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Nailing Stability during Tibia Fracture Early Healing Process: A Biomechanical Study

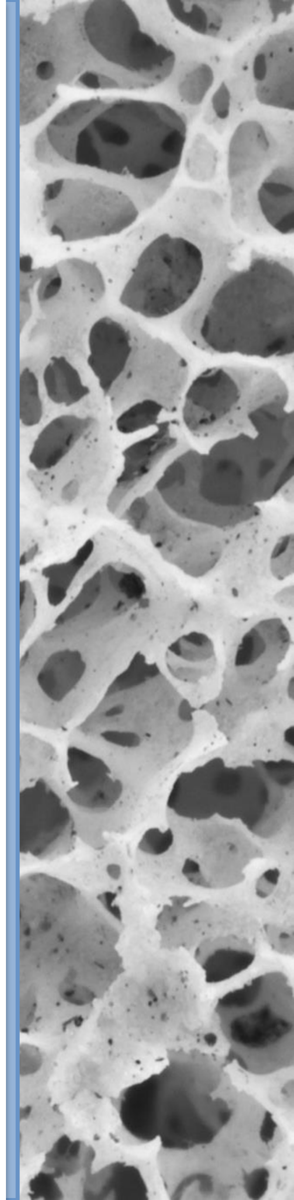
Natacha Rosa*, Fernão D. Magalhães, Ricardo Simões and António Torres Marques*

OMICS International

International Conference and Expo on

Biomechanics and Implant Design

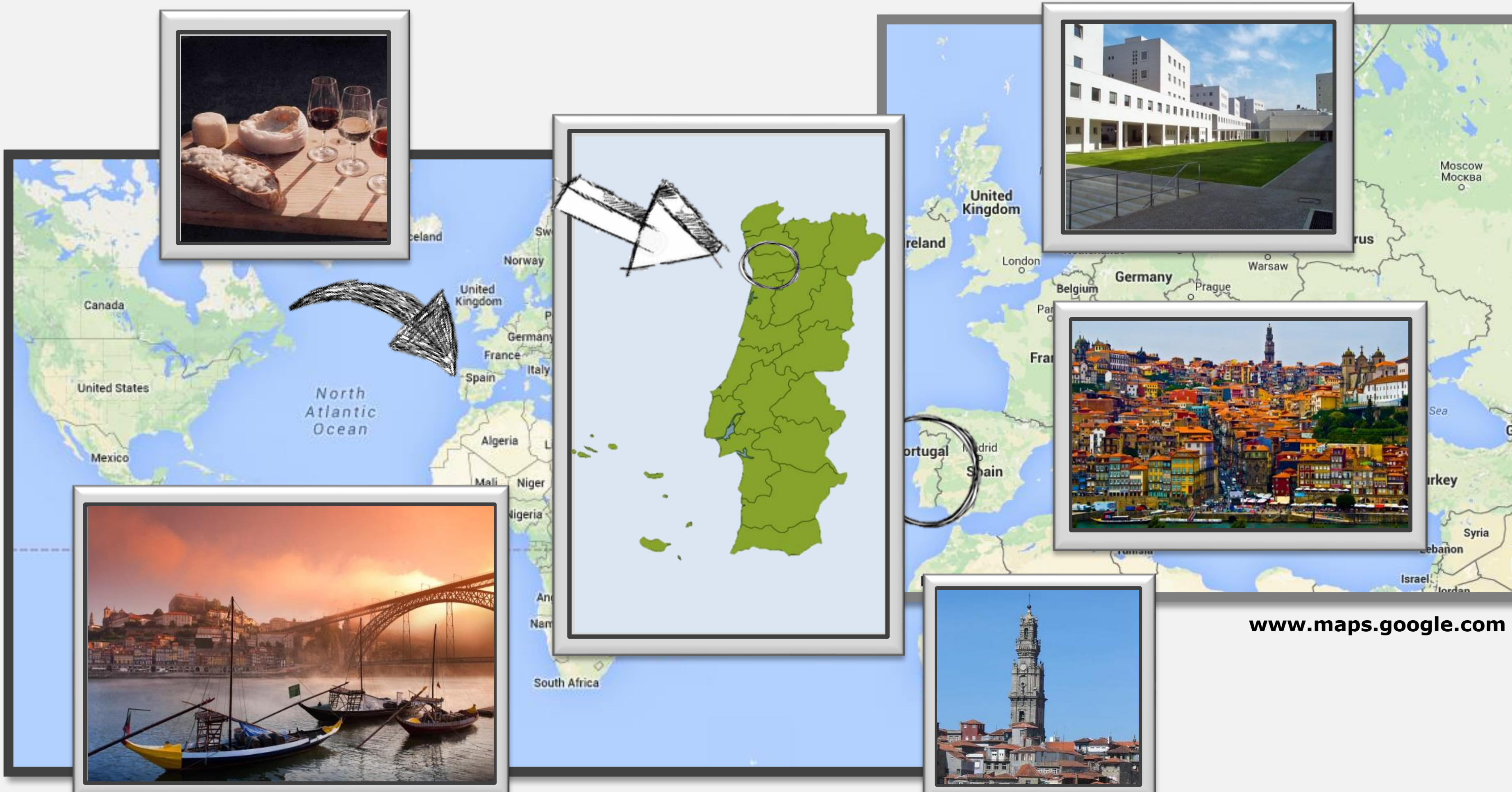
July 27-29, 2015 Florida, USA



Enhanced Bone Healing in intramedullary nailing through Mechanical Stimulation

Natacha Rosa

3nd Year Mechanical Engineering PhD Student



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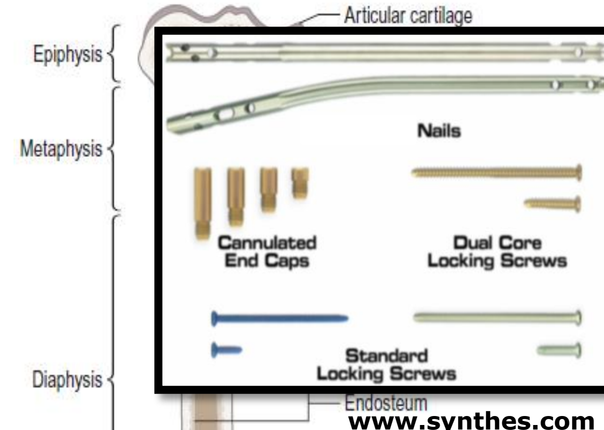
Fixation stability and healing

Stabilization technique:

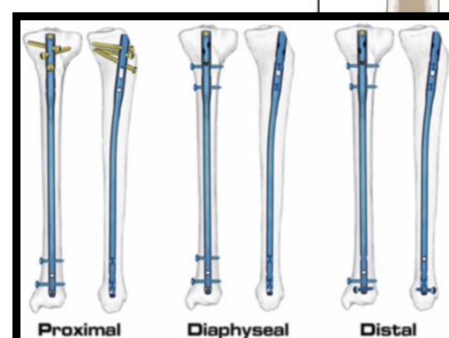
- External fixation

Tibia diaphysis fractures is ... which healing is most d...

- Plating
- Intramedullary nailing



www.synthes.com



www.synthes.com

Fixation stability and healing

Improvement of intramedullary nailing system

↓ ***Demands***

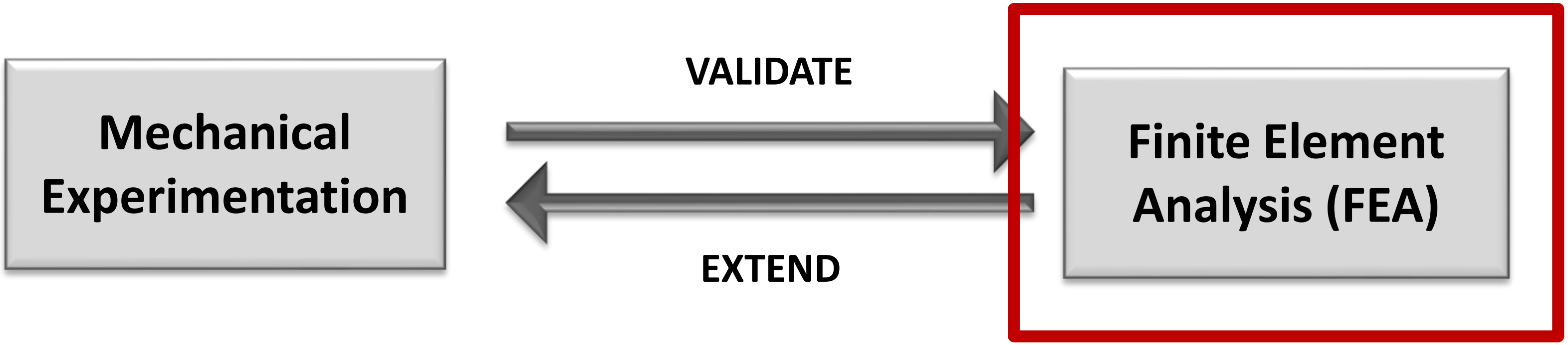
Understanding of bone-nail fixation system mechanics

- ❑ How the implant guaranties fracture stability and bone aligment;
  - ❑ How it is conducive to bone regeneration

↓ ***Compare to***

Biomechanical stability of the **whole bone**

Methodology



- Whole bone stiffness

vs

Bone-intramedullary nail Stiffness

- Interfragmentary movements

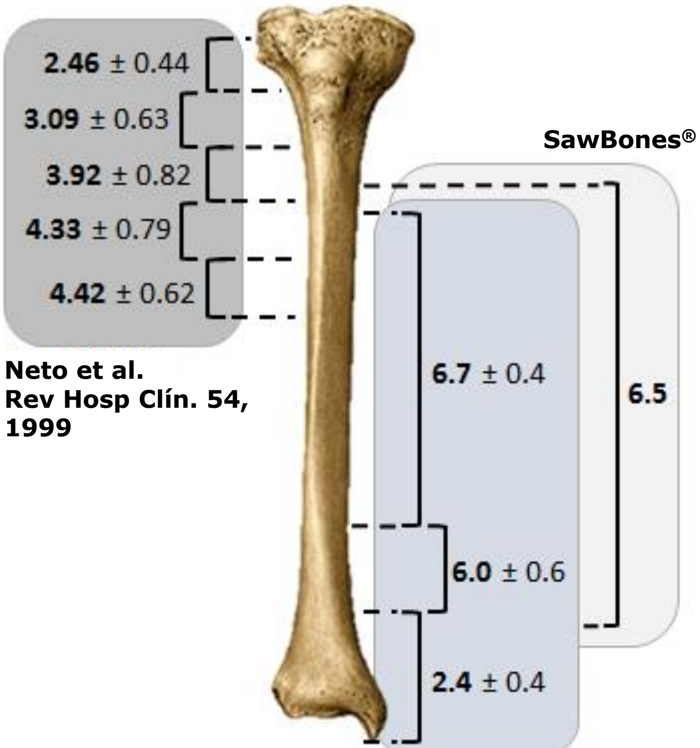
Methodology

3D Scan → **SolidWorks** → **ANSYS®**

- External surface

- Surface preparation;
- Solid model construction;
- Cortical and trabecular bone structures boundary definition;

Methodology: Whole bone system



Neto et al.
Rev Hosp Clín. 54, 1999

Heinonen et al.
Bone 29, 2001

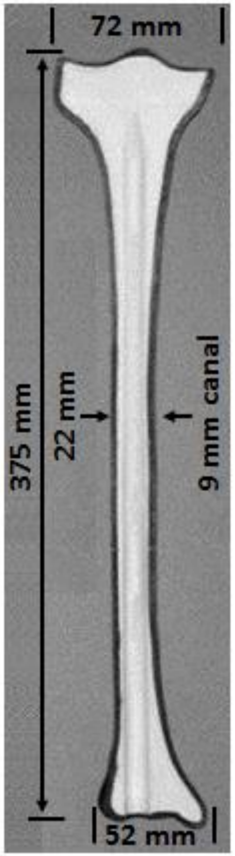
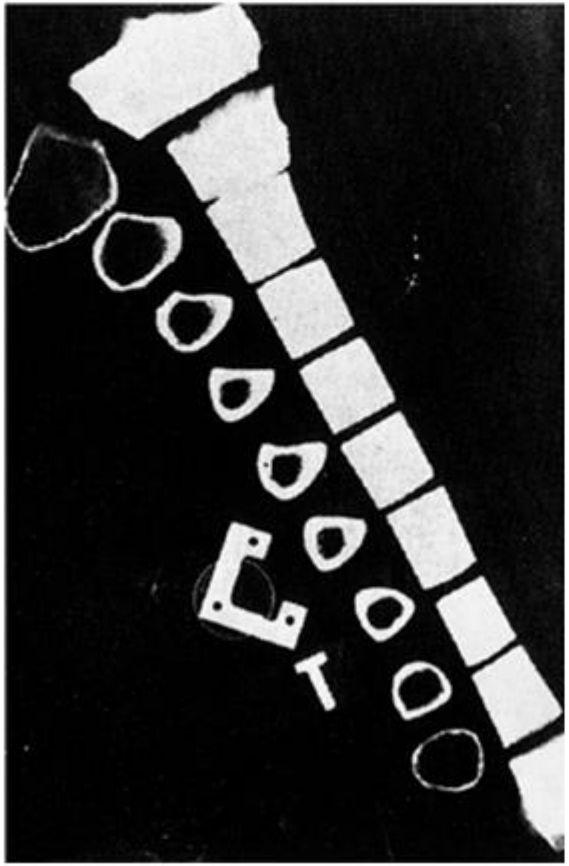
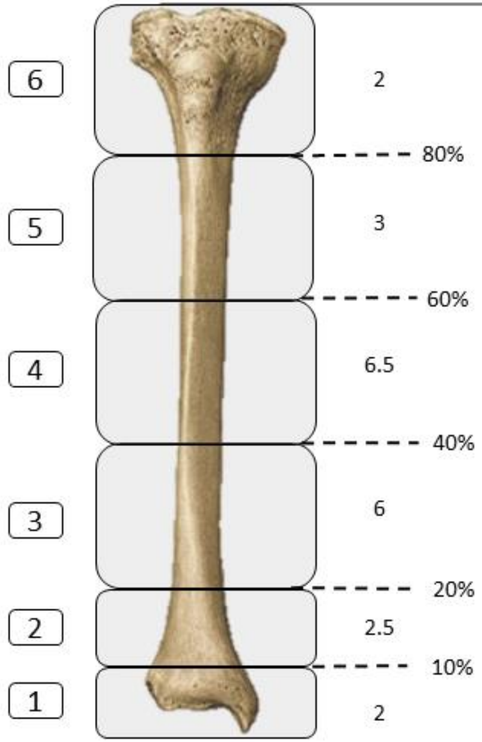


Image obtained from: **Heiner et al. J Biomech 34, 2001** and adapted with data from **SawBones®**



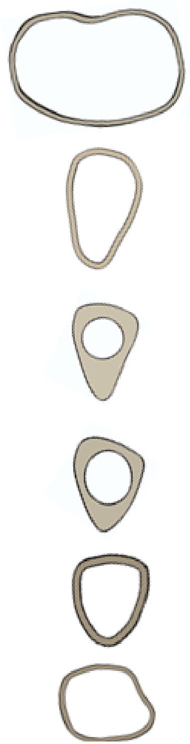
Tencer A. Biomechanics of Fixation and Fractures (Book chapter), 2006

Methodology: Whole bone system



Region	Expected cortical wall thickness (mm)	Measured cortical wall thickness: Number of measurements	Measured cortical wall thickness: Average (±std) (mm)
6	2	-	2
5	3	414	2.6 (±1.1)
4	6.5	345	5.7 (±3.0)
3	6	539	4.1 (±1.5)
2	2.5	-	2.5
1	2	-	2

Cross-section obtained



Methodology

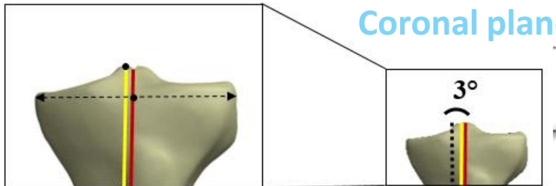
3D Scan → **SolidWorks** → **ANSYS®**

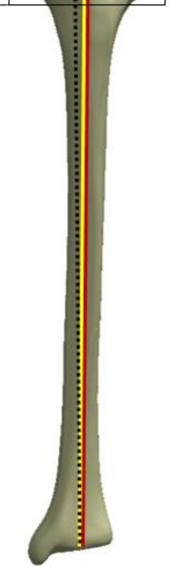
- External surface

- Surface preparation;
- Solid model construction;
- Cortical and trabecular bone structures boundary definition;
- Grips design

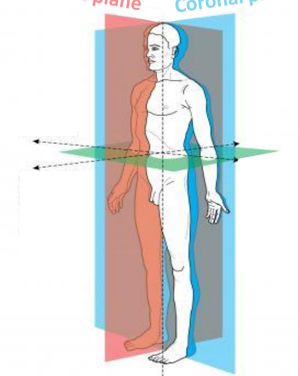
Methodology: Containers/grips

Coronal plane





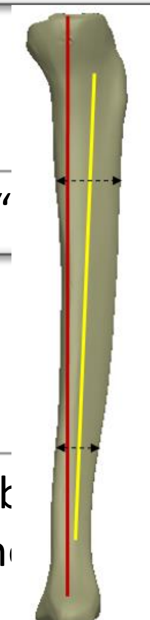
- Vertical axis
- Anatomical axis
- Mechanical axis



Pickering et al. J Bone Joint Surg, 2012

specimen is aligned paral

Sagittal plane



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Heiner et al. J Biom
Heiner et al. J Biom

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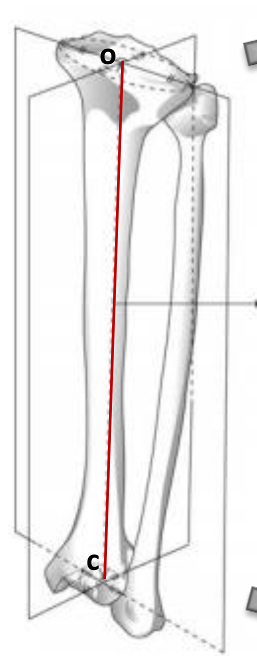

Tibial mechanical axis

Adapted from: **Han et al. Knee Surg Sports Traumatol Arthrosc, 2008**

Gray et al. Proc Inst Mec
Gray et al. J Biome

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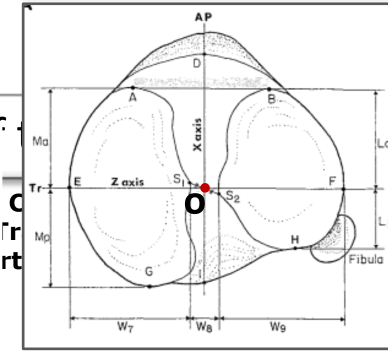
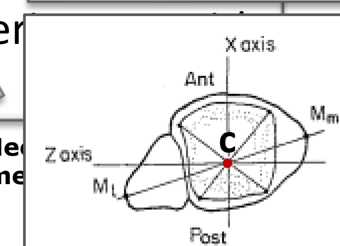
Tibial plateau



Yoshioka et al. J Orthop Res 7, 1989

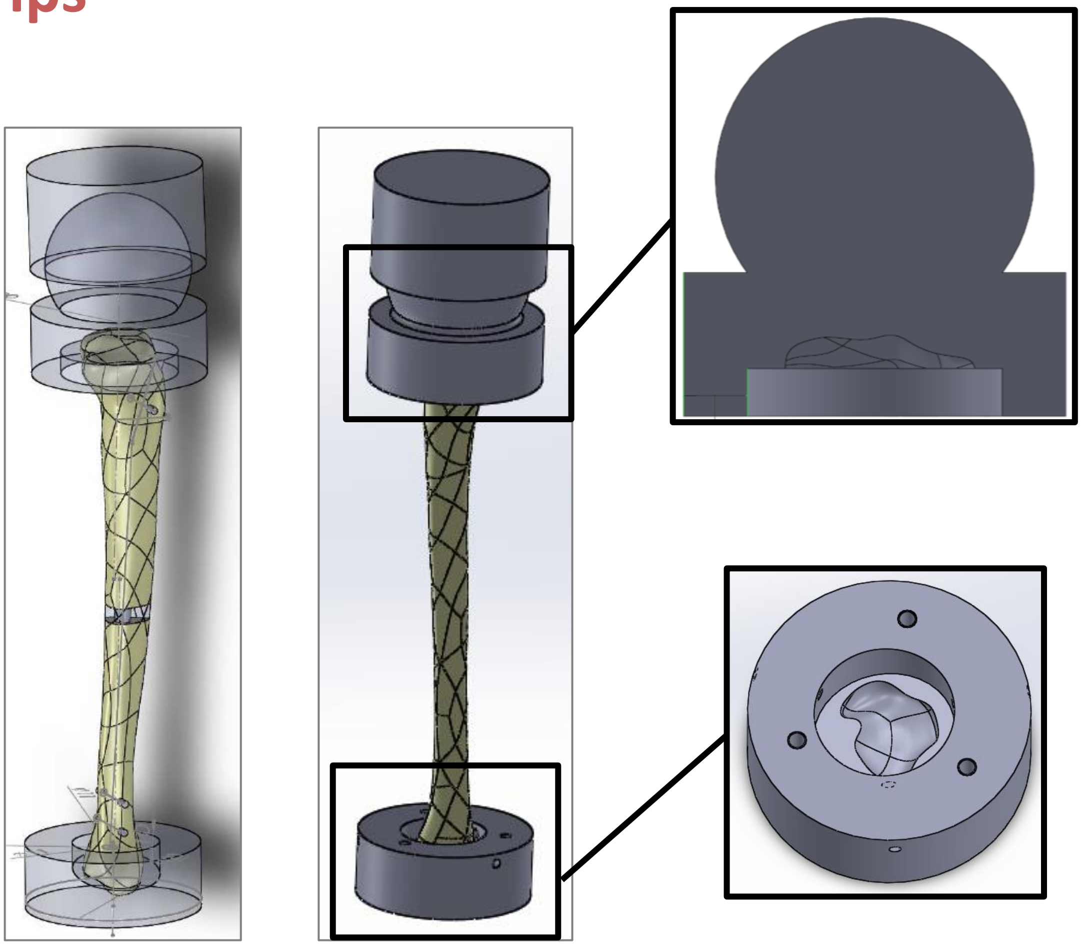
Distal tibia



Yoshioka et al. J Orthop Res 7, 1989

Methodology: Containers/grips

- All loading modes;
- The same tibia alignment guaranteed in both simulation and mechanical experimentation;
- Avoid potting bone specimens in cement;
- Misalignment of bone;



Methodology

3D Scan → **SolidWorks** → **ANSYS®**

- External surface

- Surface preparation;
- Solid model construction;
- Cortical and trabecular bone structures boundary definition;
- Grips design
- Intramedullary nail structure drawing
- Intramedullary nail implantation in the bone

Bone-implant complex (BIC) - Nail

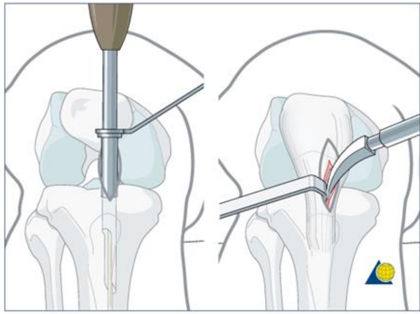
Validation through free-free boundary condition

Harmonic	Experimental (Hz)	Simulation - Ansys® (Hz)	Error (%)
1st	384	388.11	7.6
2nd	432	427.3	5.5
3rd	1057	1047.1	6.4

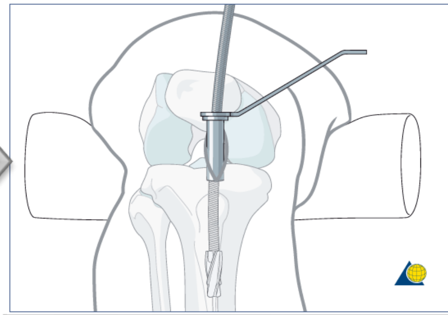
- L.A. Medical M596222 AB0366 T
- $\varnothing 9 \times 345\text{mm}$ nail ($\varnothing 0.35 \times 13.58$ *inches*)
- Circular ring cross section (inner diameter 5 mm/ *0.197 inches*)
- Stainless steel - *AISI 316L ASTM F318*

Bone-implant complex (BIC) – Nail implantation

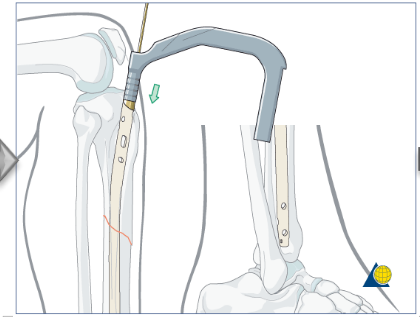
www.aofoundation.org



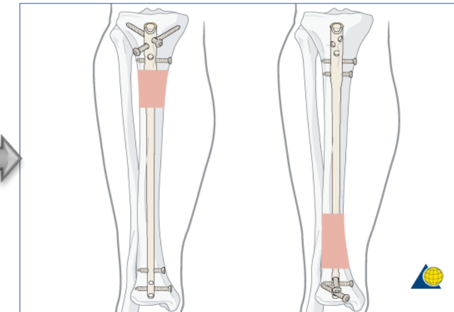
Creation of the nail entry site



Reaming



Nail inserted

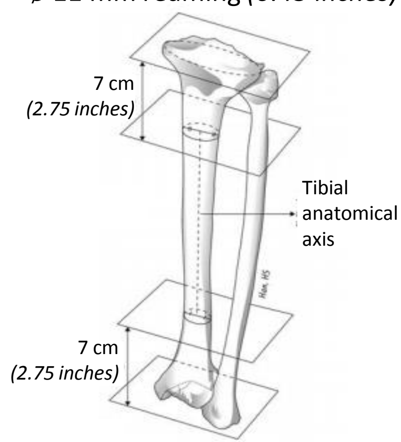


Nail locking

- Diameter: 12.7 mm *(0.5 inches)*
- Length: 60 mm *(2.36 inches)*

To accommodate the larger proximal portion in the nail

Ø 11 mm reaming *(0.43 inches)*



Han et al. Knee Surg Sports Traumatol Arthrosc, 2008

The correct position of the nail was validated by an experienced orthopedic surgeon

- Proximally: 2 screws
- Distally: 2 screws
- *Locking mode*
- *No play between the screw and the bone*

Methodology

3D Scan → **SolidWorks** → **ANSYS®**

3D Scan
- External surface

SolidWorks
- Surface preparation;
- Solid model construction;
- Cortical and trabecular bone structures boundary definition;
- Grips design
- Intramedullary nail structure drawing
- Intramedullary nail implantation in the bone

ANSYS®
- Finite element analysis

Concept

Nature has optimize this process and it would be difficult to intervene in order to improve fracture healing

There is never been determine a quantifiable relationship between the rate of healing and mechanical

Comiskey et al. J Biomech 43, 2010

High bone-implant stability and instability are detrimental for bone healing

Beneficial effects of early loading and adverse effects of delayed loading on bone healing

Bailón-Plaza et al. J Biomech 36, 2003

There is a tendency to modify the locking option for better stability

Horn et al. Injury Int J Care Injured 40, 2009

Improve treatment method for bone fracture repair by reducing the patient healing time

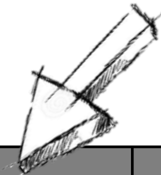
Results

Regress...

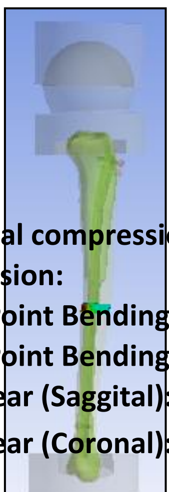
Load/mom... curve

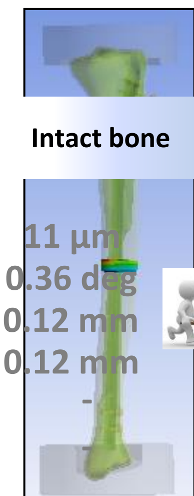
Evaluat... **et al.** J Biomech 41, 2008

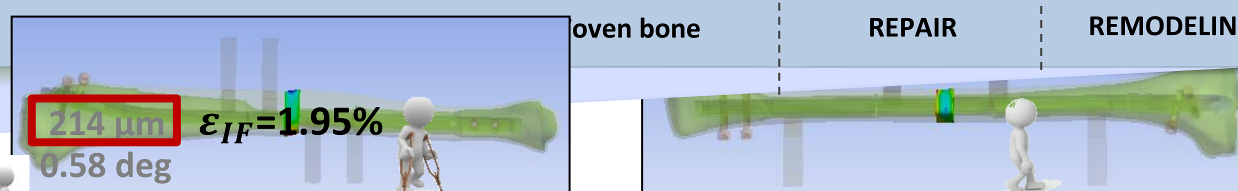
Fracture location: Central
Load: 100 N
Nail diameter: 9 mm
Fracture gap width: 8 mm
Conventional nails



Load	**Whole bone**	**BIC**			
		FE	*Penzkofer et al. (2009)*	*Horn et al. (2009)*	
Axial compression in *N/µm*	13400	1250	723 ± 421	620 ± 240 (CL)	1420 ± 421 (ASL)
Torsion (IR) in *Nm/deg*	8.9	4.5	0.8 ± 0.1		
4-Point Bending (AT) in Nm^2	146.2	51.2	37 ± 8		
4-Point Bending (LT) in Nm^2	87.08	57.6	37 ± 9		
Shear (Saggital) in *N/mm*	-	294.1	131 ± 30		
Shear (Coronal) in *N/mm*	-	309.6	164 ± 89		







Intact bone | ...oven bone | REPAIR | REMODELING

Axial compression:	11 µm	214 µm
Torsion:	0.36 deg	0.58 deg
4-Point Bending (AT):	0.12 mm	0.32 mm
4-Point Bending (LT):	0.12 mm	0.36 mm
Shear (Saggital):	-	0.65 mm
Shear (Coronal):		0.68 mm

ε_{IF}=1.95%

Low-magnitude, high-frequency mechanical signals ability to influence fracture healing

...Plaza et al. J Biomech 36, 2003
Fritton et al. (2000)
Rubin et al. (2001)
Goodship et al. (2009)

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Conclusions

Validation of the finite element model through mechanical experimentation is essential

Difficult to **compare studies** due to non-standard experimental set-up

High-frequency low-amplitude interfragmentary micromotion regime applied during early healing recovery phase may be an interesting strategy to enhance the rate and quality of bone repair without risking the disruption of the healing process

An ideal implant stiffness design **demands** an **extensively understanding** of the complex relation between the mechanical stimulus (type, magnitude, rate, duration and timing of initiation of loading) and the bone healing process

We would like to thank

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and also

International Conference and Expo on Biomechanics and Implant Design for giving the opportunity to present the work developed

Thank you for your attention!

I welcome your questions,
suggestions and comments!