Biomimicry in Implant Design: NativeStem

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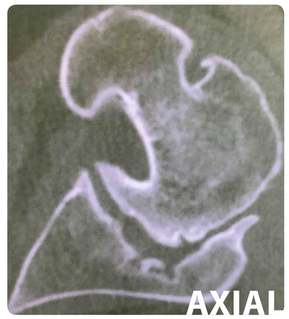
Harnessing nature's patterns and strategies to better integrate implant and bone

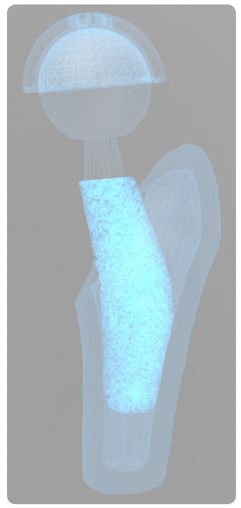
ART VANDELAY

- Male
- Active 19 year old
- Developmental Dysplasia of the Hip affecting the right hip
- Limb Length Discrepancy of the right leg (2.5 cm)
- Limited range of motion of the right hip

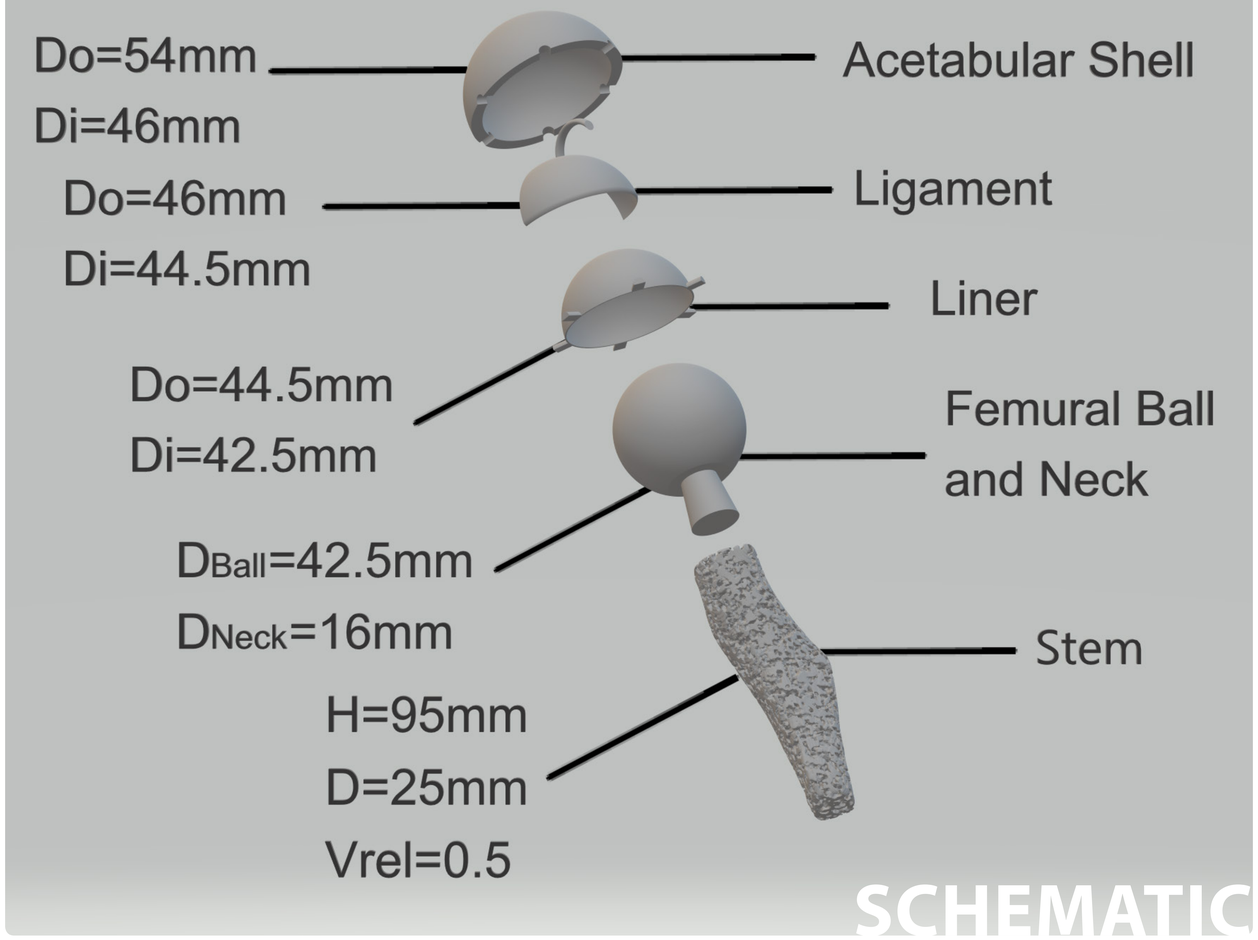


TREATMENT

- Cementless total hip arthroplasty
- Osteotomy at the base of the femoral neck to preserve maximum amount of bone[1]
- Stem is strictly fitted into the medullary canal to promote osseointegration[1,2] (see right)
- Acetabular shell is optimally fitted to the hip to promote osseointegration, but optionally fixed to the hip with nails



Right: wire-frame rendering of implant stem in femur



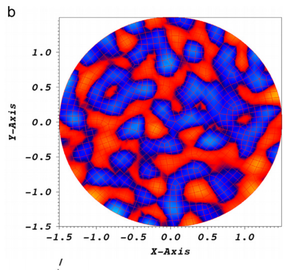
STEM

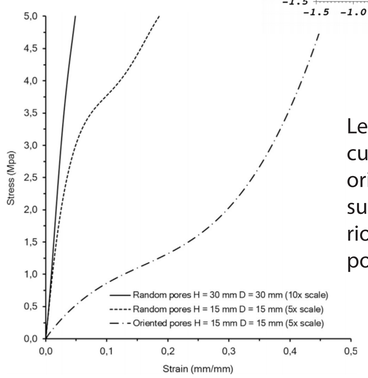
- Registration to the geometry of the medullary canal promotes osseointegration[1]
- Short stem (~50 mm) has native stress distribution[1,2]
- Absence of contact between the stem and distal cortex reduces stress shielding, bone resorption, and thigh pain[1]
- Reduces proximal stress shielding without reducing primary stability[1]
- Porous structure reduces stress shielding by ~50%[3]
- Randomly oriented pores has local fluctuations in shear stresses that are crucial to stimulating osseogenesis[1]
- Prevents catastrophic structural failure compared to periodic or regular pores[1] (see left, right)
- Fullcure MED610 photopolymer allows for 3D printing of porous structure: biomaterial used in orthopedics[4]
- Exhibits roughness that can be manipulated to control proliferation of cell growth[4]
- 3D printing orientation affects mechanical properties[4]

$$\frac{\partial u}{\partial t} - \nabla^2 u = \gamma\left(a - u + u^2 v\right)$$

$$\frac{\partial v}{\partial t} - d\nabla^2 v = \gamma\left(b - u^2 v\right)$$

Top: governing PDE of porous pattern[4]; right: 2D slice of porous stem[4]

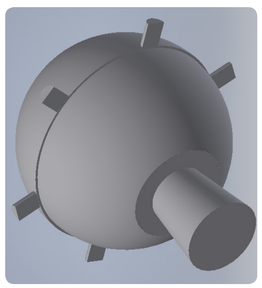




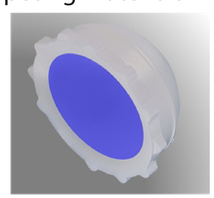
Left: stress strain curve of randomly oriented pores versus regularly or periodically oriented pores[4]

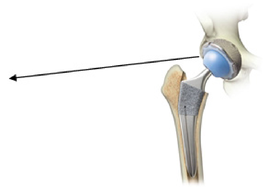
BALL AND LINER

- 42.5 mm and 16 mm titanium aluminium alloy[5] ball and neck (see top)
- 1 mm thick wear-resistant[6] cross-linked Ultra High Molecular Weight Polyethylene (UHMWPE)
- Liner protects ball from corrosion and reduces friction between ball and acetabular shell than competing materials[6]



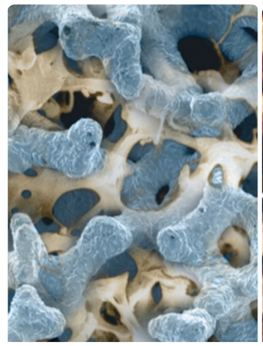
Top: CAD model of ball and liner; bottom: positioning of liner with respect to implant

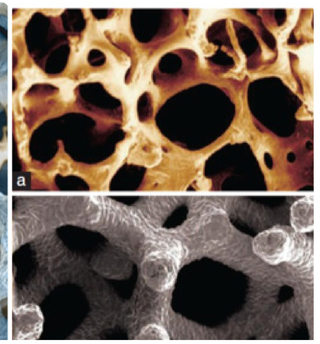




ACETABULAR SHELL

- Elliptical shape creates interference fit, which allows for maximum bone contact and stability[7]
- Notches on bottom fixes liner in place
- Trabecular metal is made of tantalum[8]
- High fatigue strength and elastic modulus allows it to elastically deform before fracture[8]
- Porous biomaterial reduces stress shielding[9]
- Similar structural, functional and physiological properties to that of trabecular bone[10] (see right)

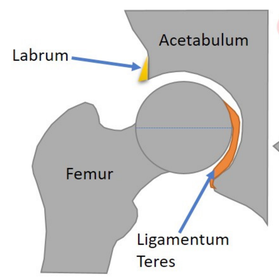


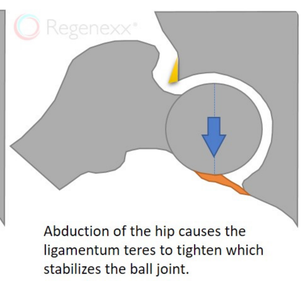


Left: bone/trabecular metal integration[10]; right: trabeculae (top) [9], trabecular metal (bottom)[9]

ARTIFICIAL LIGAMENT

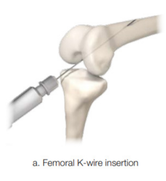
- Ligamentum Teres Femoris is crucial for range of motion of the femur[11]
- To improve patients range of motion and increase prevention of dislocation[11] (see top)
- Thin Cylindrical Attachment; almost identical in shape and function to native[12]
- Quarter Sphere; Provides additional reinforcement which helps to prevent dislocation
- LARS: Terephthalic Polyethylene Polyester[12]
- Articular woven fibres resist fatigue and can withstand a force of 5000 N[12]
- Attached to a socket and ball with K-Wire[12]



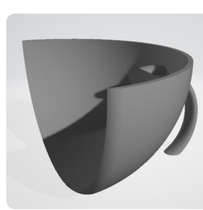


Abduction of the hip causes the ligamentum teres to tighten which stabilizes the ball joint.

Middle: CAD model of ligament; right: LARS material[12]



a. Femoral K-wire insertion



[1] Feyen et al., *Bone Joint J*, 2014.
[2] Castelli et al., *Hip International*, 2014.
[3] Altair et al., *HyperWorks Insider*, 2018.
[4] Velasco et al., *Journal of Computational Design and Engineering*, 2016.
[5] Sansone et al., *Clinical Cases in Mineral and Bone Metabolism*, 2013.
[6] Barrena et al., *The Open Orthopaedics Journal*, 2009.
[7] Resurfacingscan, *Acetabular cup: An important component of your hip prosthesis*, 2018.
[8] Zimmer Biomet, *Zimmer Trabecular Metal Technology*, 2018.
[9] Eid et al., *The Egyptian Orthopaedic Journal*, 2018.
[10] Zimmer Dental, *Trabecular Metal Technology: Introducing Osseoincorporation to implant dentistry*, 2018.
[11] O'Donnell JM et al., *Journal of Hip Preservation Surgery*, 2014.
[12] Corin Australia, *Connected Orthopedic Insights*, 2018.