

# Modèle numérique pour RI en os

J GARNON<sup>1,2</sup>

L MEYLHEUC<sup>2</sup>

C MARCHE<sup>2</sup>

C SIEFFERT<sup>2</sup>

B BAYLE<sup>2</sup>

A GANGI<sup>1,2</sup>

<sup>1</sup>Service d'Imagerie Interventionnelle, CHU de Strasbourg, France

<sup>2</sup>Equipe AVR-CNRS, laboratoire I-Cube, Strasbourg, France

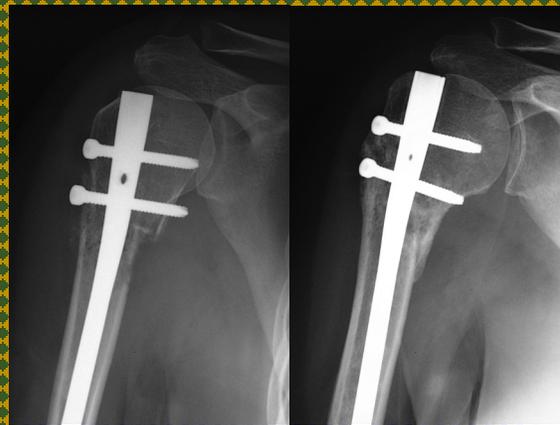
# the « oldschool » algorythm

fractures

impending fractures



surgery



surgery + radiotherapy



Harada et al. J. Radiat. Res 2010

radiotherapy

## **Prophylactic Percutaneous Consolidation of Large Osteolytic Tumors of the Pelvic Ring Using Fixation by Internal Cemented Screws**

Assouline et al. *Radiol Imaging Cancer* 2021

## **Percutaneous consolidation of bone metastases: strategies and techniques**

Cazzato et al. *Insights Imaging* 2019

## **Percutaneous osteosynthesis in the pelvis in cancer patients**

Deschamps et al. *Eur Radiol* 2016

## **Image-Guided Bone Consolidation in Oncology**

Buy et al. *Semin Intervent Radiol* 2018

## **Expanding role of percutaneous ablative and consolidative treatments for musculoskeletal tumours**

Kurup *Clin Radiol* 2017

## **Percutaneous Fixation by Internal Cemented Screws of the Sternum**

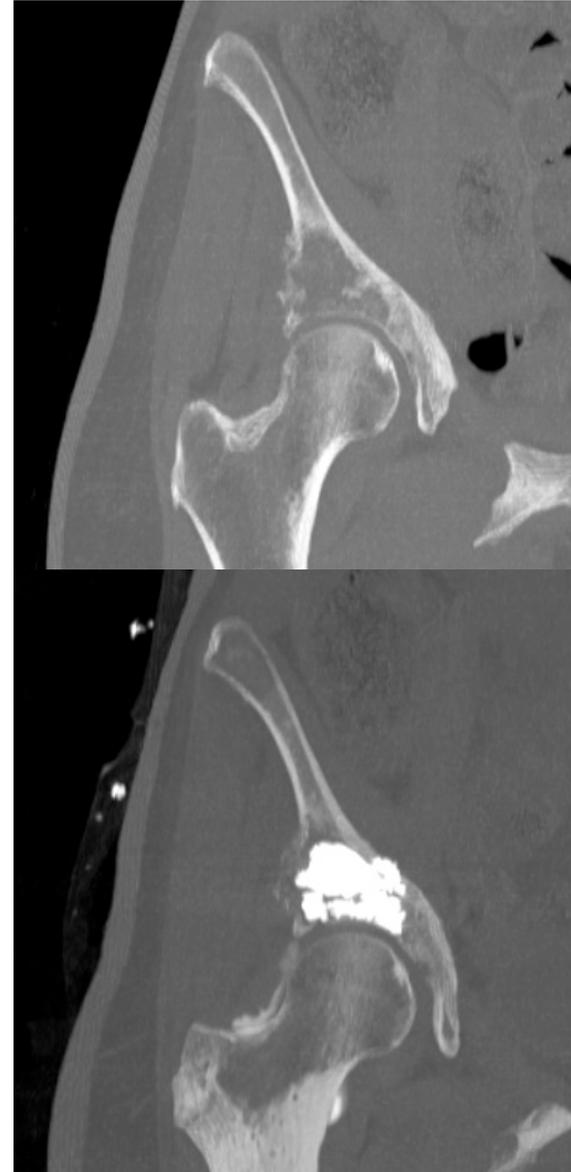
Poussot et al. *Cardiovasc Intervent Radiol* 2020

## **Percutaneous stabilization of impending pathological fracture of the proximal femur**

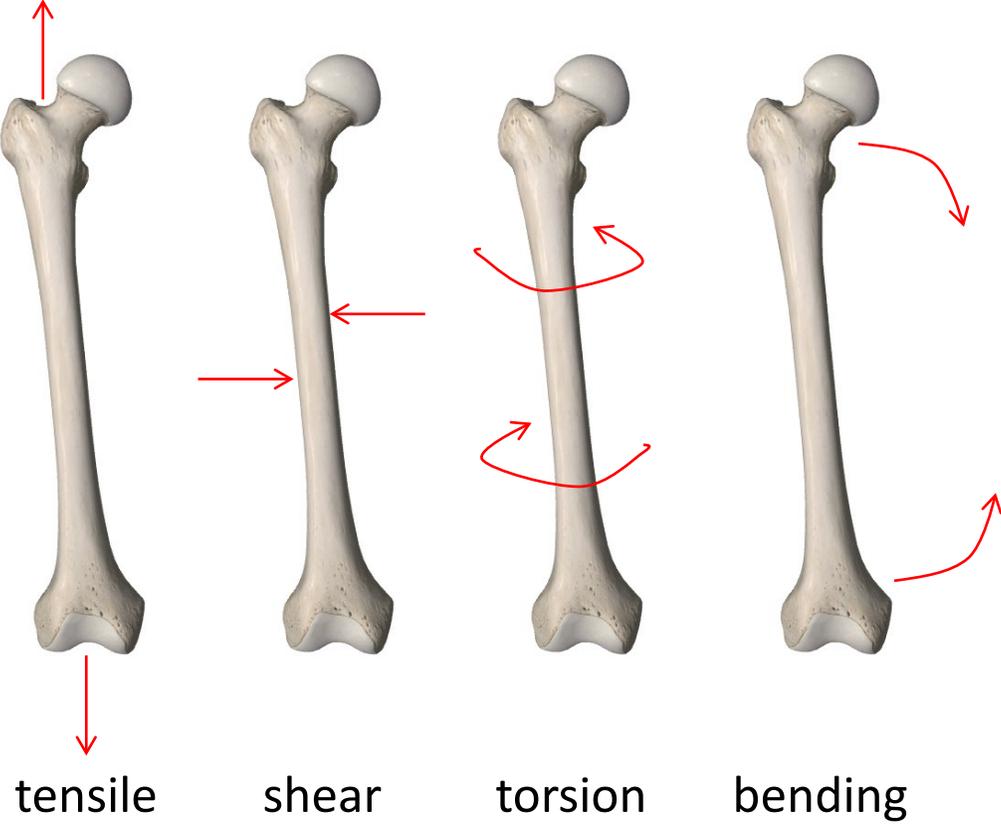
Deschamps et al. *Cardiovasc Intervent Radiol* 2012



# PMMA



# PMMA

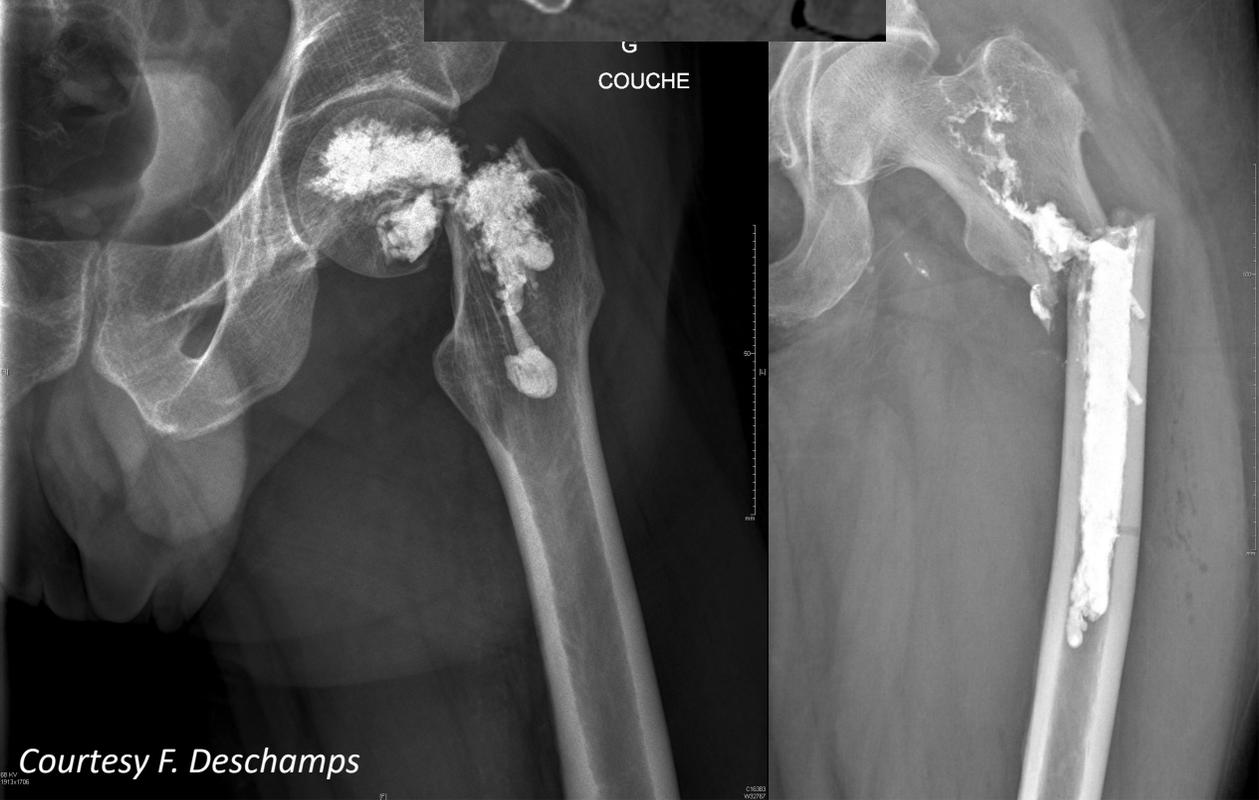
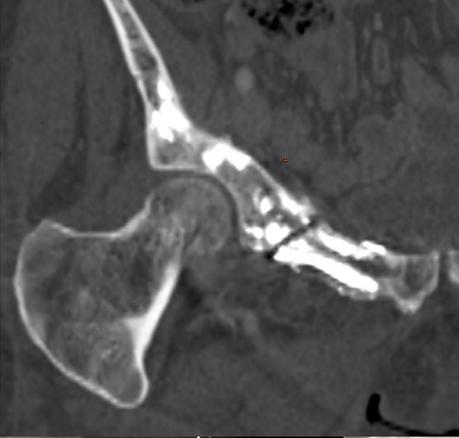


X

X

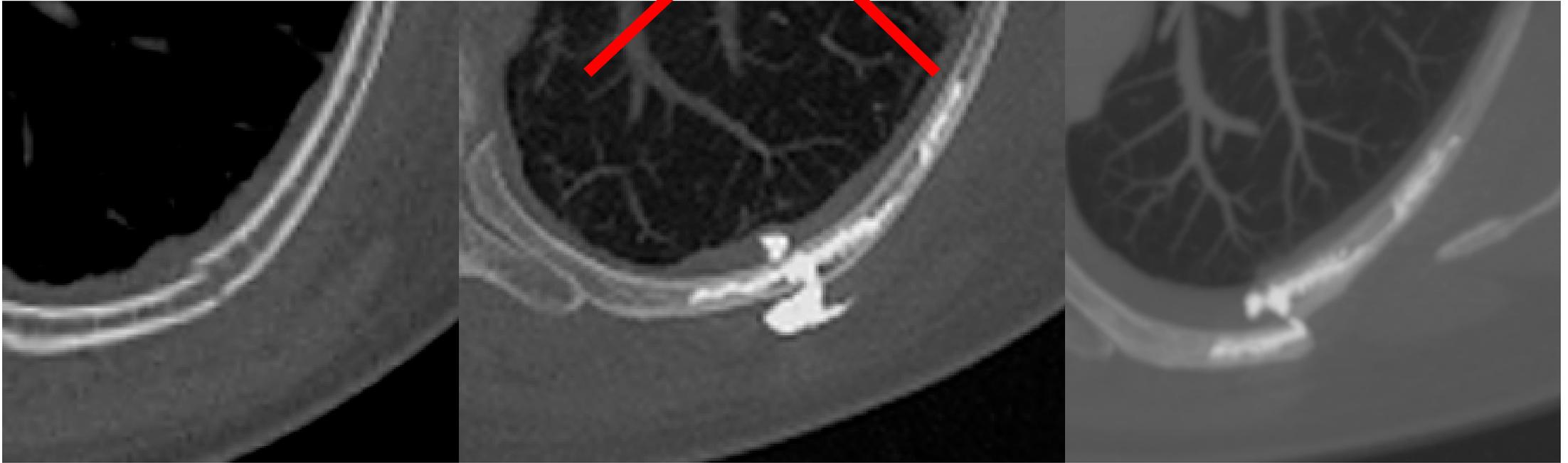
X

X

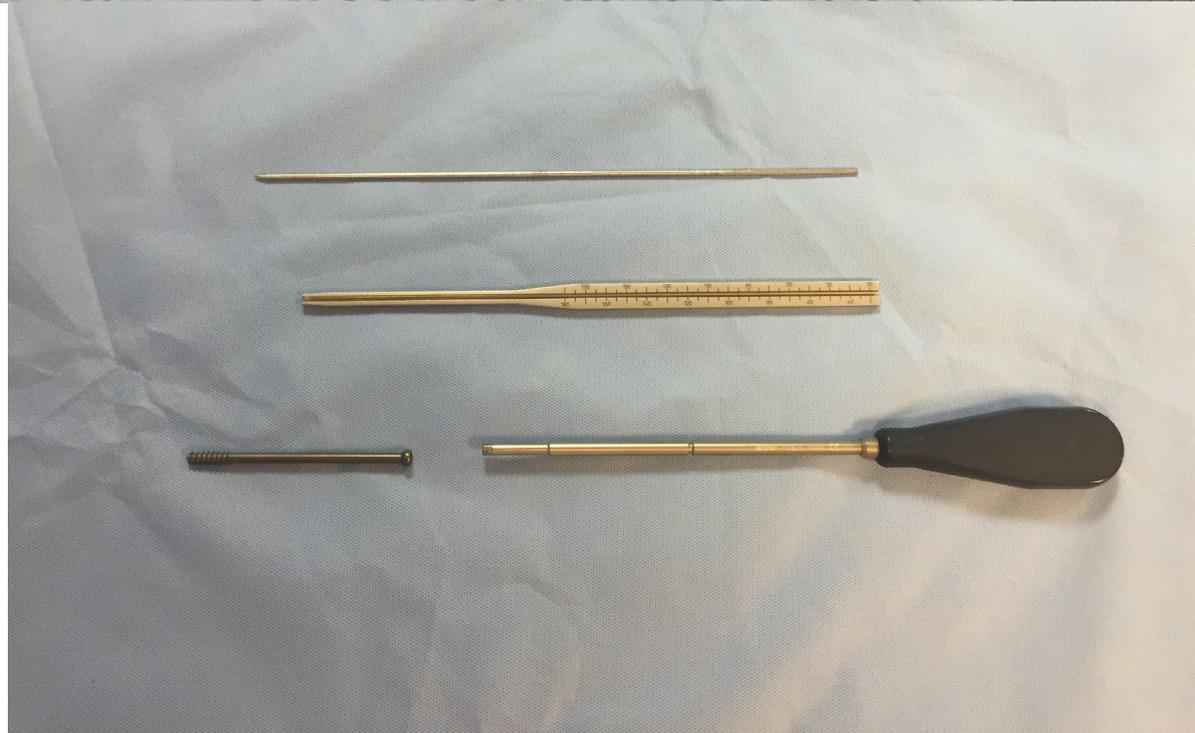
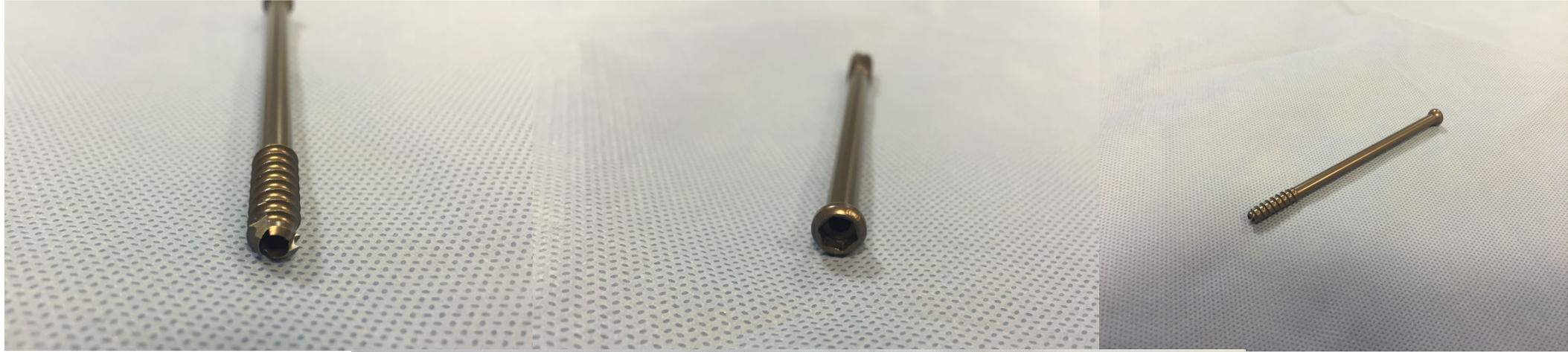


Courtesy F. Deschamps

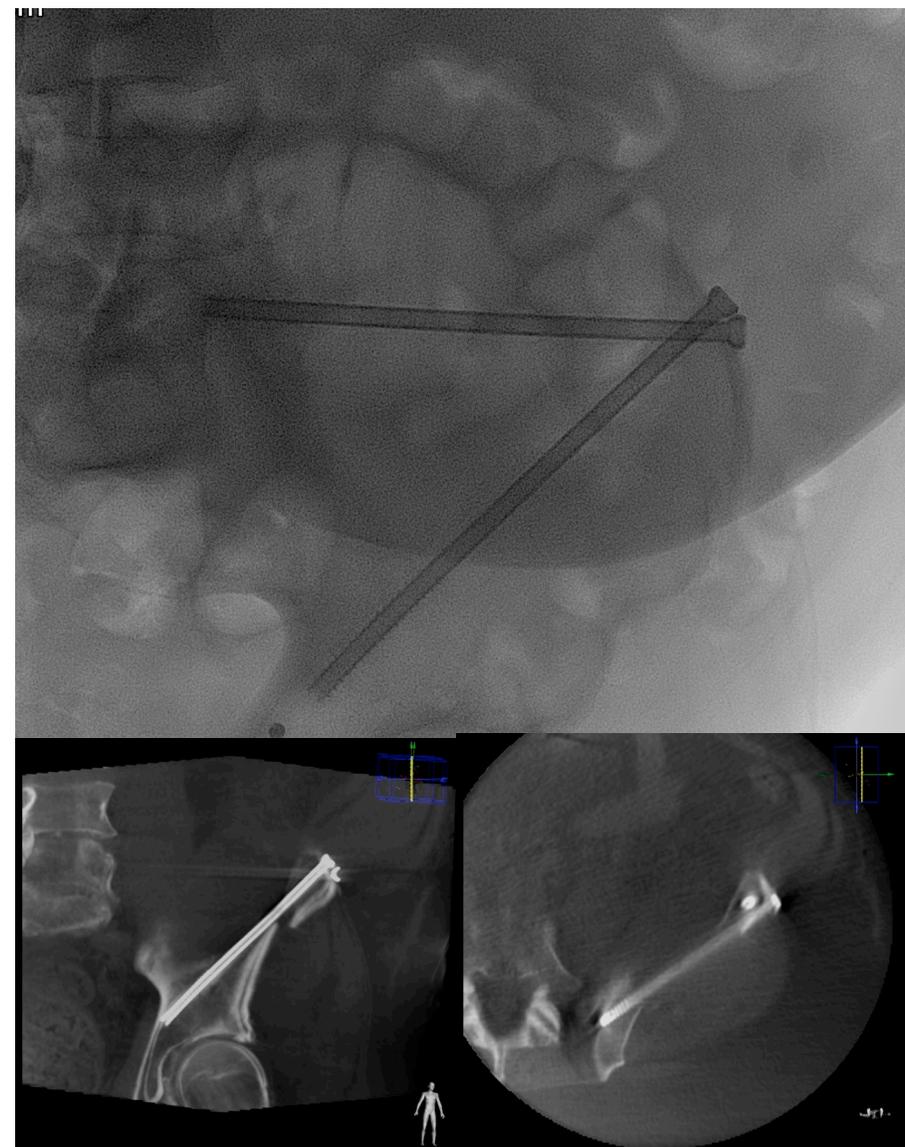
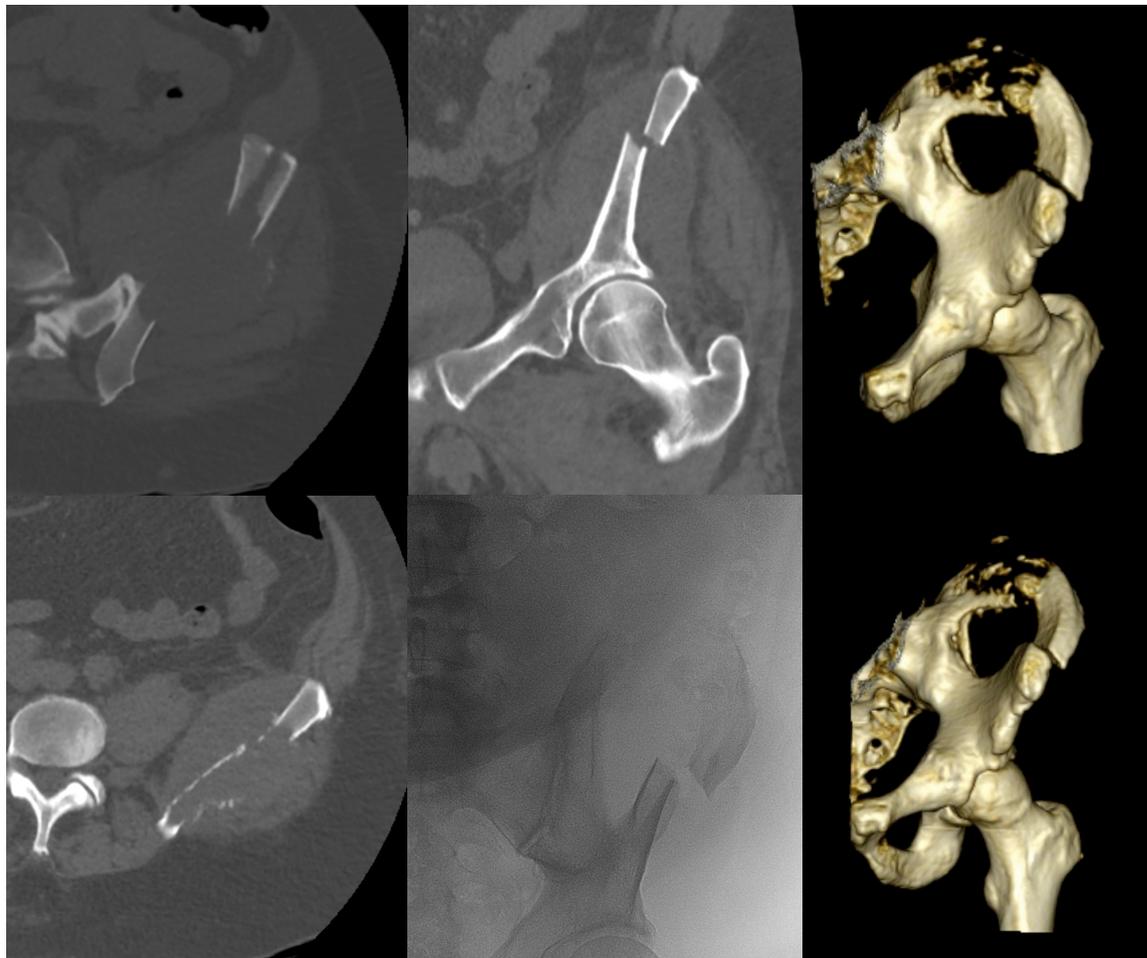
# PMMA



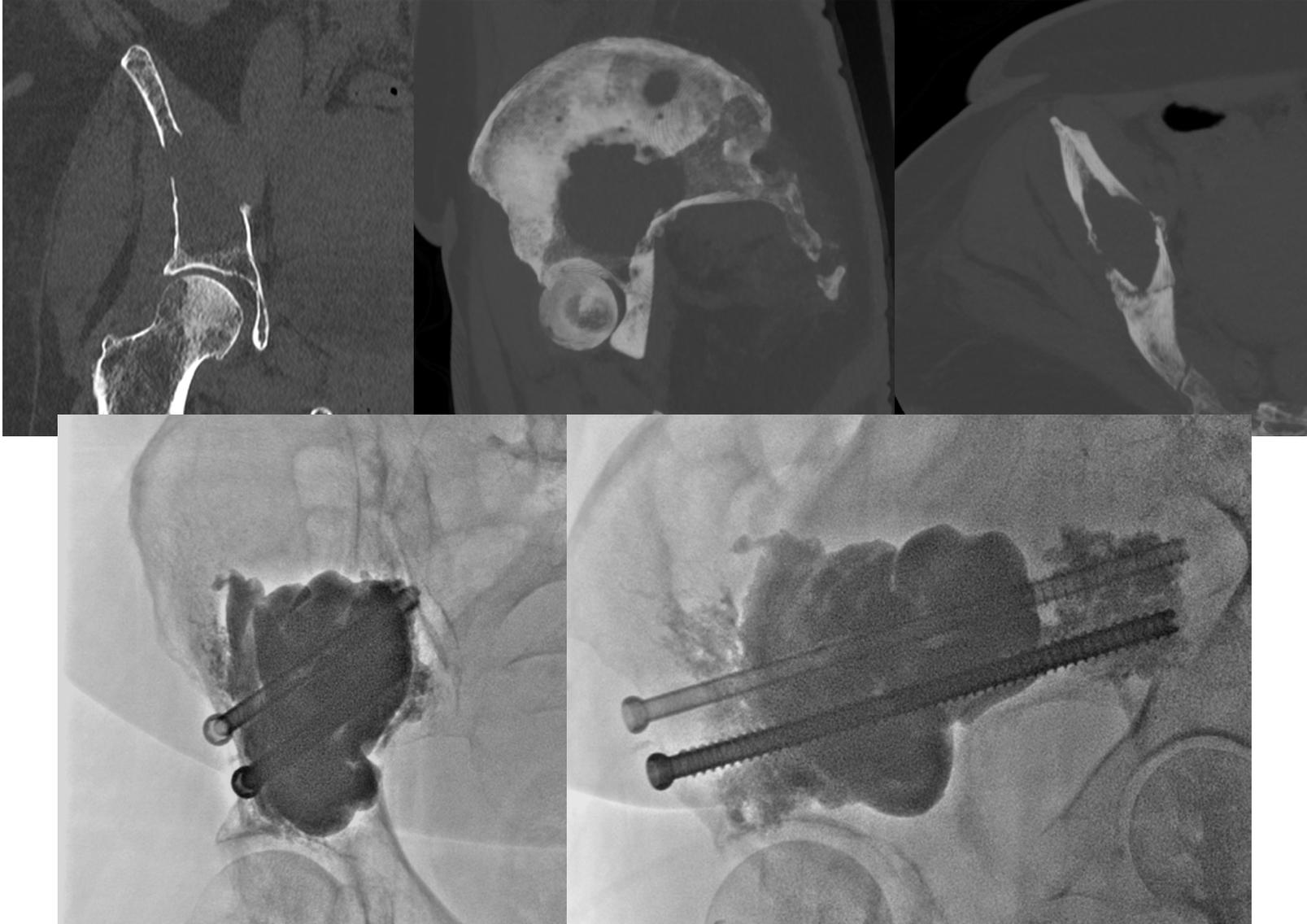
**VIS**



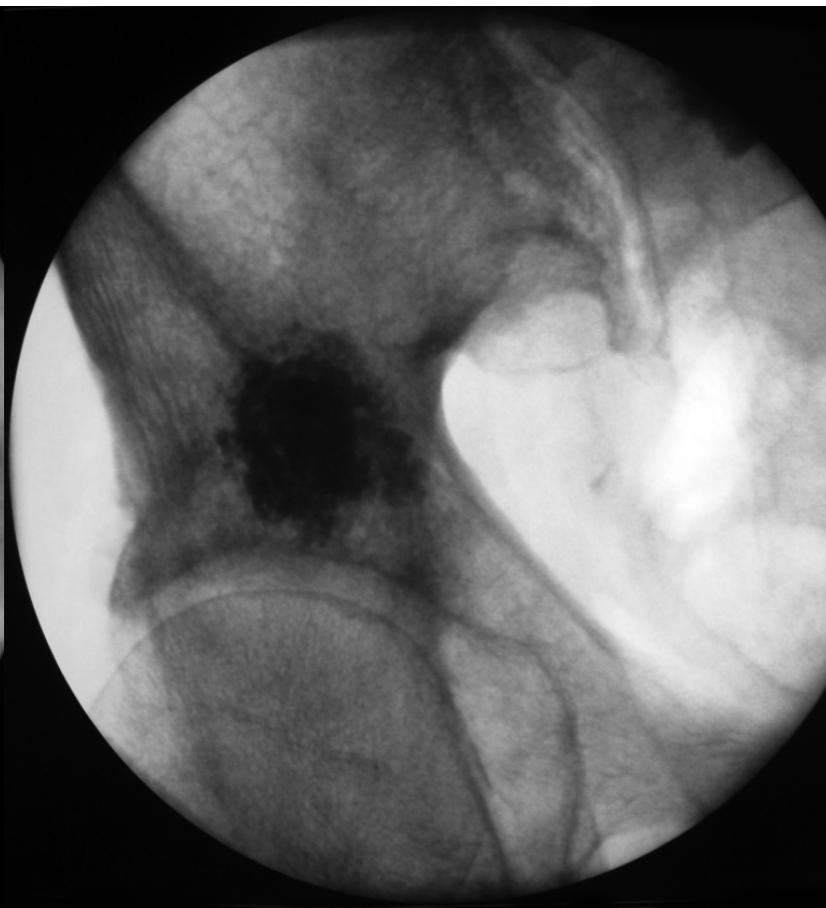
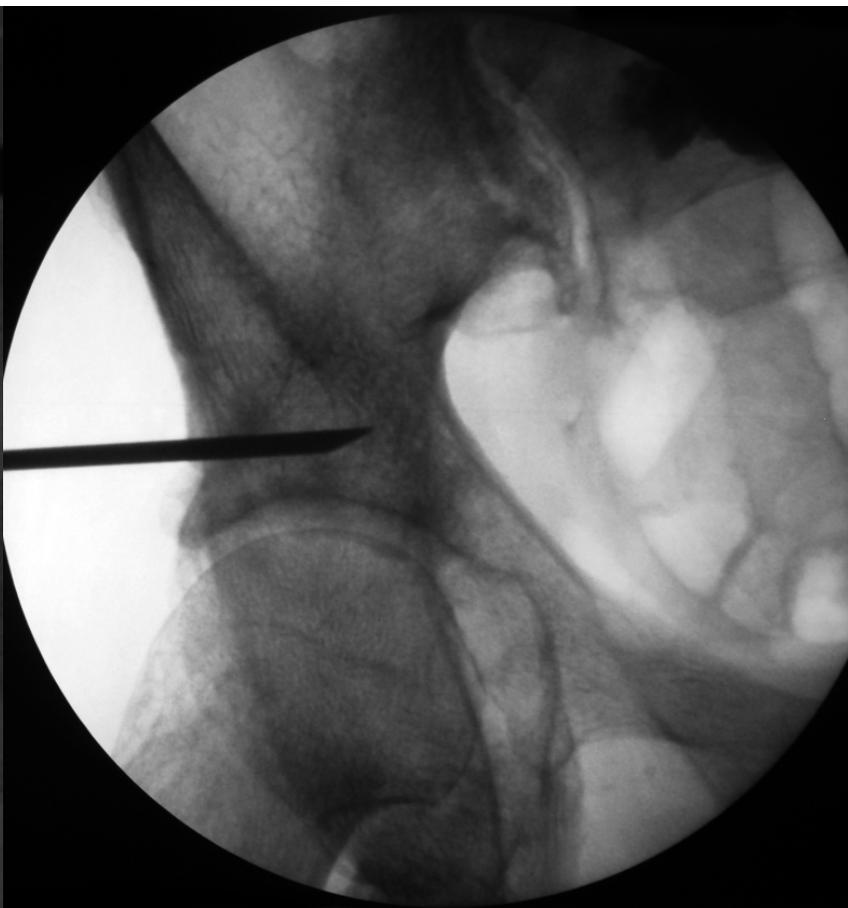
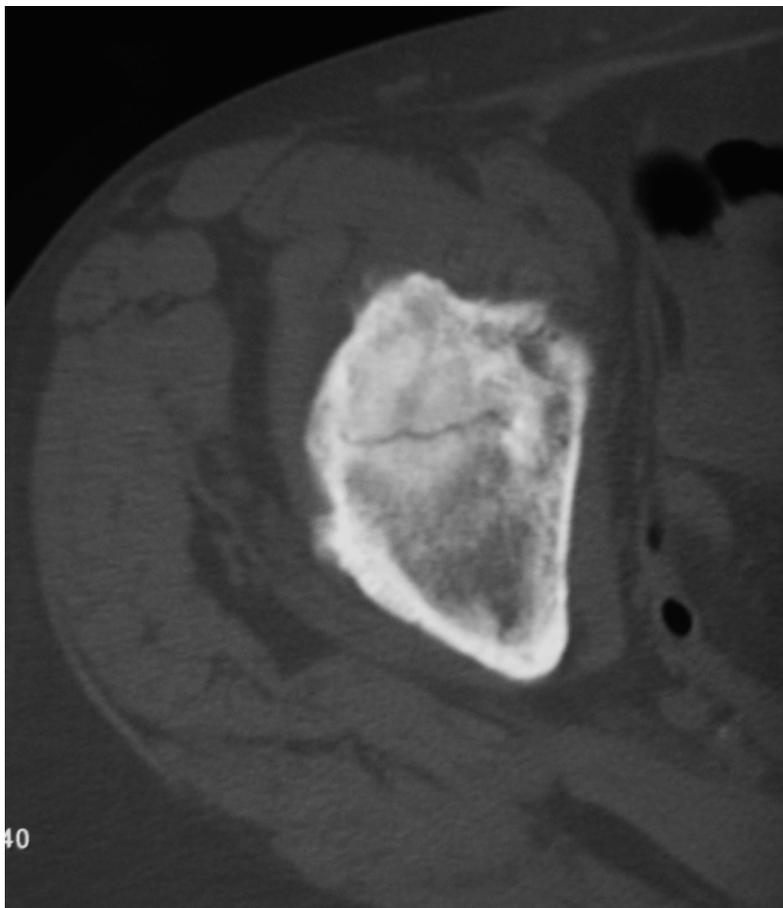
# VIS



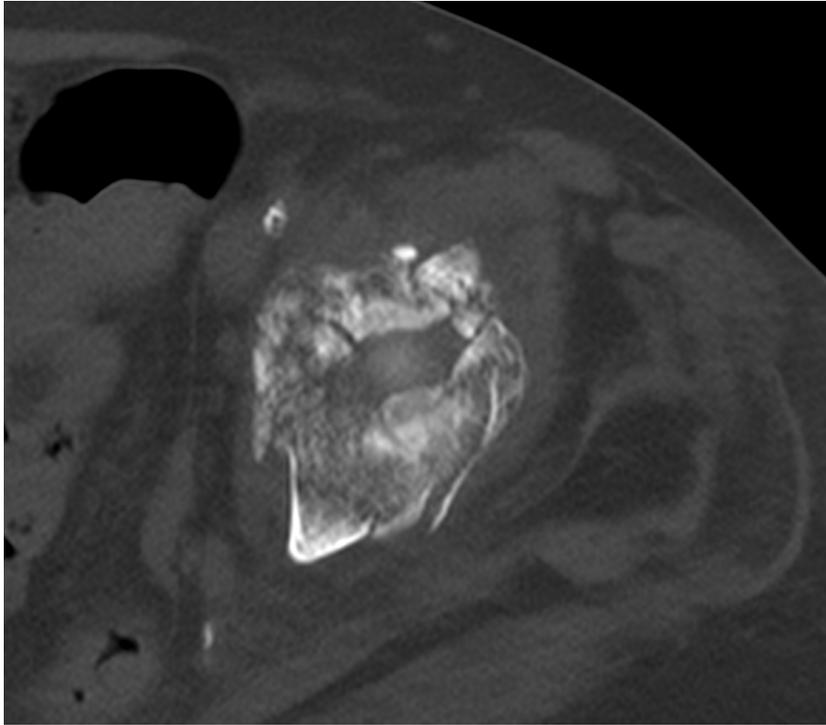
# PMMA ET VIS



# 2009



# 2023



# QUESTIONS EN SUSPENS

- vis uniquement?
- ciment uniquement?
- vis + ciment?
- quel volume de ciment?
- localisation optimale pour le ciment?
- nombre des vis?
- position des vis?

# Minimally Invasive Stabilization Using Screws and Cement for Pelvic Metastases: Technical Considerations for the Pelvic “Screw and Glue” Technique

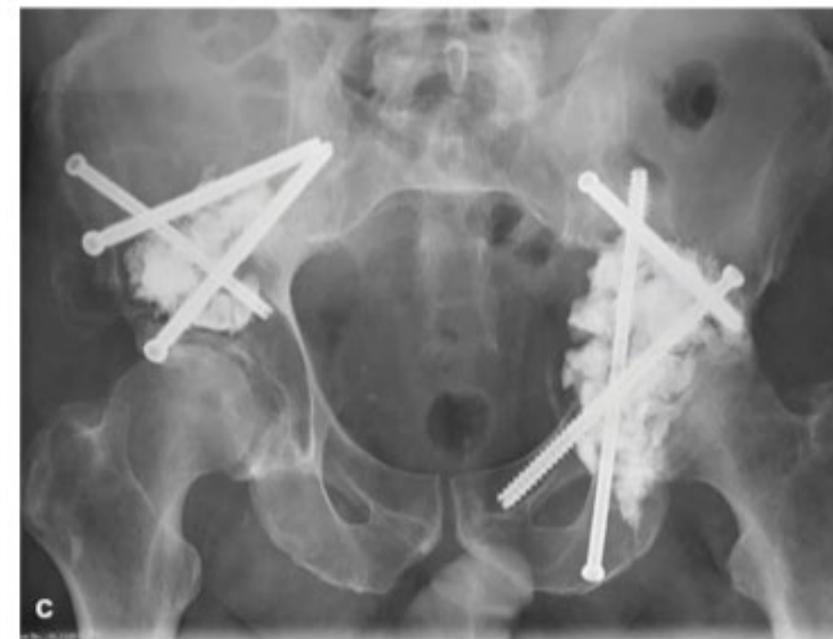
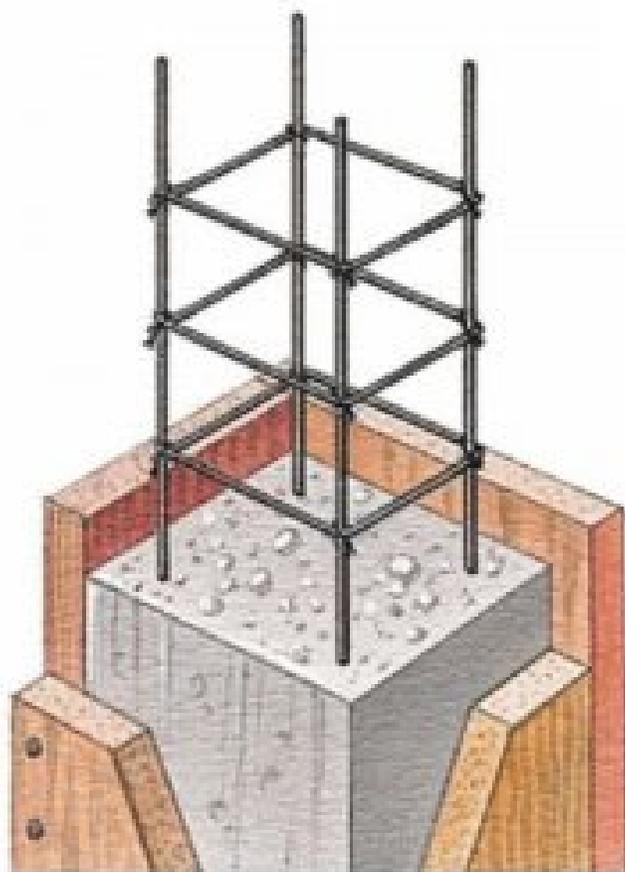
William B. Lea, MD<sup>1</sup> John C. Neilson, MD<sup>2</sup> David M. King, MD<sup>2</sup> Sean M. Tutton, MD, FSIR<sup>1</sup>

<sup>1</sup> Department of Radiology, Medical College of Wisconsin, Milwaukee, Wisconsin

<sup>2</sup> Department of Orthopaedic Surgery, Medical College of Wisconsin, Milwaukee, Wisconsin

Address for correspondence William B. Lea, MD, Division of Vascular and Interventional Radiology, Froedtert Memorial Lutheran Hospital, 9200 W. Wisconsin Avenue, Room 2803, Milwaukee, WI 53226 (e-mail: williamblea@gmail.com).

Semin Intervent Radiol 2019;36:229–240



Article

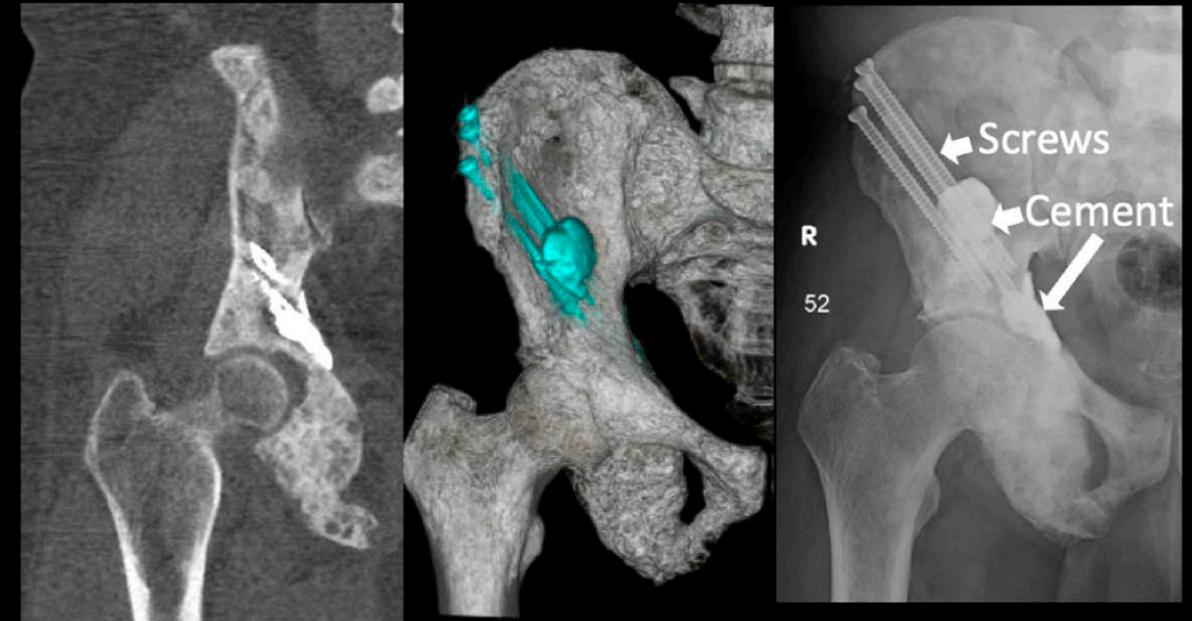
# Bone Mass Changes Following Percutaneous Radiofrequency Ablation, Osteoplasty, Reinforcement, and Internal Fixation of Periacetabular Osteolytic Metastases

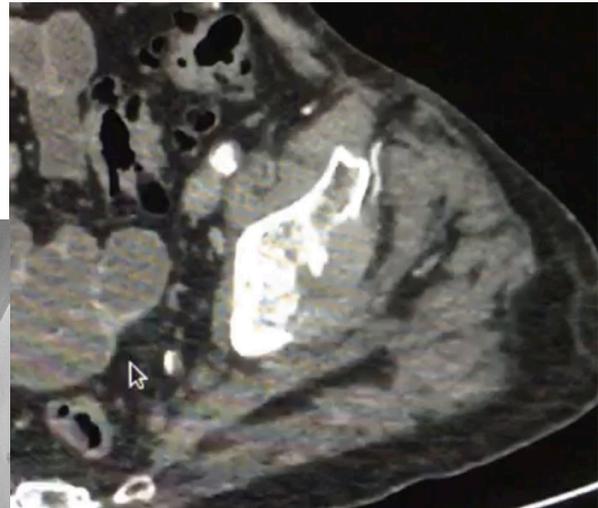
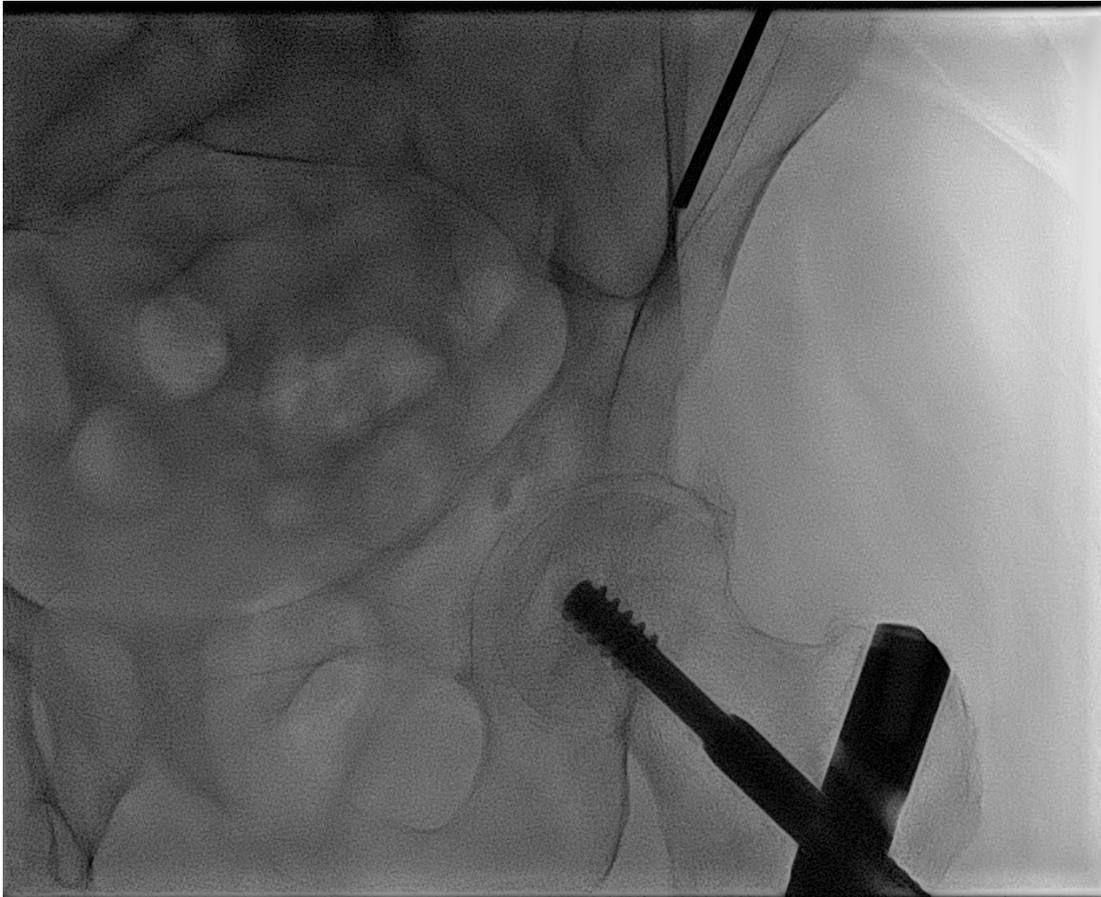
Will Jiang <sup>1</sup>, Dennis L. Caruana <sup>1</sup>, Christopher M. Dussik <sup>1</sup>, Devin Conway <sup>1</sup>, Igor Latich <sup>2</sup>, Julius Chapiro <sup>2</sup>, Dieter M. Lindskog <sup>1</sup> , Gary E. Friedlaender <sup>1</sup> and Francis Y. Lee <sup>1,\*</sup>

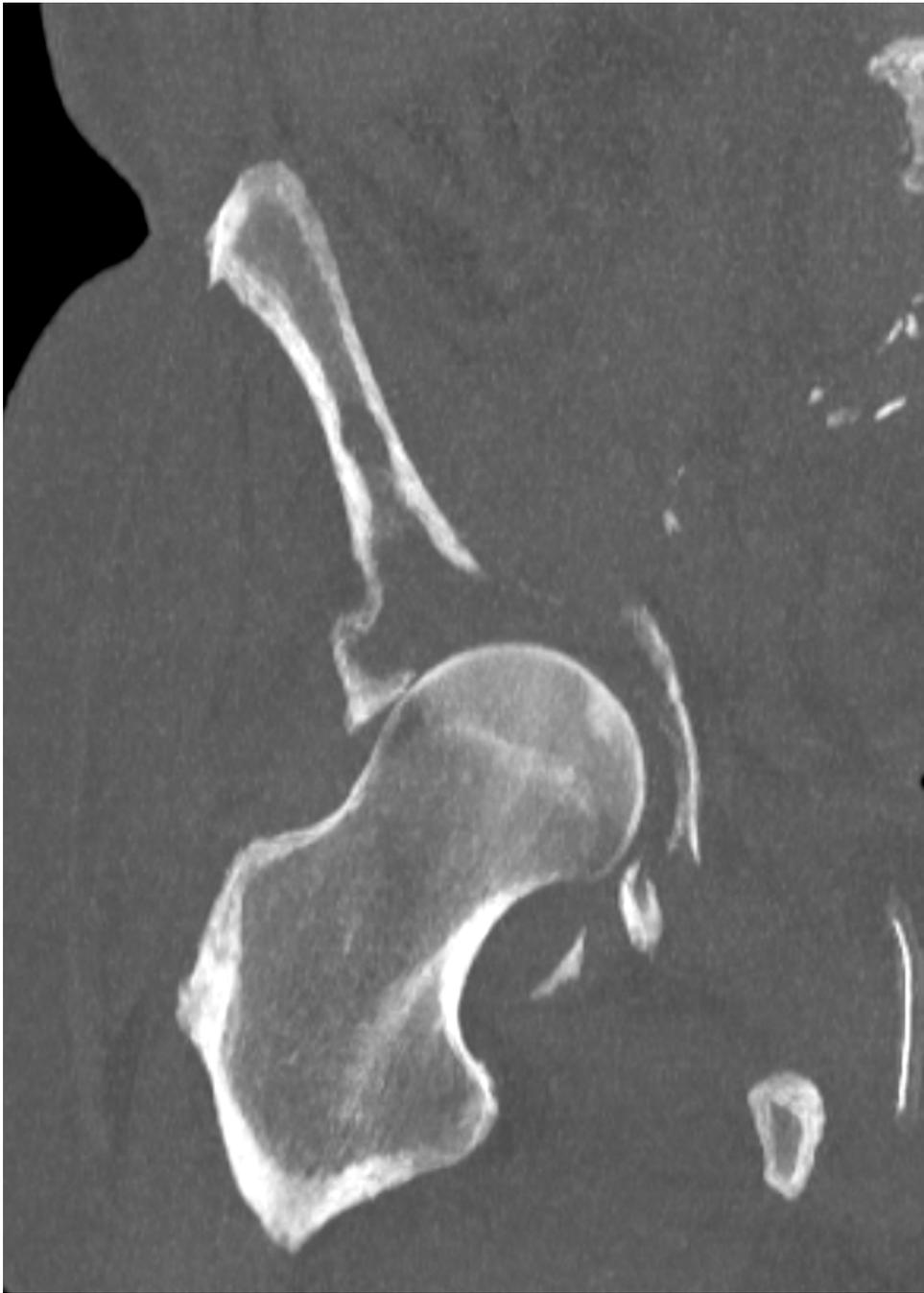
**Pre-Operative**

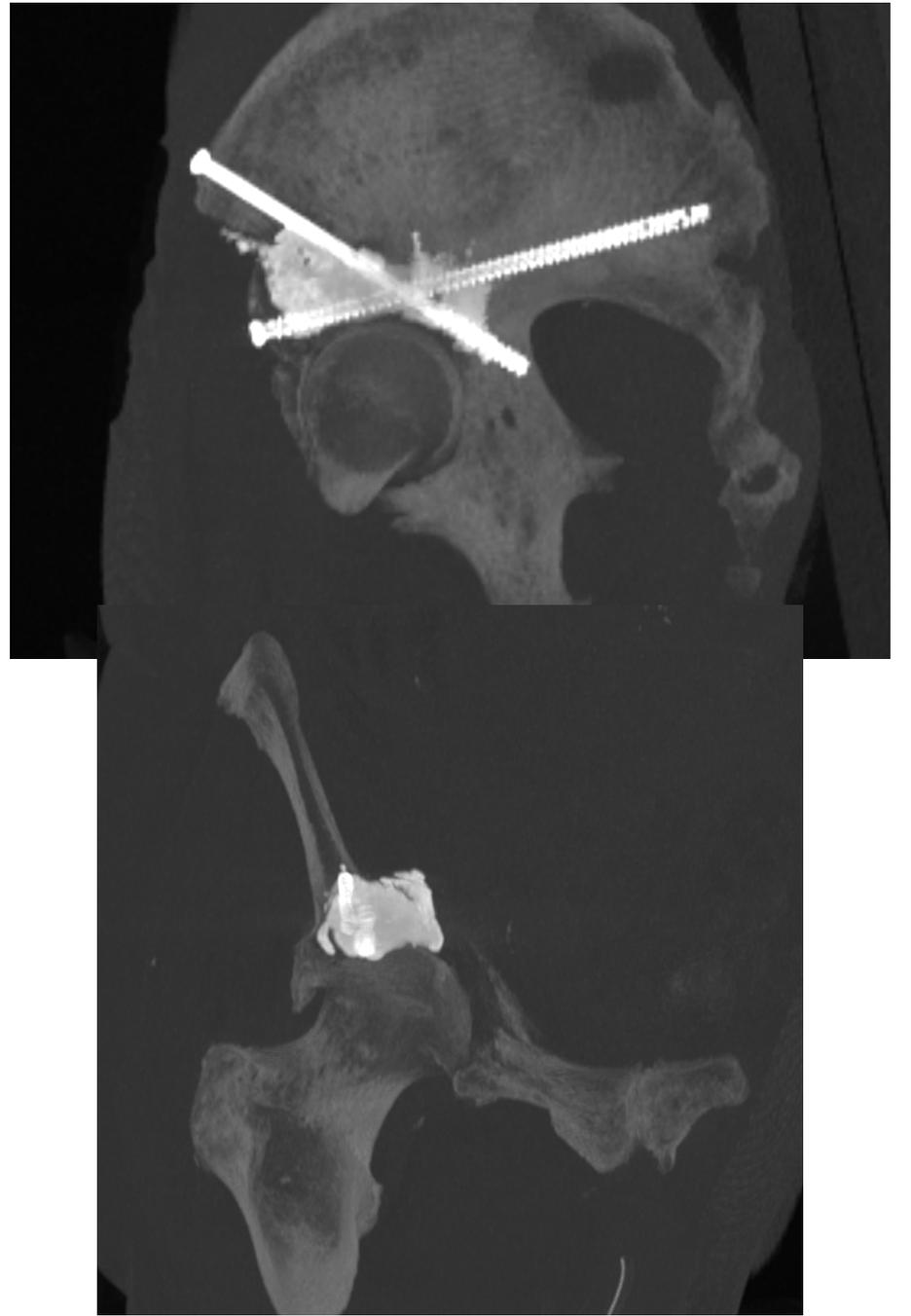


**Post-Operative**









# QUELS MODELES PRECLINIQUES?

- modèle animal: pas adapté
- difficultés techniques sur petit animal
- difficultés pour créer une simulation de tumeur
- mécanique différente de l'homme

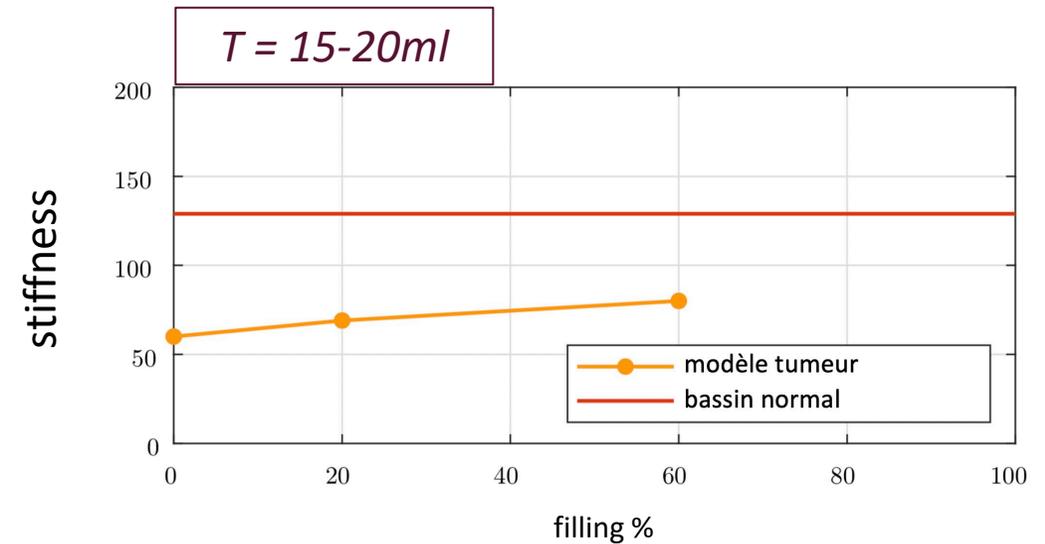
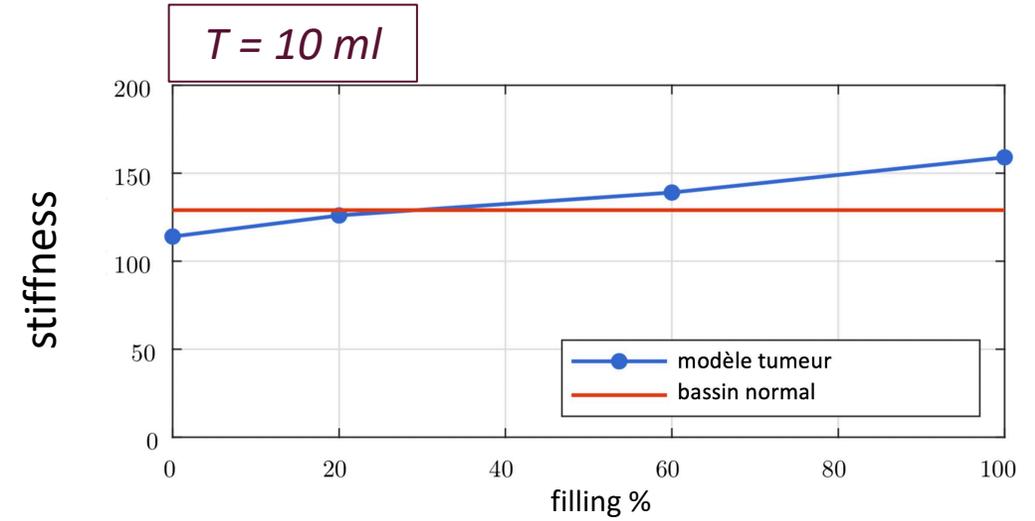
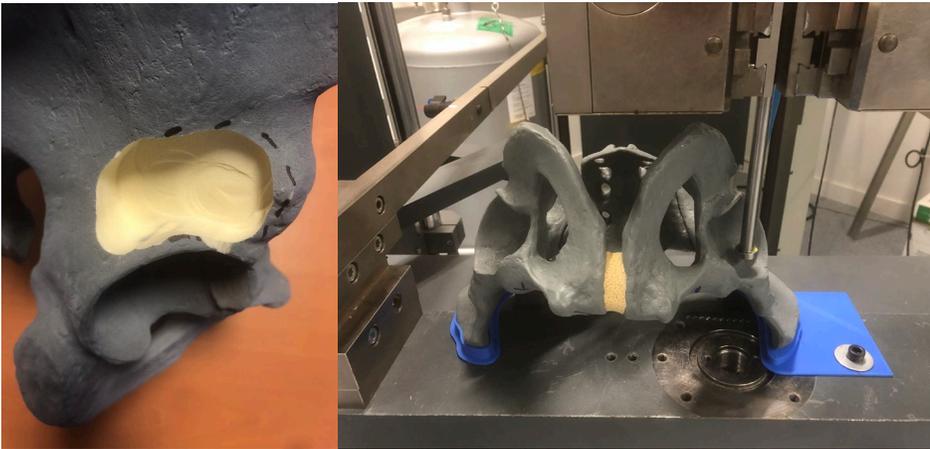
# QUELS MODELES PRECLINIQUES?

- cadavre

- difficulté d'accès
- difficultés pour créer une simulation de tumeur
- difficultés de réaliser des tests

# QUELS MODELES PRECLINIQUES?

- fantômes de bassin



# QUELS MODELES PRECLINIQUES?

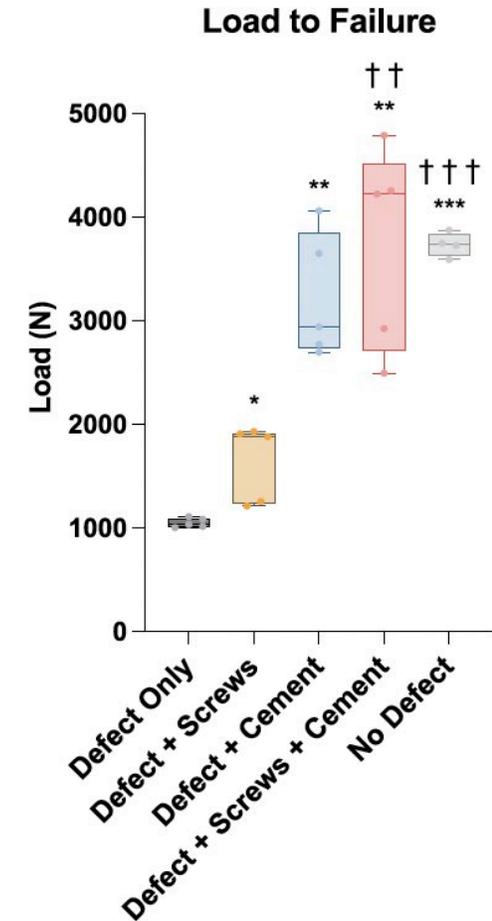
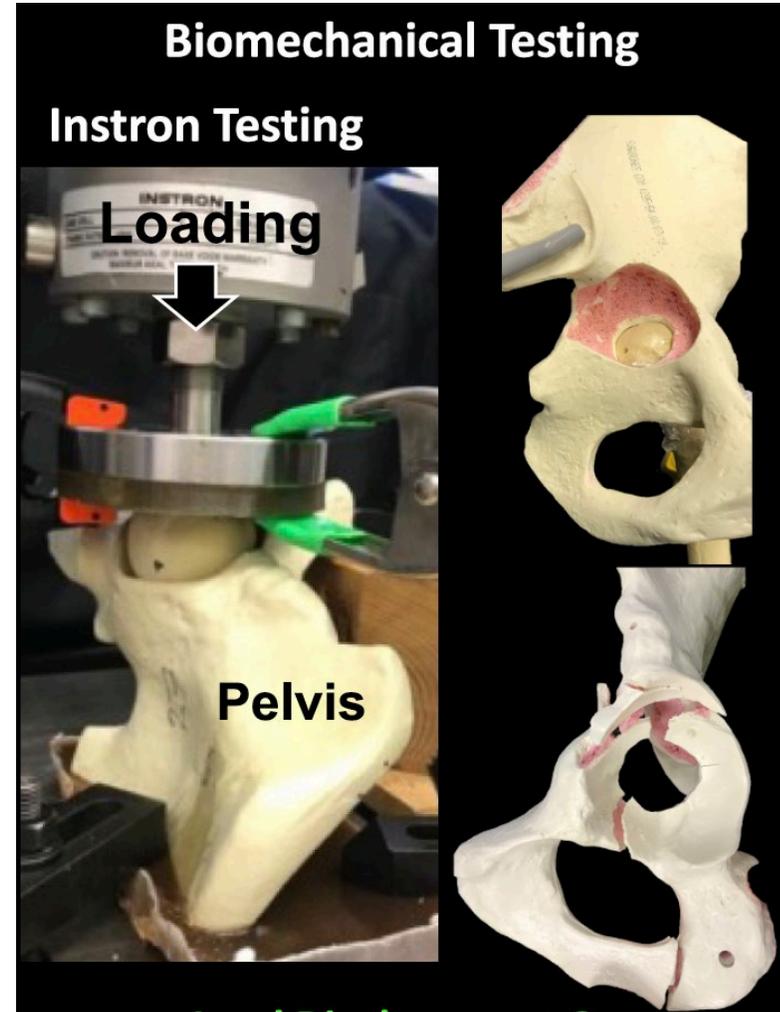
- fantômes de bassin



Original Articles

Biomechanical restoration of metastatic cancer-induced peri-acetabular bone defects by ablation-osteoplasty-reinforcement-internal fixation technique (AORIF): To screw or not to screw?

Montana T. Morris<sup>a</sup>, Kareme D. Alder<sup>a</sup>, Alexander Moushey<sup>a</sup>, Alana M. Munger<sup>a</sup>, Kenneth Milligan<sup>a</sup>, Courtney Toombs<sup>a</sup>, Devin Conway<sup>a</sup>, Inkyu Lee<sup>a,b</sup>, Fancheng Chen<sup>a</sup>, Steven M. Tommasini<sup>a</sup>, Francis Y. Lee<sup>a,\*</sup>



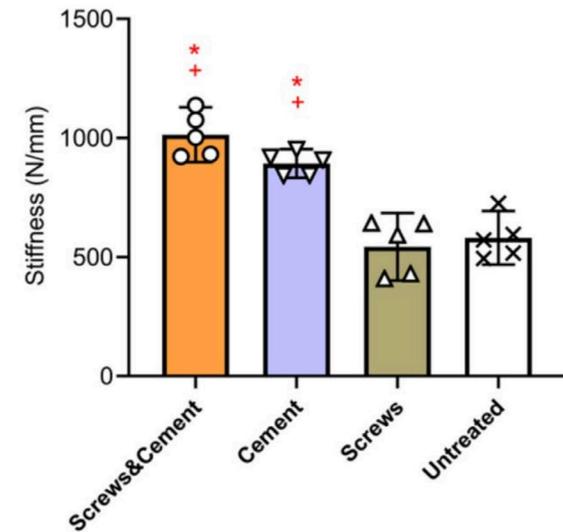
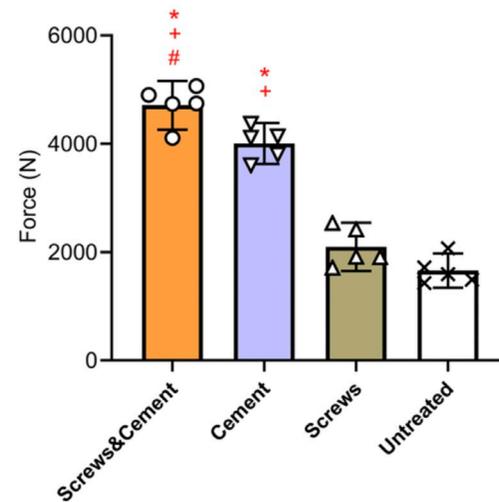
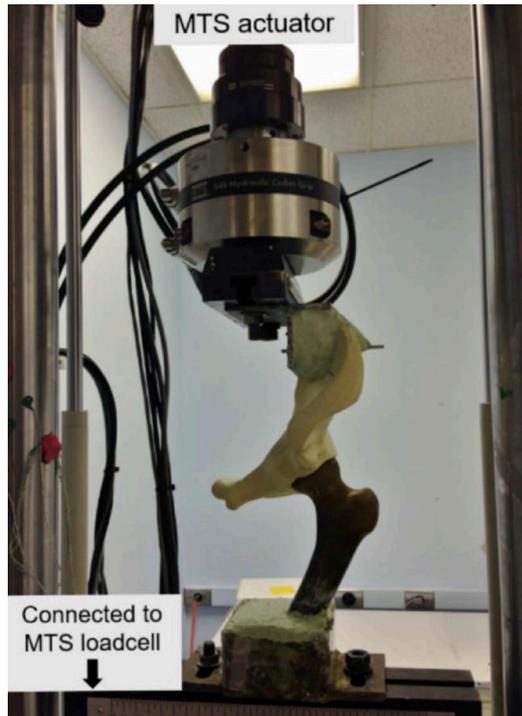
# QUELS MODELES PRECLINIQUES?

- fantômes de bassin

## Pelvis Weight-Bearing Ability after Minimally Invasive Stabilizations for Periacetabular Lesion

William B Lea<sup>1</sup>, Sean M Tutton<sup>1</sup>, Naif Alsaikhan<sup>1</sup>, John C Neilson<sup>2</sup>, Sebastian Schafer<sup>3</sup>, David M King<sup>2</sup>, Mei Wang<sup>2,4</sup>

*Journal of Orthopaedic Research*, 39(10), 2124–2129



# MODELE NUMERIQUE

Zuoping Li

Neha B. Butala

Brandon S. Etheridge

Department of Biomedical Engineering,  
University of Alabama at Birmingham,  
Hoehn 370, 1075 13th Street South,  
Birmingham, AL 35294-4440

Herrick J. Siegel

Division of Orthopaedic Surgery,  
University of Alabama at Birmingham,  
Faculty Office Tower 960,  
510 20th Street South,  
Birmingham, AL 35294-4440

Jack E. Lemons

School of Dentistry,  
University of Alabama at Birmingham,  
SDB 615, 1919 7th Avenue South,  
Birmingham, AL 35294-0007

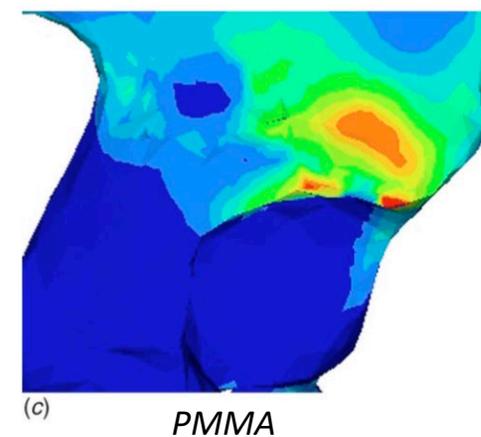
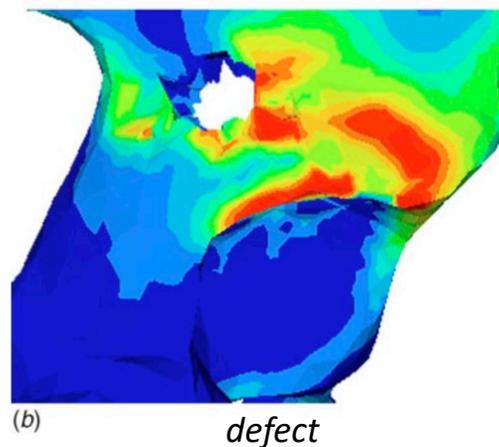
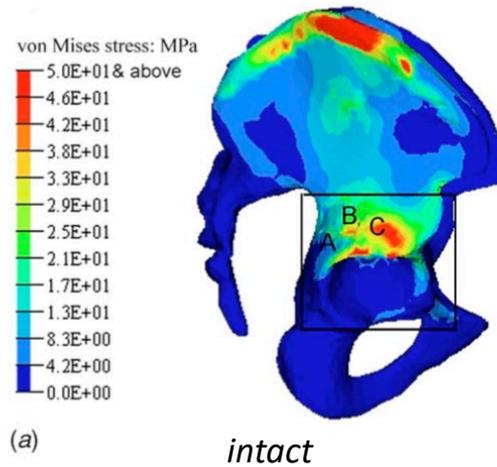
Alan W. Eberhardt

Department of Biomedical Engineering,  
University of Alabama at Birmingham,  
Hoehn 370, 1075 13th Street South,  
Birmingham, AL 35294-4440

## A Biomechanical Study of Periacetabular Defects and Cement Filling

*Periacetabular bone metastases cause severe pain and functional disability in cancer patients. Percutaneous acetabuloplasty (PCA) is a minimally invasive, image-guided procedure whereby cement is injected into lesion sites. Pain relief and functional restoration have been observed clinically; however, neither the biomechanical consequences of the lesions nor the effectiveness of the PCA technique are well understood. The objective of this study was to investigate how periacetabular lesion size, cortex involvement, and cement modulus affect pelvic bone stresses and strains under single-legged stance loading. Experiments were performed on a male cadaver pelvis under conditions of intact, periacetabular defect, and cement-filling with surface strains recorded at three strain gage locations. The experimental data were then employed to validate three-dimensional finite element models of the same pelvis, developed using computed tomography data. The models demonstrated that increases in cortical stresses were highest along the posterior column of the acetabulum, adjacent to the defect. Cortical stresses were more profoundly affected in the presence of transcortical defects, as compared to those involving only trabecular bone. Cement filling with a modulus of 2.2 GPa was shown to restore cortical stresses to near intact values, while a decrease in cement modulus due to inclusion of BaSO<sub>4</sub> reduced the restorative effect. Peak acetabular contact pressures increased less than 15% for all simulated defect conditions; however, the contact stresses were reduced to levels below intact in the presence of either cement filling. These results suggest that periacetabular defects may increase the vulnerability of the pelvis to fracture depending on size and cortical involvement and that PCA filling may lower the risk of periacetabular fractures. [DOI: 10.1115/1.2472367]*

**Keywords:** bone metastases, pelvis, finite element, percutaneous acetabuloplasty



# MODELE NUMERIQUE

## Les différentes étapes :

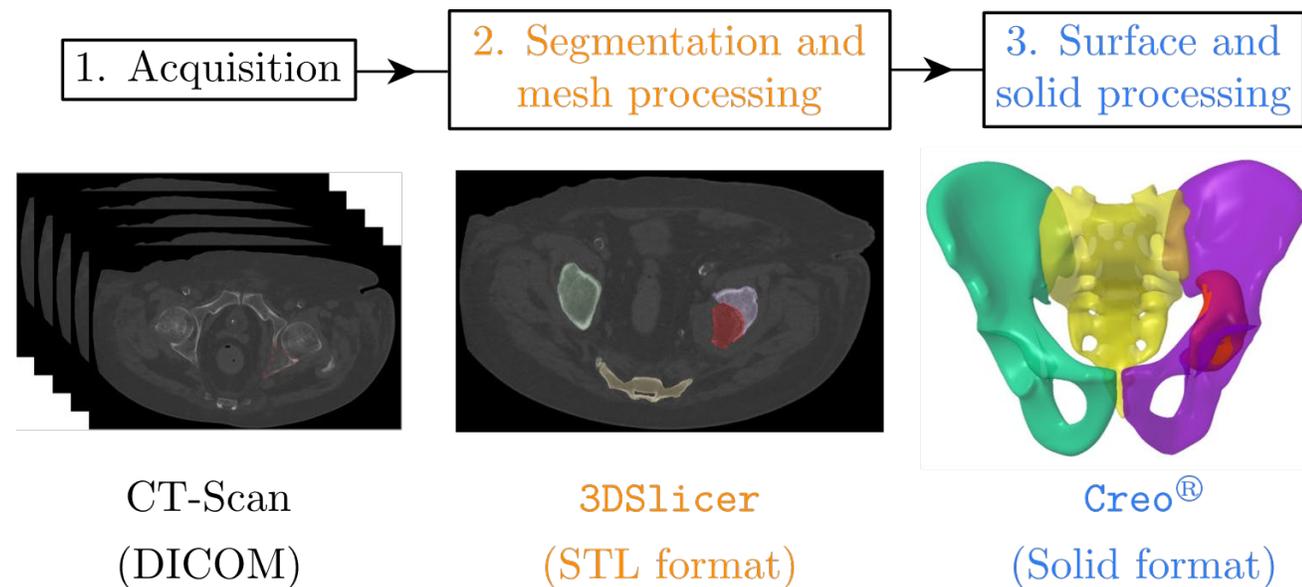
Acquisition images CT patient

Segmentation et création de l'enveloppe facétisée 3D du bassin

Détourage de la zone métastasée

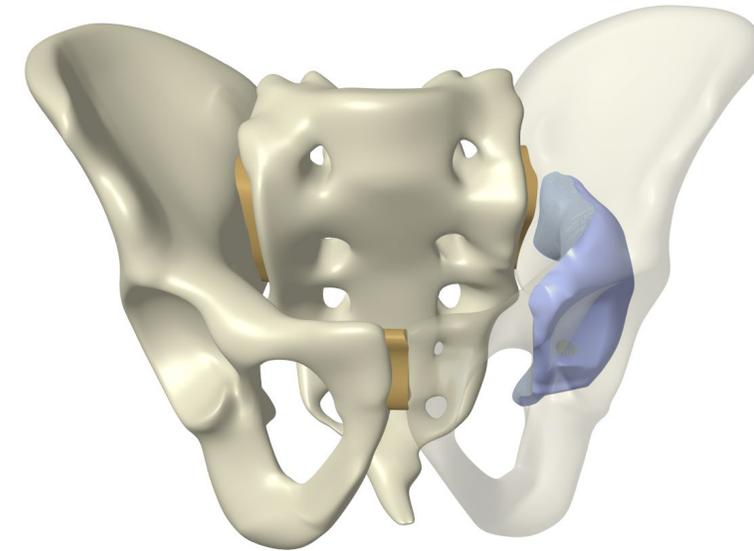
Création de l'enveloppe continue surfacique du bassin et génération 3D solide

Processus  
itératif



# MODELE NUMERIQUE

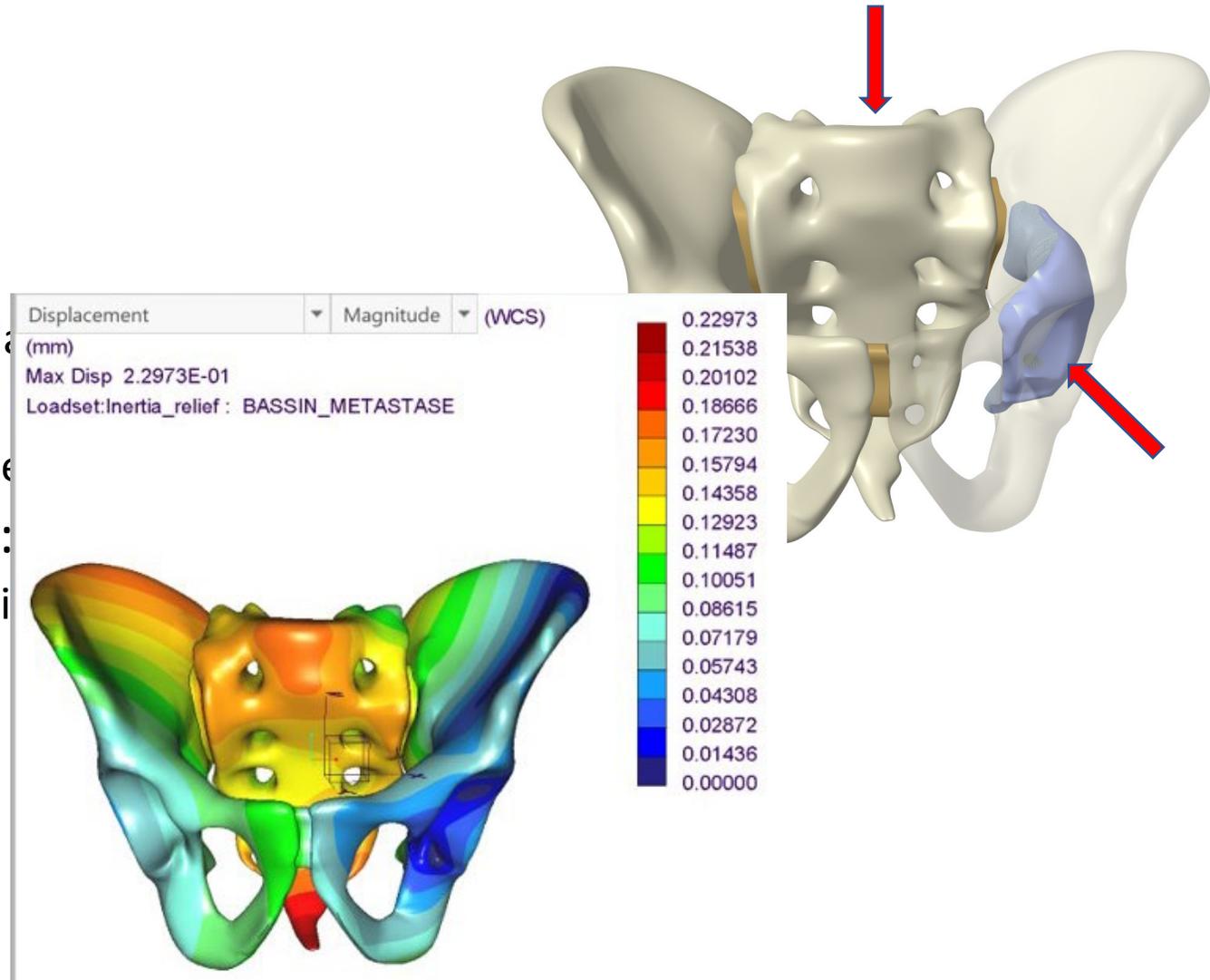
- **Les différentes étapes :**
  - Création **modèle volumique** pour le calcul
  - Création **modèle FEA** :
    - Éléments FEA :
      - coques : os cortical
      - volumiques : os trabéculaire, métastase, ciment et vis
    - Matériaux :



	Organe	Matière
Matériaux Linéaires élastiques isotropes	Sacrum	Os cortical : $E=18 \text{ GPa}$ $\nu=0,3$
	Aile iliaque gauche	Os trabéculaire : $E=150 \text{ MPa}$ $\nu=0,2$
	Aile iliaque droite	<b>Os métastasé : <math>E=50 \text{ MPa}</math> (30% de la rigidité initiale) <math>\nu=0,2</math></b>
	Symphyse	Articulation : $E=150 \text{ MPa}$ $\nu=0,3$
	Articulation sacro-iliaque	
	Ciment	$E = 2 \text{ GPa}$ $\nu=0,3$

# MODELE NUMERIQUE

- Les différentes étapes :
  - Création **modèle FEA** :
    - Conditions Limites : marche unipodale
    - Recherche équilibre statique
    - Résultats : déplacements, contraintes
  - Comparaison différents modèles :
    - sain, métastasé sans ciment, avec ciment



# MODELE NUMERIQUE

=> Simulation de la restauration mécanique en cimentoplastie

- **Objectifs :**

- **Quantifier** les options de restauration mécanique d'un bassin métastasé par simulation numérique
- Etablir des modèles **patient-spécifique**
- Fournir une **aide à la décision** pré-opératoire

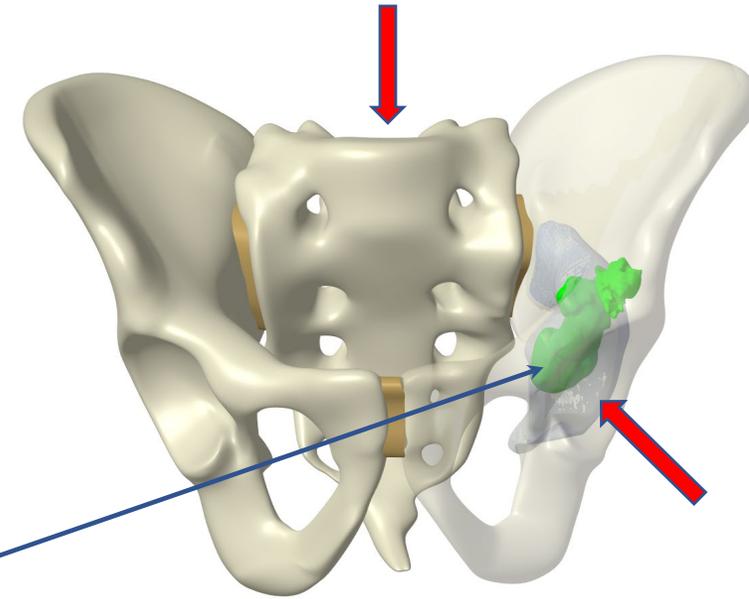
- **Méthodes :**

- **Segmentation** images pré-opératoires
- Modèle numérique :
  - **3D** bassin -> ailes, sacrum, zone métastasée
  - **FEA** -> modélisation marche unipodale : influence du volume de ciment, nombre et placement vis

# MODELE NUMERIQUE

**Cas clinique étudié : métastase cotyle**

Résultats **sans vis**:



	Sain	Métastasé	Ciment réel	Ciment full
Déplacement max (mm)	0.23	0.31	0.30	0.25

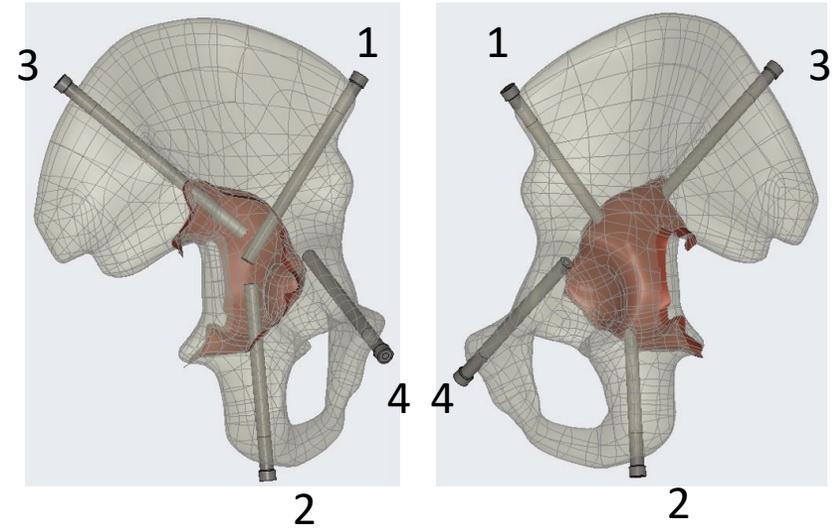


- Baisse de 35 % de la rigidité
- Restauration à 90 % si le volume de ciment max, mais pas possible
- Si pas d'atteinte corticale = bassin sain

# MODELE NUMERIQUE

- Résultats **avec** vis:

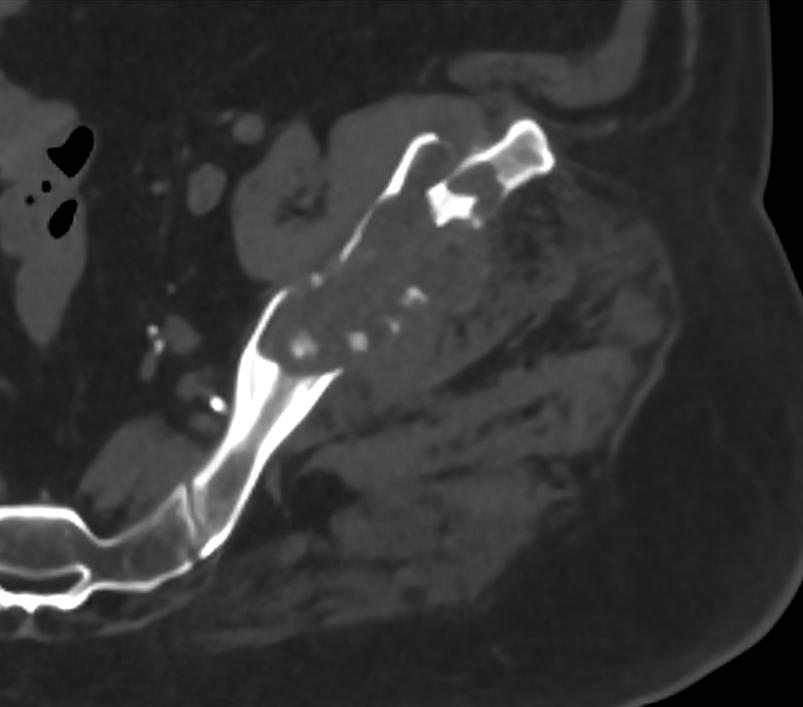
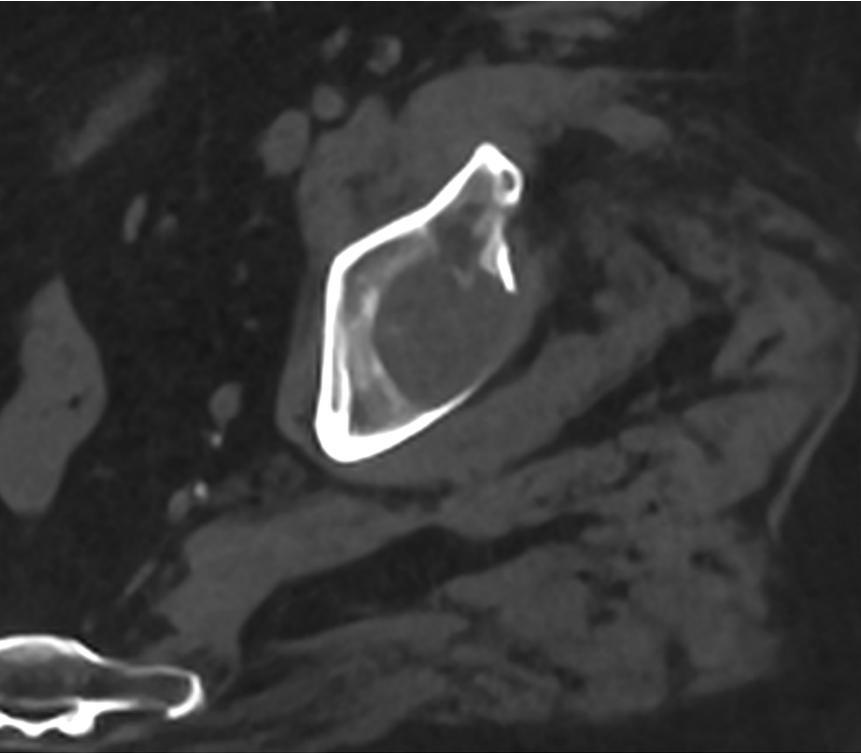
Sans Ciment	1	2	3	4
Déplacement max (mm)	0.30	0.27	0.29	0.31
Avec Ciment	1	2	3	4
Déplacement max (mm)	0.25	0.25	0.25	0.25



- Meilleur placement sans ciment (2), restauration = 83 %
- Si présence de ciment, restauration équivalente à 90%



- Permet de quantifier la restauration de différents scénarios
- Influence de l'épaisseur de l'os cortical, de l'anisotropie de l'os trabéculaire?
- Etudier d'autres cas cliniques



CREO Simulate

	Pièces étudiées	Matière
Matériaux Linéaires élastiques isotropes	Sacrum	Os cortical : E=18 GPa v= 0,3
	Aile iliaque gauche	Os trabéculaire : E=150 MPa v=0,2
	Aile iliaque droite	<b>Os métastasé : E=50 MPa (30% de la rigidité initiale) v =0,2</b>
	Symphyse	Articulation : E=150 MPa v=0,3
	Articulation sacro-iliaque	
	Ciment	E = 2 GPa v= 0,3 (PFE Cécile)

Os trabéculaire : solides ailes et sacrum

**Os cortical : épaisseur corticale 3D réelle**

Idéalisations

**Articulation sacro-iliaque et symphyse pubienne : solides idéalisées**

**Métastase : volume region**

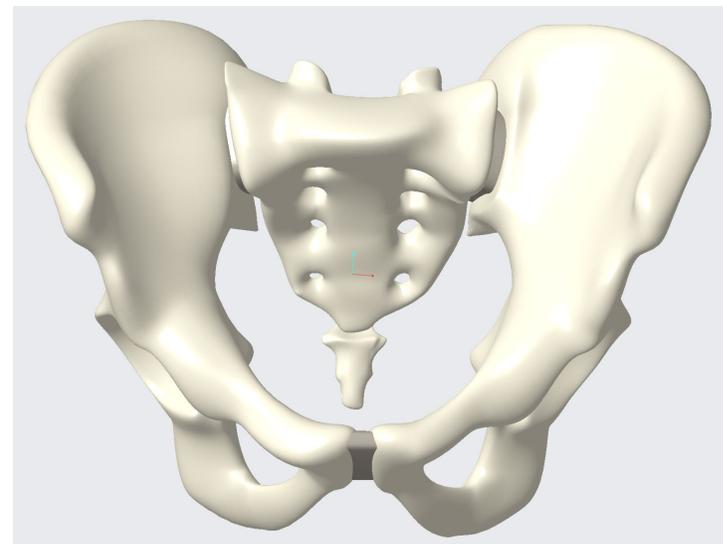
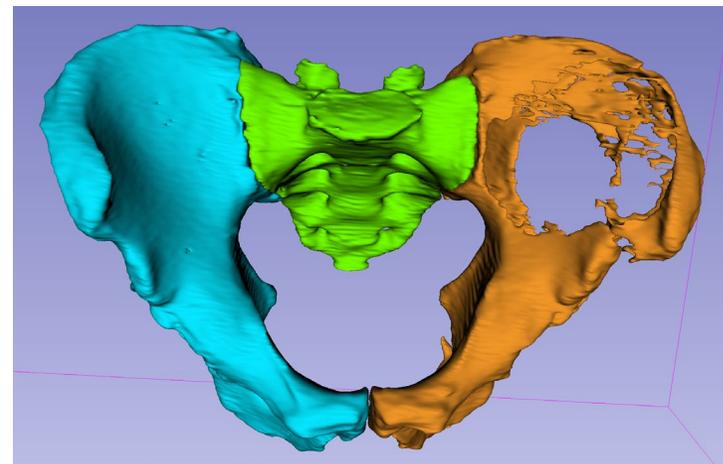
**Ciment : volume region**

Contraintes

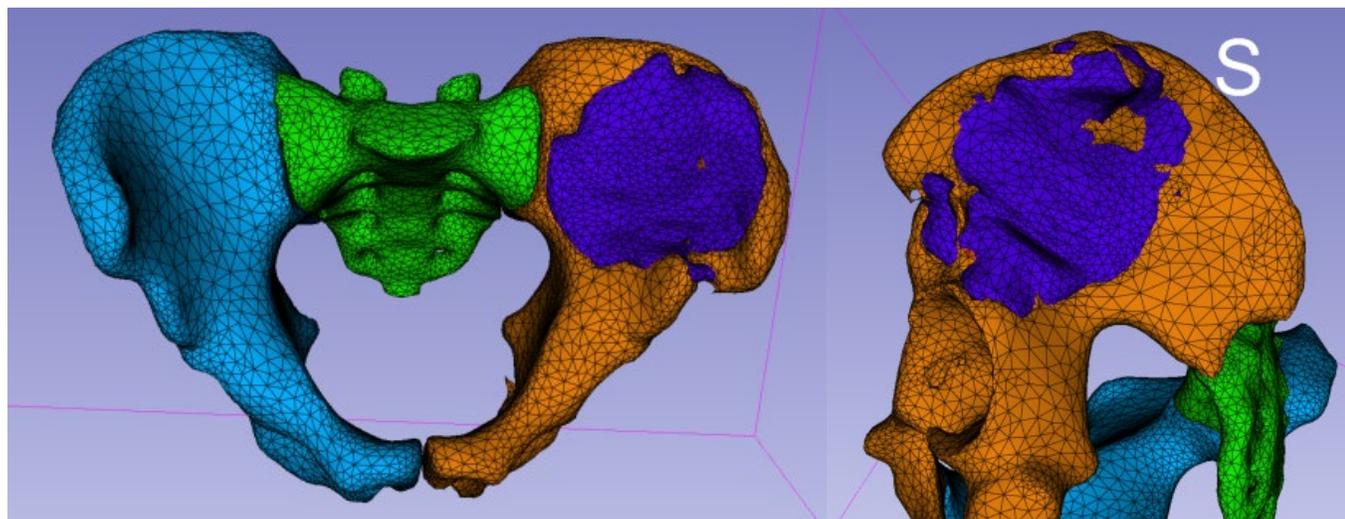
**Force de 1000N sur le promontoire sacral**  
**Force de 1000N dans l'acetabulum**

Type d'analyse

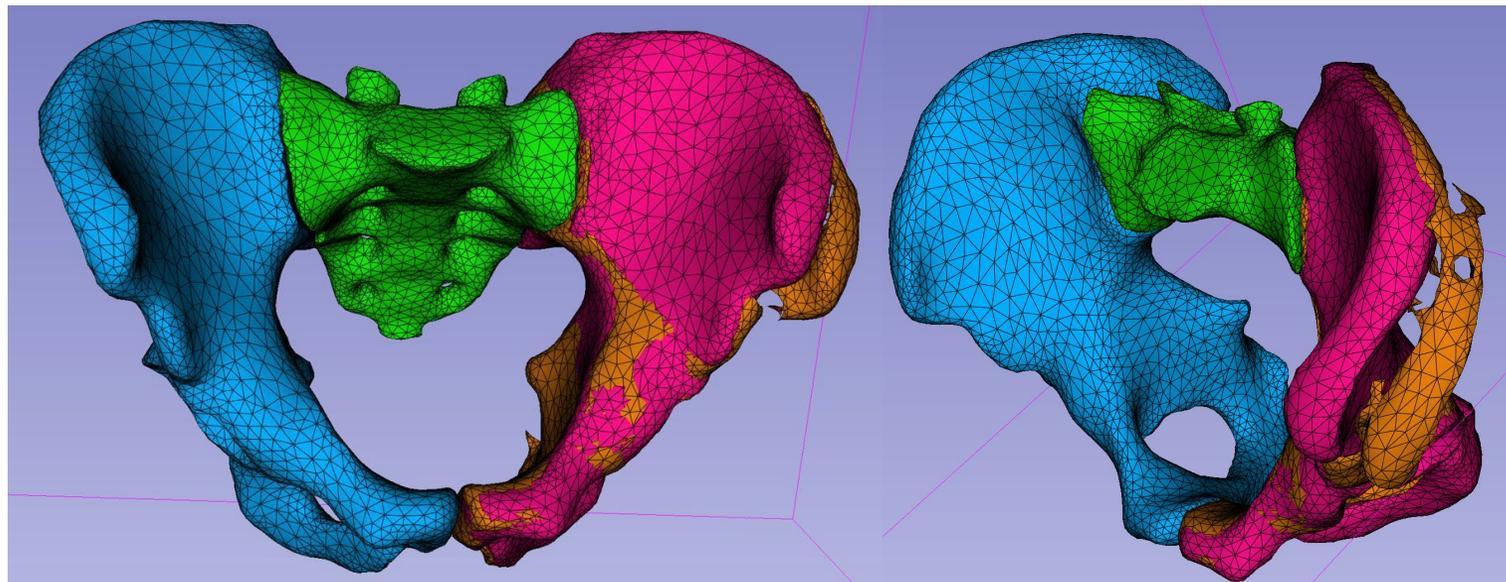
Linéaire



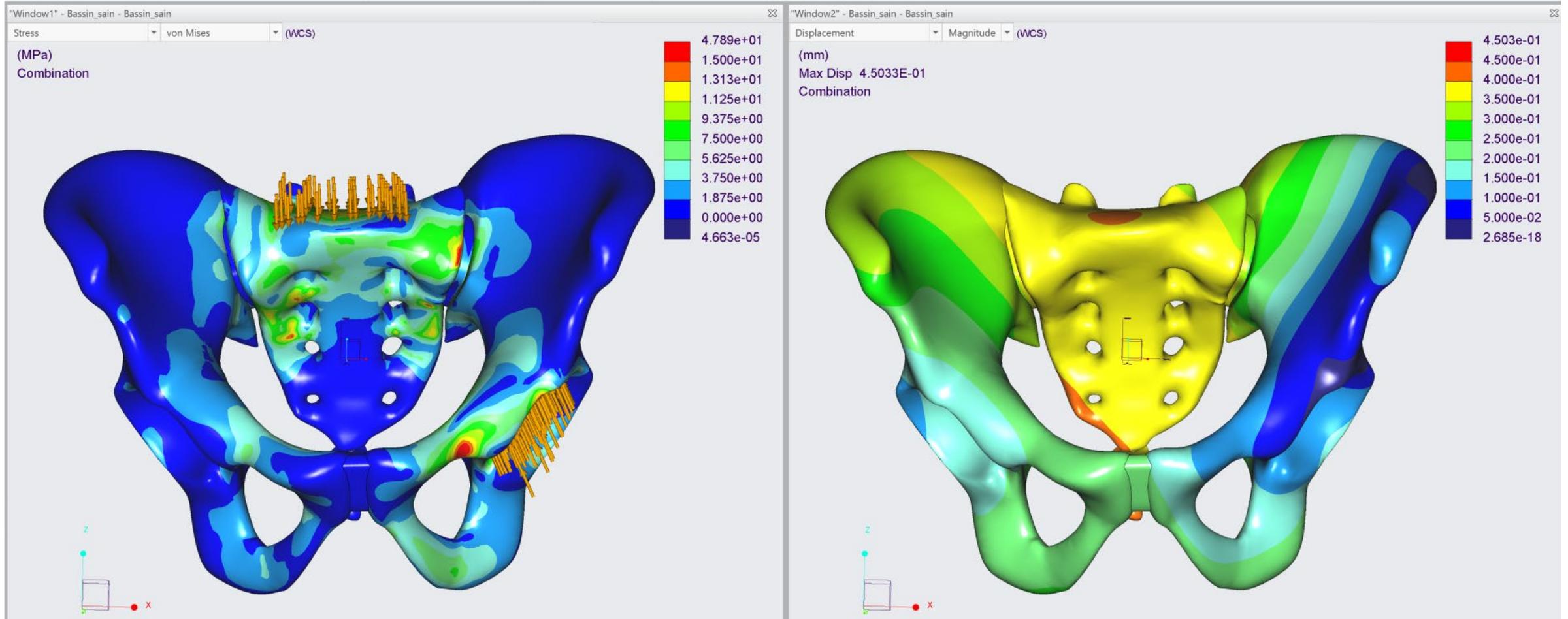
- **Bassin malade** : segmentation de la métastase



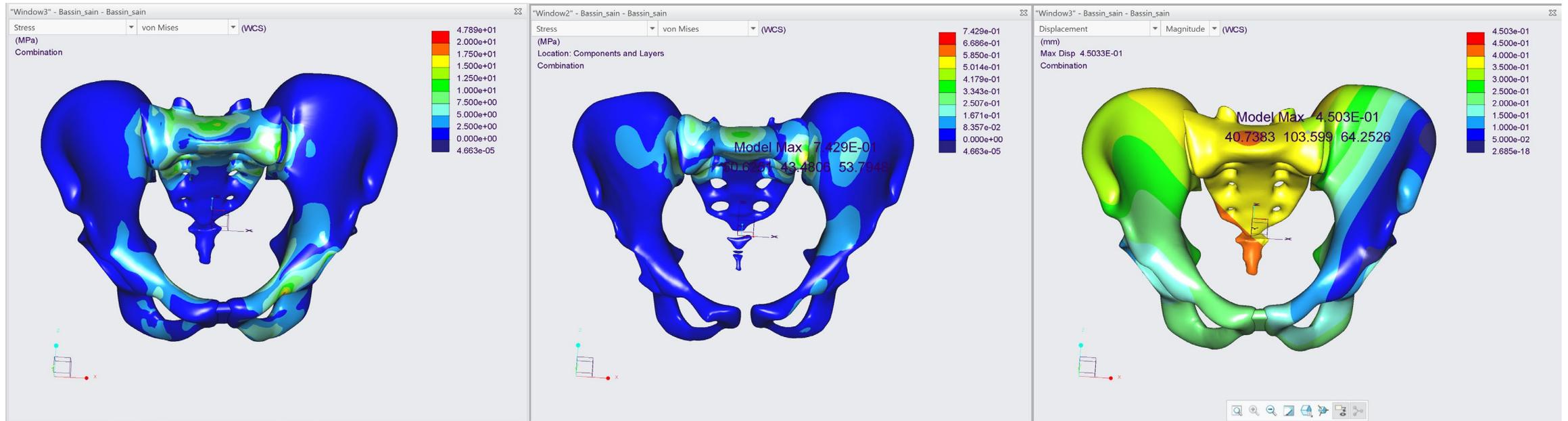
- **Bassin sain** : miroir de l'aile opposée puis recalage



# Simulation sur bassin sain



# Simulation sur bassin sain



Déplacement max  
[ mm ]

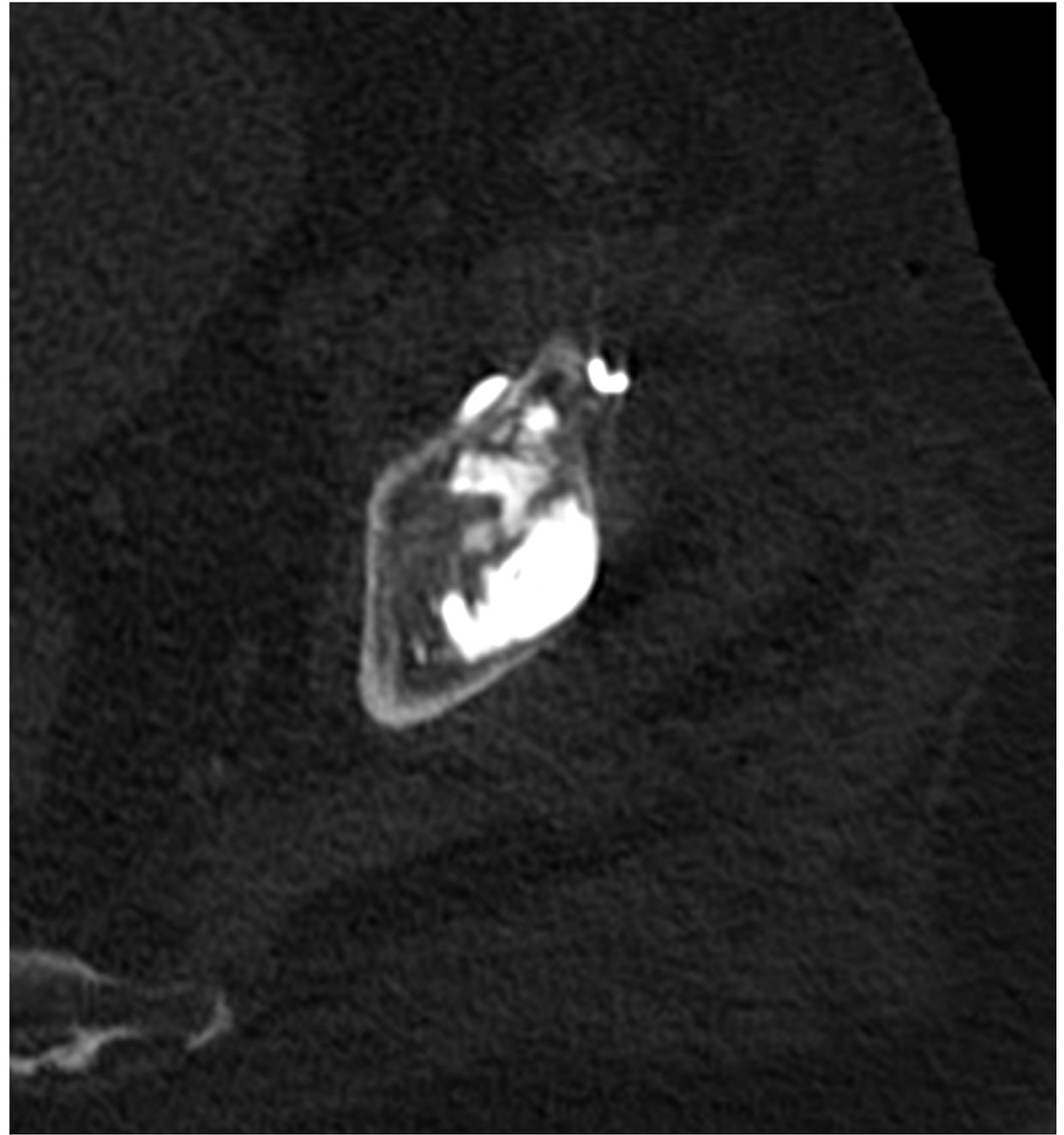
Contrainte max bassin  
[ MPa ]

Contrainte max os trabéculaire [MPa]

0.45

47.89

0.74



# OBJECTIFS

<b>Etudes</b>	A Biomechanical Study of Periacetabular Defects and Cement Filling Li et al 2006	Biomechanical restoration of metastatic cancer-induced peri-acetabular bone defects by ablation-osteoplasty-reinforcement-internal fixation technique (AORIF): To screw or not to screw? Montana et al. 2022	Notre démarche
<b>Bassin étudié</b>	Cadavre humain sans pathologies	Sawbones	Patient pathologique
<b>Type de lésion</b>	Trou créé par un chirurgien expérimenté avec une dremmel	Trou créé par un bras robotique	Métastase réelle
<b>Remplissage de la lésion</b>	100 % de ciment	100% de ciment	≠ % de remplissage (notamment avec le ciment réellement injecté)
<b>Vis</b>	Pas de vis	2 vis dans une seule configuration	≠ configuration et nombre de vis

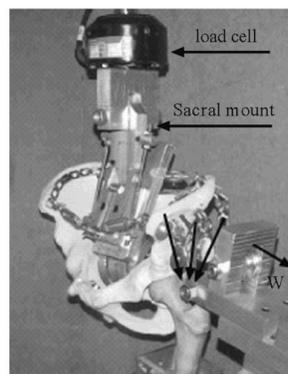
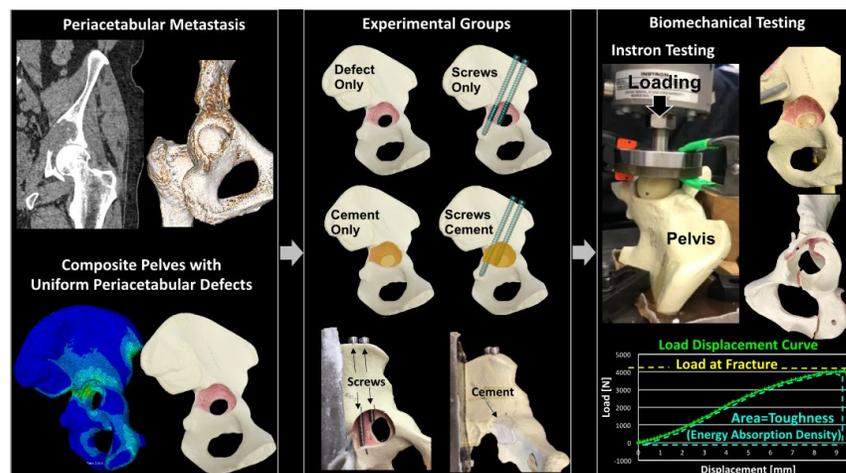
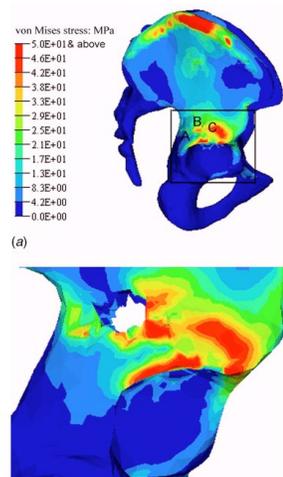
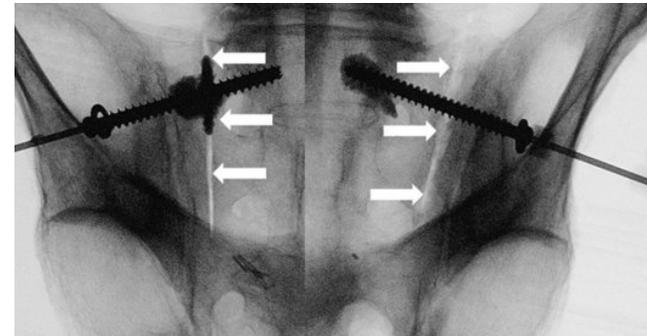
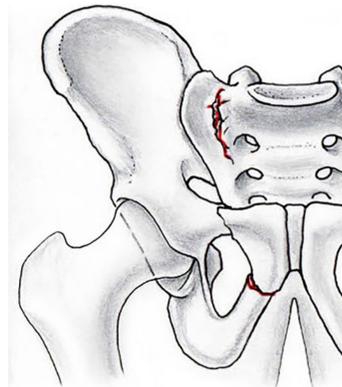
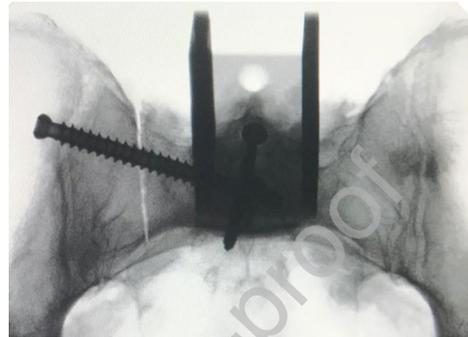
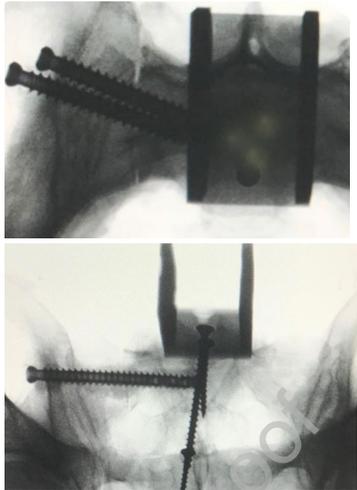


Fig. 3 Experimental apparatus for simulating the pelvis in single-legged stance loading (plastic model shown). The pelvis was connected to the load cell through the sacrum via the sacral mount. Abductor forces (three arrows) were generated with a pulley system and hanging weight W.



# OBJECTIFS

<b>Etudes</b>	Biomechanical stability of sacroiliac screw osteosynthesis with and without cement augmentation  Suero <i>et al.</i> 2021	The ideal site of cement application in cement augmented sacroiliac screw fixation: the biomechanical perspective  Albers <i>et al.</i> 2022	<b>Notre démarche</b>
<b>Bassin étudié</b>	Cadavre humain sans pathologies	Cadavre humain sans pathologies	<b>Patient pathologique</b>
<b>Type de lésion</b>	Scie oscillante sous CT Scan	Scie à ruban manuelle et scie à métaux	<b>Métastase réelle</b>
<b>Remplissage de la lésion</b>	2 techniques d'injection : en bout et au milieu de la vis  2 à 3 ml de ciment	10 ml de ciment	<b>≠ % de remplissage (notamment avec le ciment réellement injecté)</b>
<b>Vis</b>	3 configurations : 1 vis 2 vis 1 vis cimentée	1 vis	<b>≠ configuration et nombre de vis</b>



# LIMITES

- nombreuses structures non étudiées: tendons, ligaments, cartilage...
- simulation approximative d'appui monopodal
- pas d'étude dynamique