Additive Manufacturing Rapid-Fire

Colleen Wivell
Biomedical Engineering Manager
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What is 3D Printing?

3D Printing = Rapid Prototyping = Additive Manufacturing
= Building parts layer by layer
Why 3D Printing for Medical?

1970’s

• Sir Gofried Hounsfield
  • 1971 First CT Scan
  • 1975 First whole body scan
Scan to 3D Model

Scanner ➔ 2-D Cross Sections ➔ 3D model

*Mimics®*
Medical 3D Printing History

1990’s

Anatomical models

Before Phidias project

1992

1995
Medical 3D Printing History

- Anatomical models
- Custom Instruments & Devices

1999

1999

2002

2007

2010
Medical 3D Printing History

1990’s: Static anatomy, often ‘bone’

2000’s: ‘Moving’ anatomy

2010: Soft Tissue Implant

Dr. Hollister, University of Michigan & Dr. Green, C.S. Mott Children’s Hospital, USA
Medical 3D Printing History

1990’s - Static anatomy, often ‘bone’
2000’s - ‘Moving’ anatomy
2010 - Soft Tissue Implant
2013 -
FDA Perspectives

- 85 approved medical devices made using 3D printing
  - *Majority 510K or emergency use cases*

- Hosted Public Workshop: Additive Manufacturing of Medical Devices (October 2014)
Custom hip replacement

Pre-op

- **Case**: Female, age 15
- **History**:
  - Von Recklinghausen disease
- **Classification**:
  - Extensive bone loss
  - Severely deformed bone

*Not cleared for use in the United States*
Design

Not cleared for use in the United States
Screw placement

Not cleared for use in the United States
Simulation

Individualized muscle model, stress analysis and kinematics
Titanium printing

Implant

Not cleared for use in the United States
Outcome

Post-op


Not cleared for use in the United States
Thank You!
# Agenda

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Direct Metal Printing of Porous Titanium and Tantalum Implants

MANUFACTURING THE FUTURE

Ruben Wauthle, PhD | 3D Printing Business Development Manager, Healthcare
OMTEC 2015, Chicago, IL
ruben.wauthle@3dsystems.com
The need for implants increases rapidly

Growing active population and growing life expectancy

Increasing number of surgeries and revision surgeries

Limited availability of bone and associated risks
Porous metal implants offer a solution

Sufficient implant strength to guarantee mechanical stability

Properties close to human bone to avoid stress-shielding

Bone ingrowth into open pores to ensure long-term implant fixation
3D printing is the best way to produce porous metal implants.

Any implant shape complexity for free patient-specific and standard.

Controlled porosity and mechanical properties.

Solid implants with porous part in just one printing step.
Direct Metal Printing of porous Ti and Ta implants

Large joints
- hip, knee

Small joints
- shoulder, elbow

Other
- spinal, dental
Direct Metal Printing of porous Ti and Ta implants

Direct Metal Printing

Ti6Al4V implants

Pure tantalum implants

Pure titanium implants

Productivity improvements
Direct Metal Printing
of porous Ti and Ta implants

Direct Metal Printing
an introduction

Ti6Al4V implants

Pure tantalum implants

Pure titanium implants

Productivity improvements
Direct Metal Printing is a 3D printing technology

Layer by layer process

Laser beam melts metal powder
The production of porous implants involves different steps:

- **Implant design**
  - geometry
  - material

- **DMP process**
  - build orientation

- **Post-processing**
  - heat treatment
Direct Metal Printing
of porous Ti and Ta implants

Direct Metal Printing

Ti6Al4V implants
The reference for metal implants

Pure tantalum implants

Pure titanium implants

Productivity improvements
The design strongly effects the performance

Density
overall porosity
pore size
strut size

Architecture
unit cell design
The design strongly affects the performance

Static test
strength
stiffness

Influences
density
architecture
The design strongly affects the performance

Dynamic test
fatigue strength

Influences
applied load
architecture
Improper build orientation results in bad quality

Orientation during DMP

Different layers surface properties
Improper build orientation results in bad quality

Avoid horizontal struts

Choose appropriate build orientation

Take account of implications

![Bar chart showing comparison of strength between two orientations](attachment:chart.png)

- **Strength [MPa]**
  - Orientation 1: 200
  - Orientation 2: 100
Heat treatments change the microstructure

Microstructure
mechanical properties

Stress relief
remove residual stresses

Hot isostatic pressing
high pressure
Heat treatments change the microstructure

As built
no heat treatment

Oxidation
brittle fracture

HIP
plastic deformation
Direct Metal Printing of porous Ti and Ta implants

- Direct Metal Printing
- Ti6Al4V implants
- Pure tantalum implants
  - A highly biocompatible metal
- Pure titanium implants
- Productivity improvements
Porous tantalum deforms continuously

- No fracture
- Plastic deformation
- High strength under dynamic load
- Deformability of porous implants

![Graph showing stress-strain relationship for Ti6Al4V and Tantalum]
Tantalum implants show excellent *in vivo* performance

Almost full bridging of the critical size femur defect

Strong implant–bone interface
good quality of regenerated bone
Direct Metal Printing of porous Ti and Ta implants

Direct Metal Printing
Ti6Al4V implants
Pure tantalum implants
Pure titanium implants
The revival for use in orthopedics
Productivity improvements
Porous pure titanium deforms like porous tantalum

Porous Ta has similar static strength

Porous Ti6Al4V is stronger under static load
The fatigue strength is higher compared to Ti6Al4V

Porous Ta has higher fatigue strength

Porous Ti6Al4V is weaker after $10^6$ cycles
Direct Metal Printing of porous Ti and Ta implants

Direct Metal Printing
Ti6Al4V implants
Pure tantalum implants
Pure titanium implants

Productivity improvements
Because cost matters
Production cost reduced with equal implant quality

Identical strut density
relative density
static strength

Productivity multiplied by 3 potentially by 5

![Graph showing build rates](image)
Direct Metal Printing of porous Ti and Ta implants

Direct Metal Printing
Ti6Al4V implants
Pure tantalum implants
Pure titanium implants
Productivity improvements
DMP porous implants define a new application area

Material selection charts
DMP porous implants define a new application area

Overview of possibilities

Process variables to keep in mind

Reduced cost with equal quality
Direct Metal Printing of Porous Titanium and Tantalum Implants

MANUFACTURING THE FUTURE

Ruben Wauthle, PhD | 3D Printing Business Development Manager, Healthcare
OMTEC 2015, Chicago, IL
ruben.wauthle@3dsystems.com
References

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Ruben Wauthle et. al., Materials Science and Engineering: C, Volume 54, 1 September 2015, Pages 94–100

“Effects of build orientation and heat treatment on the microstructure and mechanical properties of selective laser melted Ti6Al4V lattice structures”
Ruben Wauthle et. al., Additive Manufacturing, Volume 5, January 2015, Pages 77–84
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Are you 3D-Printing yet?

Inspiration: 20min | 10 slides
- Past, Present and Future?
2003-2010
(ZPrinter Sales Asia Pacific)

2012-2013
(Built NA Referral Agent Channel)

2013-2014
(Global Sales of 3D Rendering Software)

2010-2012
(ProJet & BFB Sales in USA)

2013-2013
(via Merger)

Current
(Metal 3DP Sales in North America)
Ti > PEEK > Ti+PEEK > Ti3D

Additive Manufacturing Timeline: The Shift in Additive Manufacturing Applications

Product Design
Prototyping and Customization

1986 AM Invented (SLA)
1989 AM Rapid Prototype System (FDM)
2007 RepRap Movement
2008 User Generated Art
2009 FDM Patent Expires – Growth in Consumer 3DPs

Production
Scaling in Volume, Size, and Availability

2014 Selective Laser Sintering Patent Expires
2012 3D System Acquires Z Corp
2016 Mass Production LEAP engine part
2030-2050 (Estimated) Completed Product

Source: Deloitte

Impacts on Aerospace Industry
1986 Rapid Prototyping
2004 Component Manufacture
2007 Real-time Spare Parts Manufacture
2011 SULSA Prototype

GE Acquires Morris Technology

## Application Maturity

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*High volume production*  *Low volume production*  *Under evaluation*
Strong Consolidation
TranPham Triangle3D

Material

Software

Hardware

Material

3D+

Additive

Subtractive

3D
# Materials & Industries

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Source: Company data, Credit Suisse research
Laser
1/2/Quad Beams
200W/400W/1000W
2 Cu/Hour
Nitrogen/Argon
Un-heated chamber
Non-Stackable
15-45 micron
TI64: $500+/Kg
Residual Stress
No-Pre Heat
“Anchors”

Electron
50+ Beams
3,000W
5 Cu/Hour
Vacuum
Heated Chamber
Stackable (build)
45-106 micron
TI64: $200/Kg
Min. Residual stress
Pre-Heat (support)
“Heat-sink”

DMLS (SLM)

Aluminum
Cobalt Chrome
Maraging steel
Stainless
Gold

TI64
IN718
TiAl

EBM
Design Considerations

Modeling = Add Lattice/Topology

Fix => Structure => Build Proc.

3D-Printing/Additive

Subtractive

- Magics
- Structures
- Autodesk
- WithinLab
- NetFabb
- FIT
- Deskarts
- HyperWorks
- SolidThinking
- Uformia
More “Integrators” WANTED
"Inspirational Metal Orthopedic 3D-Printing in Booth #615"
# Agenda

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Additive Manufacturing – Applications in the medical field

Everlee DeWall
EOS Area Sales Manager – Central Region NA
June 18th, 2015
Key Benefits of Additive Manufacturing for Medical Applications

- Customization
- Freedom of design
- Cost advantage
- Productivity advantage
Key Benefits of Additive Manufacturing for Medical Applications

**Customization**
- Individualized parts
  - Patient-/Surgeon-/Procedure-specific adaptations
  - Cost efficient small series up to "lot size one"
- Freedom of design
- Cost advantage
- Productivity advantage
Perfect Fit for Cranial Implants through Additive Manufacturing

Case study: Cranial implant by CEIT Biomedical Engineering, s.r.o.
 Improved Quality of Life thanks to Cranial Implants produced with Additive Manufacturing

Case studies: Cranial implants by Oxford Performance Materials (OPM) and Novax DMA

Permeable skull implant made of titanium

Source: OPM, Alphaform, Novax DMA
Custom-Designed, 3D printed Splint saves Life of Babies

Case study: Bioresorbable splint by University of Michigan

Source: University of Michigan
Key Benefits of Additive Manufacturing for Medical Applications

- **Customization**
- **Freedom of design**
- **Cost advantage**
- **Productivity advantage**

**Lightweight parts**

**Complex components**
- e.g. porous surfaces

**Design-Driven Manufacturing**
Design-Driven Manufacturing

Application

• Lightweight spinal instrument prototype for minimal invasive surgery
• Multiple prototype iterations in a few days reduce lead time
• Shift from design for manufacturability to design for functionality

Material

• Stainless steel materials for surgical instruments include 17-4 and 15-5 PH, ongoing development for further stainless steel

Prototype of Expedium SFX Cross Connector
Acetabular Hip Cup Impactor

DMLSTM Acetabular Cup Impactor

- Functional 17-4 Stainless Steel
- Complex component parts produced in less than 48 hours
- Greater than 50 percent cost savings
A Complex Trabecular Lattice is applied on a Hip Cup for Improved Osseointegration

Case study: Lattice structure hip cup design by Within

Source: Within, EOS
Key Benefits of Additive Manufacturing for Medical Applications

- **Customization**
- **Freedom of design**
- **Cost advantage**
- **Productivity advantage**

**Reduced waste**
- **No tooling cost**
- **Reduced assembly and logistics cost**
- **Reduced inventory**

**Faster surgeries**
- Pre-operative planning
- Patient-matched instrumentation/implants
Increased Efficiency, Precision and Success through Patient-Matched Instrumentation

Case study: Visionaire patient matched instrumentation by Smith&Nephew

Source: Smith&Nephew
Key Benefits of Additive Manufacturing for Medical Applications

- Customization
  - Rapid prototyping and serial applications
  - Fast feasibility feedback of virtual models
  - Haptic feedback
- Freedom of design
- Cost advantage
- Productivity advantage

Mass customization

Additive vs. Subtractive (conventional mfg)
DMLSTM Saw Guide

**Requirement**
- Rapid functional prototype of a sawing guide for implant surgery comprises 7 parts with complex geometry

**Solution**
- DMLSTM with 17-4 Stainless Steel

**Result**
- Completed in <1 week instead of conventionally 6 weeks (machining + EDM)

Sawing guide to implant a metacarpophalangeal prosthesis (big toe joint), in test on a corpse. Dimensions: ~60 x 25 x 15 mm
Medical Sawing Guide - Fabrication

- Steps in DirectPart fabrication analysis work support structure building on EOSINT M 2xx finishing/machining
- 10 pieces in one job:
  - Support design: 2 h
  - Fabrication: 15 h
  - Finishing: 10 h
  - Total: 2 days

Above: details of part design, orientation and supports
Build Area: 160 x 160 mm
Job Height: 41 mm
Volume: 18 cm³
Outlook: Many more Attractive Applications in Medical

- Crowns & Bridges
- Orthopedic Recon
- Orthopedic Trauma
- Orthodontics
- Diagnostic Imaging
- Hearing Aids
- 3D Models
- Bench-top Testing
- Incontinence & Ostomy
- Cochlear Implants
- General Capital Equipment
- Orthopedic Spine
- Exoskeleton
- Dentures
- Prosthetics
- Dental Implants
- Stents
- Advanced Wound Care
- Corrective Lenses
- Blood Vessels
- Esthetics
- Bone Replacement
- Heart Valves
- Pancreas Dialysis
- Heart Replacement

Source: Morgan Stanley Research, September 05, 2013: MedTech: 3D Printing – A Solution for Innovation
Today’s Research already shows Promising Results for Potential Future Applications

Source: upper picture from Jake Evill & Cortex Cast system, lower pictures from Wake Forest School of Medicine
The Future? – Bionic Design

Light Weight Structures – Reducing of Stress Shielding

Hip (Trabecula)  Internal Stress Directions  Today's Massive Solution

Additive Manufacturing – the manufacturing technology that will change the medical world!

Source: Materialise
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