PERCUTANEOUS SCREWS FOR THE TREATMENT OF LONG-BONE FRACTURE NON-UNION:

A FINITE ELEMENT ANALYSIS

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1. BACKGROUND

- ~41% of fractures are long-bone fractures [1]
- ~8% of these fail to fully unite [1] ⇨ **'Non-union'** ⇨ Chronic + physically disabling

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1. Schmal *et al.*, EFORT Open Rev 2020

1. BACKGROUND

- ~41% of fractures are long-bone fractures [1]
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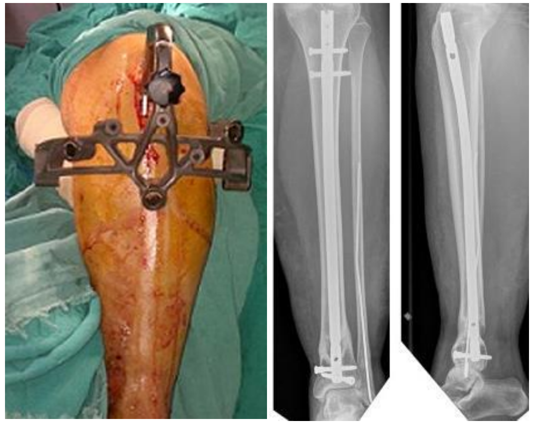
Diaphyseal Fracture

Plating [2]

Intramedullary Nailing [2]



- Caused by an insufficiently stiff construct

  ⇨ IFM exceeds level tolerated by bone [3]

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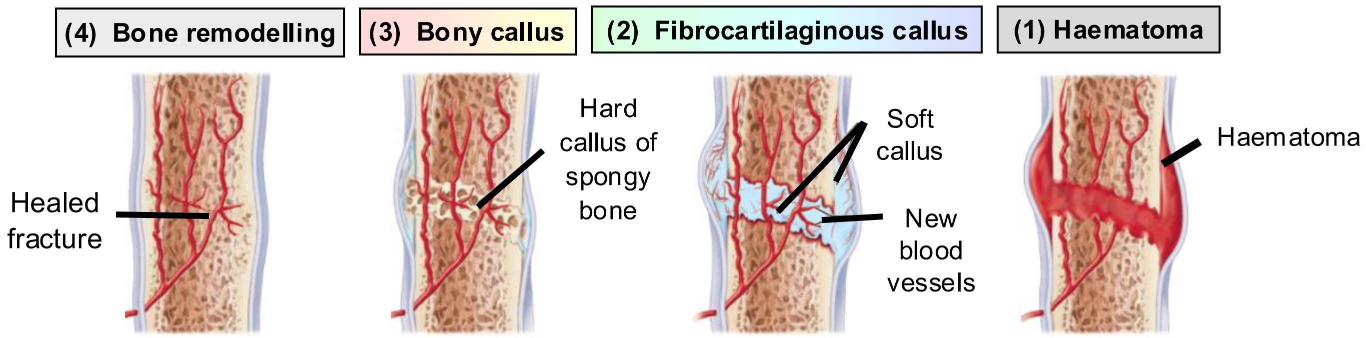
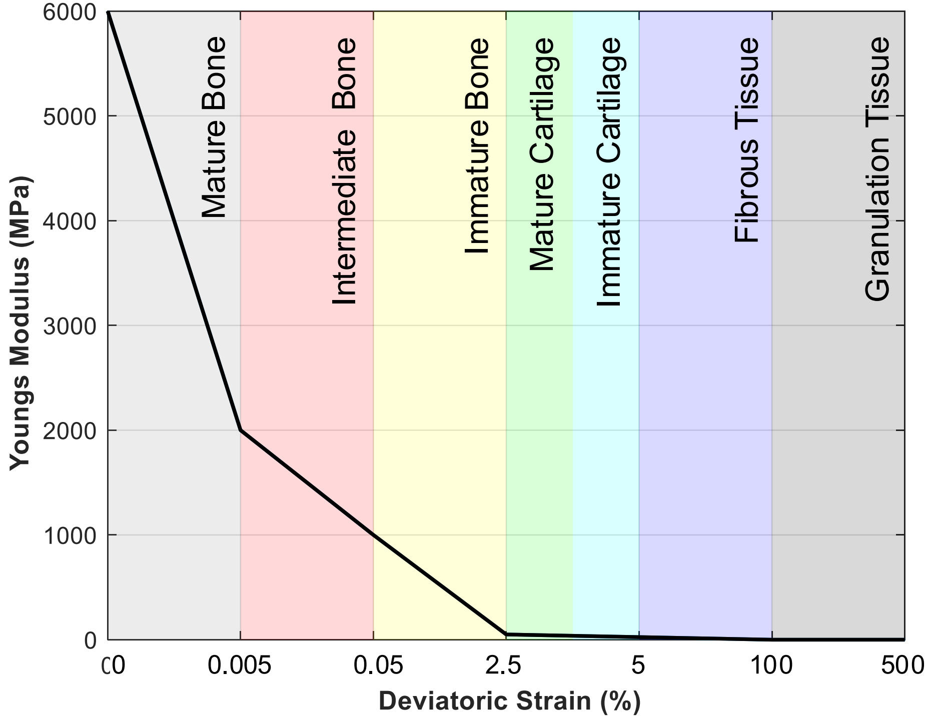
1. Schmal *et al.*, EFORT Open Rev 2020 2. Bottlang *et al.*, J Ortho Trauma 2020 3. Elliot *et al.*, Bone Joint J 2016

- Secondary, indirect healing [4]

- Construct bridges a small gap
  - ✓ Swift and straightforward [5]
  - ✓ Limits bone exposure [5]





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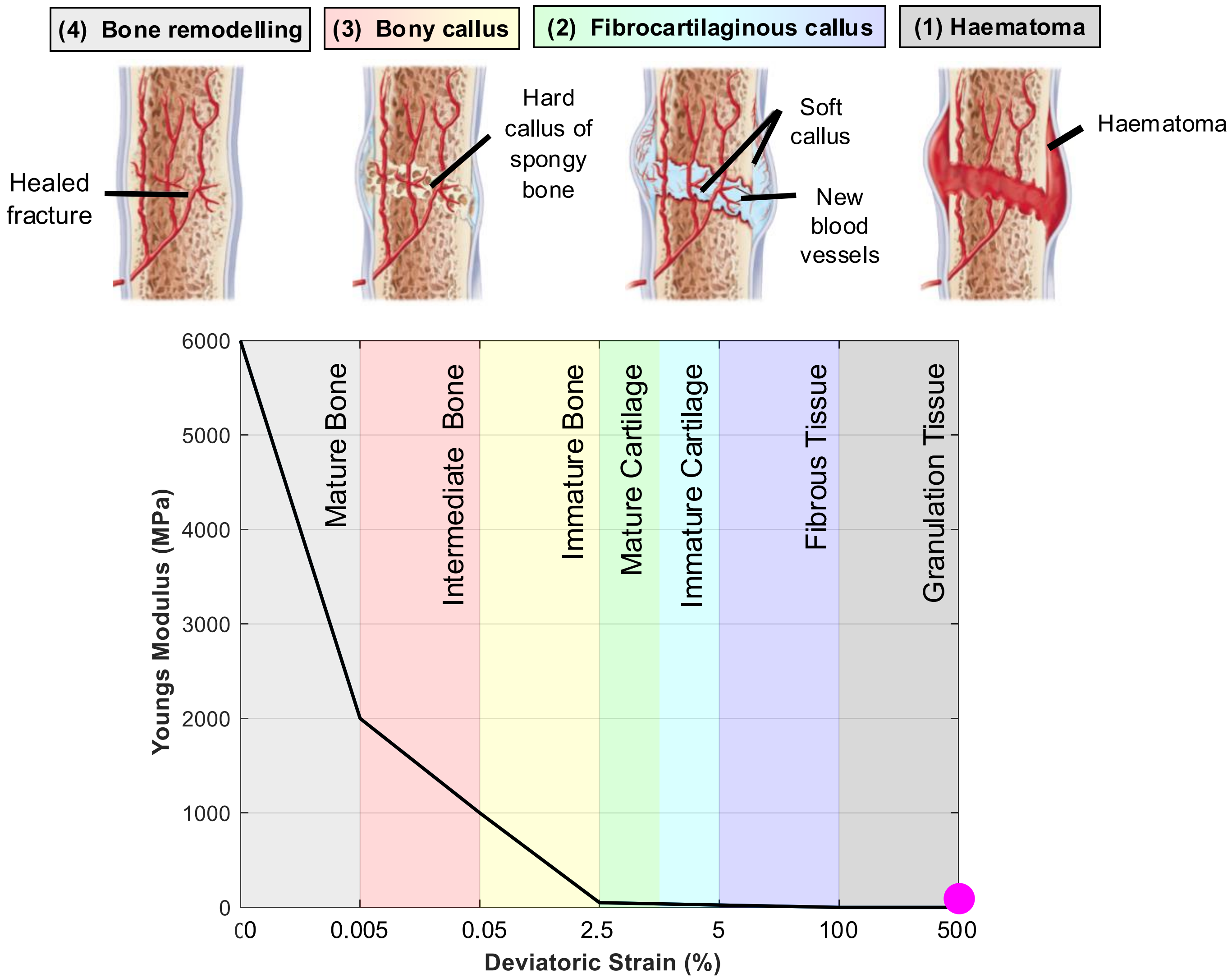

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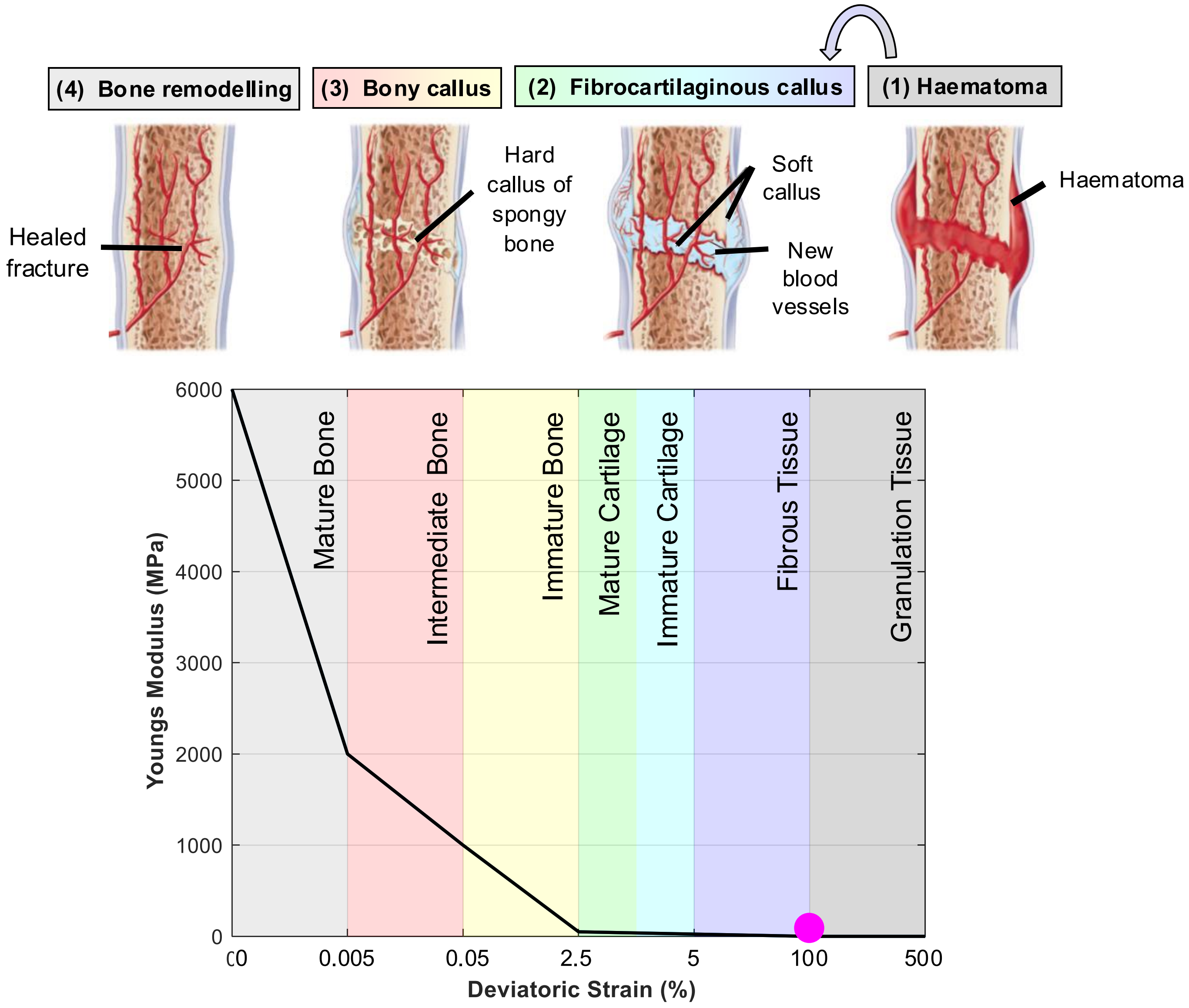

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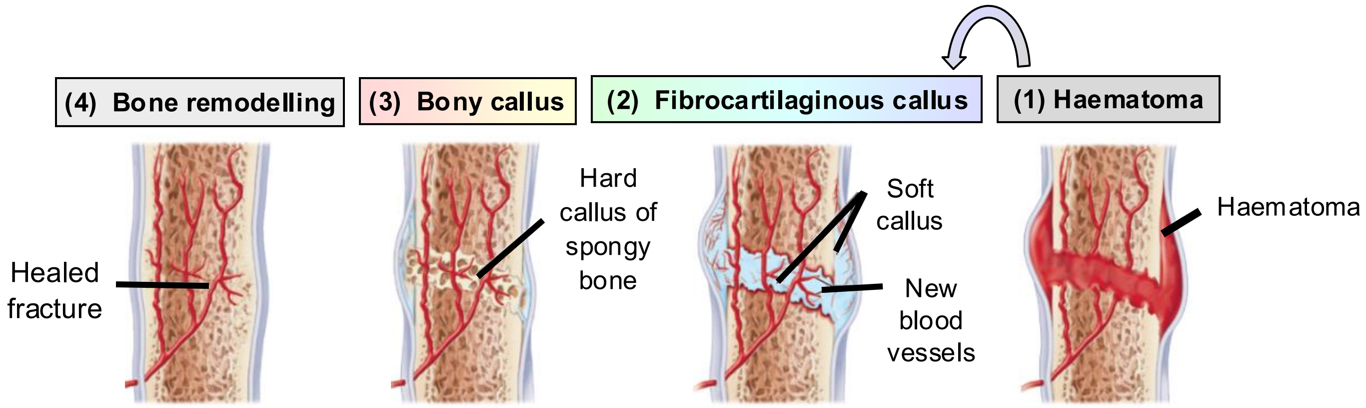

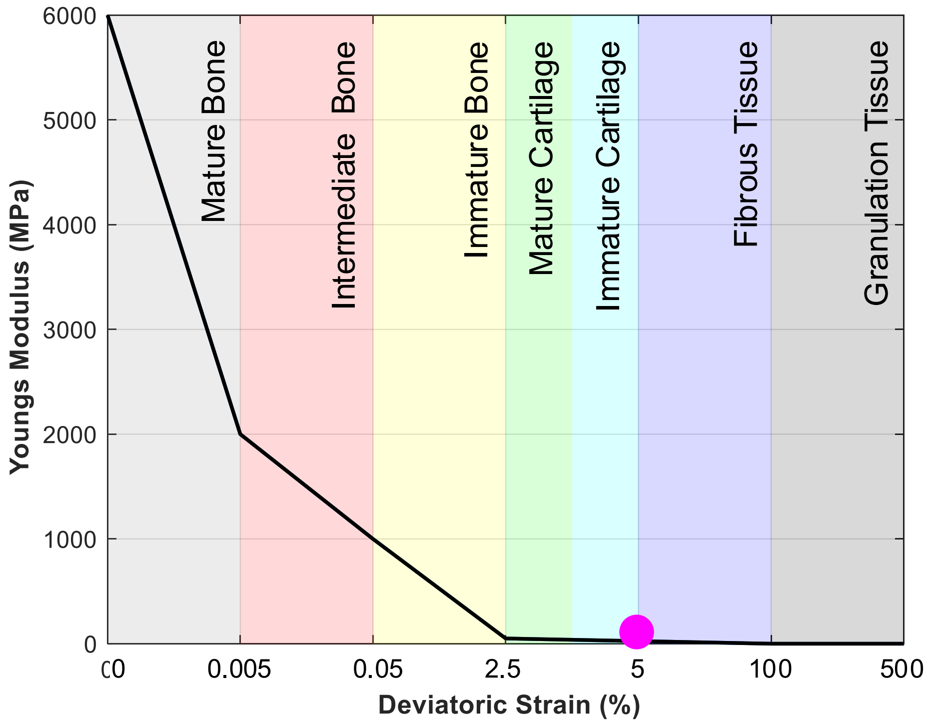

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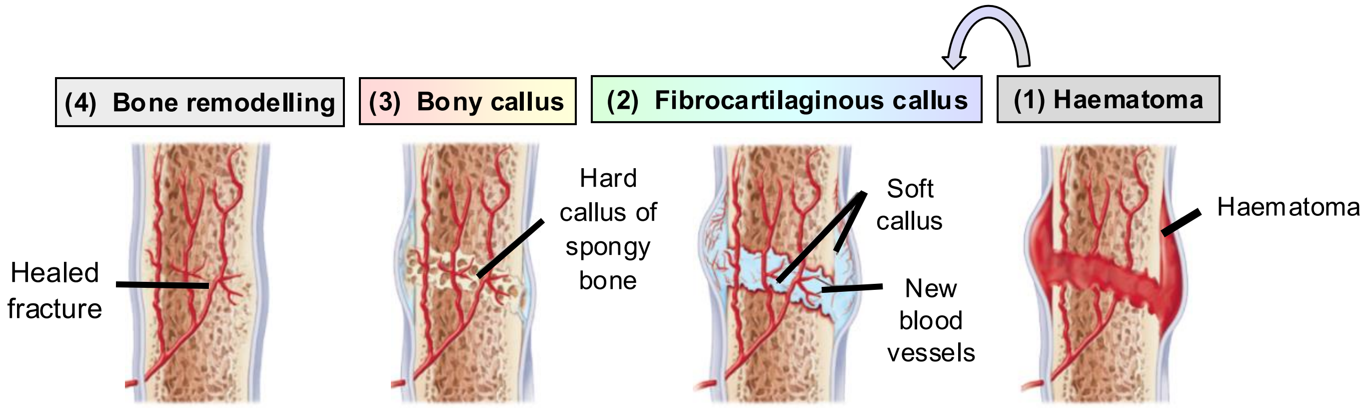

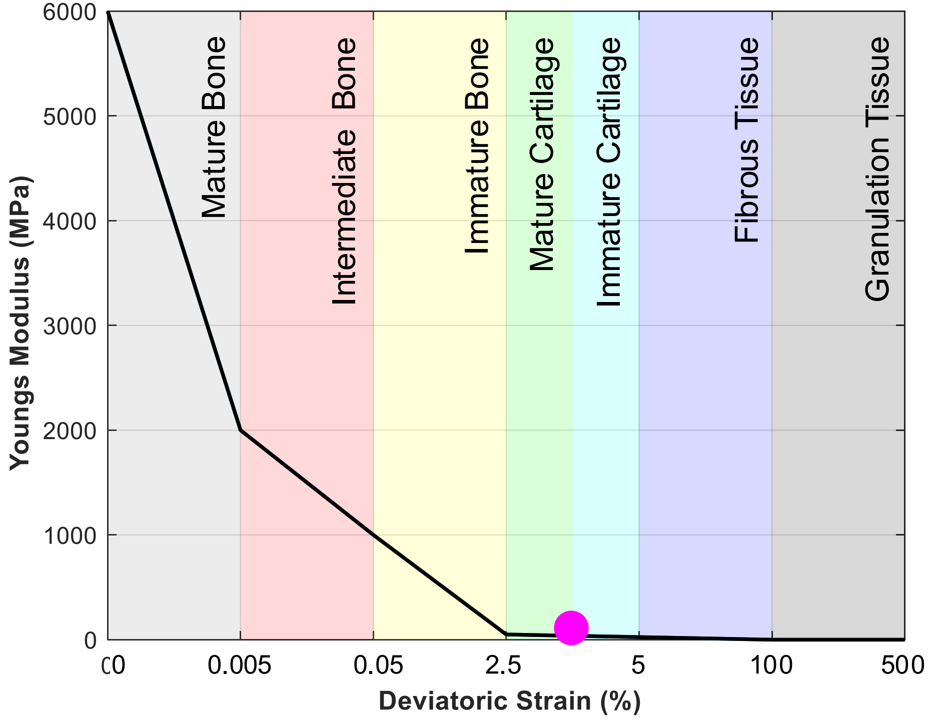

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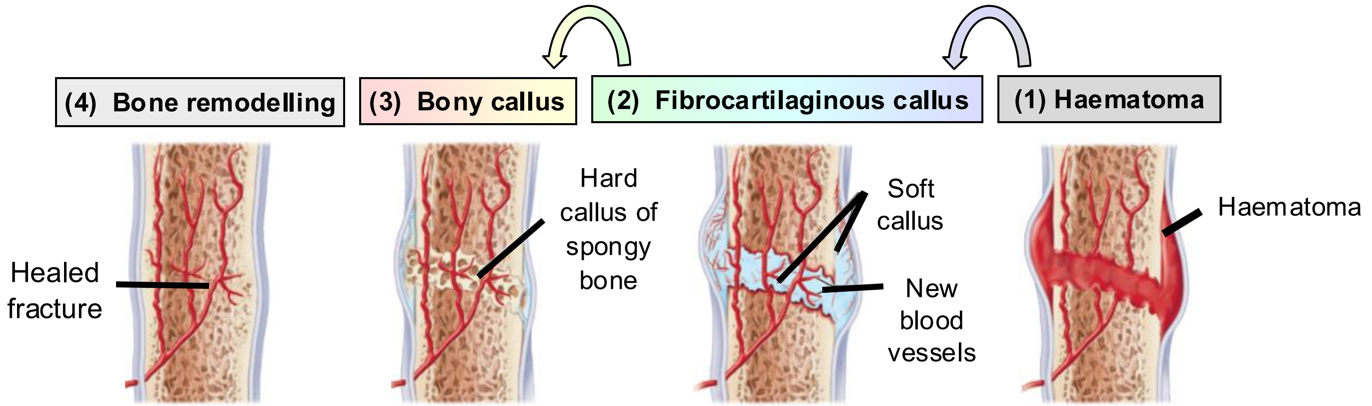

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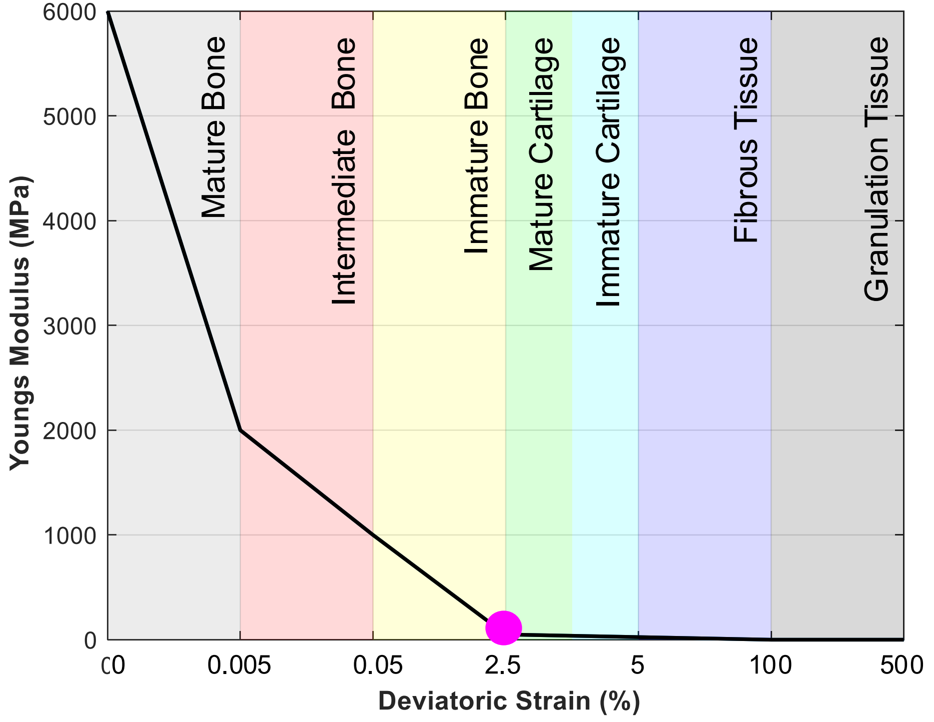

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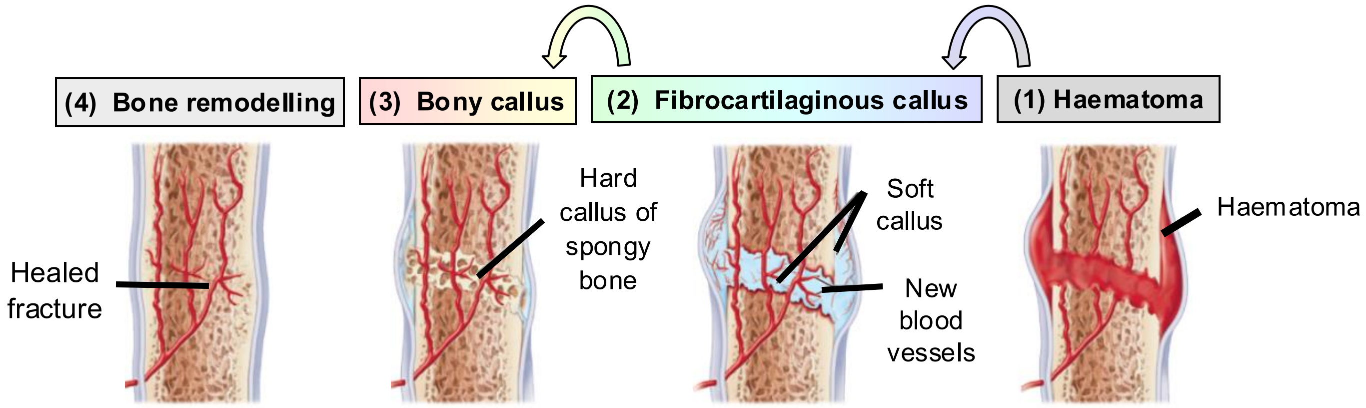

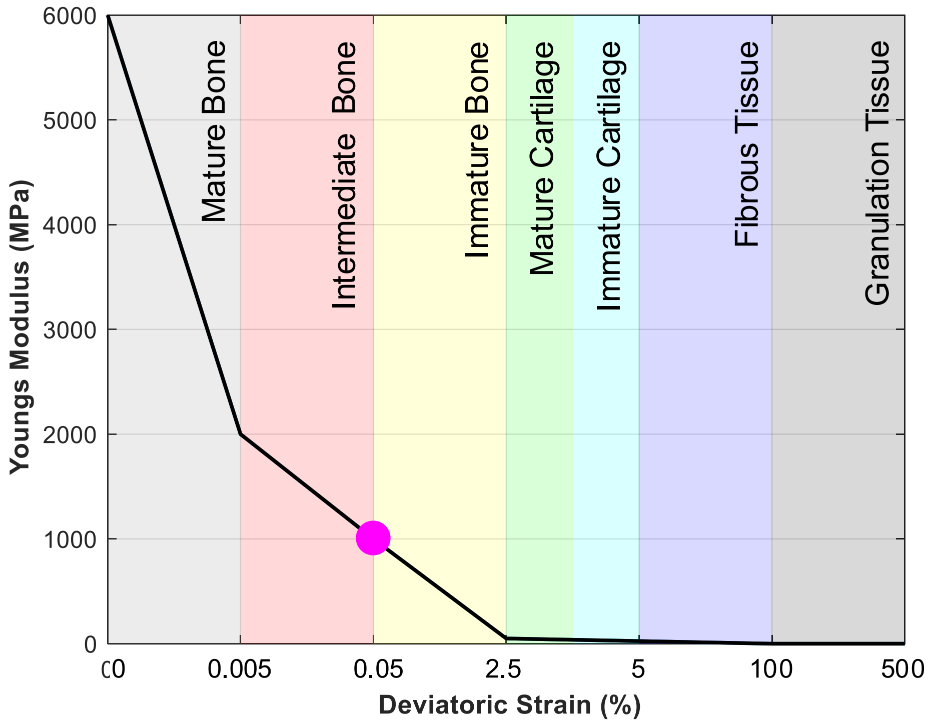

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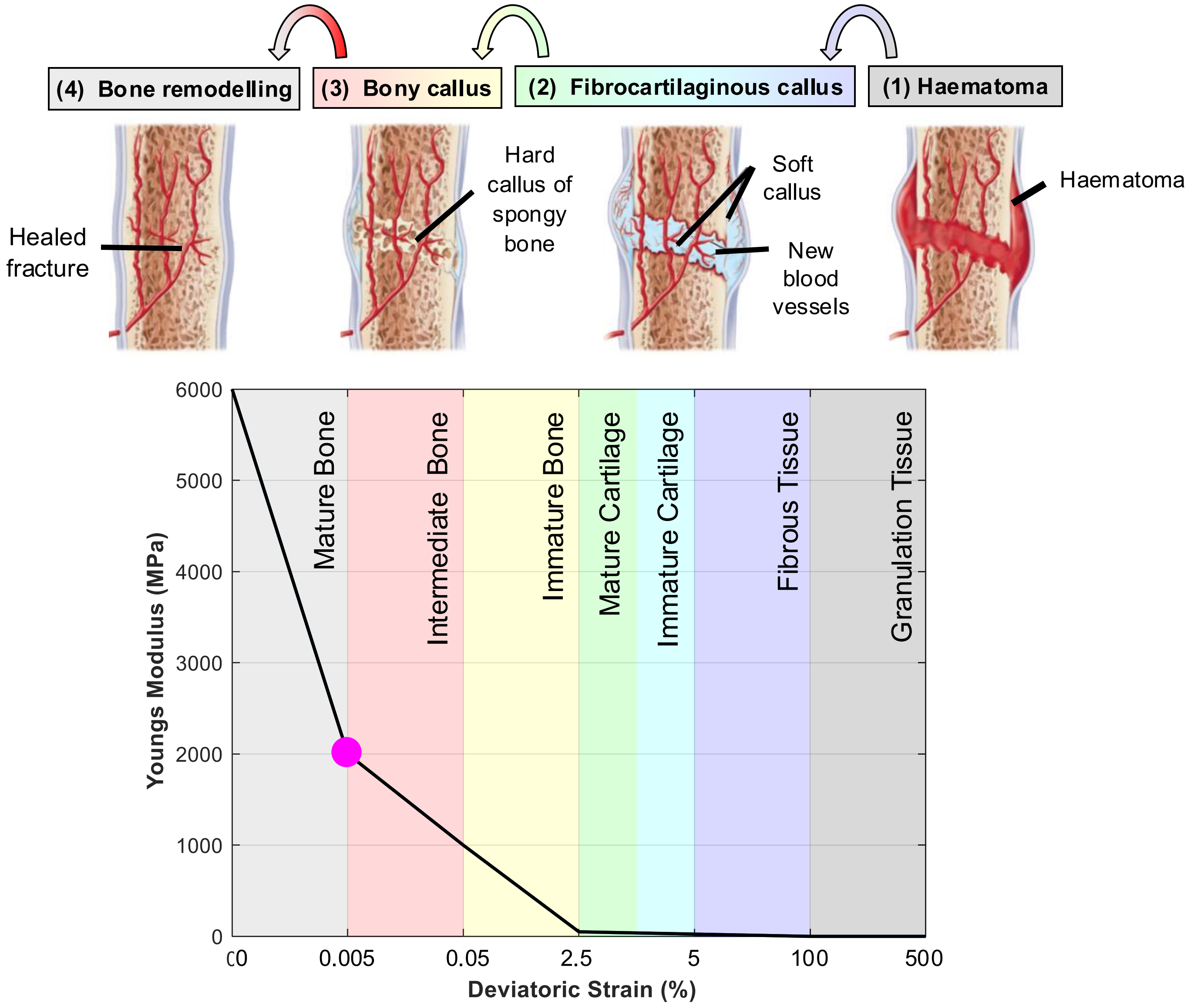

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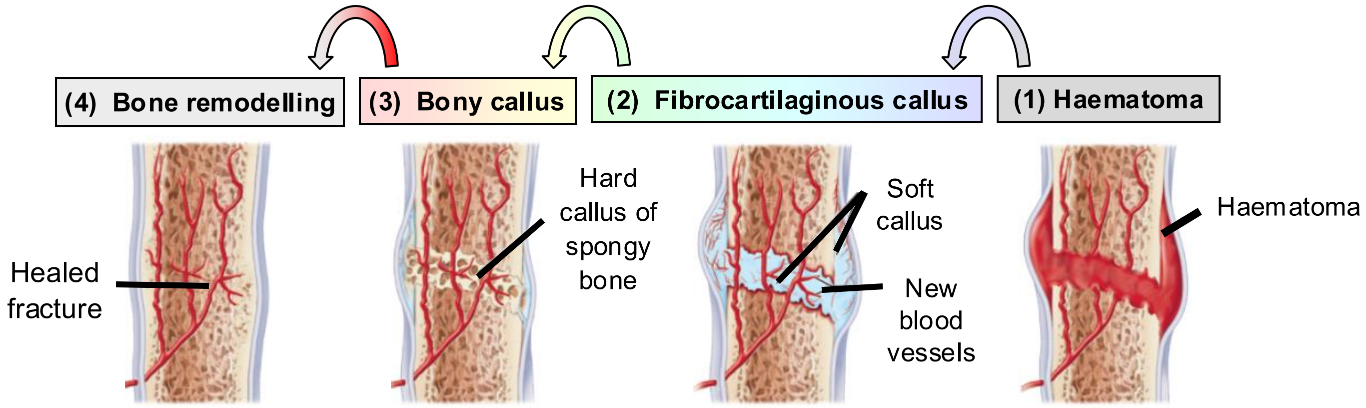

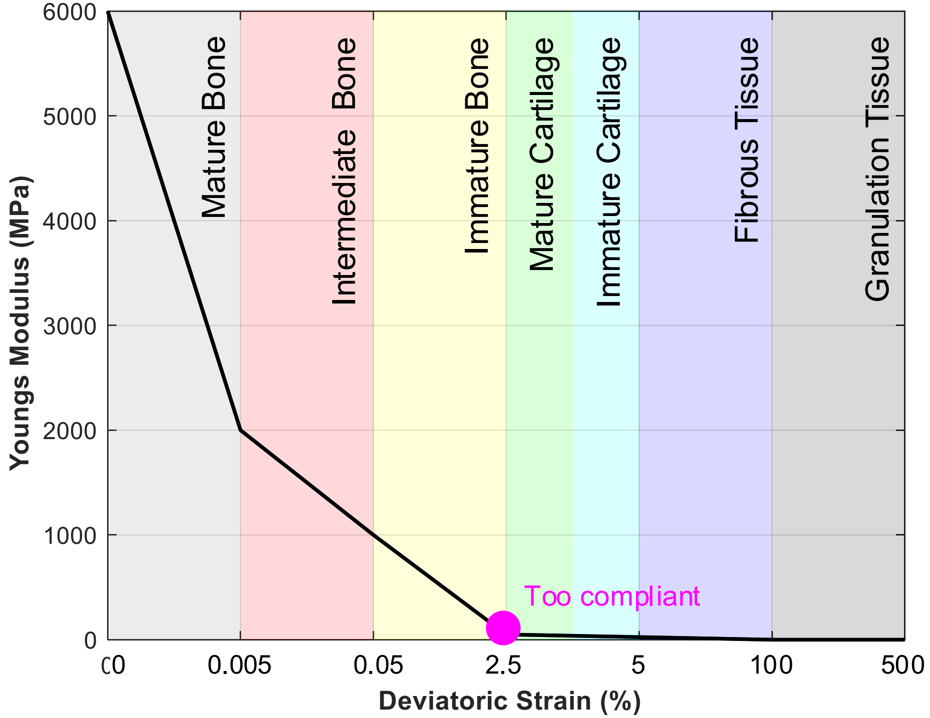

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- Secondary, indirect healing [4]
- Construct bridges a small gap
  - ✔ Swift and straightforward [5]
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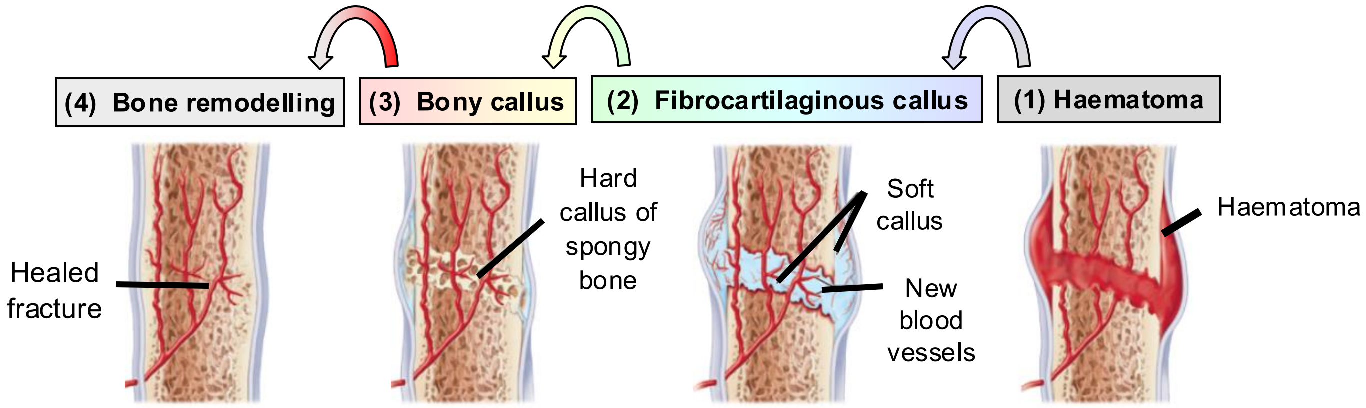
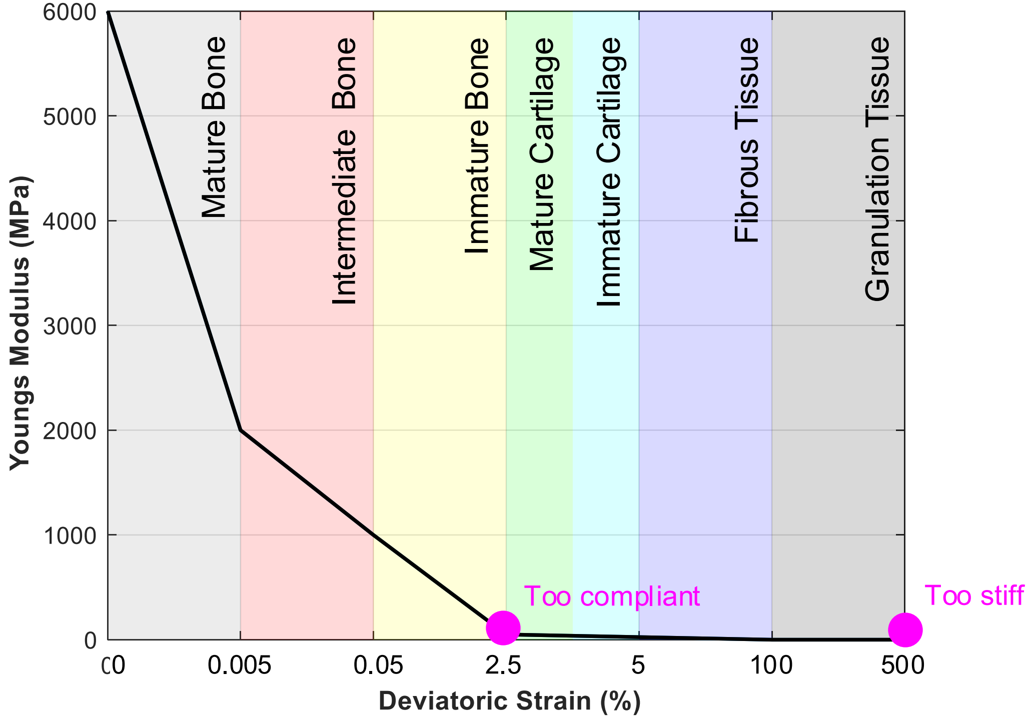
- NOT permitted by an overly stiff construct [4]





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- Treatment ⇨ Exchange construct for a stiffer one
  - ✗ Painful
  - ✗ Complications are common
  - ✗ £7,000 - £79,000 per surgical revision [6]

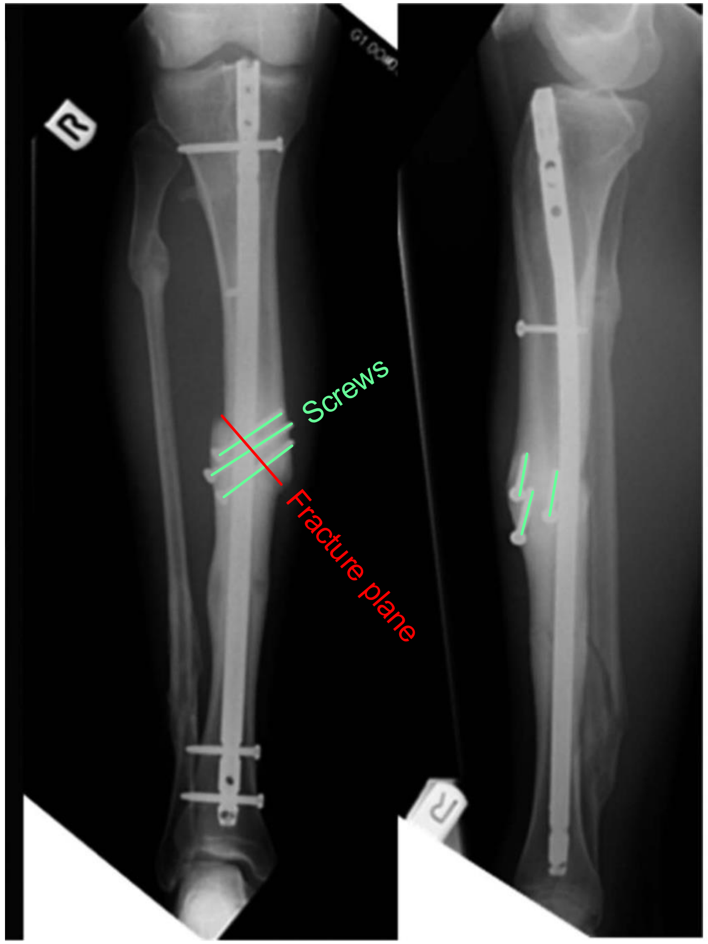
- Is there a less invasive, more cost-effective, viable alternative?

Exchange Nailing

6. Stewart, Malaysian Ortho J 2019

- Clinical findings suggest so [7] :
  - ⇨ 2 or 3 inter-fragmentary strain reduction screws.
  - ⇨ Percutaneously inserted.
  - ⇨ Perpendicular to the fracture plane.

Percutaneous Screws

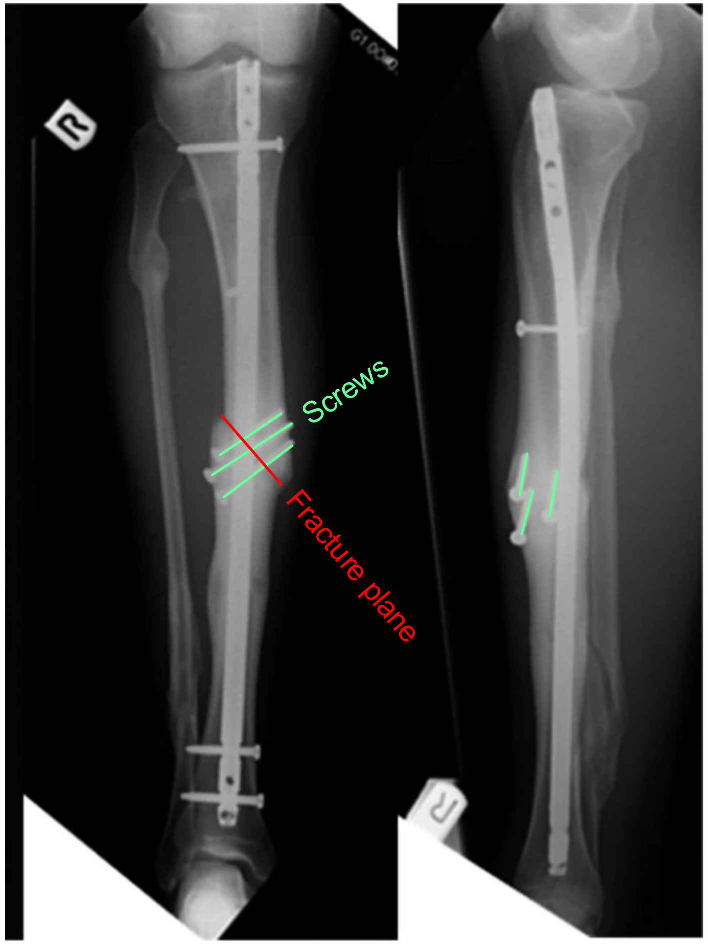


7. Kothari *et al.*, J Ortho Trauma 2019

- Clinical findings suggest so [7] :
  - ⇨ 2 or 3 inter-fragmentary strain reduction screws.
  - ⇨ Percutaneously inserted.
  - ⇨ Perpendicular to the fracture plane.

- This study aimed to **biomechanically assess the efficacy** of such a treatment.

Percutaneous Screws



7. Kothari *et al.*, J Ortho Trauma 2019

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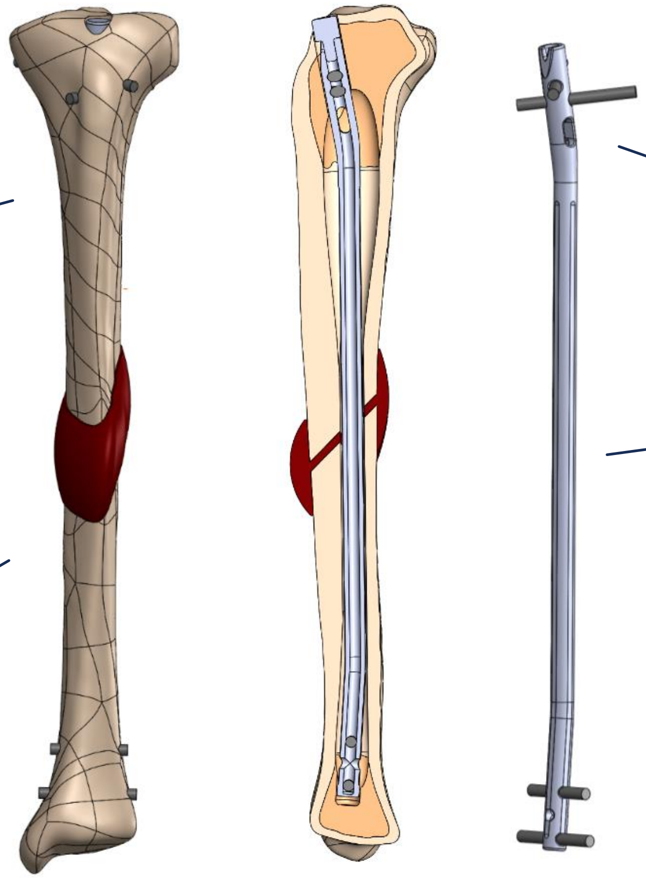
1 3D CAD Model



Sawbones 3401 Tibia
Reamed using Stryker operative technique

Callus
Uni-phasic granulation tissue

Simple, Oblique Fracture
3 mm fracture gap with 45ML-45AP obliquity

Locking Screws
12-46 screw configuration

Stryker T2 Nail
Reverse engineered with 10mm diameter

2 Loading + BCs

- Physiological loading at 45% gait [8]
- 50% weight-bearing

8. Duda *et al.*, J of Biomechanics 2001

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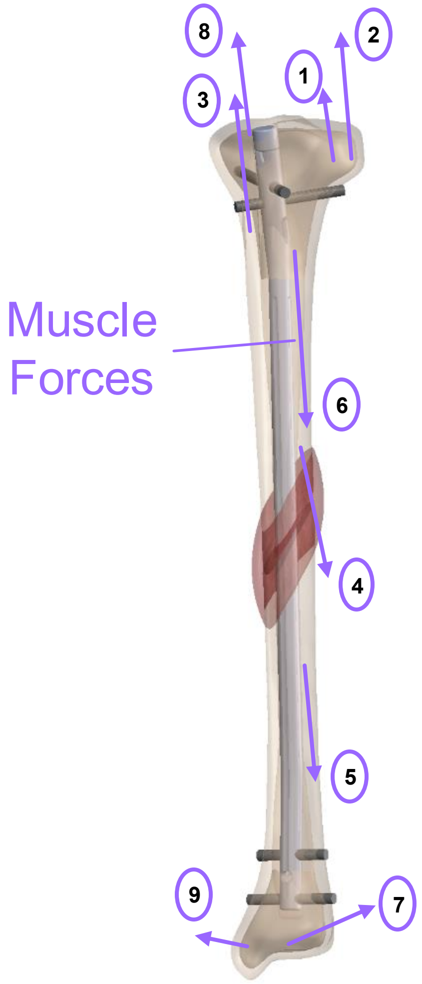

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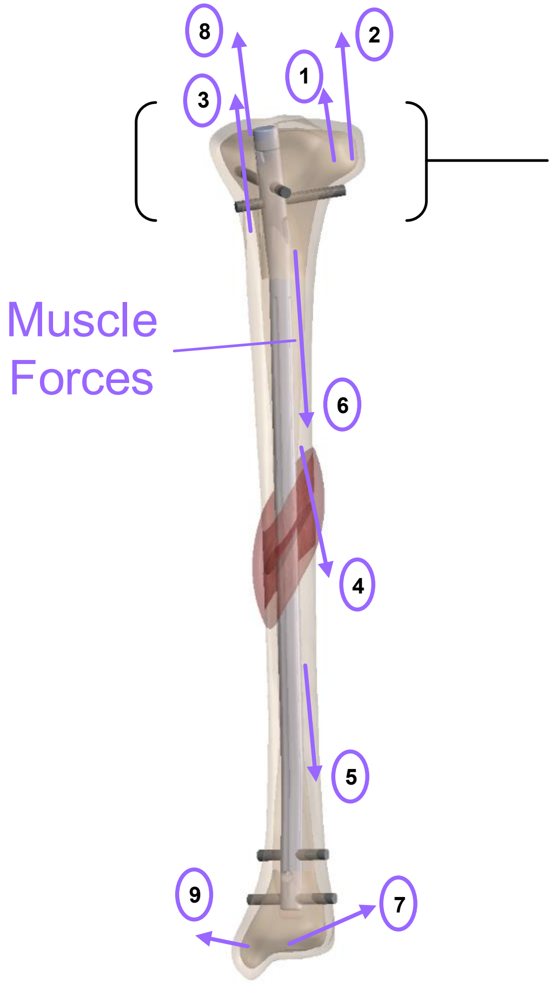

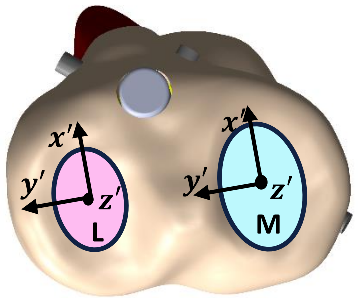

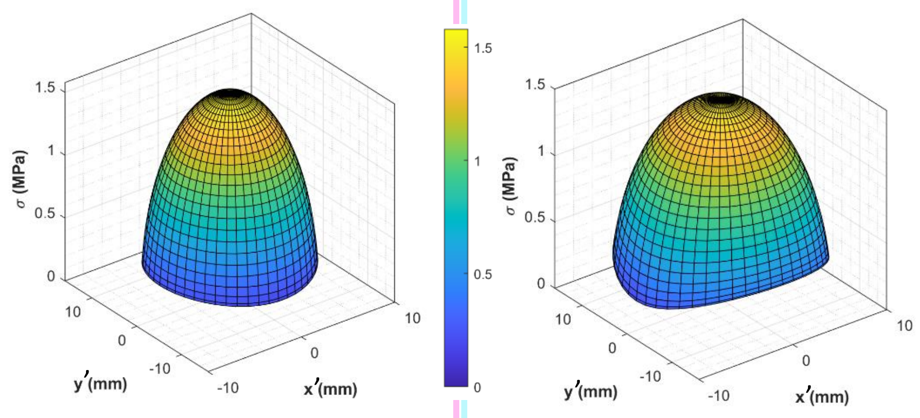

$$\sigma = \sigma_0 \sqrt{1-\left(\frac{x'}{a}\right)^2-\left(\frac{y'}{b}\right)^2} \qquad where \qquad \sigma_0 = \frac{3}{2}\cdot\frac{F}{A}$$

0.4 x 50% BW

0.6 x 50% BW

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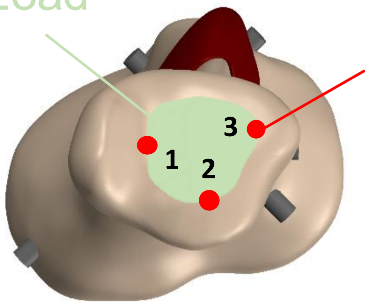

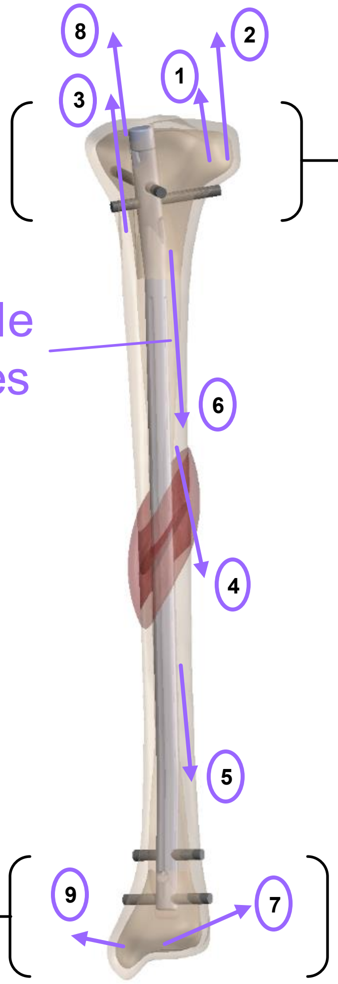

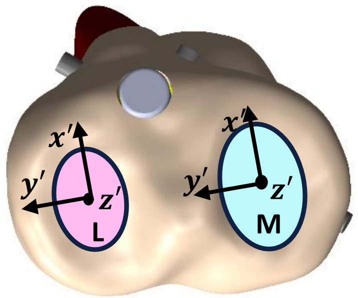

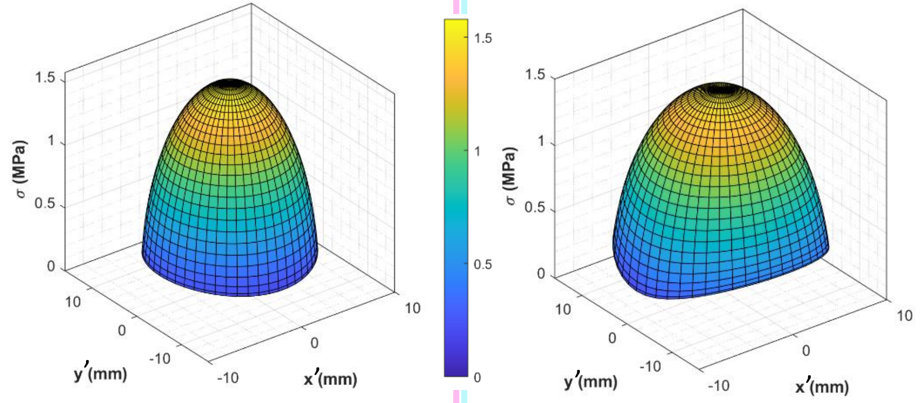

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3 Contact Settings

Contact	Normal Component	Tangential Component

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Screw / Nail		

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Derived From Literature [9]

9. Moazen *et al.*, J of Eng in Med 2013

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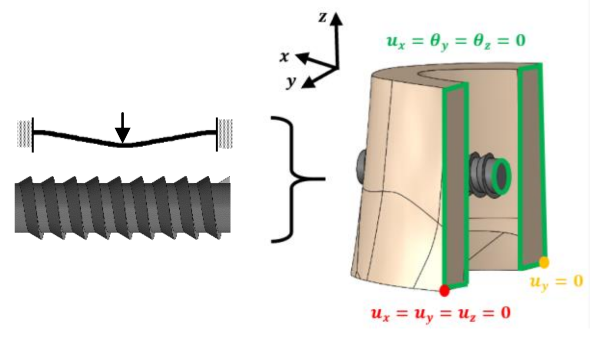
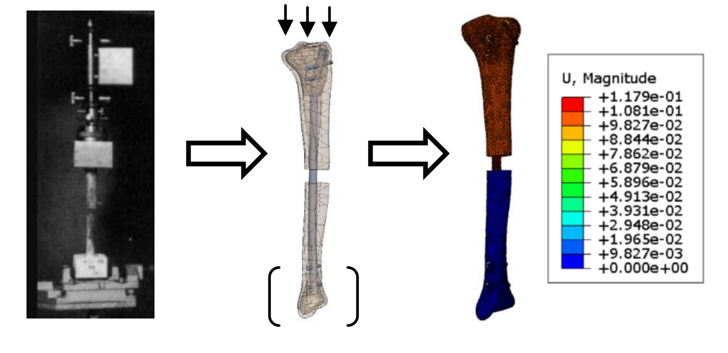


Tuned via Sub-Modelling



Validated Using In-Vitro Study [10]

9. Moazen *et al.*, J of Eng in Med 2013
10. Finlay *et al.*, J of Biomech 1982

4 Post-Processing

Elemental callus strains

⇩

Elemental tissue stiffnesses

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Elemental callus strains

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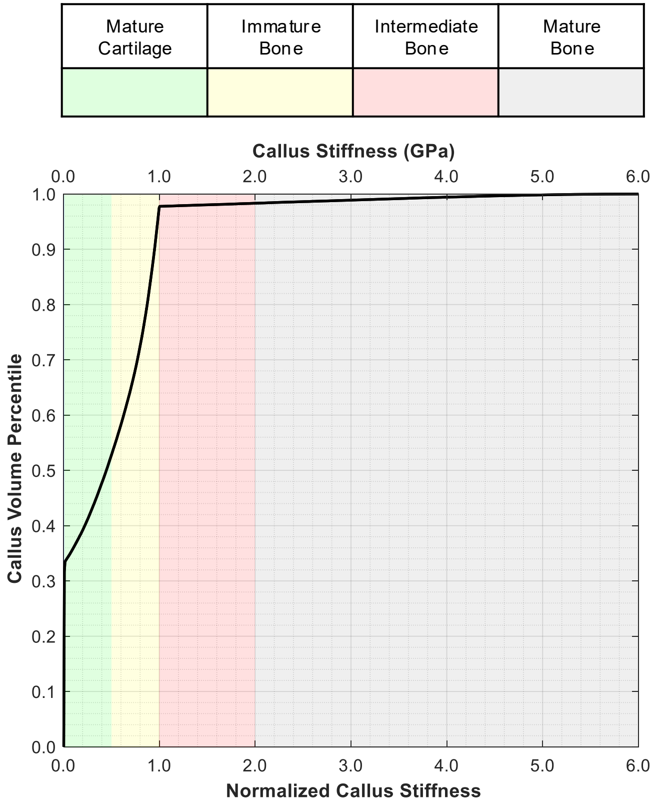
Elemental tissue stiffnesses

⇩

Cumulative distribution of tissue stiffness



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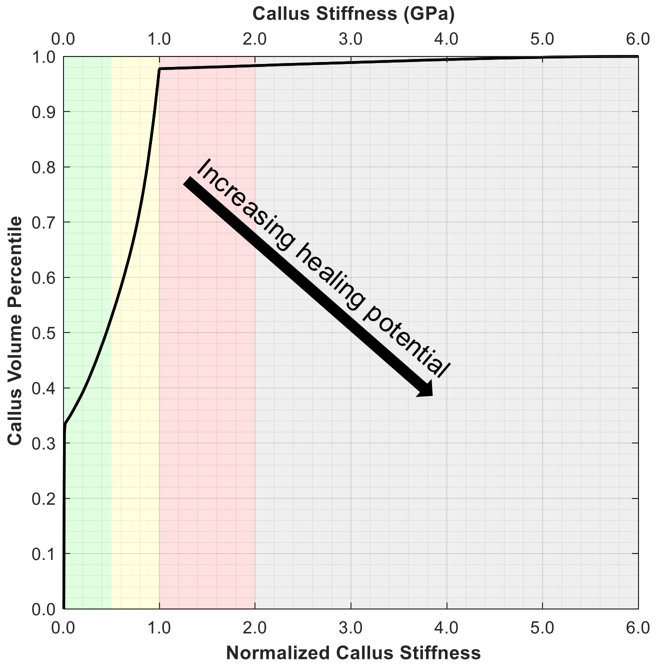
Cumulative distribution of tissue stiffness

Mature Cartilage	Immature Bone	Intermediate Bone	Mature Bone



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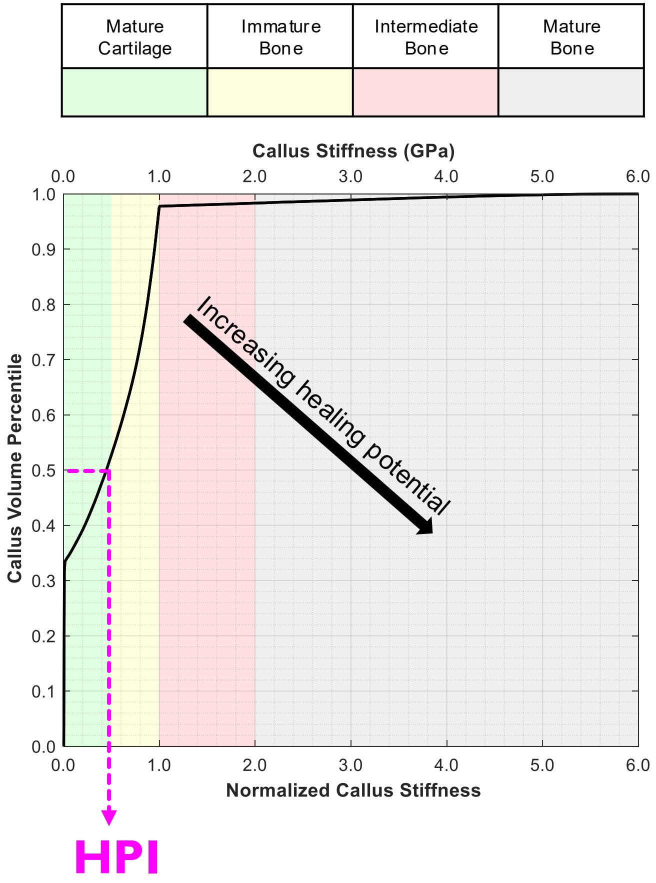
Healing performance index



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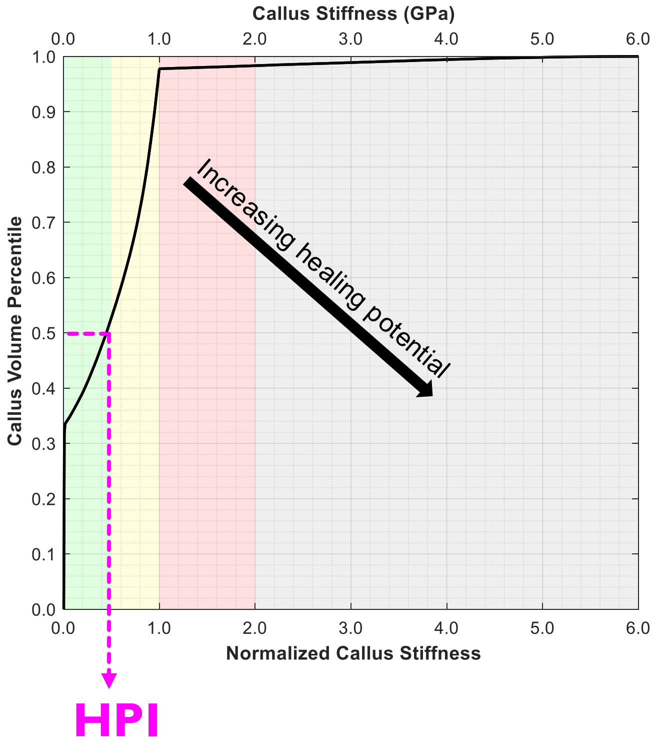

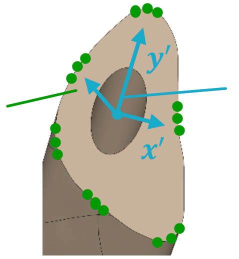

⇩

$$IFM_{axial} = |\Delta u_{axial}|$$

$$IFM_{shear} = \sqrt{(\Delta u_{x}')^2 + (\Delta u_{y}')^2}$$

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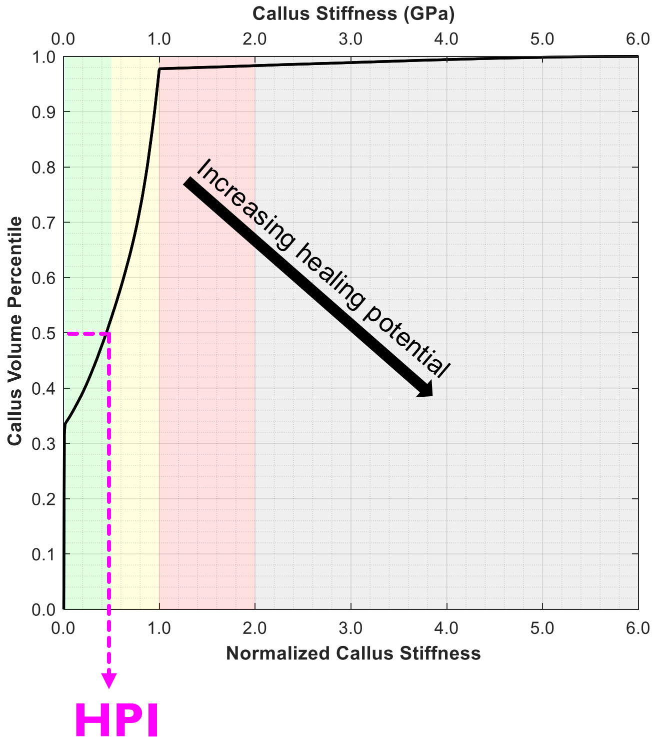

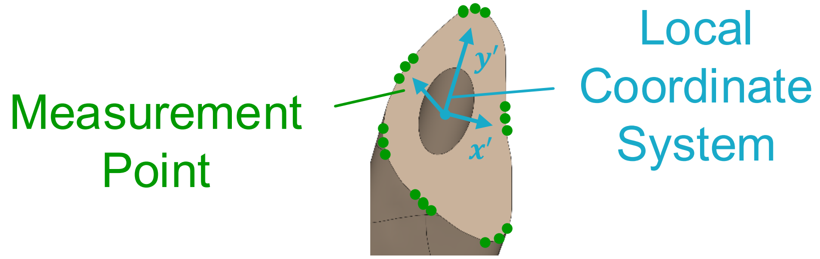

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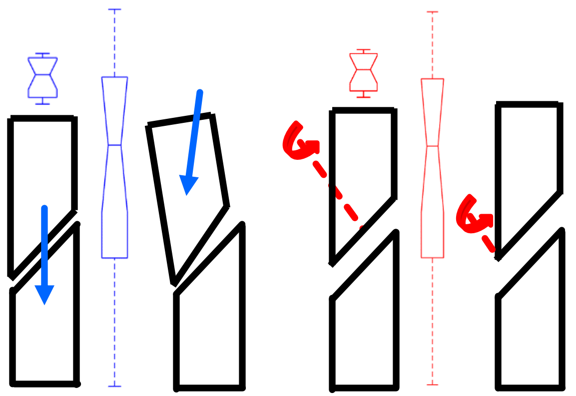
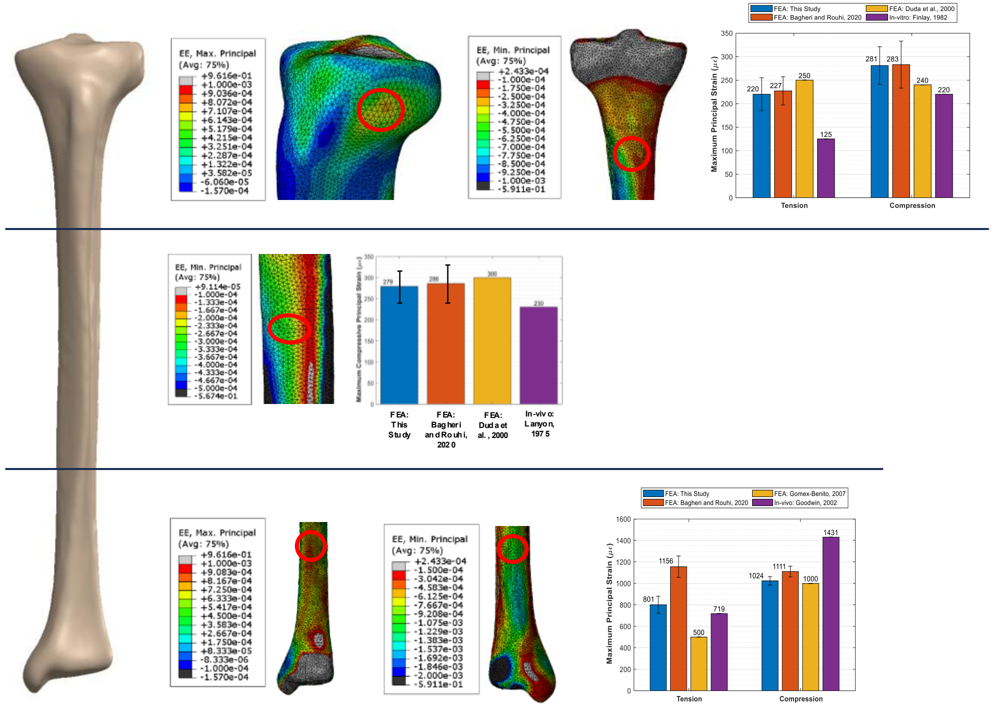


5 Validation



- ✓ Bone Material Properties
- ✓ Bone Morphology
- ✓ Physiological Loading

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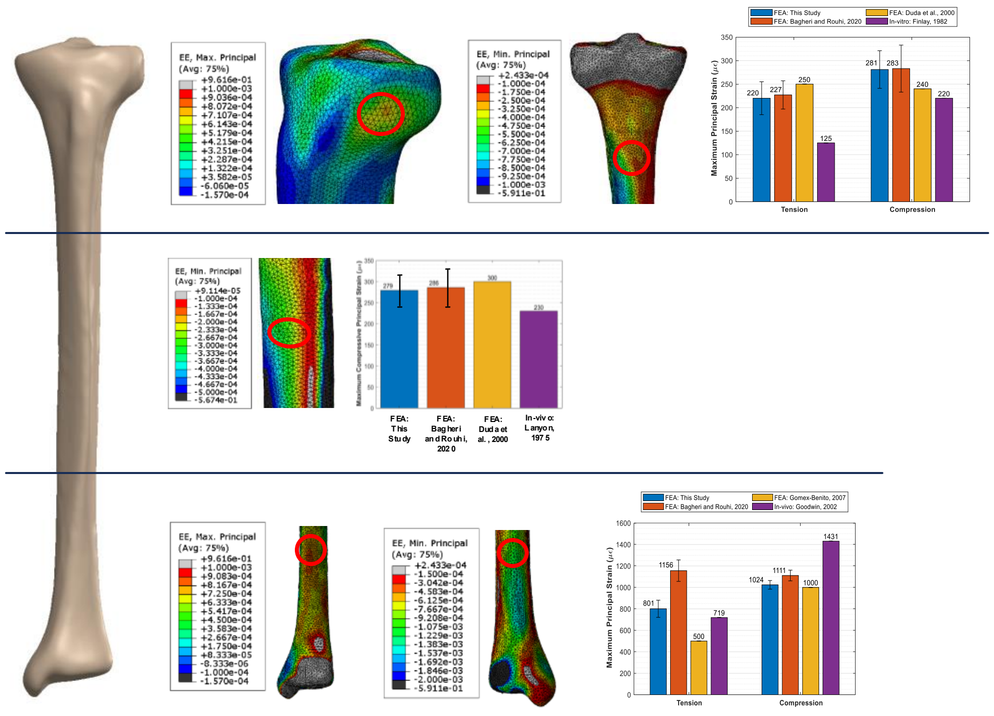

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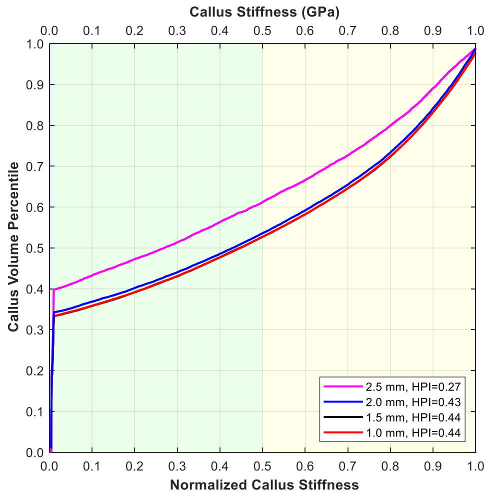

✓ Mesh Convergence

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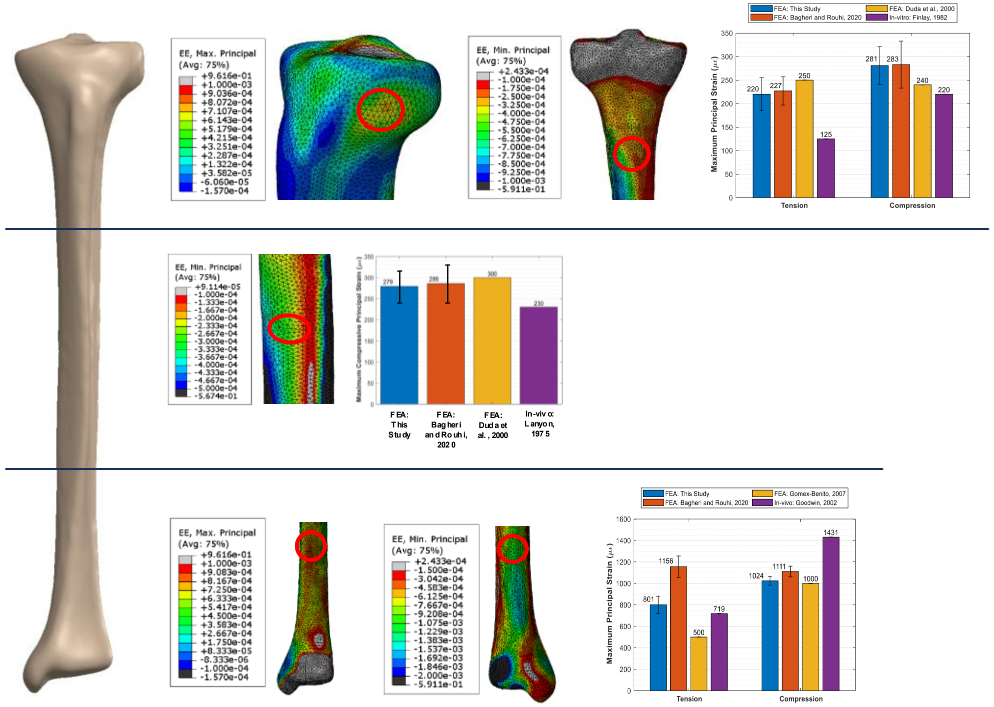

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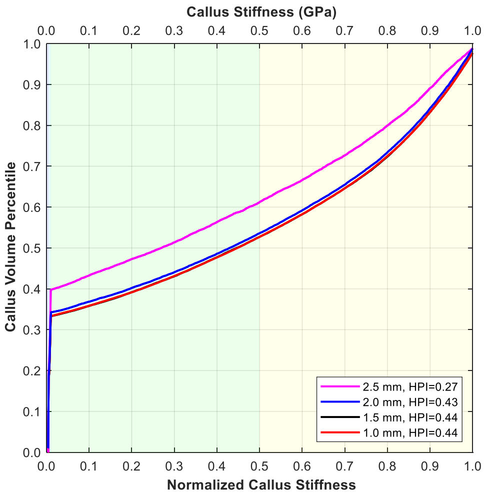

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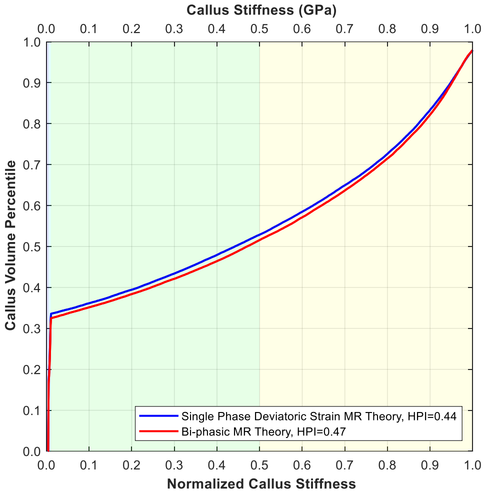

✓ Callus MR Theory

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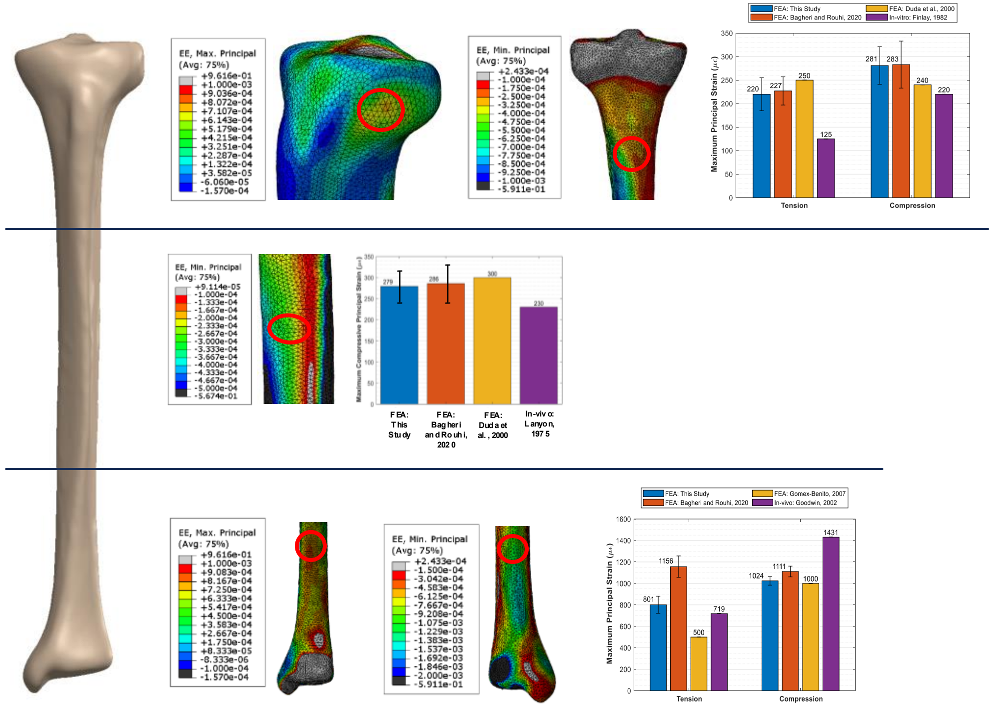

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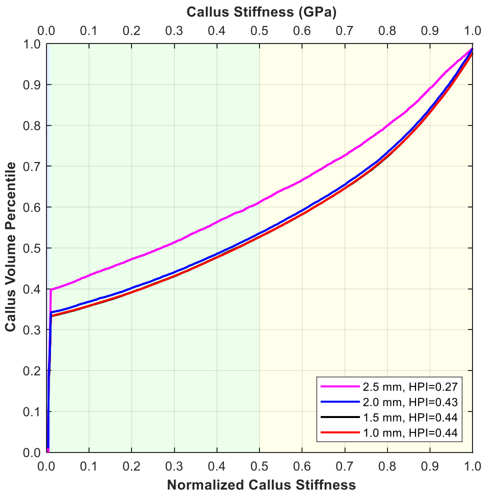

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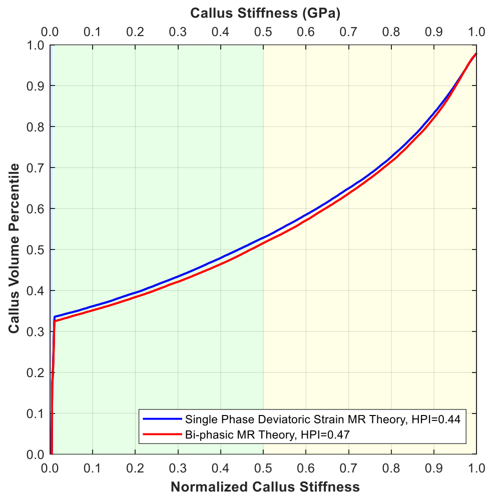


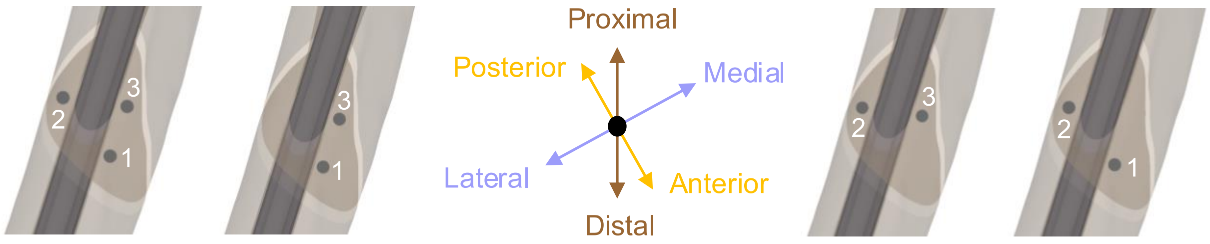
✓ Callus MR Theory

			Base Model	Sensitivity Study: Friction Coefficient		Spring Stiffness		Normal Contact Stiffness	
Contact Settings	μ	-	0.3	0.15	0.6	0.3	0.3	0.3	0.3
	k_s	N/mm	389	389	389	195	778	389	389
	k_c	N/mm	1000	1000	1000	1000	1000	500	2000
IFM	Axial	mm	0.332	0.338 +1.81%	0.327 -1.46%	0.333 +0.30%	0.331 -0.30%	0.336 +1.17%	0.323 -2.71%
	Shear	mm	0.718	0.718 0.00%	0.694 -3.34%	0.721 +0.04%	0.716 -0.03%	0.719 +0.17%	0.717 -0.14%
HPI			0.44	0.43 -2.3%	0.43 +1.3%	0.43 -2.3%	0.44 0.0%	0.45 +2.3%	0.45 +2.3%

✓ Contact Settings

6 Parameterization

- Exchange Nails: 11 mm, 12 mm
- Percutaneous Screw Configurations:



6 Parameterization

- Exchange Nails: 11 mm, 12 mm
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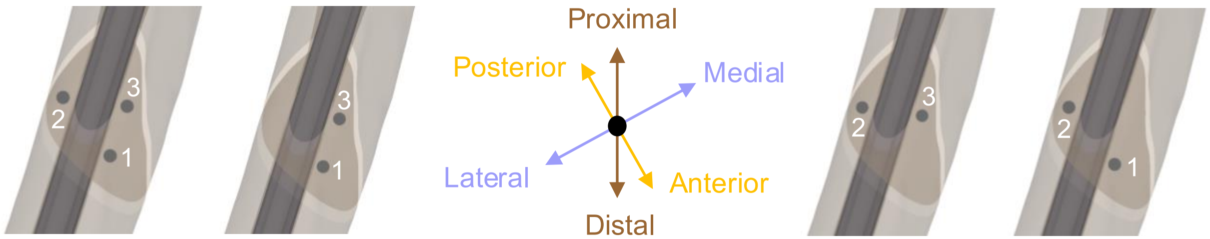


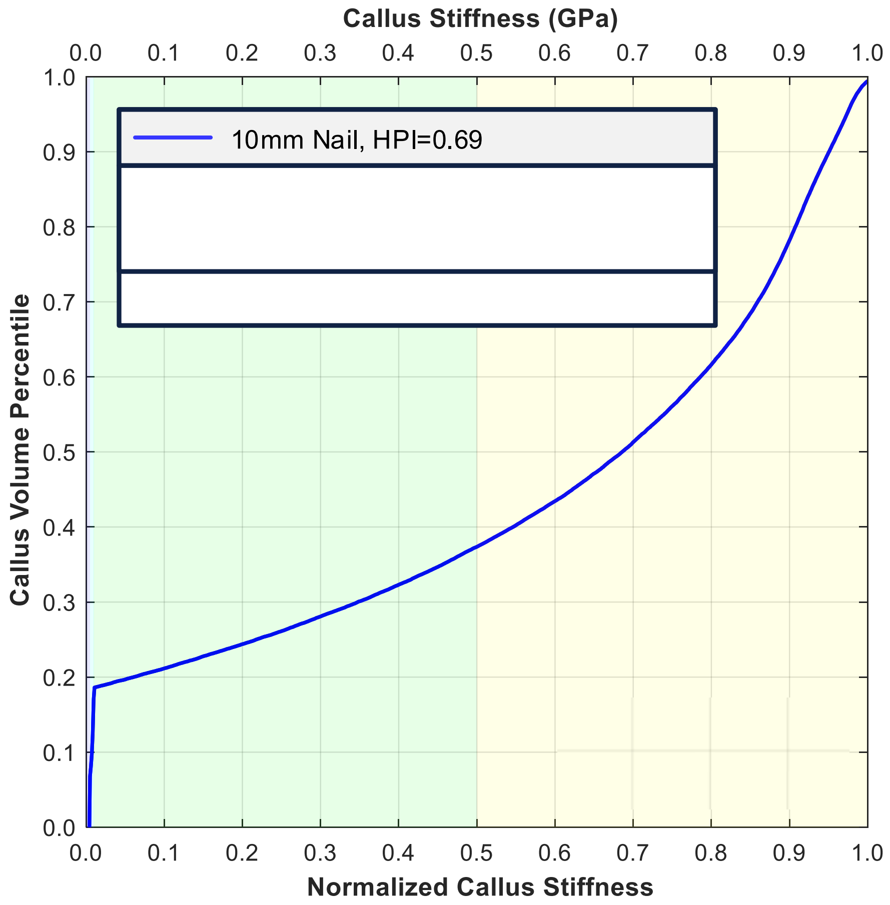
- Fracture Gap Size: 2 mm, 3 mm, 4 mm
- Fracture Orientation:

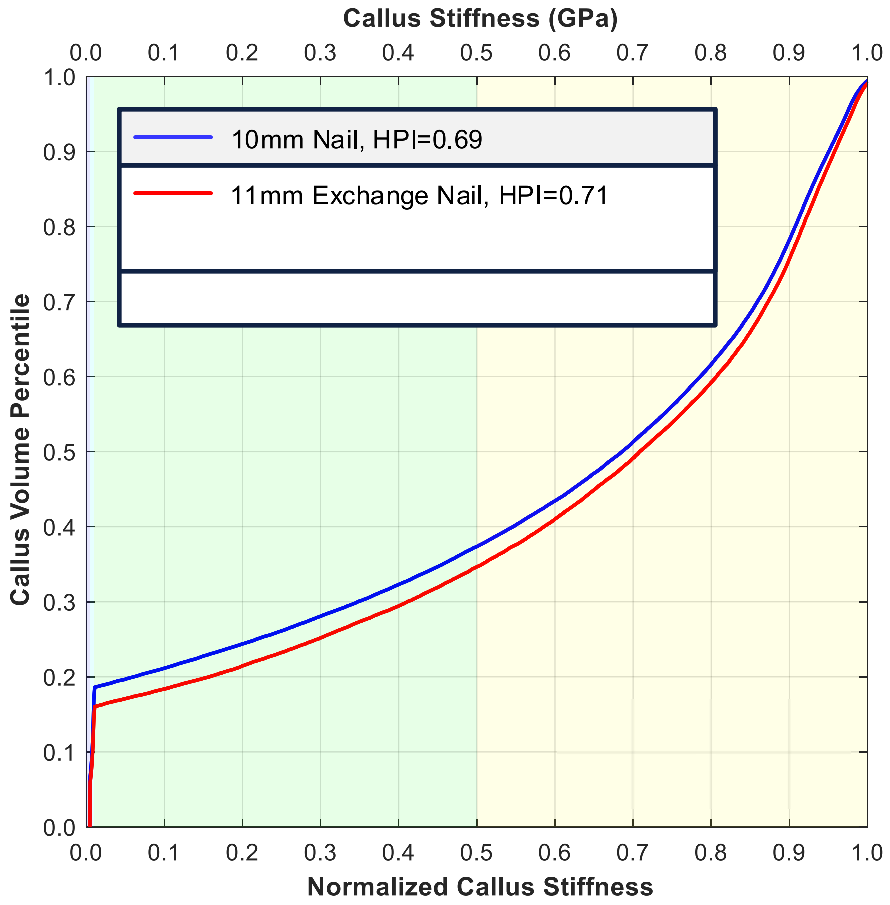
Medial-Lateral Direction (°)	20	70	45	45	45
Anterior-Posterior Direction (°)	45	45	45	20	70

- Degree of Weightbearing: 0%, 25%, 50%, 75%

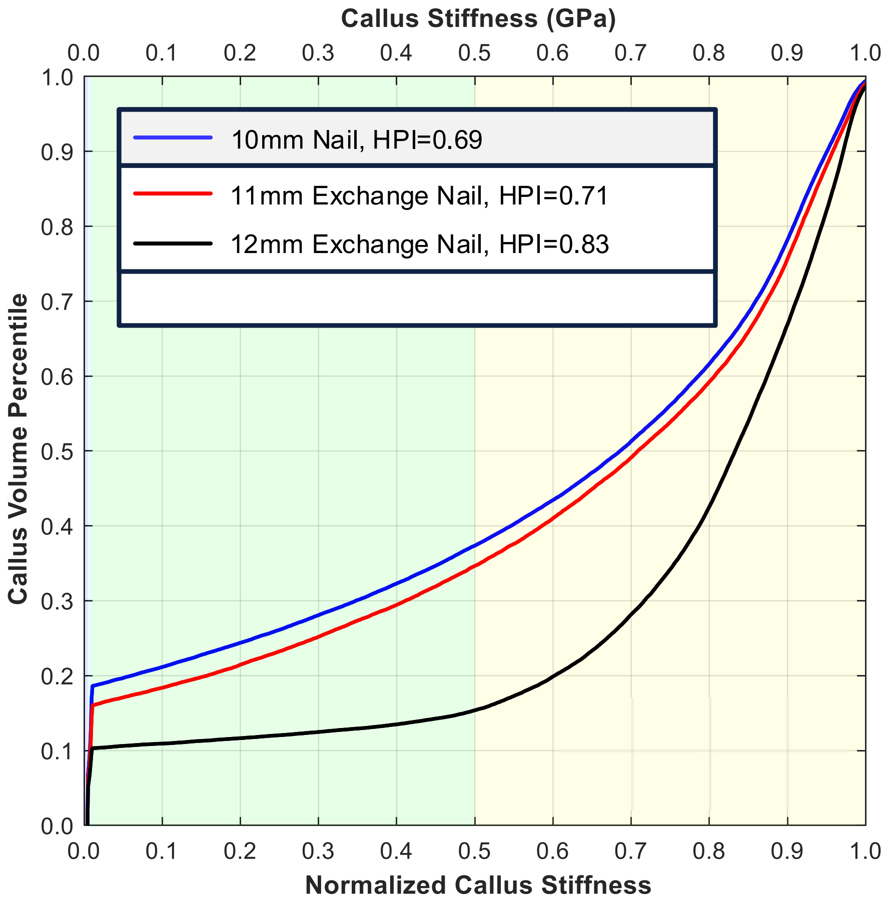
CONTENTS

3. RESULTS + DISCUSSION




Callus Stiffness (GPa)
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
10mm Nail, HPI=0.69
11mm Exchange Nail, HPI=0.71
Callus Volume Percentile
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Normalized Callus Stiffness

3. RESULTS + DISCUSSION



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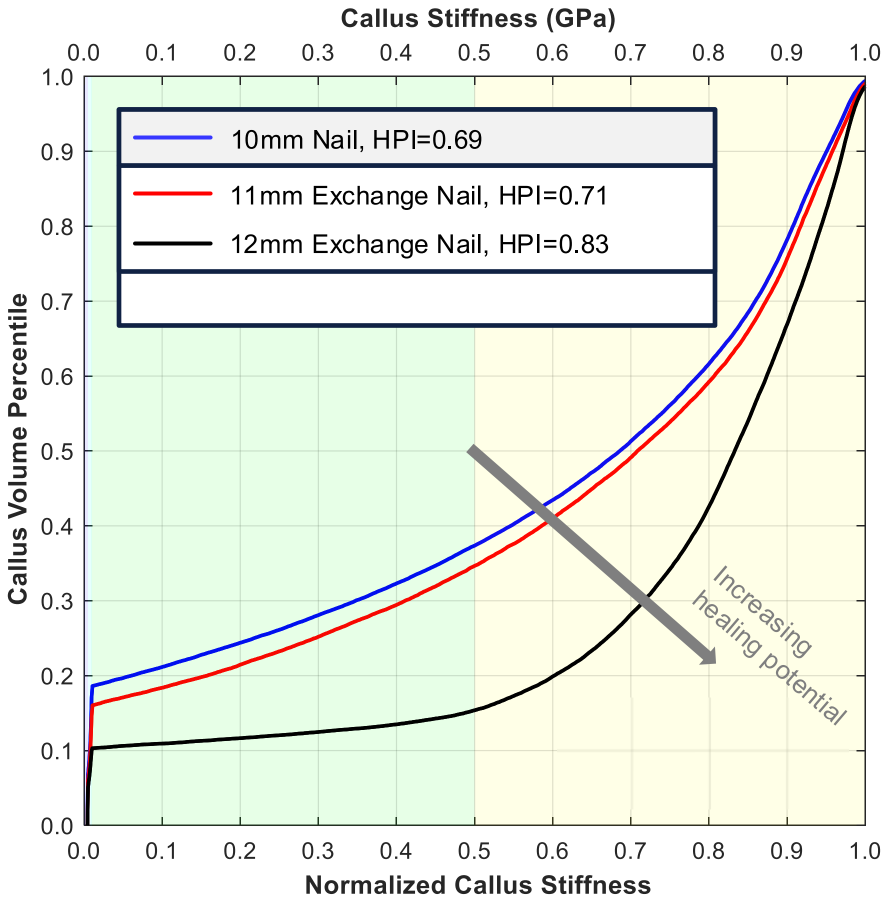

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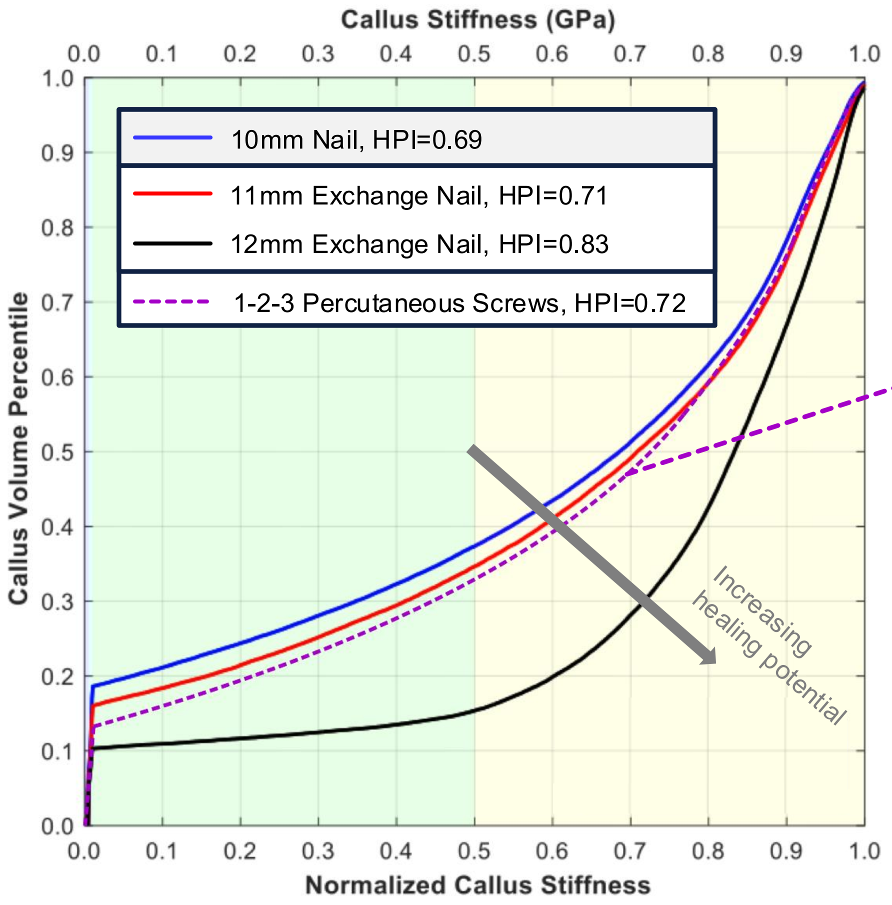
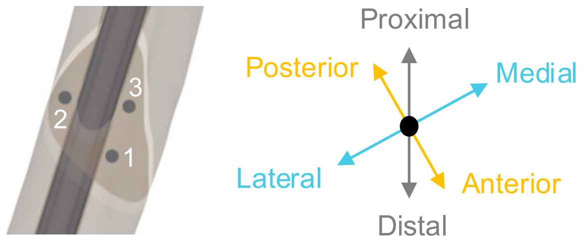
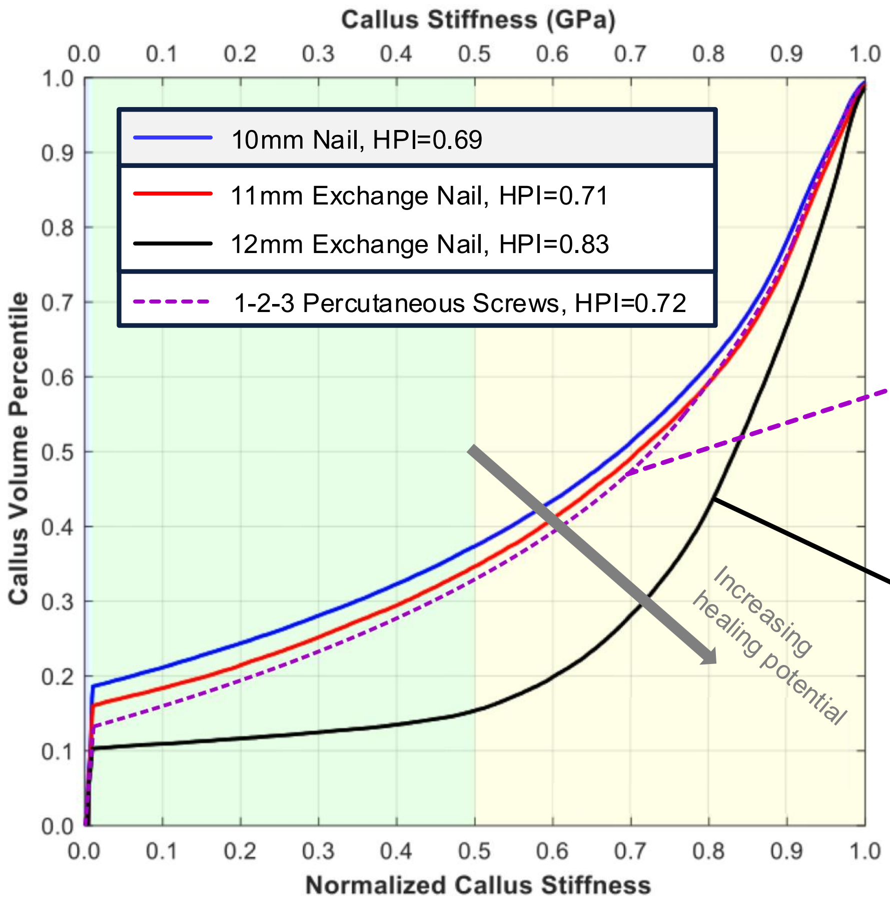
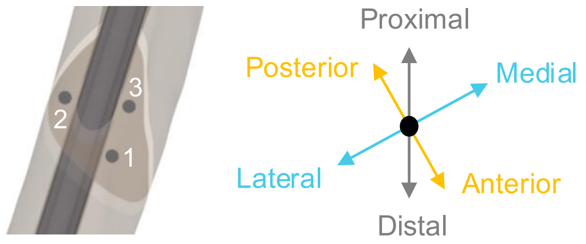




Can be as **effective** as exchange nailing

3. RESULTS + DISCUSSION

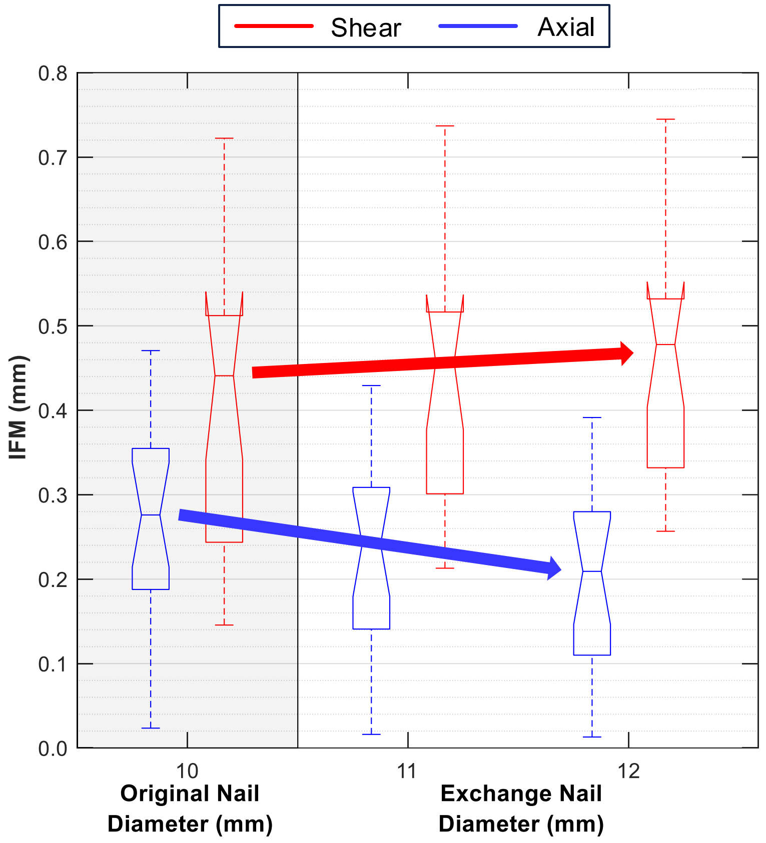




Can be as **effective** as exchange nailing

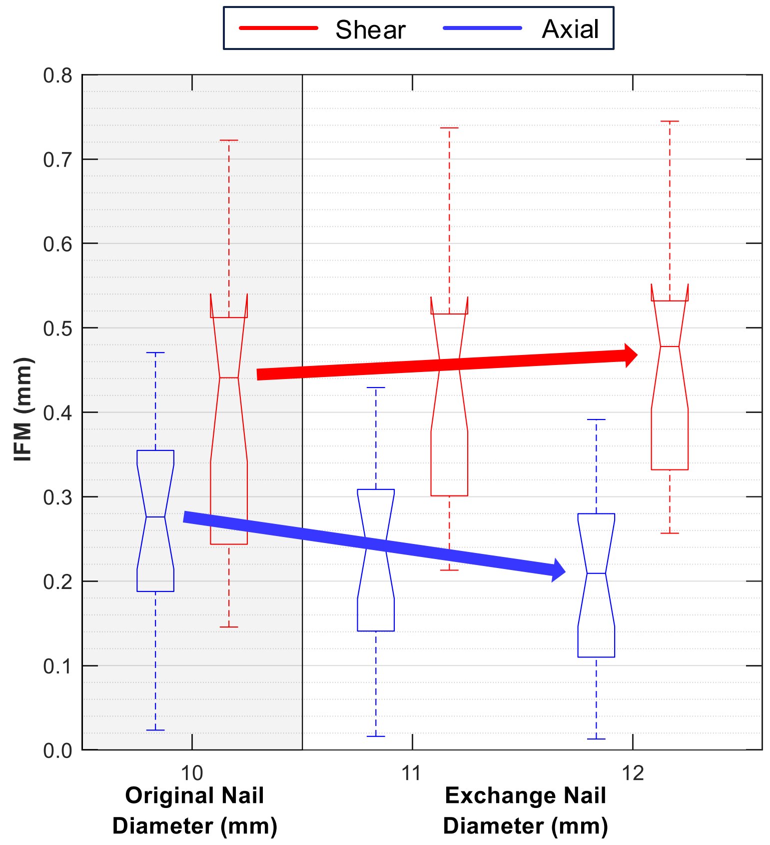
Necessary for the most unstable fractures

Exchange Nailing



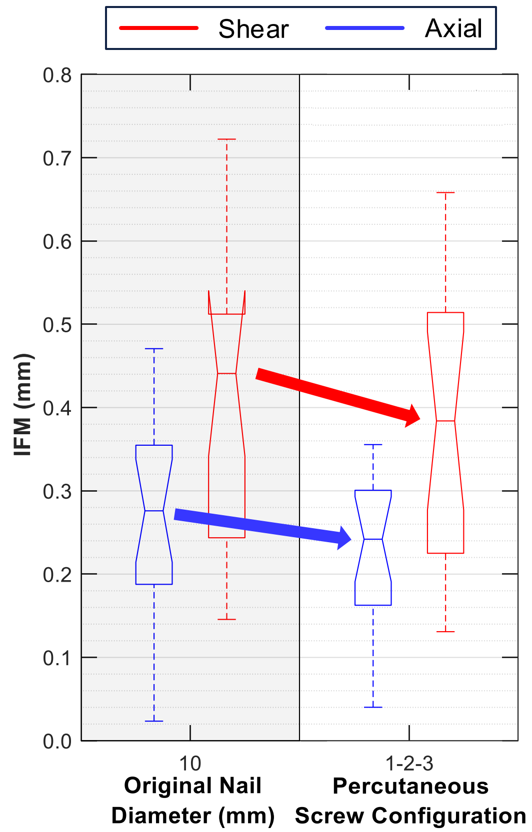
⇩ axial IFM **ONLY**

Exchange Nailing



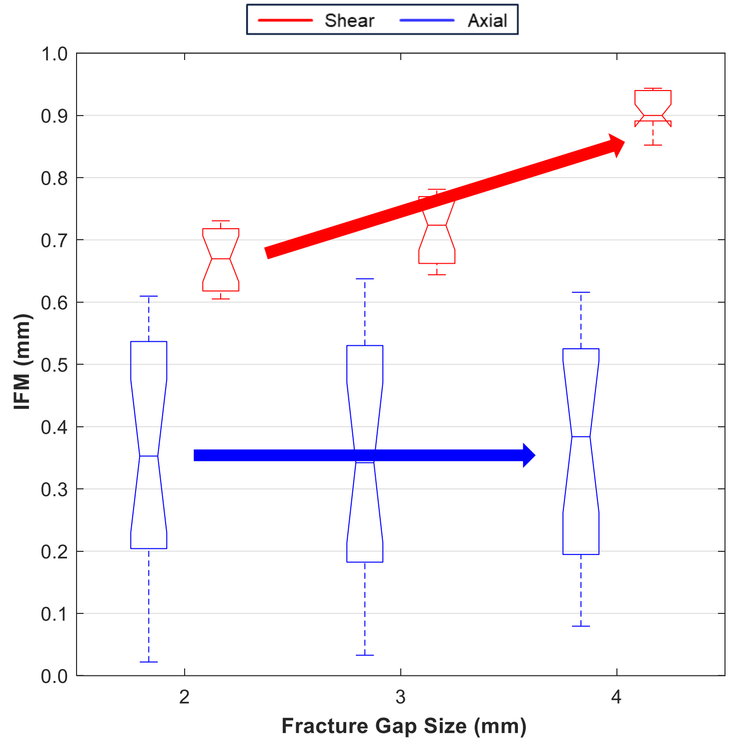
⇩ axial IFM **ONLY**

Percutaneous Screws

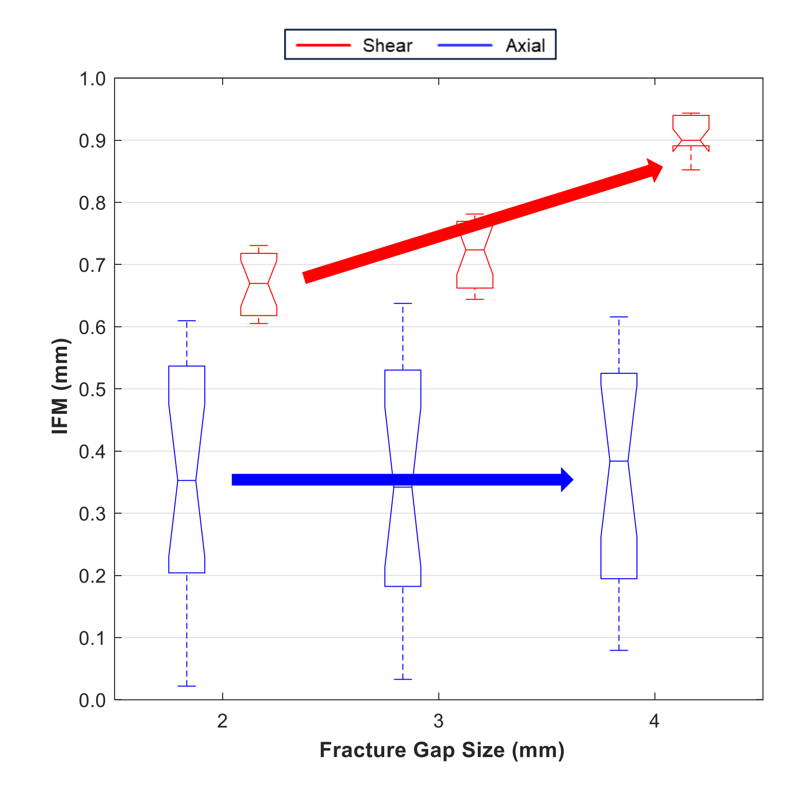


⇩ axial **AND** shear IFM

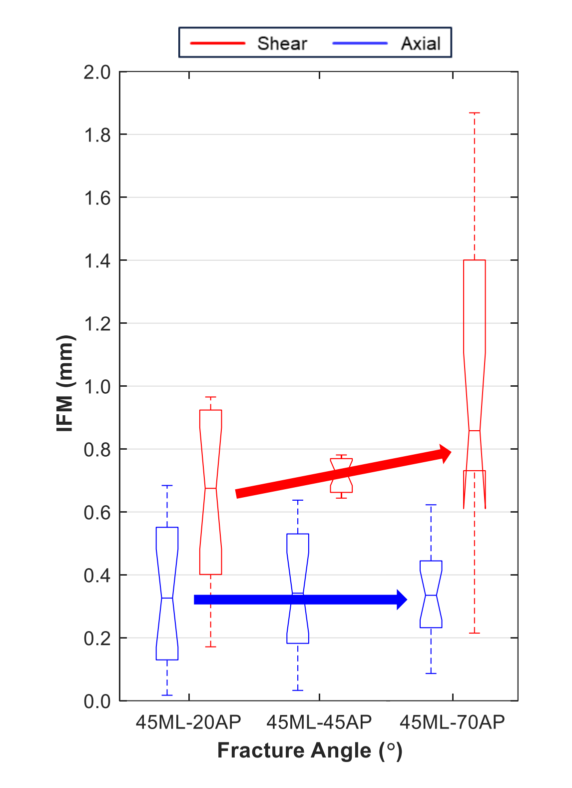
⇧ Fracture Gap Size

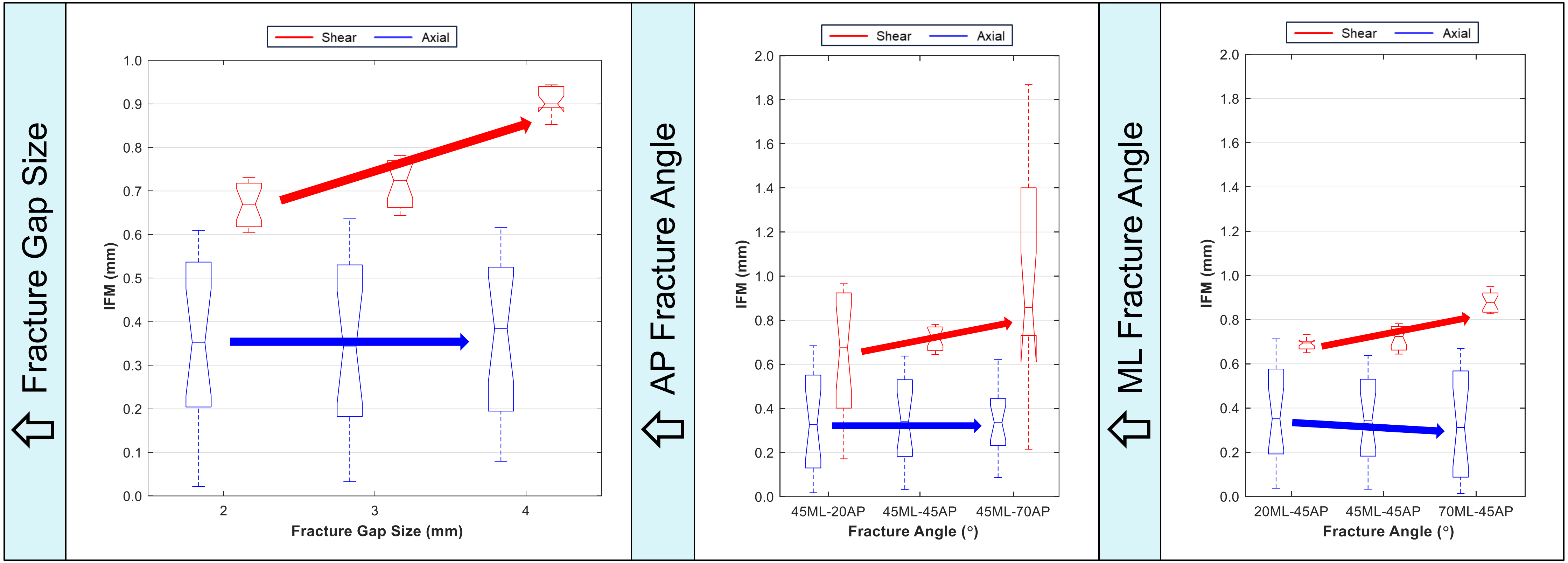


⇧ Fracture Gap Size



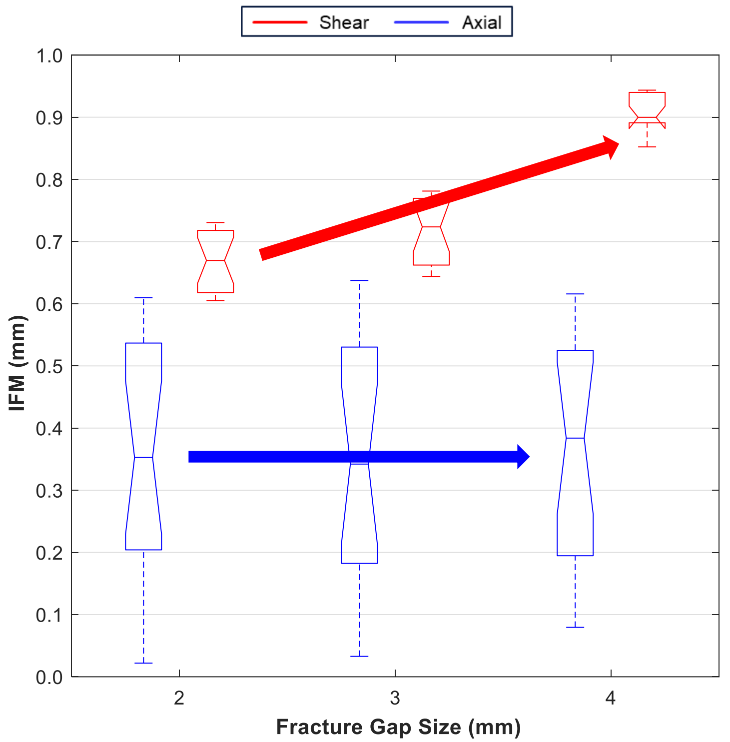
⇧ AP Fracture Angle



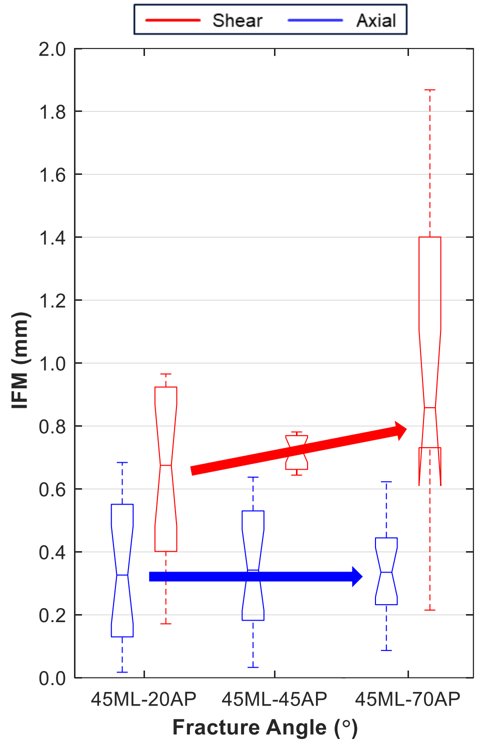


Fracture Gap Size
Shear
Axial
IFM (mm)
Fracture Gap Size (mm)
AP Fracture Angle
45ML-20AP
45ML-45AP
45ML-70AP
Fracture Angle (°)
ML Fracture Angle
20ML-45AP
45ML-45AP
70ML-45AP
Fracture Angle (°)

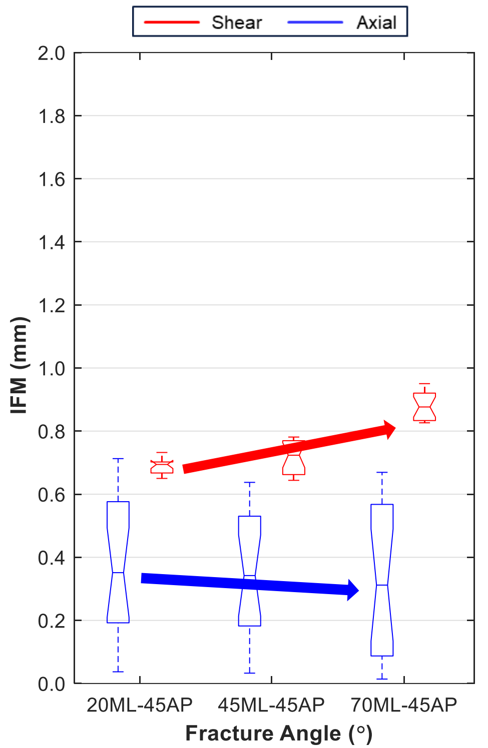
⇧ Fracture Gap Size



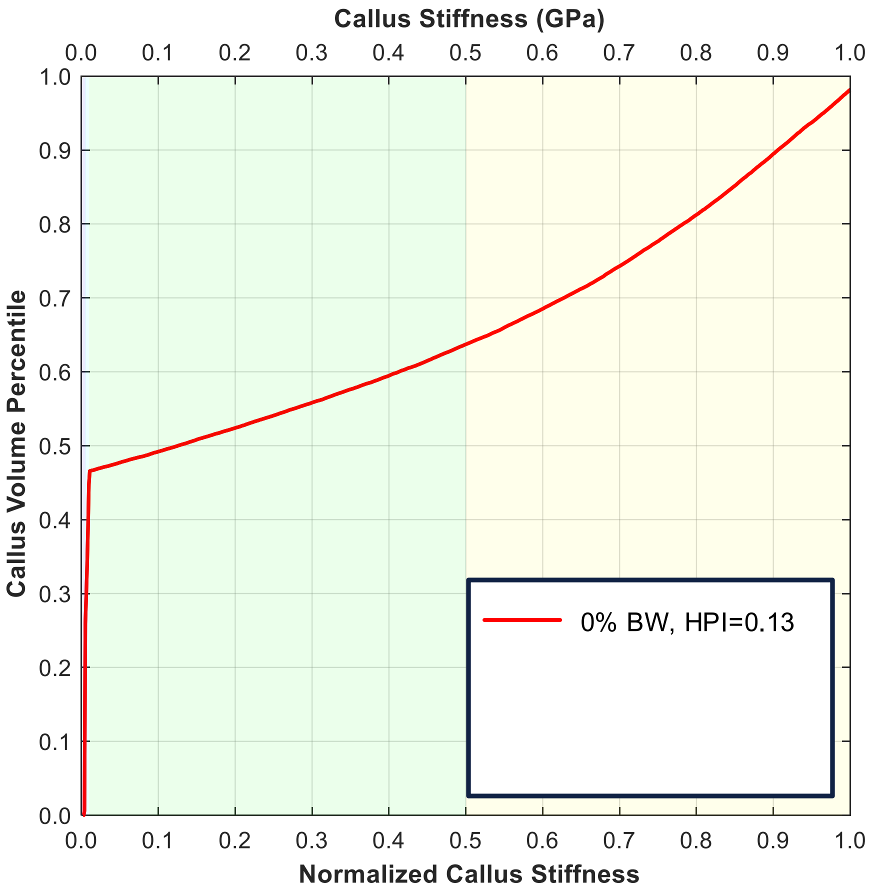
⇧ AP Fracture Angle

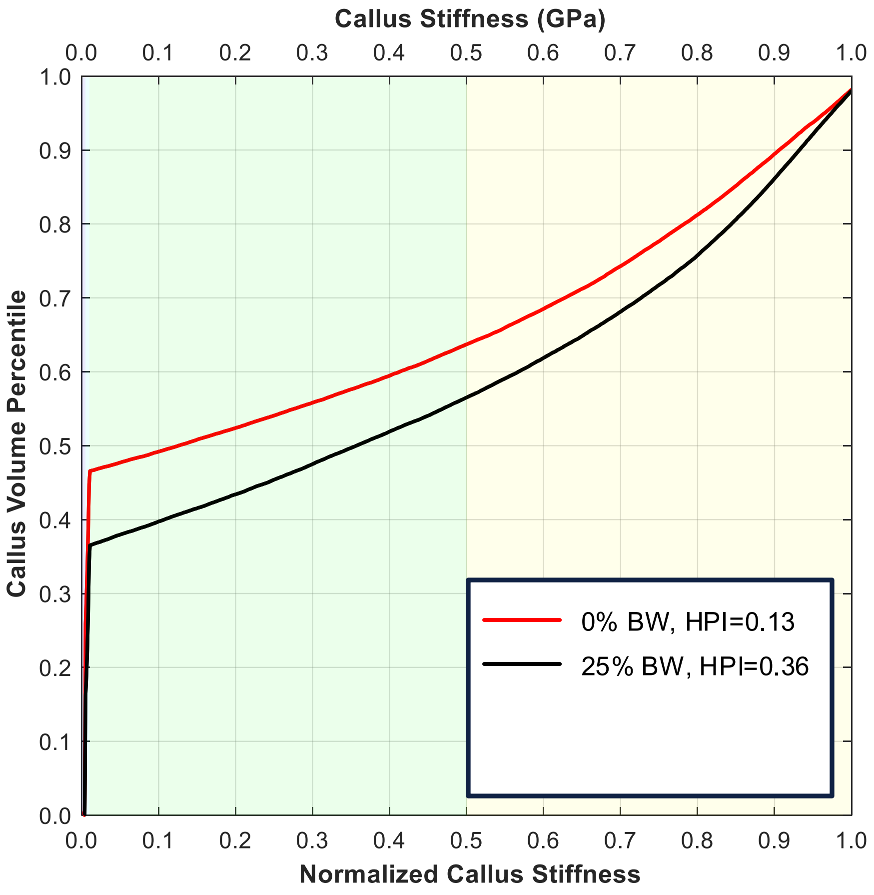


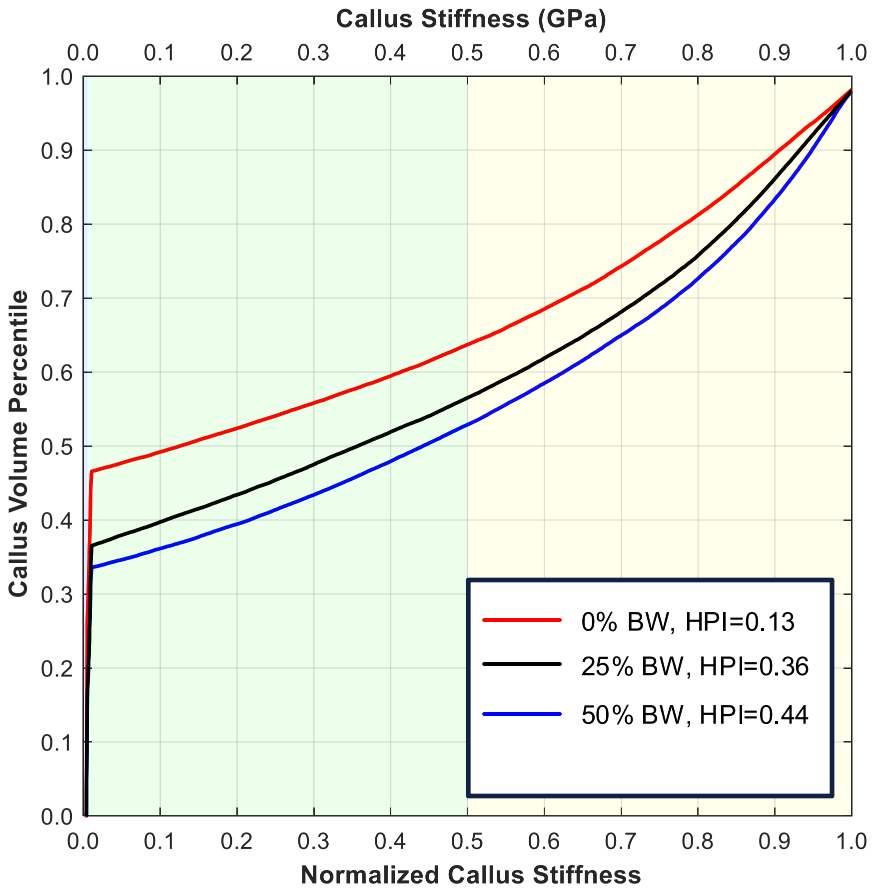
⇧ ML Fracture Angle



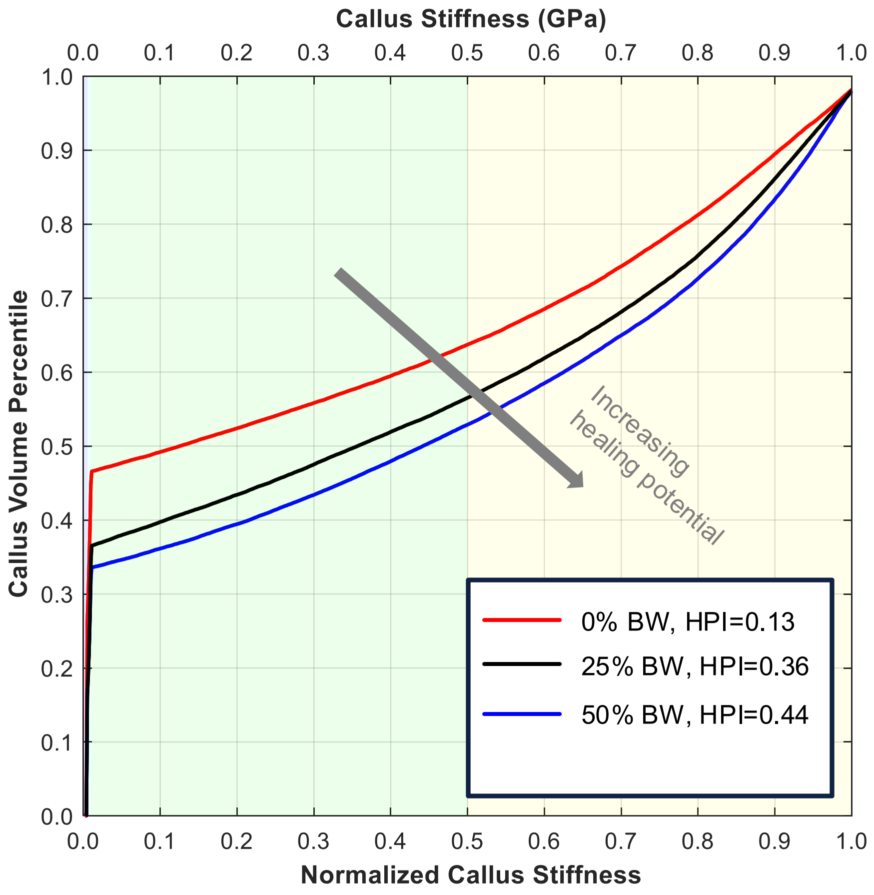
⇧ shear to axial IFM = ⇧ viability of percutaneous screws

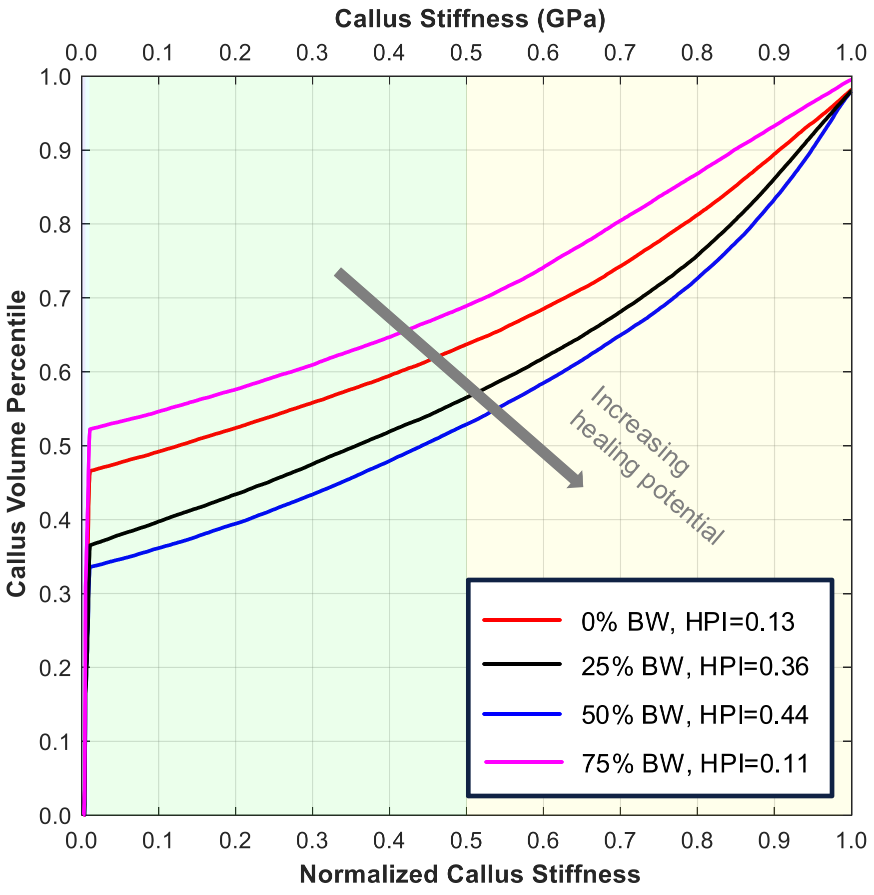

Callus Stiffness (GPa)
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Callus Volume Percentile
1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0
0% BW, HPI=0.13
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Normalized Callus Stiffness


Callus Stiffness (GPa)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Callus Volume Percentile
Normalized Callus Stiffness
0% BW, HPI=0.13
25% BW, HPI=0.36

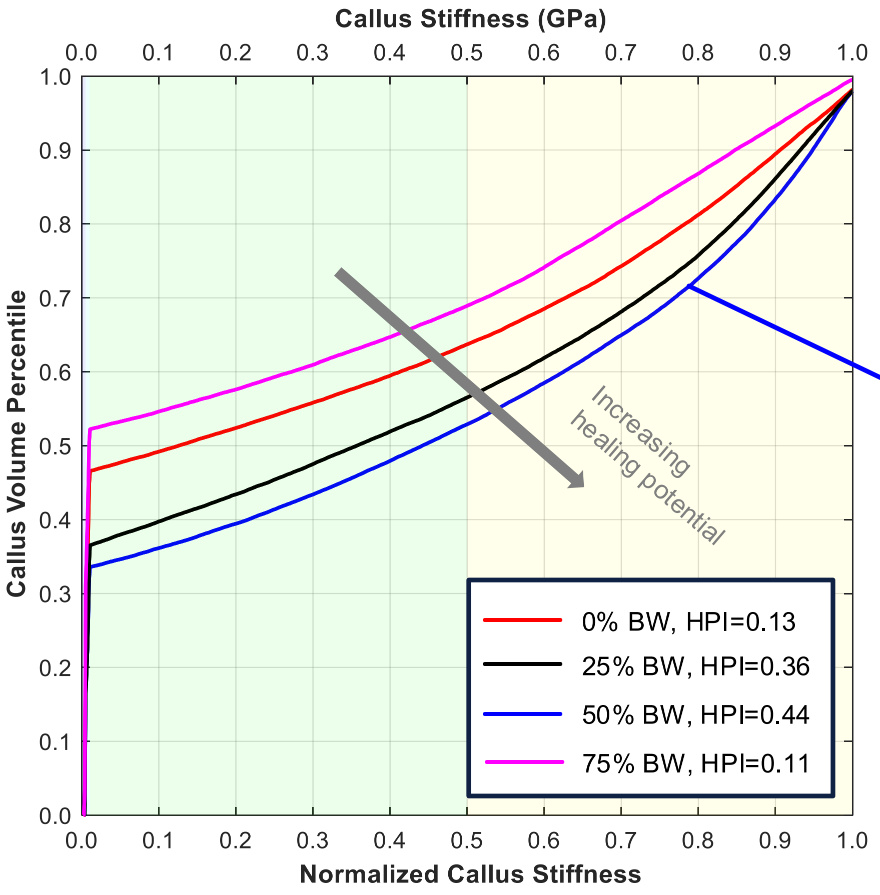


Callus Stiffness (GPa)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Callus Volume Percentile
0% BW, HPI=0.13
25% BW, HPI=0.36
50% BW, HPI=0.44
Normalized Callus Stiffness


Callus Stiffness (GPa)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Callus Volume Percentile
Normalized Callus Stiffness
Increasing healing potential
0% BW, HPI=0.13
25% BW, HPI=0.36
50% BW, HPI=0.44



Callus Stiffness (GPa)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Callus Volume Percentile
Normalized Callus Stiffness
Increasing healing potential
0% BW, HPI=0.13
25% BW, HPI=0.36
50% BW, HPI=0.44
75% BW, HPI=0.11



Encourage small amount of weightbearing immediately following treatment

- ⇨ Counteracts muscle forces
- ⇨ Keeps joint loads small
- ✓ Benefits clinically observed [11]

11. Trompeter, Bone Joint J 2020

CONTENTS

4. CONCLUSIONS

- Percutaneous screws are indeed a viable treatment for non-union
  - ⇨ Good stabilizing effect
  - ⇨ Low invasivity
  - ⇨ Cheap

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4. CONCLUSIONS

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  - ⇧ Fracture angle
  - ⇨ Small amount of weightbearing

- Further research opportunities:
  - ⇨ In-vitro experimental study
  - ⇨ Assess full healing pathway via iterative analyses
  - ⇨ Femoral fractures

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