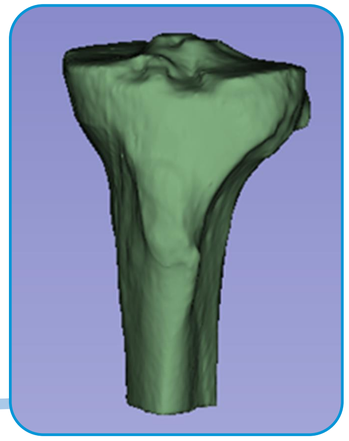
Source: Di Wang et al., (2017)

Patient-Specific Biomechanics

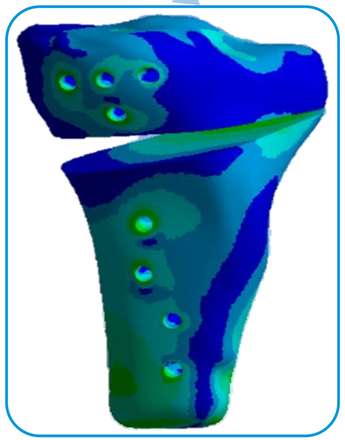


Patient-Specific Fixation via Generative Design

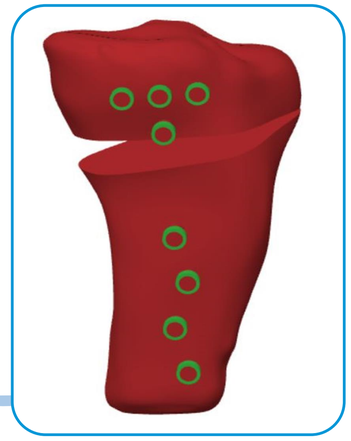
CT Image



3D Model



Biomechanical Analysis



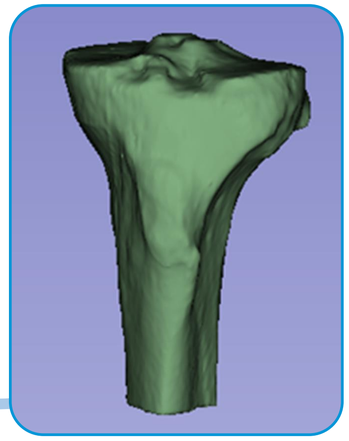
Generative Design

Patient-Specific Designs

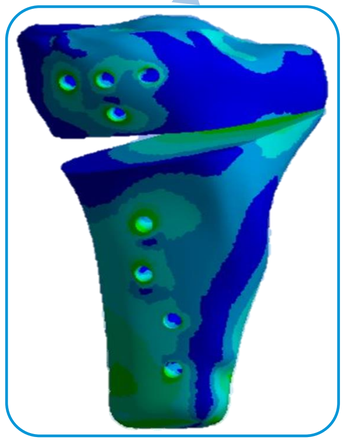
Manufacture

Patient-Specific Fixation via Generative Design

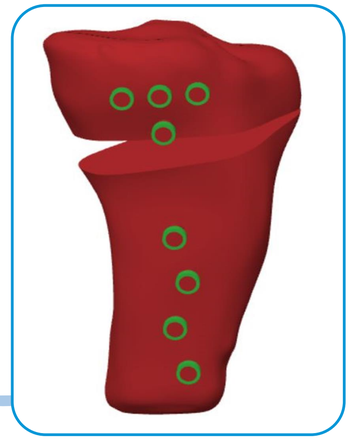
CT Image



3D Model



Biomechanical Analysis



Generative Design

Patient-Specific Designs

Manufacture

Generative Design Process Walkthrough

Patient CT Scan

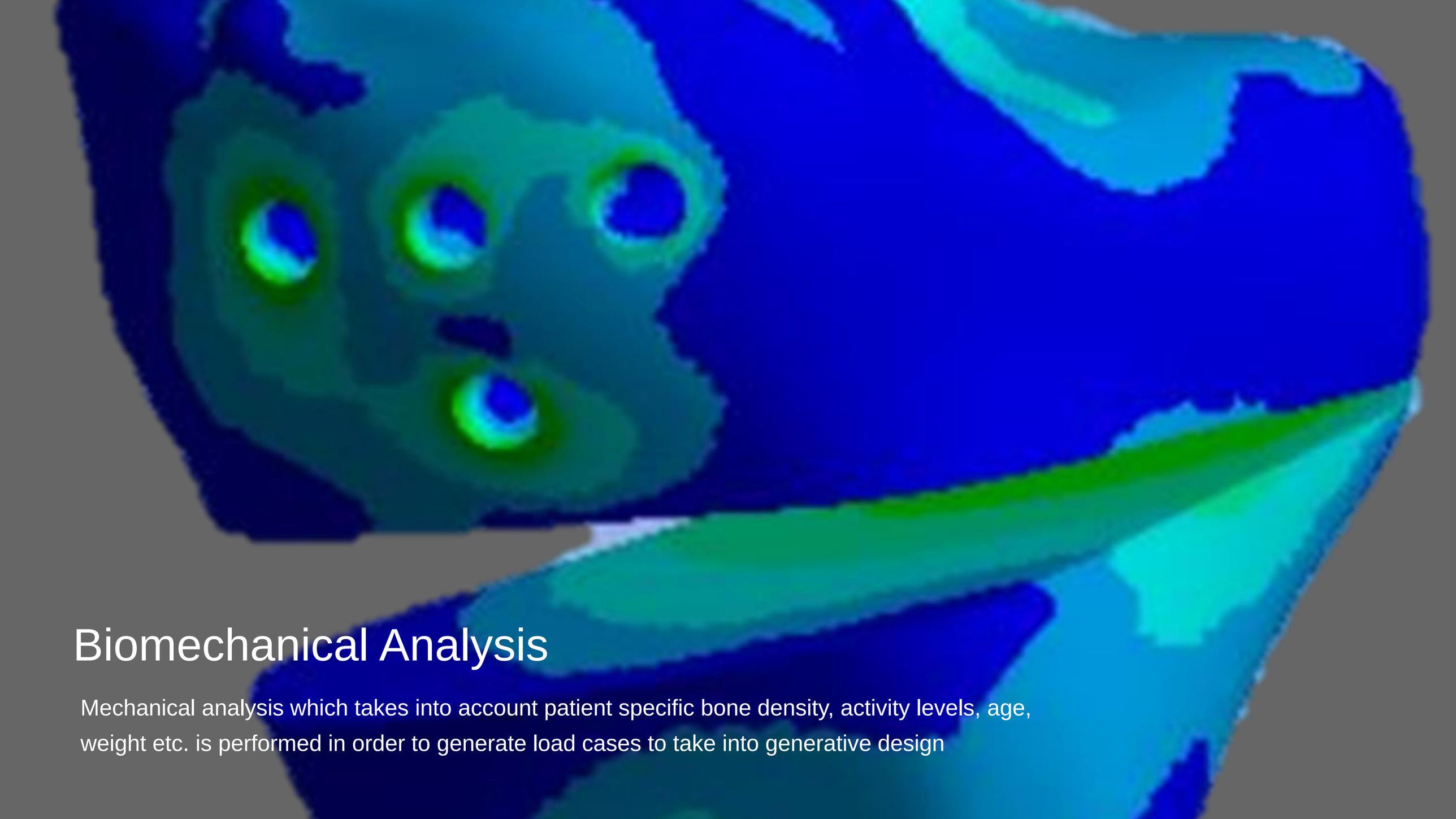
A CT scan is taken of the patients knee. This provides information about the geometry of the bone itself, as well as mechanical information such as bone density

Photo credit goes here

Geometry Reconstruction

Multiple 2D scans are pieced together to create a 3D model of the patients knee joint

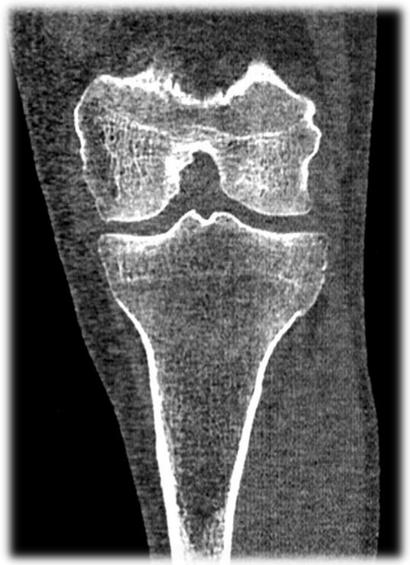
Photo credit goes here



Biomechanical Analysis

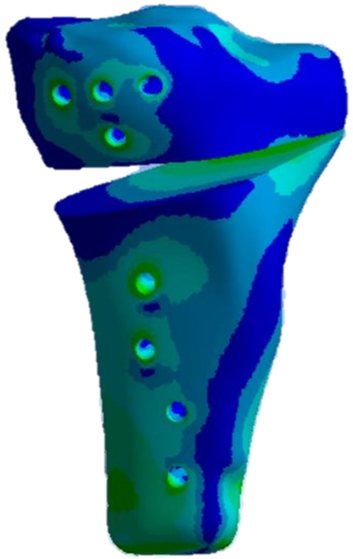
Mechanical analysis which takes into account patient specific bone density, activity levels, age, weight etc. is performed in order to generate load cases to take into generative design

Patient-Specific HTO Design Process



Patient CT scan

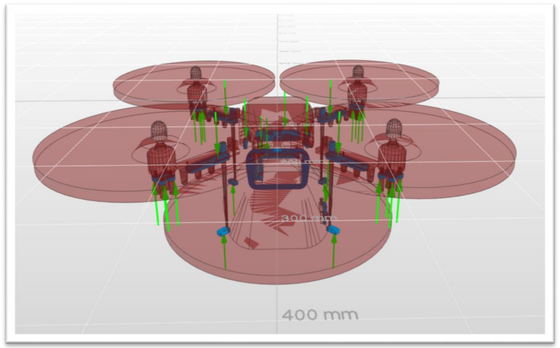
3D Geometry Reconstruction



Biomechanical Analysis

Generatively Designed Implant

Generative Design Workflow

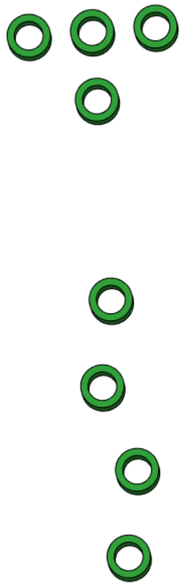


Define

Generate

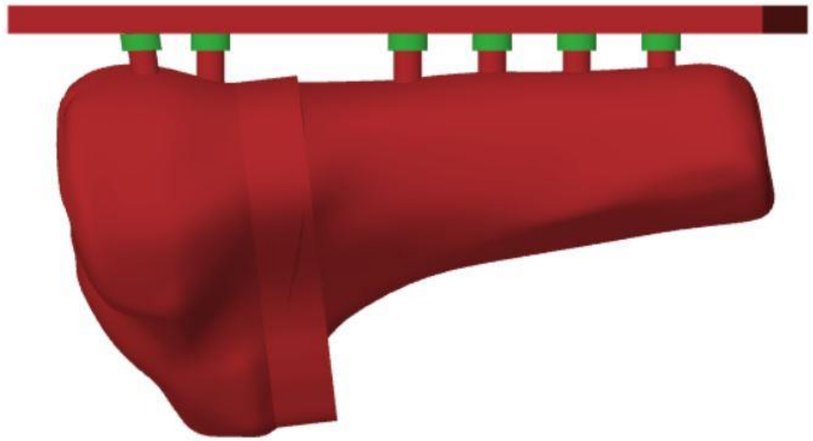
Explore

AUTODESK.



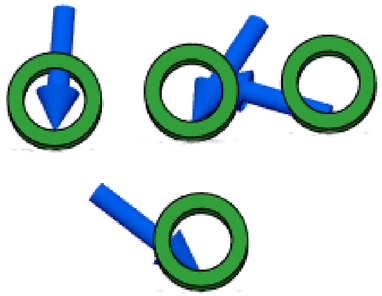
Fixation Points

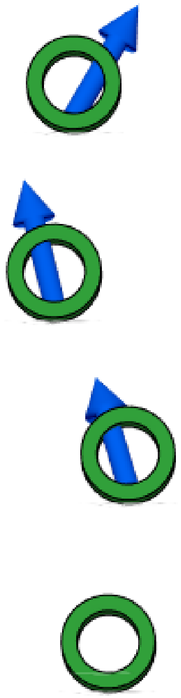
The fixture needs to be securely fastened to the bone, the orientation and position of these connection points can be kept as default, or oriented on the bone by the operator in order to avoid previous fracture sites



Vasculature, Bone and Soft Tissue Avoidance

Ligaments and muscle attachments bond the upper and lower limb. Arteries supplying blood and nerves providing sensation and muscle control to the lower limb. It is vital that these structures are preserved during surgery and not impeded on by the implant





Biomechanical Loading

Information about the types of forces acting on the implant are taken from the Biomechanical analysis, to simulate realistic load cases which are specific to the patient.

These forces are able to take into account factors such as bone density and patient age, weight and degree of activity.

Manufacturing Methods

The manufacturing methods which are available to the designer can be selected as constraints. Each design outcome created, will have a unique manufacturing goal in mind, the parameters of which can be customized to the users liking.

Generate

Once the problem is fully defined, results can be generated simultaneously using the power of cloud computing.

Autodesk Fusion 360 (Education License)

Tomofix 4mm v9

Seale Lauren Thomas

GENERATIVE DESIGN

EXPLORE

DISPLAY

FINISH EXPLORE

Outcome filters

Sort by: Processing status

Processing status
- Converged (16)
- Completed (4)

Study
- Study 3 - Generati...
- Study 4 - SS Gene...

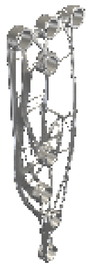
Visual similarity
- Ungrouped (20)

Design file
- Created from outcome
- Not created from outcome

Tech-Preview
- Tech-Preview
- Not Tech-Preview

Manufacturing method
- Unrestricted
- Additive

Converged



Study 3 - Generative - Outcome 1
Converged

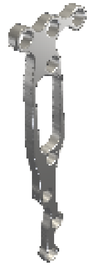
Study 3 - Generative - Outcome 2
Converged

Study 3 - Generative - Outcome 4
Converged

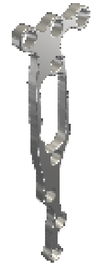
Study 3 - Generative - Outcome 5
Converged

Study 3 - Generative - Outcome 6
Converged

Study 3 - Generative - Outcome 8
Converged



Study 3 - Generative - Outcome 9
Converged



Study 3 - Generative - Outcome ...
Converged

Autodesk Fusion 360 (Education License)

Tomofix 4mm v9

Seale Lauren Thomas

GENERATIVE DESIGN

EXPLORE

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Outcome filters

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- Created from outcome
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- Tech-Preview
- Not Tech-Preview

Manufacturing method
- Unrestricted
- Additive

Max von Mises stress (MPa)

441.3
441.25
441.2
441.15
441.1
441.05

Click drag to zoom

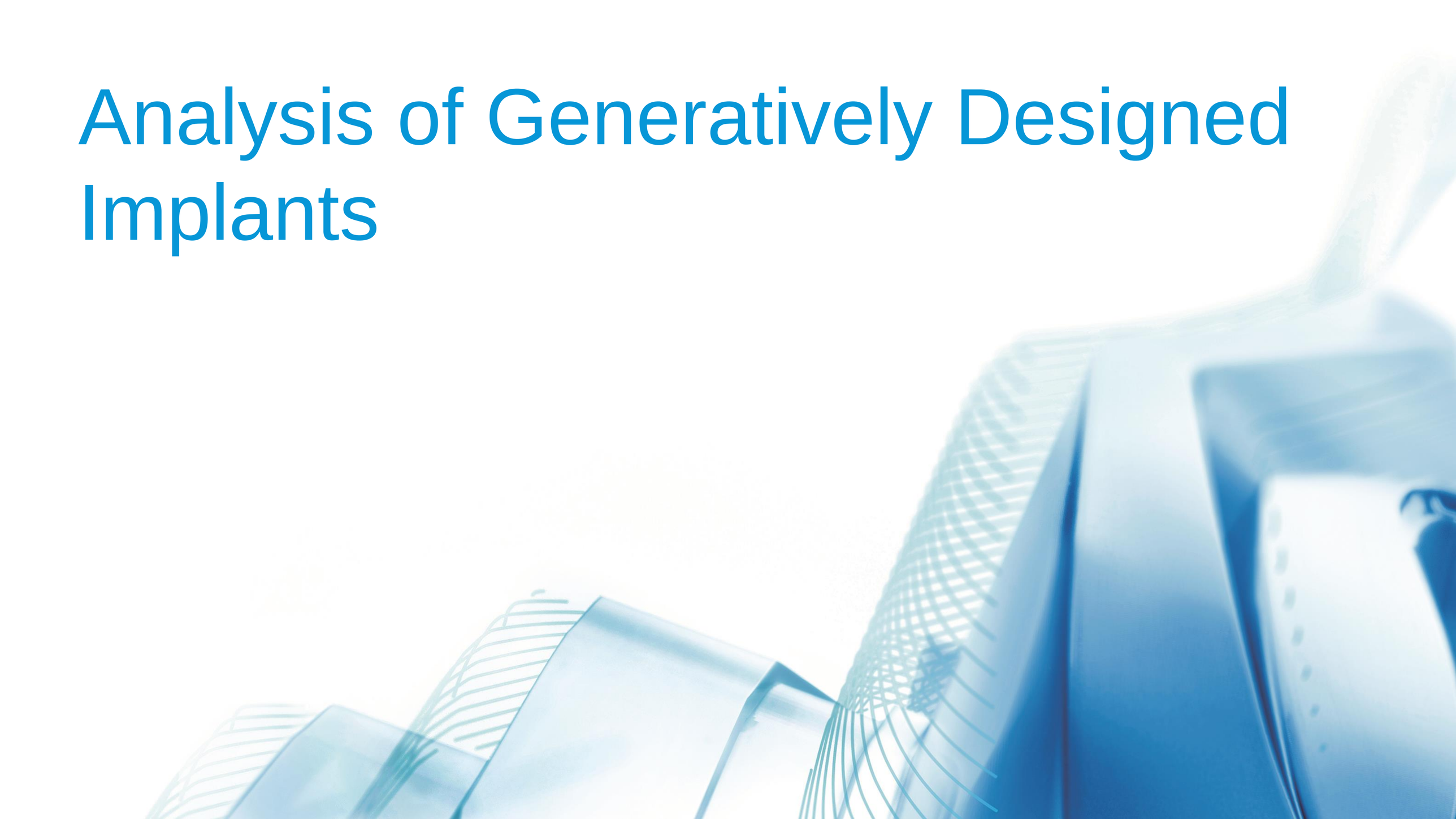
Mass (kg)

Symbols

Manufacturing method

- 2.5 axis milling
- 3 axis milling
- 5 axis milling
- Additive
- Unrestricted

Analysis of Generatively Designed Implants



Standard vs Generative Comparison

Standard

Outcome 1

Outcome 2

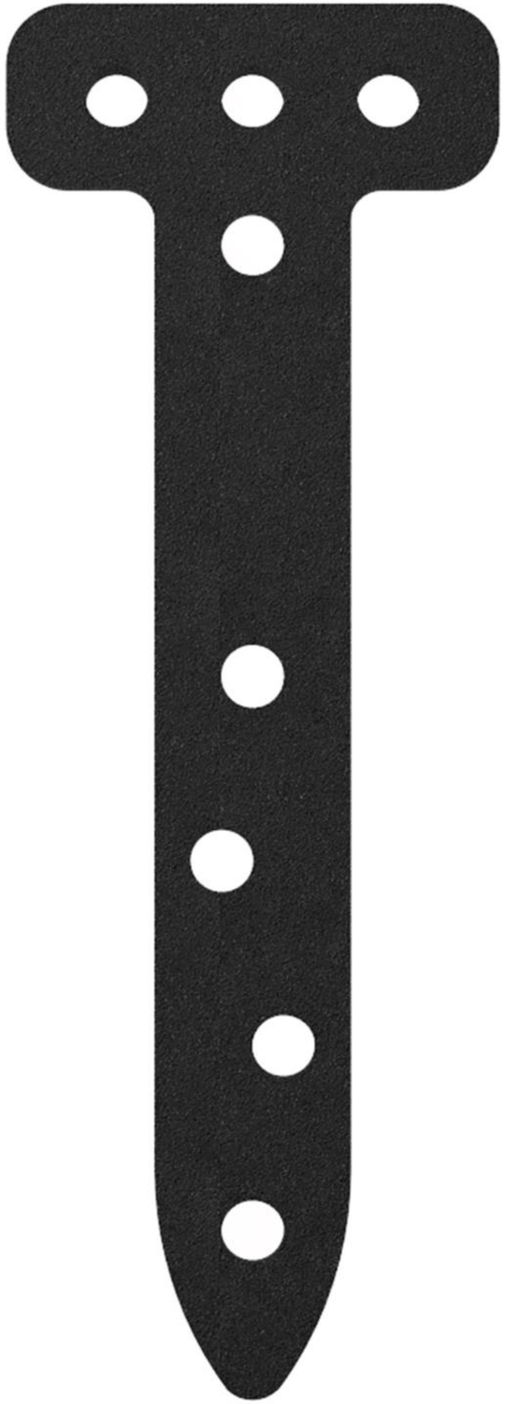
Outcome 3

Implant prominence

- 80% reduction in implant mass

Implant prominence

- 80% reduction in implant mass
- 40% reduction in overall area

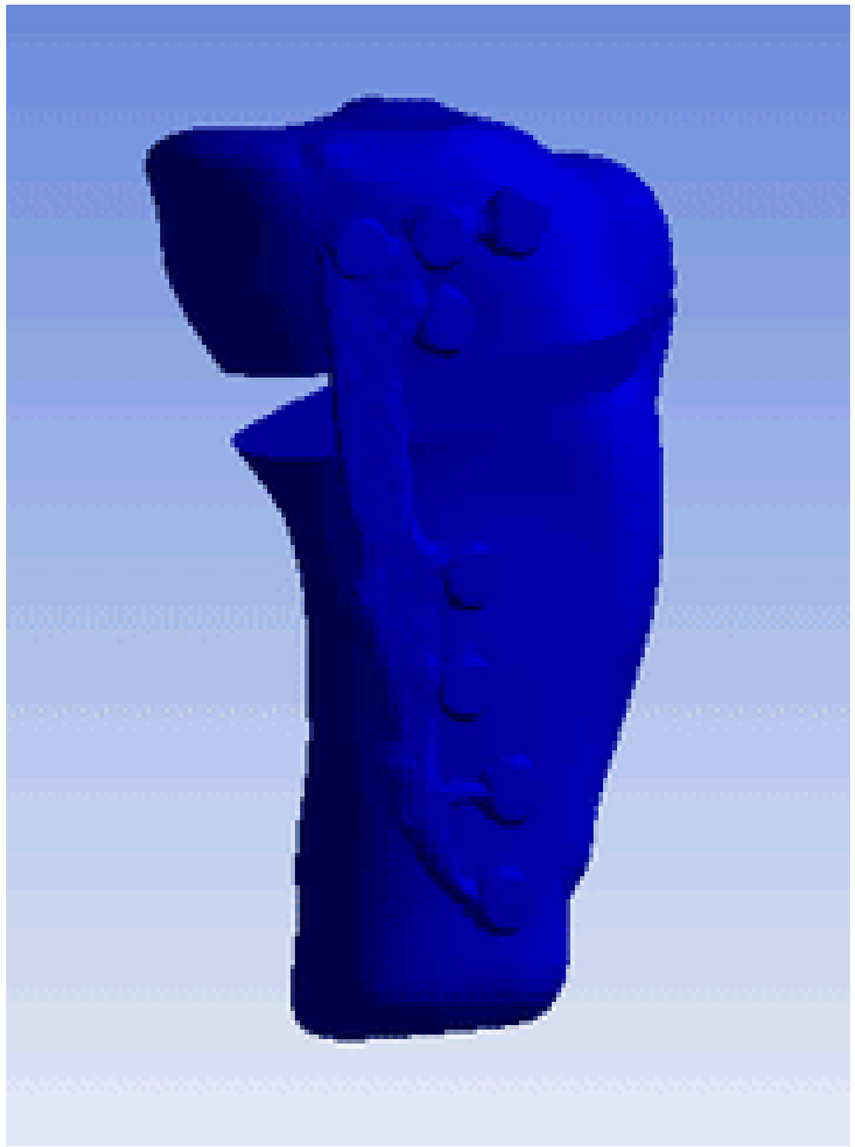


Implant prominence

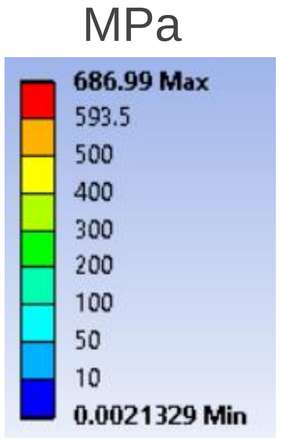
- 80% reduction in implant mass
- 40% reduction in overall area
- **Low profile plates reduces discomfort and skin infection**

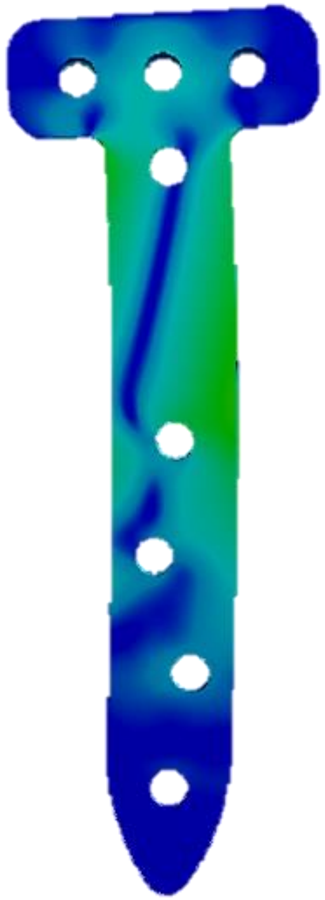
Source: E. Hasenboehler et al., (2006)

Physiological Loading (3 x body weight)



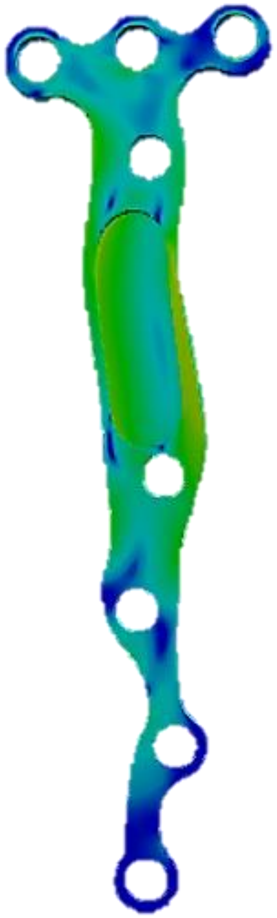
Physiological Loading (3 x body weight)



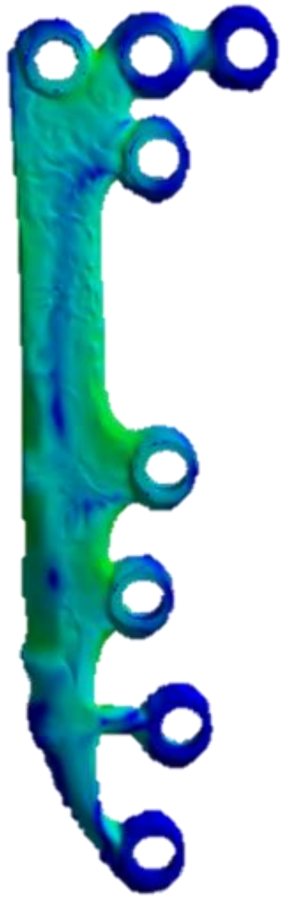


Standard

Outcome 1

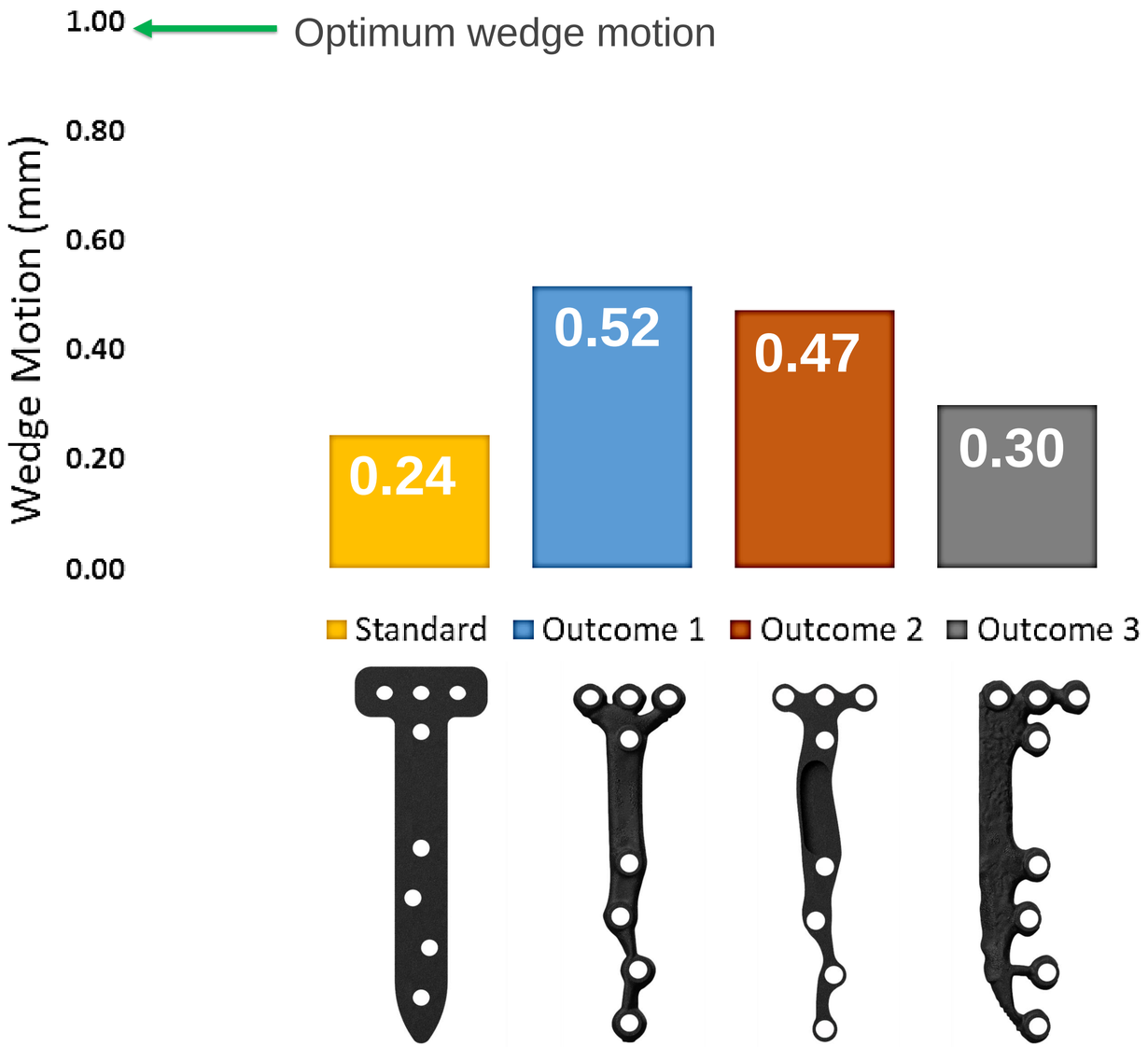


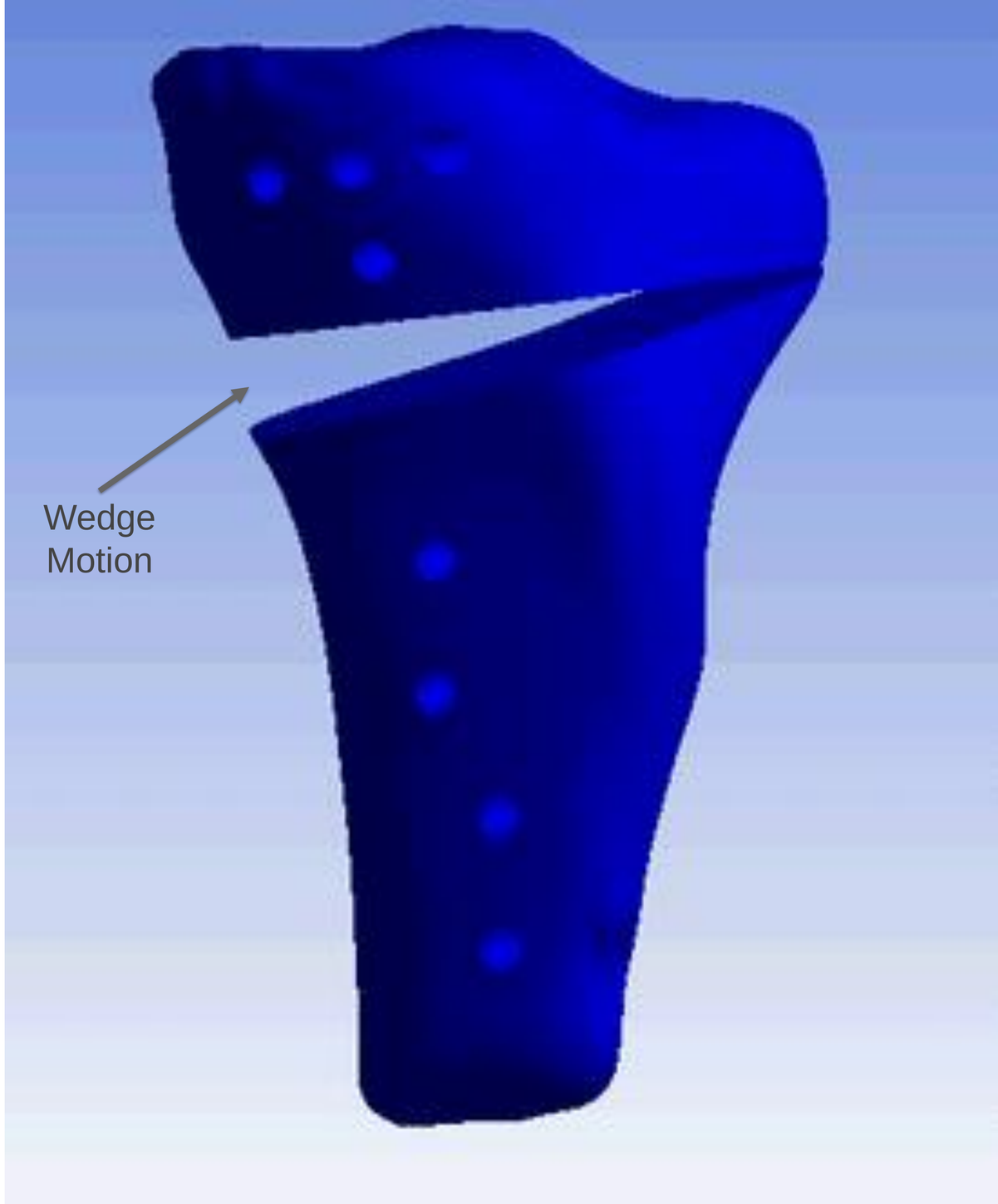
Outcome 2



Outcome 3

Implant Stiffness





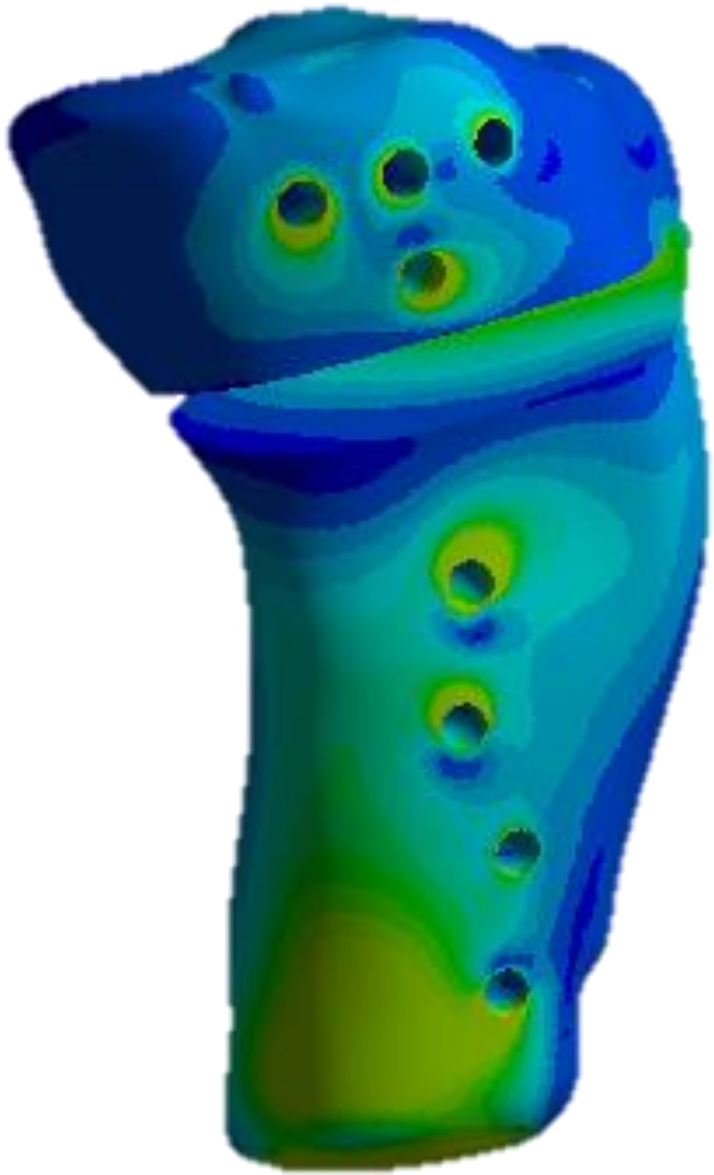
Implant Stiffness

- Optimal wedge motion **1mm**
- Standard (0.24mm) vs Outcome 1 (**0.52mm**)
- **117%** increase in wedge motion with generative design - much improved healing environment for bone compared to standard implant
- Reduced implant stiffness allows for bone to undergo higher stresses, minimising stress shielding effect and thus preserve bone density

Bone-Screw Interface

- Average strain around bone-screw interface has reduced

- Reduced risk of implant loosening and thus revision surgeries can be avoided



Pre-operative Planning

Summary

STAN[illegible]LANT

“One-Size-Fits-All” plate

High stiffness affects physiological loading of the bone

Absolute stability inhibit biological healing

Soft tissue irritation

Implant loosening, refracture and increased risk of revision surgery

GENERATIVELY DESIGNED IMPLANT

Personalised plate with patient-specific biomechanics

Reduced stiffness allow physiological stresses and thus preserve the bone remodelling process

Increased flexibility provides an optimal healing environment

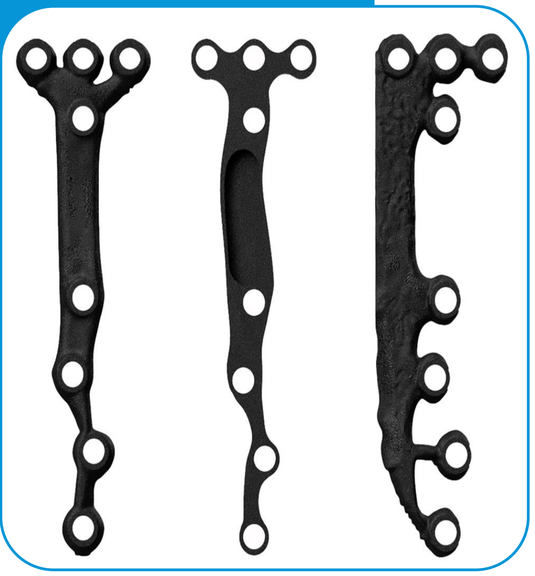
Reduced risk of infection and discomfort

Minimised risk of implant loosening and revision surgery

Pre-operative planning flexibility

Future Work

Detailed Design



Additive Manufacture

Mechanical Testing

Image Courtesy of S.Miramini et al., (2015)

Computational Validation

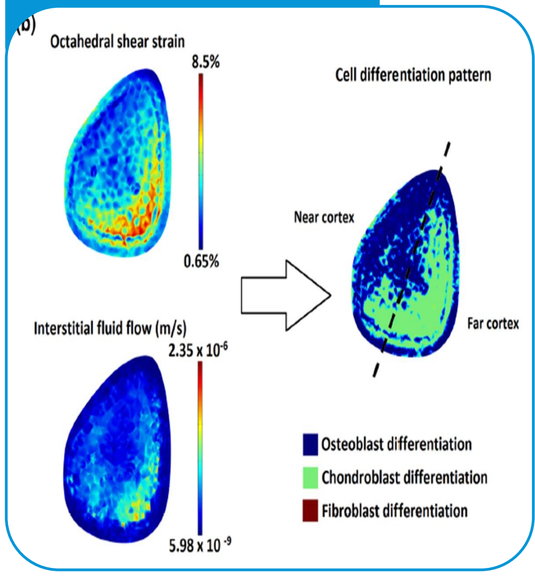


Image Courtesy of S.Miramini et al., (2015)

mtc
Manufacturing
Technology Centre

Questions

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