

THE MECHANICAL AND BIOMECHANICAL PRINCIPLES OF TRUSS STRUCTURES FOR INTERBODY FUSION

ORTHOKINETIC TECHNOLOGIES & ORTHOKINETIC TESTING TECHNOLOGIES

Lisa A. Ferrara, Ph.D.

lisa@orthokintech.com

Voice: 910.253.9883

Email: lisa@orthokintech.com

Website: www.orthokintech.com



DISCLOSURES

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



OVERVIEW

- Mechanical Principles of Truss Structures
- Biomechanical Principles of Truss Structures
- Overview of the 4WEB Truss Architecture
- Truss Behavior at the Bone Interface
- Mechanotransduction



INTRODUCTION

- Trusses - triangular units connected at nodes
- Lends to multiplanar strength & stability
- Bending moments expressed as stress transfer to surrounding substrate at truss interfaces
- Viable structure for spine and orthopedic implants
 - constantly exposed to bending moments
 - greatest moments at the terminal endpoints

TRUSS STRUCTURES

- Multiple triangular units oriented in 2D or 3D configuration for superior structural support
 - **Planer Truss**
 - Members & nodes lie in 2D plane
 - **Spacer Truss**
 - Members & nodes lie in 3D plane
- High mechanical strength
- Additive manufacturing -3D Printing
- Open architecture
- Complex shapes

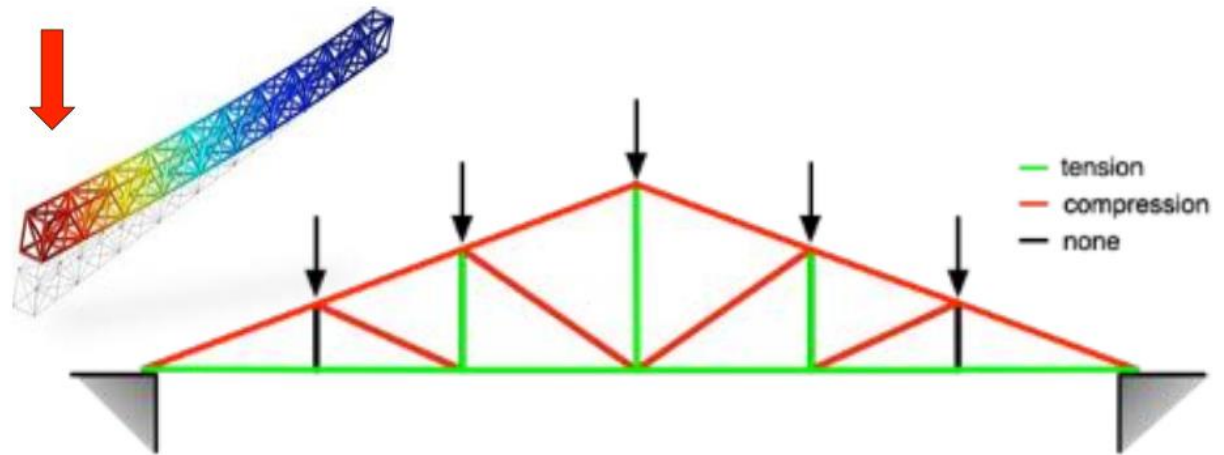
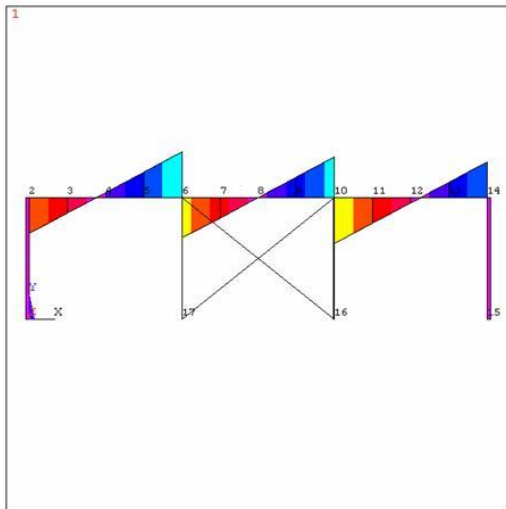


BASIC MECHANICAL PRINCIPLES



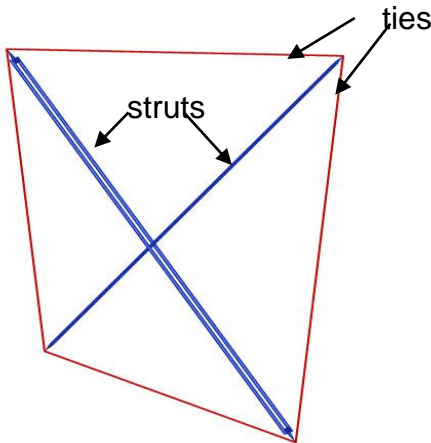
LOADING DISTRIBUTION OF TRUSSES

- Compression & Tension Forces along struts – work in unison
- Isotropic stress transfer through each strut
- Distribution of stresses THROUGHOUT truss structures
- Ensures stress transfer - deep within complex configurations

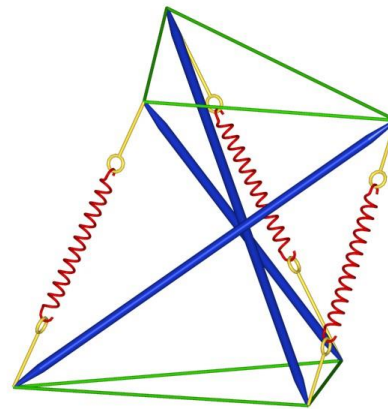


TENSEGRITY

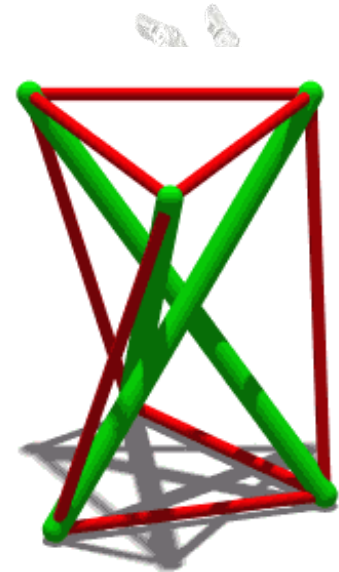
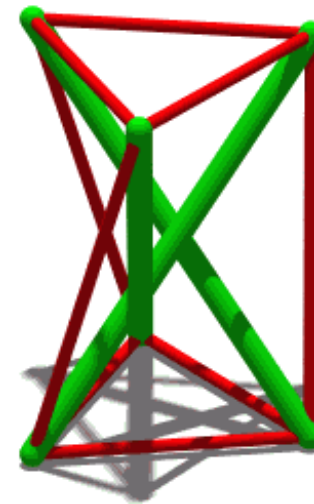
- Structural principle - Combination of simple design patterns = complex component = high strength
- Loading members under compression or tension
 - work in unison under loading
- Self-Stabilizing structures
- 2D and 3D planes



2D- planar tensegrity

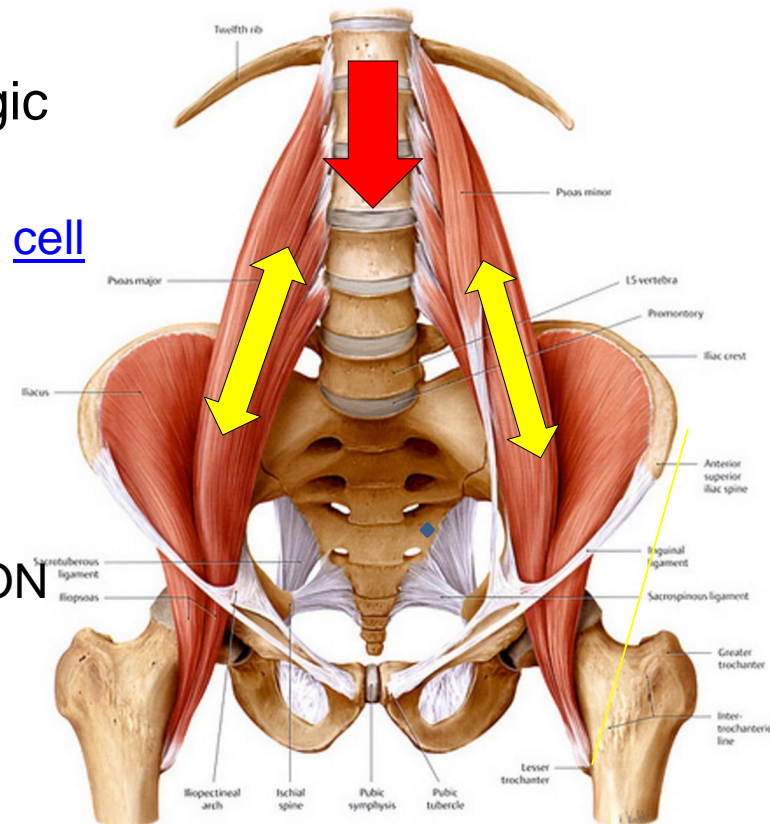


3D-Spatial tensegrity



BIOTENSEGRITY

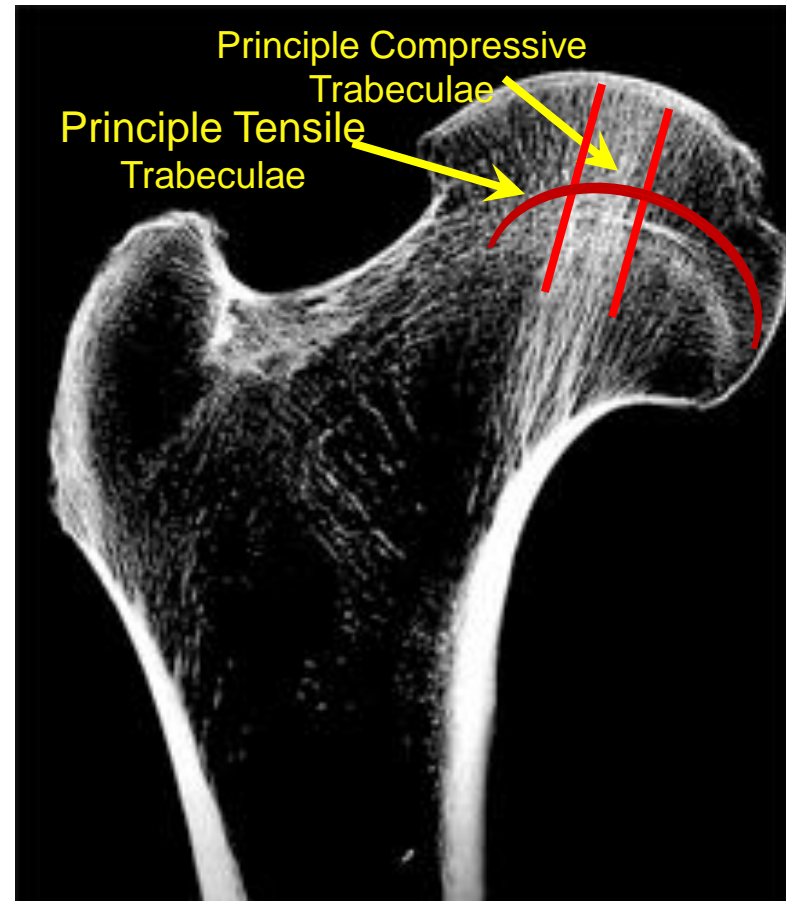
- Coined by Dr. Stephen Levin
- Application of tensegrity principles to biologic structures
 - muscles, bones, fascia, ligaments, tendons, cell membranes
- Superior strength from unison tension + compression of tissue structures
- Muscular-skeletal system
 - Muscles & connective = continuous TENSION
 - Bones = discontinuous COMPRESSION



WOLFF'S LAW

Form Follows Function

- Bone will remodel along lines of stress / resorb in lack of stress-strain
- **Function** – Walking
- **Form** – Results in Bone remodeling along lines of greatest stress during function
- Dynamic System – Bone remodeling is a constant process responding to constant stimuli



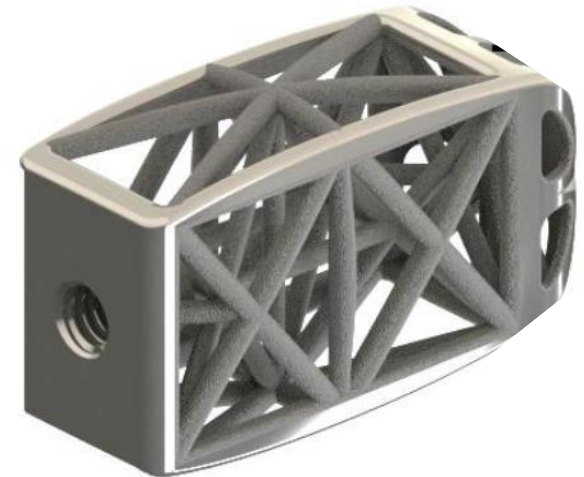
ELASTIC MODULUS

- Defines compliance 'elasticity' of material
- $EM = \text{Stress} / \text{Strain}$
- Material Modulus – $T_i = \text{Stress/strain of bulk material}$
- Global modulus – Stress/Strain of implant
- Localized modulus – Stress/strain of strut member



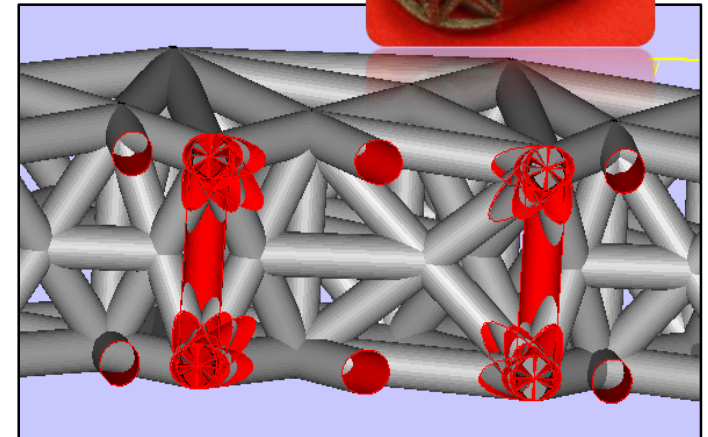
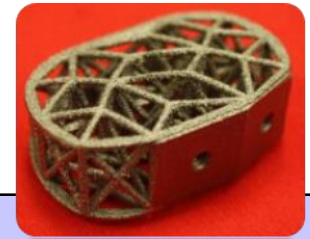
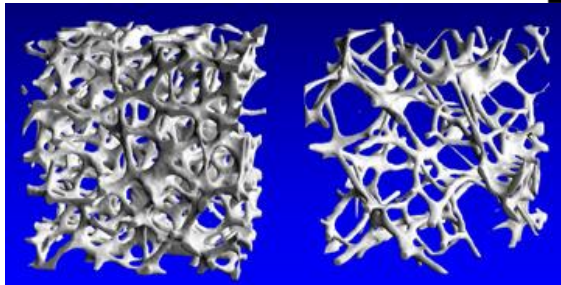
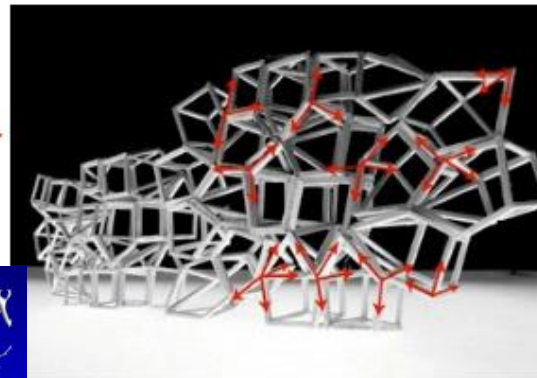
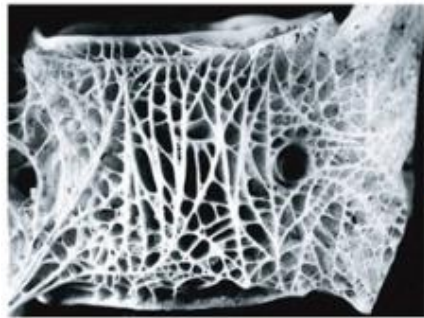
4WEB Truss Structure

- Rebar/Scaffolding Concept
- High strength
- Open architecture ~93% porosity
- Force distribution results in tensile & compressive forces in strut members
- Multiplanar influence at bone interface
- Forces + reactions to forces act at nodes



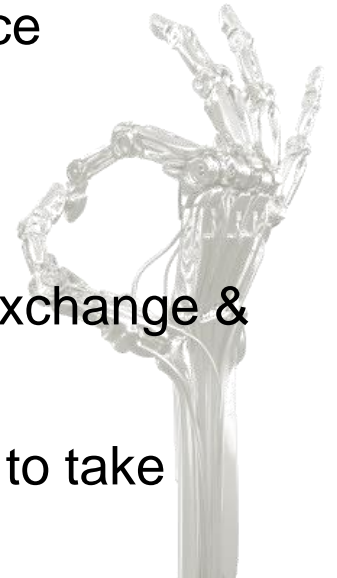
BIOMIMICRY OF TRUSS MATRICES

- The truss structure mimics biological architecture & can function analogous to bone with respect to stress transfer
- Multiplanar stress distribution throughout structure



BIOMECHANICAL OBJECTIVES

- Provide a biomechanically viable & structurally supportive matrix for optimal bone exchange & improved fusion healing
- Distribution of stresses throughout & within entire implant
 - Significantly greater contact surface area at bone interface
 - Truss CIBF– multiplanar – total area = **210mm²**
 - PEEK CIBF – axial plane, central pore – total area = **40mm²**
 - Multiplanar stress distribution for multi-directional bone exchange & incorporation = better biomechanical stability
 - Local stress/strain to individual struts throughout implant to take advantage of Wolff's law at a macro/micro/nano level



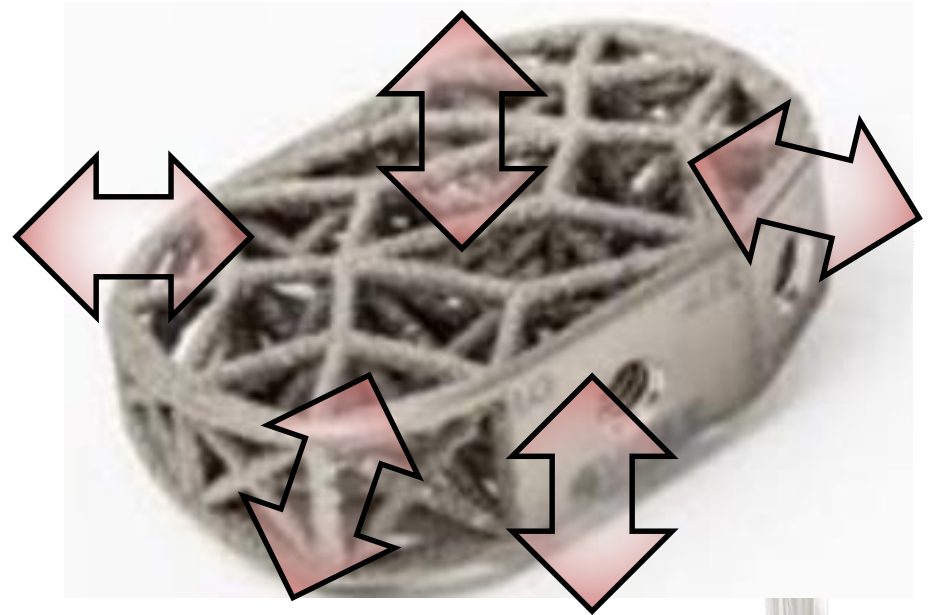
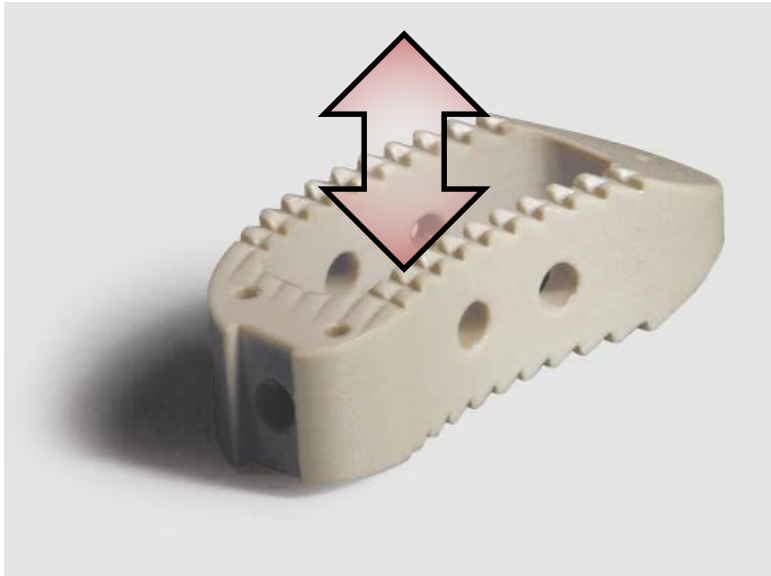
4WEB TRUSS MANUFACTURING

- Manufactured through additive manufacturing - ONLY mechanism to allow fabrication of Truss architecture
- BUT – it's about the DESIGN of Implant and the innate mechanical behavior of truss structures
- 3D printing is the vehicle for manufacturing complex designs



TRADITIONAL VS. OPEN TRUSS IBF

- Bone growth – uniaxial direction vs. multiplane

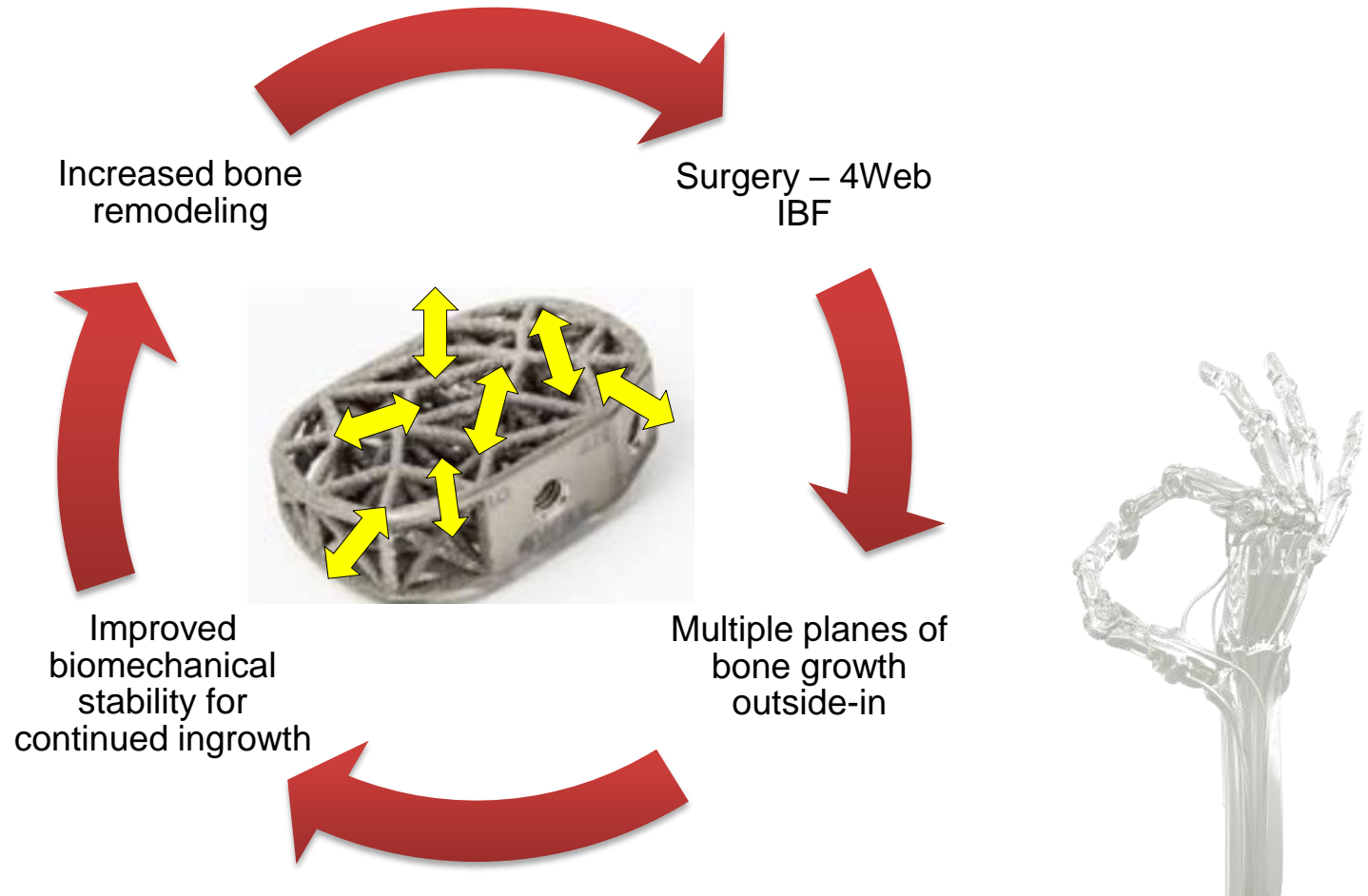


BIOMECHANICS OF TRUSS DESIGN

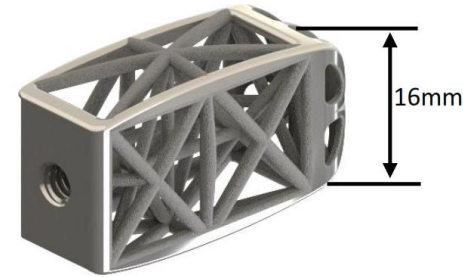
- Multi-directional bone exchange & incorporation = better biomechanical stability
- Improved stability allows for further ingrowth towards center- throughout implant
- Greater fusion footprint – better stress distribution throughout implant



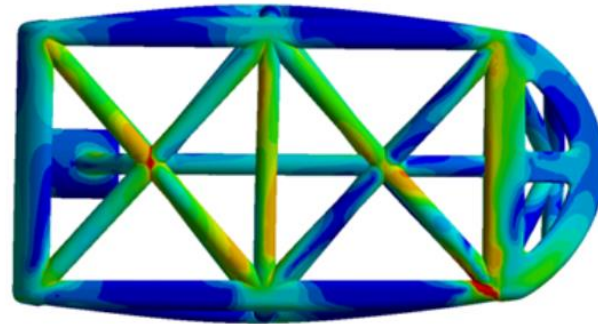
BIOMECHANICAL FUSION CASCADE



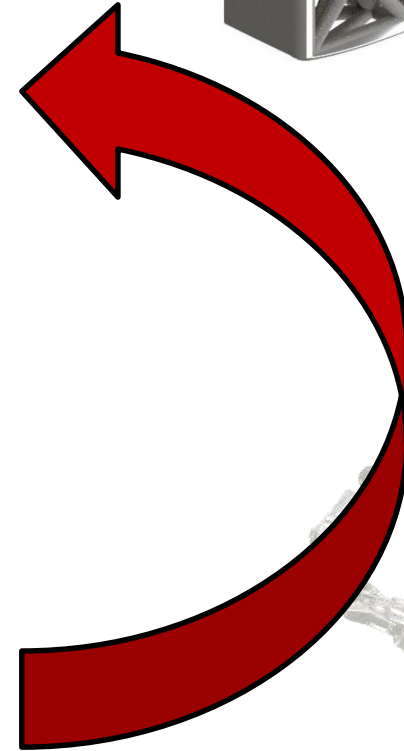
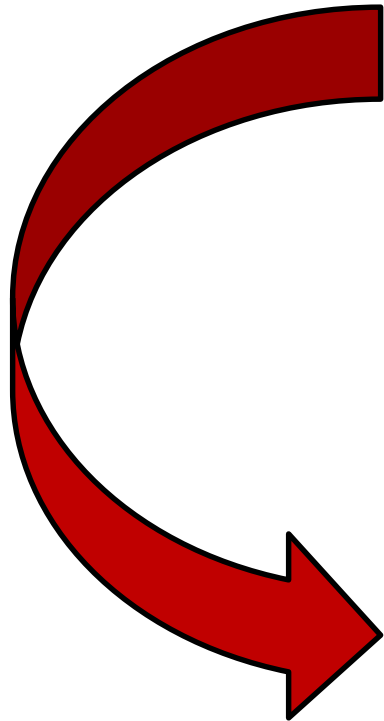
4WEB TRUSS DESIGN



FORM



FUNCTION



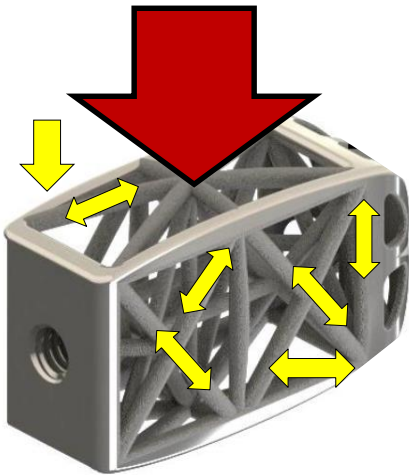
TRUSS DESIGN & WOLFF'S LAW

- **Macro** – Global loads to implant result in transfer of stresses throughout /within implant= strain of entire implant under loading - macrostrain
- **Micro** – Stress distribution to struts of each truss = LOCAL microstrain at bone interface
- **Nano** – surface texture



STRUT STRAIN

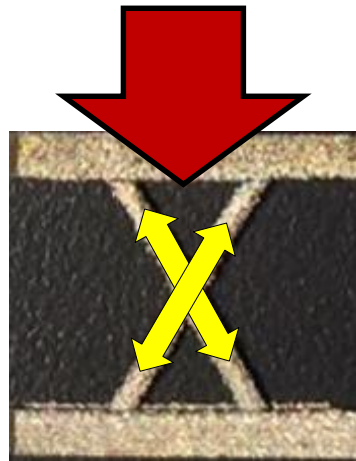
MACRO



Macro load (stress vs. strain) applied results in:

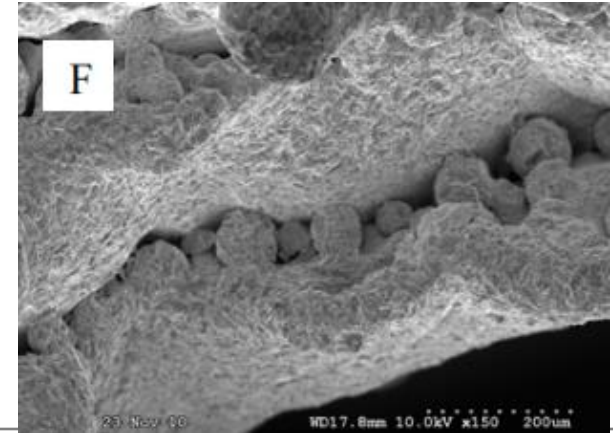
- Global implant strain
- Multidirectional strut microstrain

MICRO



Individual truss loading
Microstrains along each strut at the local bone interface – deep within the cage to the peripheral

NANO

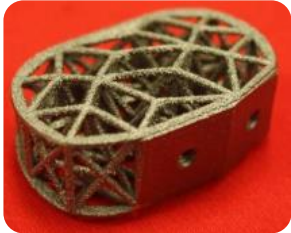


Surface demonstrates repeating microstructure at micro and nanoscale surface features <50mm- Micro and Nanostrain

- Induce mechanotransduction,
- Increases Coef Friction

MACRO





STRESS DISTRIBUTION ON IMPLANT

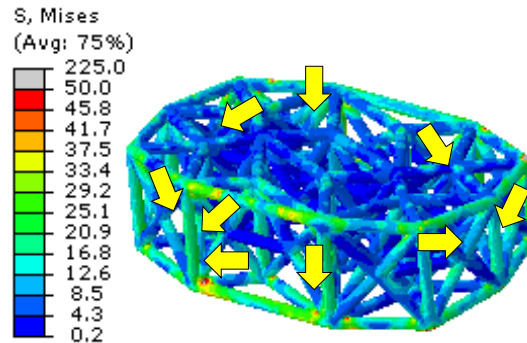
COMPRESSION

- Applied load of 500N to surface of simulated bone surrounding implant
- 500N - approximately = weight of torso
- Stress can be seen on peripheral ring & within implant
- Greater compressive load = greater stress along struts within implant
- Greater stress transfer on thinner struts & shorter implants for this design

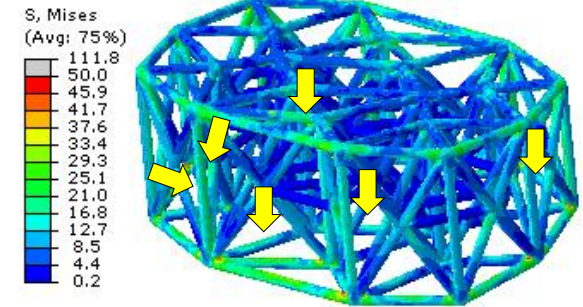


500N Compression

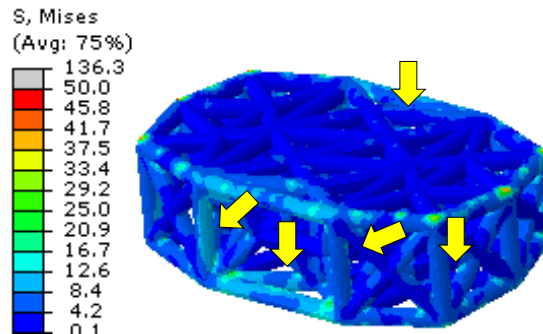
10 mm – strut 1.0 mm



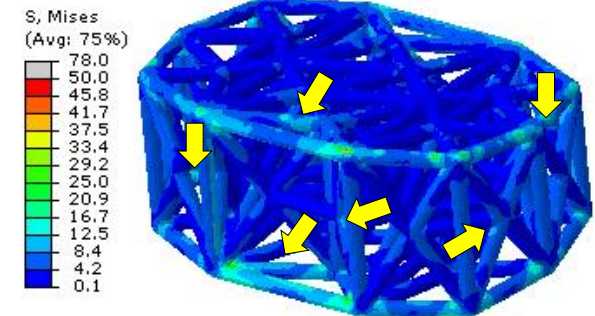
17 mm – strut 1.0 mm

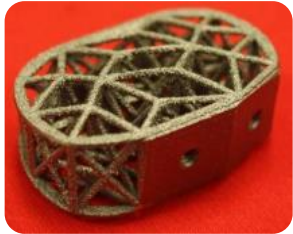


10 mm – strut 1.5 mm



17 mm – strut 1.5 mm



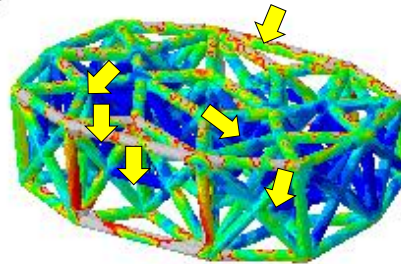
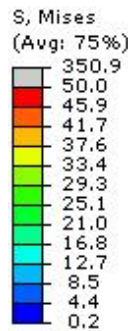


FLEXION

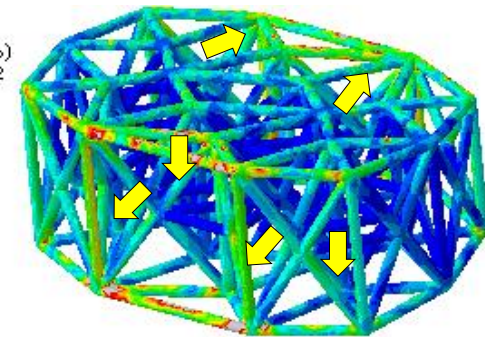
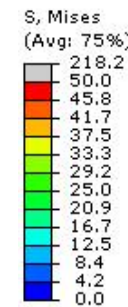
STRESS DISTRIBUTION ON IMPLANT

- Applied 5Nm to surface of simulated bone surrounding implant
- 5Nm – Physiological Bending Moment
- Stress can be seen on peripheral ring & within implant – greater on anterior rim at load application
- Greater bending moment = greater stress along struts within implant
- Greater stress transfer on thinner struts & shorter implants for this design

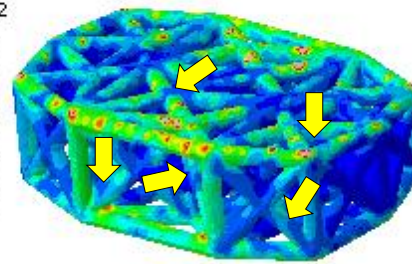
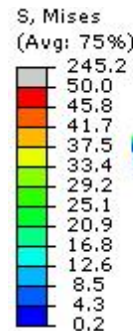
10 mm – strut 1.0 mm



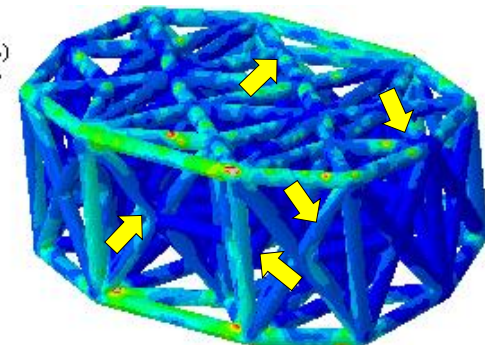
17 mm – strut 1.0 mm



10 mm – strut 1.5 mm



17 mm – strut 1.5 mm



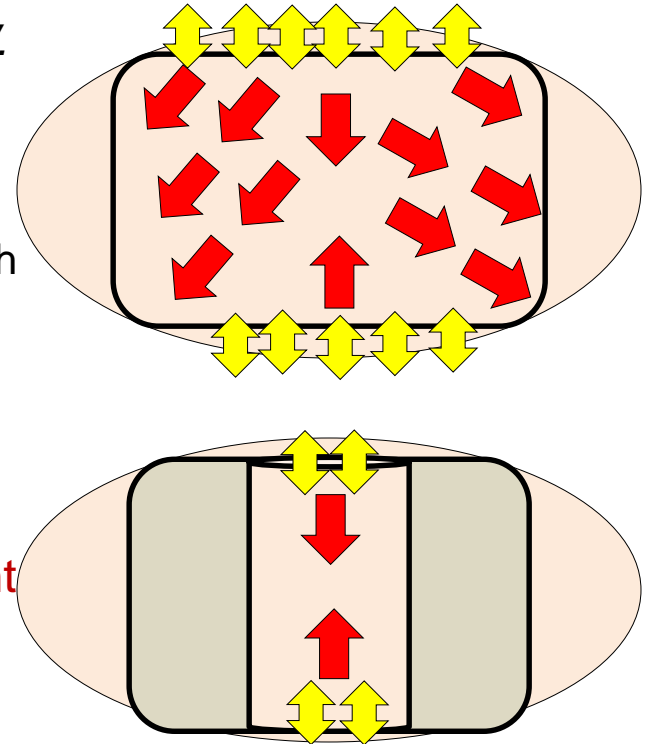
STRESS EXCHANGE & VOLUMETRIC DISTRIBUTION

- **Bone to Bone Contact Area** - (*bone exchange area at V. Endplate*)

- Area of contact at endplate & exposed bone in cage (arrows)
- Multiplanar Volumetric Distribution of Stress through Truss CIBF vs. PEEK
- It is not about Modulus of MATERIAL

- **It is about:**

- **Stress Distribution** –
 - Volumetric distribution through implant
 - Less stress at surface
- **Stress exchange from implant to vertebral endplate lessened**



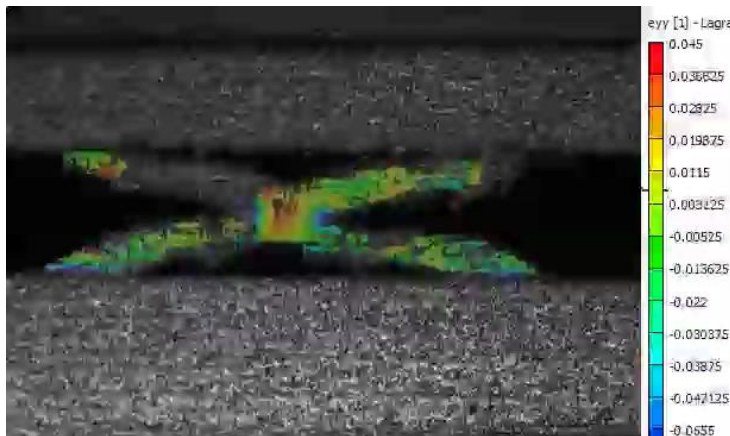
MICRO



MICROSTRAIN - STRUTS

- In vivo Sheep study – 4WEB implants – lumbar spine
- 2 groups – implants with different strut diameters evaluated
- DIC on individual struts exhibit different strain patterns for different strut dimensions
- Can optimize bone healing & remodeling
- Sheep study demonstrated improved remodeling for a specific strut diameter
- Why – optimized local microstrain + macrostrain

SHEEP IBF @ 3mos.

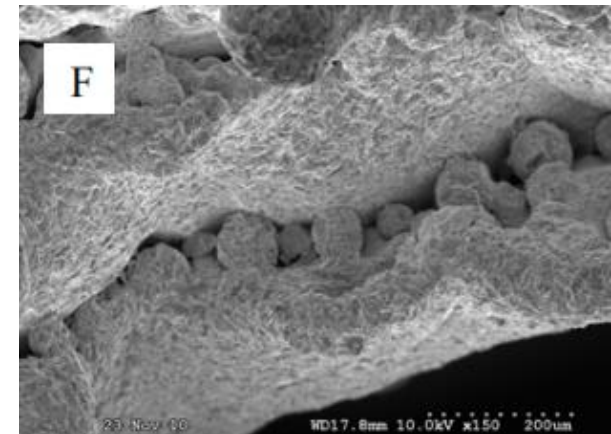
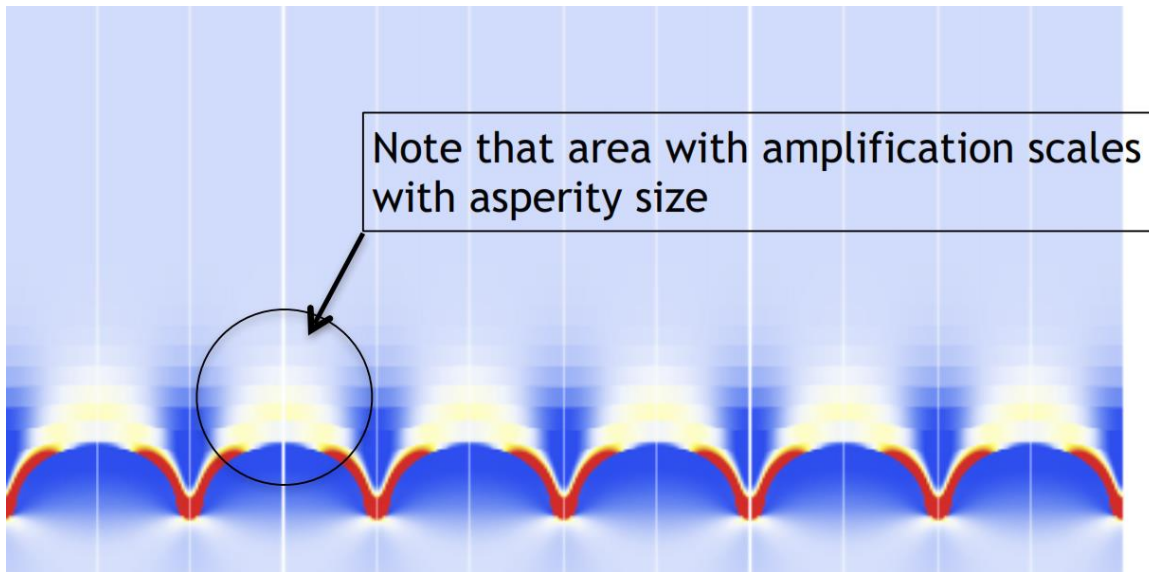


SURFACE STRAIN (MICRO & NANO)



SURFACE STRAIN

- Surface roughness had micro & nano structures that form peaks / valleys - strain responses during loading
- Study showed that optimal biological responses to specific surface geometries
Lending to different strain patterns



Surface Textures - Mechanotransduction

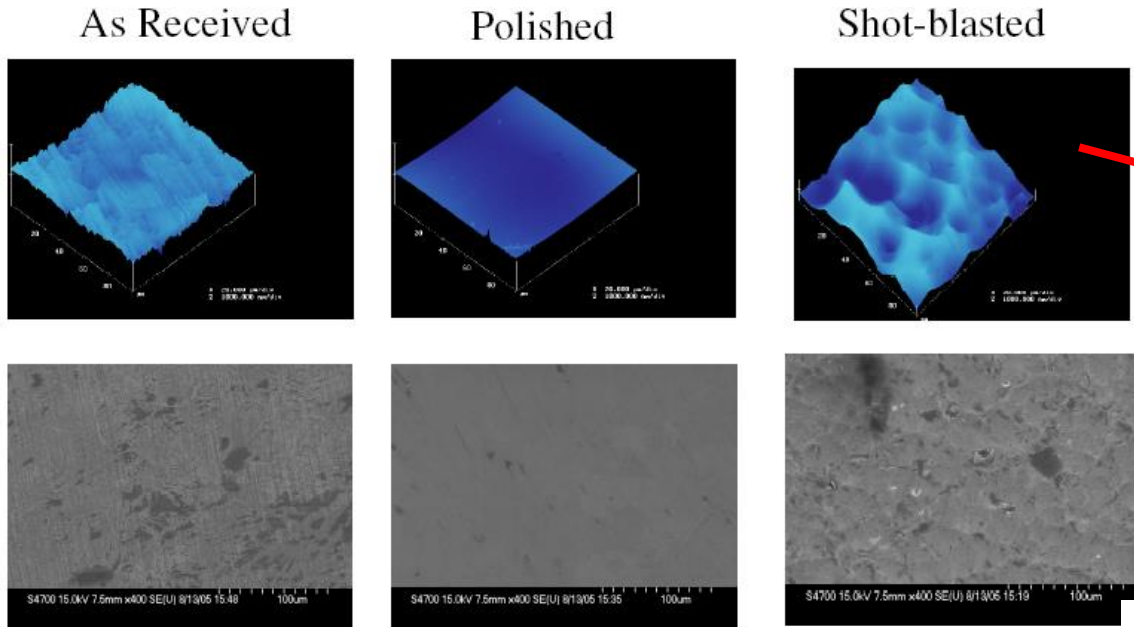
- Induce mechanotransduction
- Guide cellular growth
- Increased cell proliferation – or -
- Increased cell efficiency
- On Metals: use of surface textures
 - Increase fatigue performance of implant
 - Careful not to compromise strength
 - Titanium = improve osseointerdigitation



Evidence of Mechanotransduction



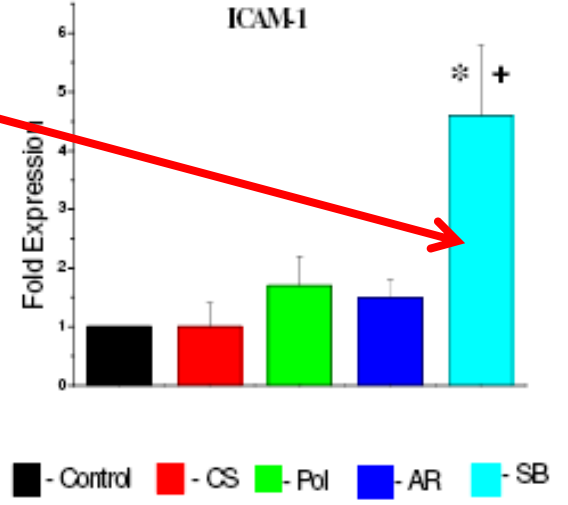
Biomaterial – Cell Interactions



Rms: 95.8 ± 5.7 nm

Rms: 40.9 ± 1.8 nm

Rms: 671.8 ± 27.8 nm

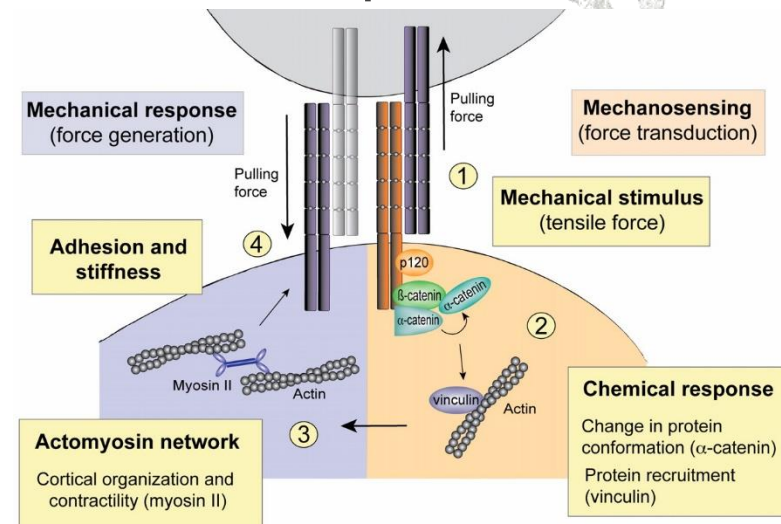


Control - Tissue Culture Polystyrene
 CS - Coverslip
 Pol - Polished
 AR - As received
 SB – Shot-Blasted

- Surface Texture effects cell response
- Shot blast textures = Increased **endothelial** cells

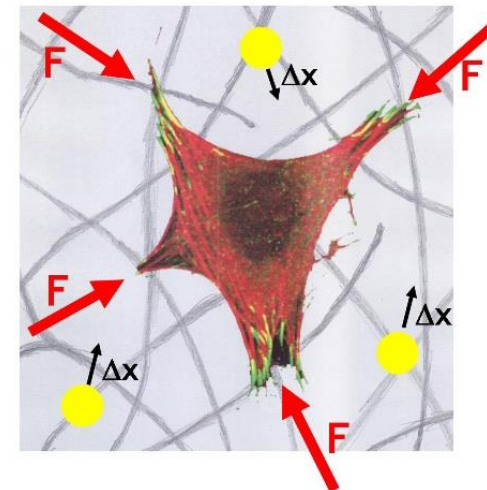
Mechanotransduction

- Process where mechanical energy is converted into electrical and biochemical signals.
- Mechanical stimuli ↔ Tissue ↔ individual Cells
- Cellular Mechanotransduction – the mechanism by which cells convert mechanical signals into biochemical responses.



Cellular Mechanotransduction

- All eukaryotic cells - mechanosensitive
- Forces (gravity, tension, compression, shear,) influence cell behavior (growth and tissue remodeling).
- Cells respond to applied force stimuli to tissue --- AND---
- Internal forces generated from cell cytoskeleton respond by generating contractile forces
- Continuous, dynamic cyclical process



TRUSS - INTELLIGENT DESIGN



- Future – current studies lead us to a programmable ‘smart’ implants with great potential for patient specificity with individualized and optimized
 - Mechanical Response
 - Biological Response
 - Improved fusion success rates



THANK YOU

