ADDITIVE MANUFACTURING

ORTHOKINETIC TECHNOLOGIES & ORTHOKINETIC TESTING TECHNOLOGIES

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DISCLOSURES

- OKT – Strategic Planning & Regulatory Consulting
- OKT² – ISO 17025 A2LA Accredited Test Facility

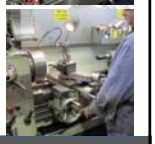
OVERALL GOAL

- Additive Manufacturing Introduction
- Pros / Cons
- Enhanced Osseointegration
- 3D Printing in Medicine

MANUFACTURING & MEDICAL IMPLANTS PAST – PRESENT - FUTURE

MANUFACTURING – SUBTRACTIVE TECHNOLOGY

- Machining, cutting, grinding, milling,
- Subtractive Technology
- Require multiple costly equipment
- Skilled employees
- Large Space
- May require multiple resources & outsourcing
- Can create stress risers through machining
- Substantial material waste
- Limited to monolithic components (no compositional changes or complex graded structures)



PAST-PRESENT MANUFACTURING- LIMITATIONS - 1

- SUBTRACTIVE TECHNOLOGY
  - Lengthy time to production & Cost Prohibitive
  - Lacks efficiency
  - Multiple manufacturers & machines = $$$$$ + potential mistakes
  - Lack control of the manufacturing (if outsourced)
  - Revisions & next generation designs – costly & increase time to market
  - Cost & time prohibitive for multiple designs
  - Design & material limitations
  - Instrumentation limitations

ADDITIVE MANUFACTURING

- Process of joining materials to make objects from 3D models
- Additive – Layering approach
- 3D Printing
- Value added
  - Can build complex structures that are difficult to machine
  - Characterized by rough surface quality – improved cellular response
  - Designed, controlled, interconnected porosity
  - High purity – restricted presence of O_2
  - High power processing velocity – rapid serial production of implants
  - Customize fit to patient anatomy

ADDITIVE MANUFACTURING

- Pros
  - Create complex open architectures
  - Rapid process
  - Metals & polymers
  - Customize surfaces, graded densities & porosities
- Cons
  - Speed of build can alter mechanical integrity
  - Tolerances not as tight – must validate each lot
  - Internal voids can form – early failure of part – overcompensate in design for void

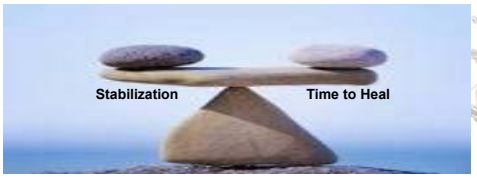
ADDITIVE MANUFACTURING

- AM is ONLY a mechanism to allow fabrication of open architectures and complex structures
- BUT – it's about the DESIGN, MATERIALS, ENVIRONMENT and more……. of Implant
- 3D printing serves as a vehicle for manufacturing complex designs

BENEFITS OF AM FOR MEDICAL DEVICES

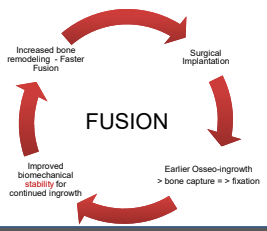
IMPROVE INTERFACE MECHANICS

- Why?
- Balance between Time & Stabilization: Fixation α Stability
- Decrease Healing Time = Decrease Failure Risk
- Improved Interface mechanics



BIOMECHANICAL FUSION CASCADE

- Improvement of Bone Interface fixation
- Enhanced Osseointegration – early stabilization
- Early biomechanical stability = faster fusion



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UNIAXIAL VS. MULTIPLANAR AREA FOR BONE EXCHANGE

Multiplanar – New Wave, New Manufacturing processes

- Optimized osseointegration – open architechture
- Multiple planes for bone ingrowth
- Greater surface area for bone – improved stability
- Stress/strain distribution throughout implant
  - Understand the micromechanics throughout implant design

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Incorporate Surface Textures for Mechanotransduction

- Induce mechanotransduction
- Global mechanical stimuli = response at cell level
- Increased cell proliferation –and/or -
- Increased cell efficiency
- Biomimicry – roughness mimics cancellous bone
- Coef. Friction increase

Printed Ti – Trabecular Pattern
Courtesy of Camber Spine

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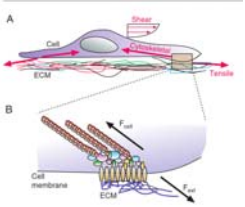
STIMULATE MECHANOTRANSDUCTION

- Cells convert mechanical stimulus into electrochemical activity.
- Trigger restructure of cytoskeleton
- Adherent cells generate tensional force Exert (transfer) forces to surrounding cells & ECM
- Cells spread when under tension forces and transfer forces to new adhesions
- Continuous feedback system

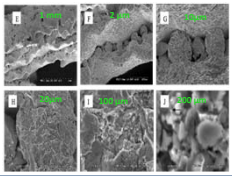


Optimization

- AM “3D Printing” – optimize surface structures, textures, coatings
  - Bone Ongrowth
  - Surface texture is not a ‘coating’ – graded substrate
- Create repeatable surface structures
- Control, Modulate Micromechanics
- Build implantable scaffolds – cell seeding
- Build open & structurally sound structures
  - Bone Ingrowth
  - Create Macro-Micro-Nano Biomechanical Environment

Titanium Plasma Coating

Established Coating – Bone Ongrowth
Friction Interference Fit:
- < 150 µm - osseo-integration
- > 150 µm - fibrous interface
- Wide Range – not consistent



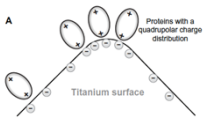
- Printed Titanium

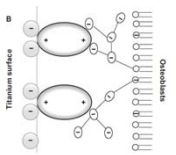
Printed technology has capability to create entire component including control of the surface roughness
- (macro – micro – nano)
- Bone Ingrowth

Mallory *et al*, 1990, *Engh et al*, 1992, Bourne *et al*, 1996

ADHERENT CELLS TO TI

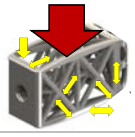
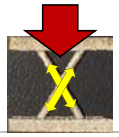
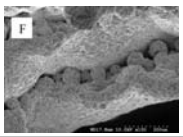
- Adhesion of cells to nano-rough Ti surface
- Attraction between negatively charged Ti & osteoblast mediated by charged proteins
- Osteoblasts are strongly bound to sharper peaks of surface – region of greatest negative charge
- Design controlled surface structures





Gongadze E: *et al*, *Int J Nanomed* 2011:6 1801-1816.

Control & Predict Macro/Micro/Nano Mechanics

MACRO	MICRO	NANO
		
Macro load (stress vs. strain) applied results in: • Global implant strain • Multidirectional strut microstrain	Individual truss loading Microstrains along each strut at the local bone interface – deep within the cage to the peripheral	Surface demonstrates repeating microstructure at micro and nanoscale surface features <50mm- Micro and Nanostrain • Induce mechanotransduction, • Increases Coef Friction

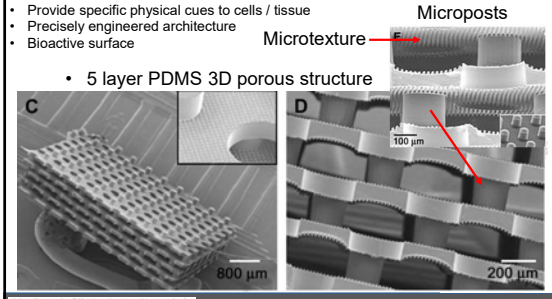
BUILD CONTROLLED STRUCTURES TO GUIDE CELL GROWTH

- Provide specific physical cues to cells / tissue
- Precisely engineered architecture
- Bioactive surface

Microposts

Microtexture

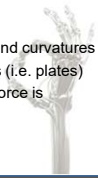
- 5 layer PDMS 3D porous structure



Biomaterials 30 (2009) 4610–4617

AM & SURGICAL PLANNING

- Common in Dental Industry – crowns printed in office
- Combine different software for virtual planning (skeletal movement + 3D reconstruction)
- Virtual planning of surgical techniques
- Virtual planning of cutting planes
- Design matching tooling & cutting guides
- Design implants & guides that match anatomical contours and curvatures
- No risk of creating stress risers through bending of implants (i.e. plates)
- Improved fixation through optimal surface area of contact (force is distributed over greater surface area)

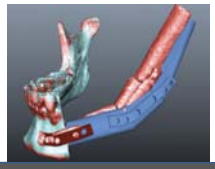


PATIENT SPECIFIC IMPLANTS + TOOLS

- Precision fit, conformity, improved osseofixation (better contact area)
- Added mesh = bone graft or substitutes – improved osseointegration
- Improved healing & interface fixation, stability Significant reduction in surgical time

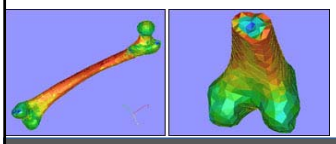
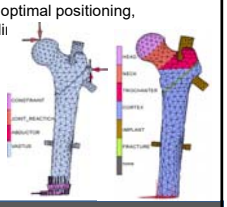
Good Agreement:

- Dark blue is the preoperative treatment plan.
- Red the postoperative treatment outcome.

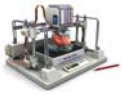

FUTURE – PATIENT SPECIFIC PREOPERATIVE PLANNING

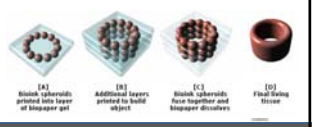
- Mesh design allows for computer modeling
- Patient specific stress profiles pre & post implantation
- Model blood/fluid flow patterns – heart/stent/kidneys
- Identify patient specific optimal positioning, techniques, sizing, loadi

BIOPRINTING USING AM

- ORGANS / FACIAL PRINTING / TISSUE SCAFFOLDS
  - Artificially constructs living tissue / organs
  - Spheroids contain aggregate of tens of thousands of cells
  - Builds layer-upon-layer of living cells from the patient's own body
  - Reduces rejection to almost zero.
  - Organovo + Invetech created commercial bioprinter - NovoGen MMX. Loaded with bioink spheroids w/cells, substrated collagen / protein matrix etc.…
  - December 2010, Organovo created first blood vessels bioprinted using cells cultured from a single human.





THE NEXT GENERATION OF MEDICAL IMPLANTS

- MATERIALS + DESIGN + MANUFACTURING – Can produce optimized implants for greater longevity
- Design implants to mimic surrounding tissue
- Design implants to mimic biomechanics/physiology
- Development new generation of implants
  - Personalized Medical Devices

NEW TECHNOLOGIES LEAD TO NEW ERA OF IMPLANT EVALUATION

- Understand bone-implant interface for improved osseointegration
- Faster biomechanical stability
- Understanding the Micromechanics

Evolution of Technology & Medicine

- Continue to innovate
- Improve outcomes, quality of life, longevity
- Continue to progress – good & bad

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THANK YOU