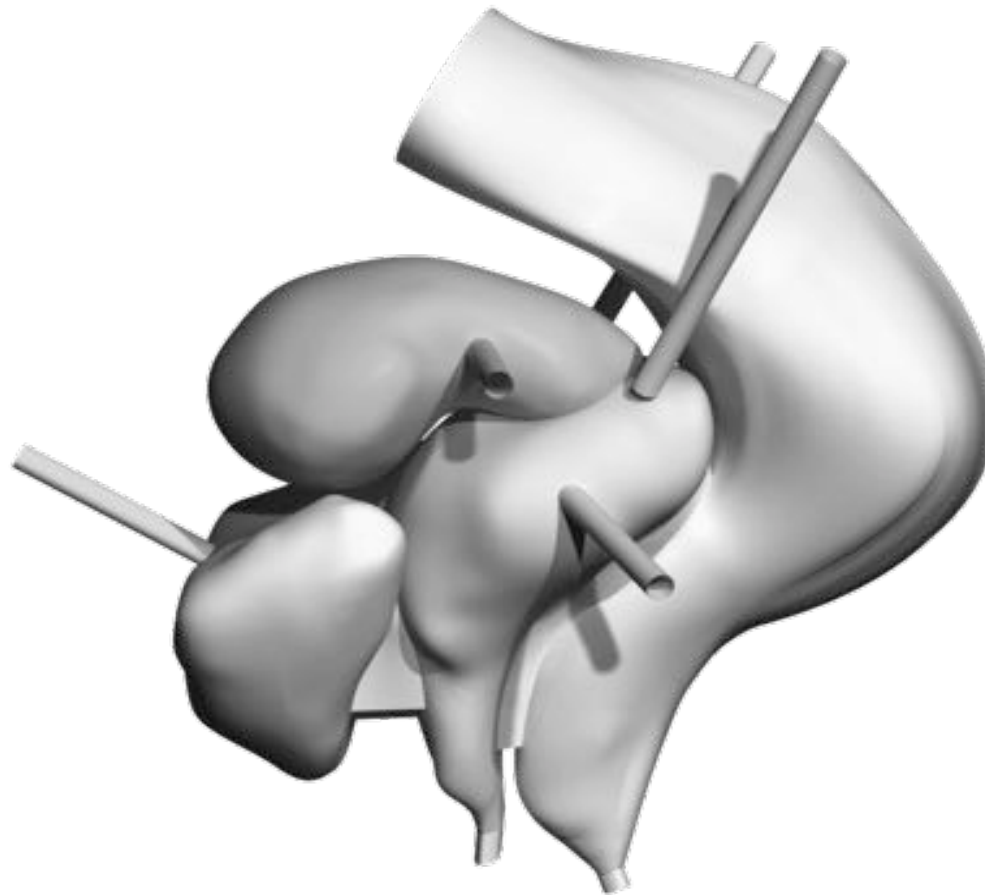


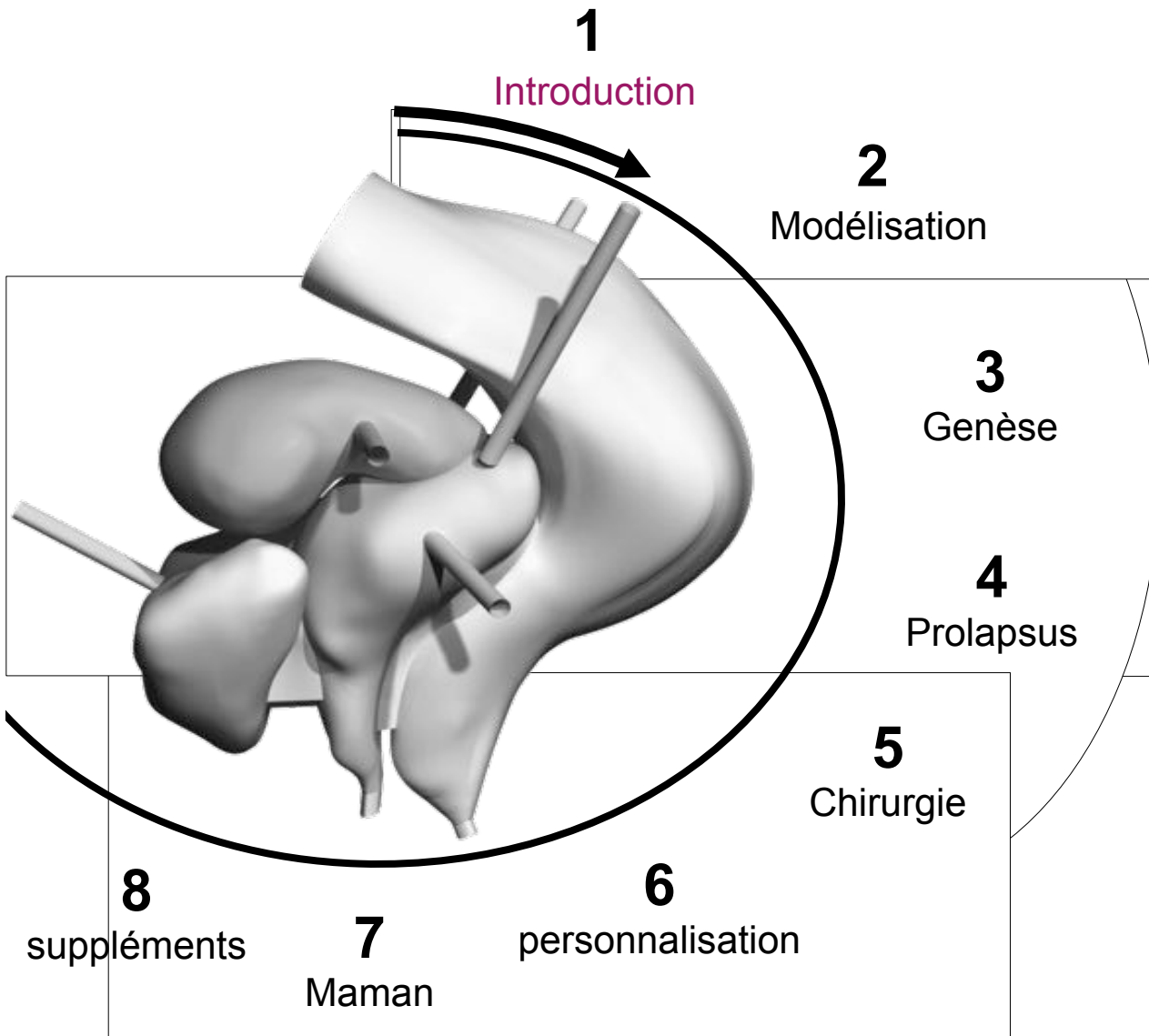


ReClip UE3 - Vendredi 07 novembre 2014 – 17h00/18h00
Applications des modèles biomécaniques pelviens
P. Michel COSSON, **Olivier MAYEUR**





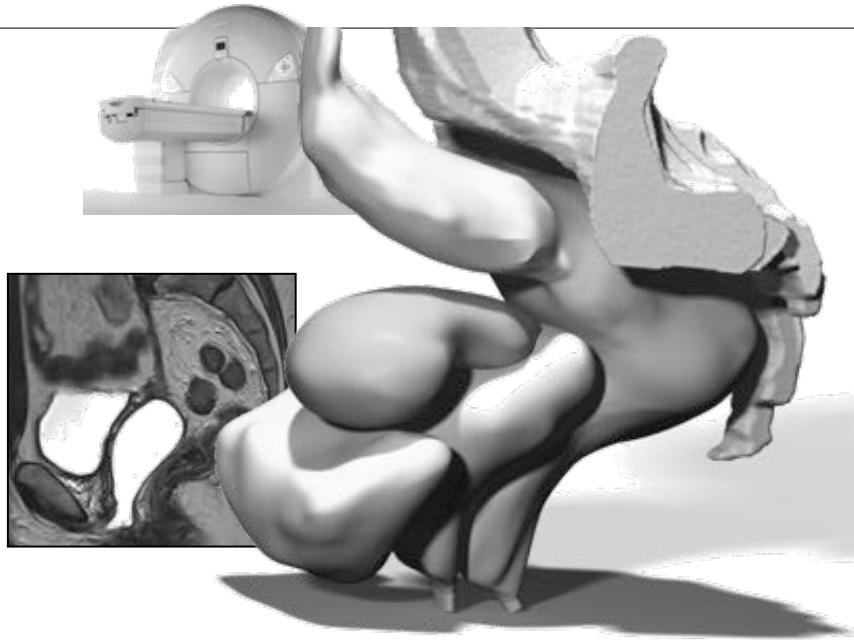
ReClip UE3 - Vendredi 07 novembre 2014 – 17h00/18h00
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Introduction

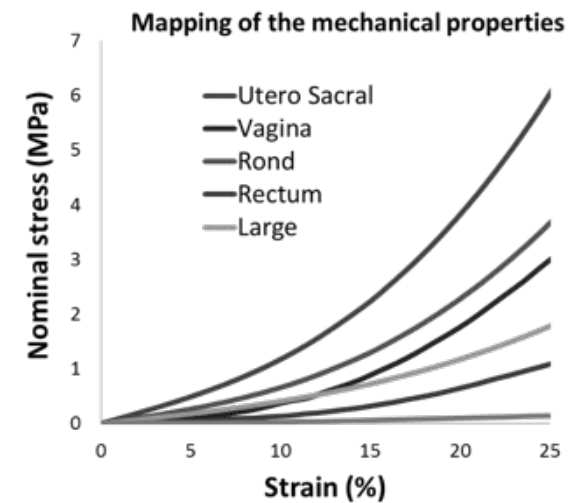
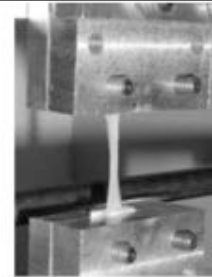
To make biofidelic model, we need to characterize the organs following two aspects:

Geometrical characterization
representative model of the pelvic system



Cours de Laurent PATROUX

Mechanical behavior
Experimental test of soft tissues

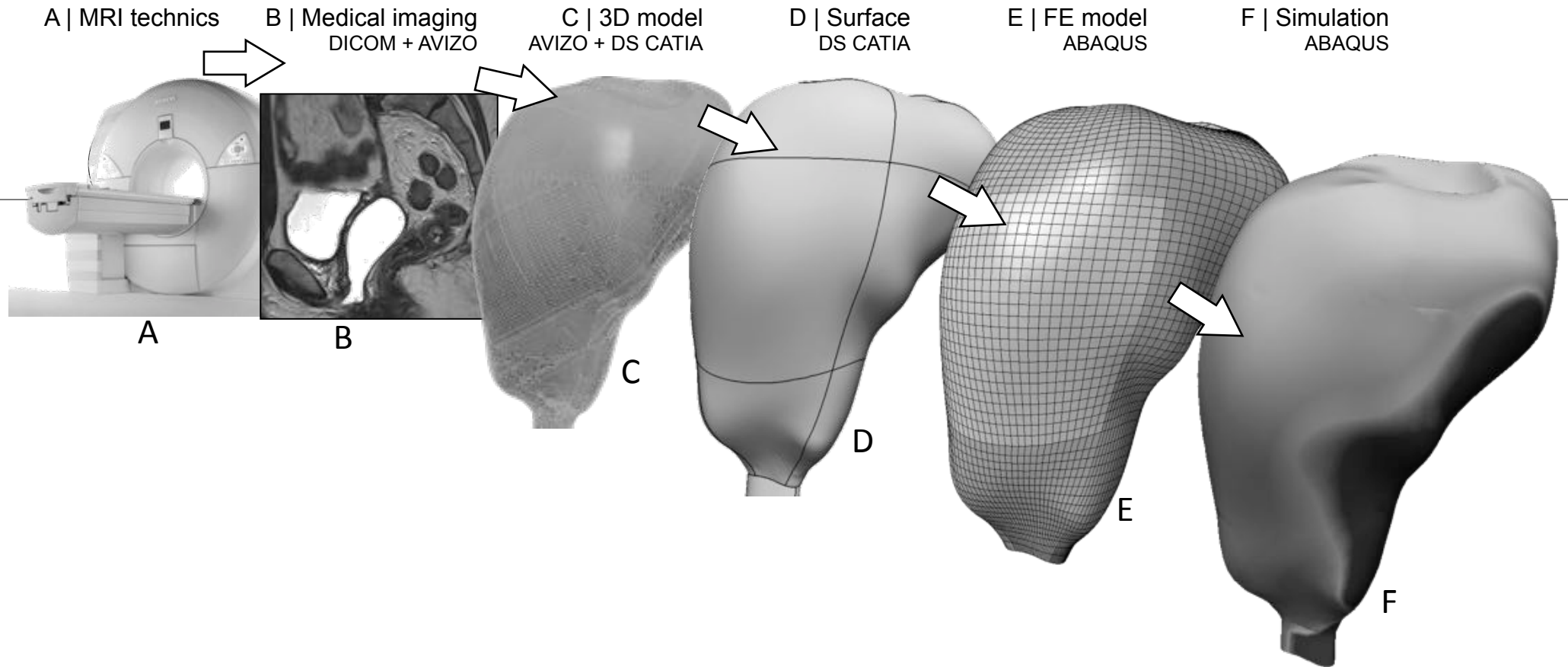


Cours du Prof. Mathias BRIEU

1 Introduction

Etapes de modélisation (Application sur le vagin)

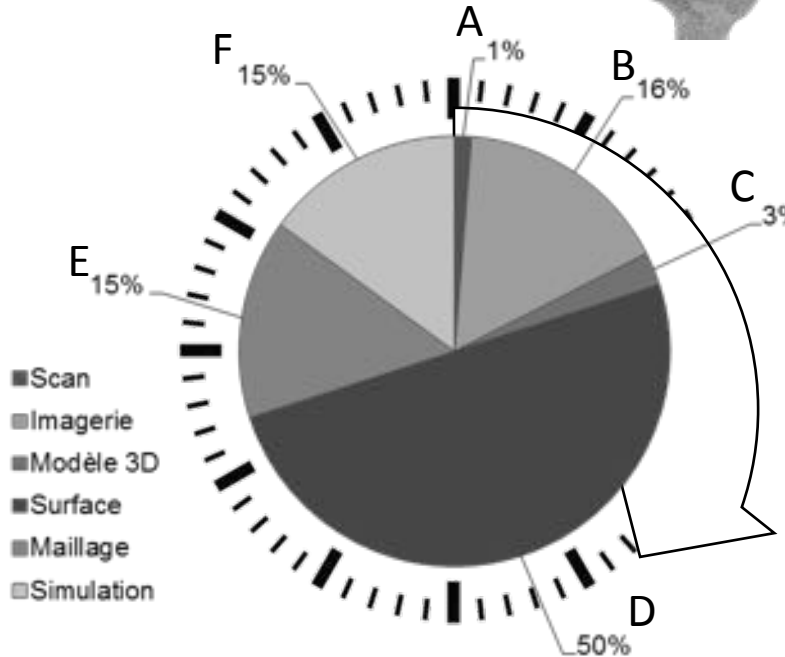
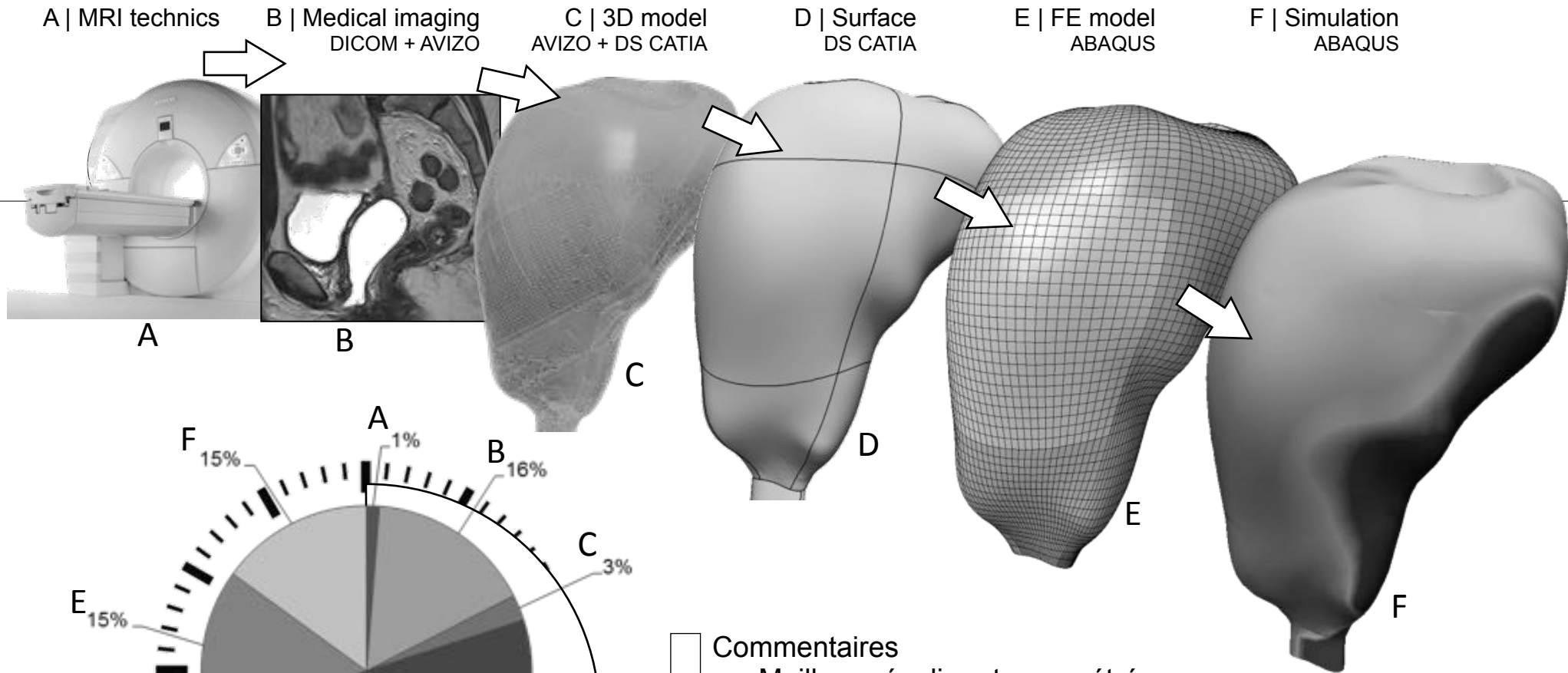
La modélisation EF du corps humain suit une démarche ordonnée comprenant plusieurs étapes:



1 Introduction

Etapes de modélisation (Application sur le vagin)

La modélisation EF du corps humain suit une démarche ordonnée comprenant plusieurs étapes:



- Commentaires
- Maillage régulier et paramétré
 - Garantir la convergence du calcul numérique
 - Chronophage
 - Protocole rigoureux, technique et complexe

1 Introduction

Etapes de modélisation (Application sur le vagin)

B | Medical imaging
DICOM + AVIZO

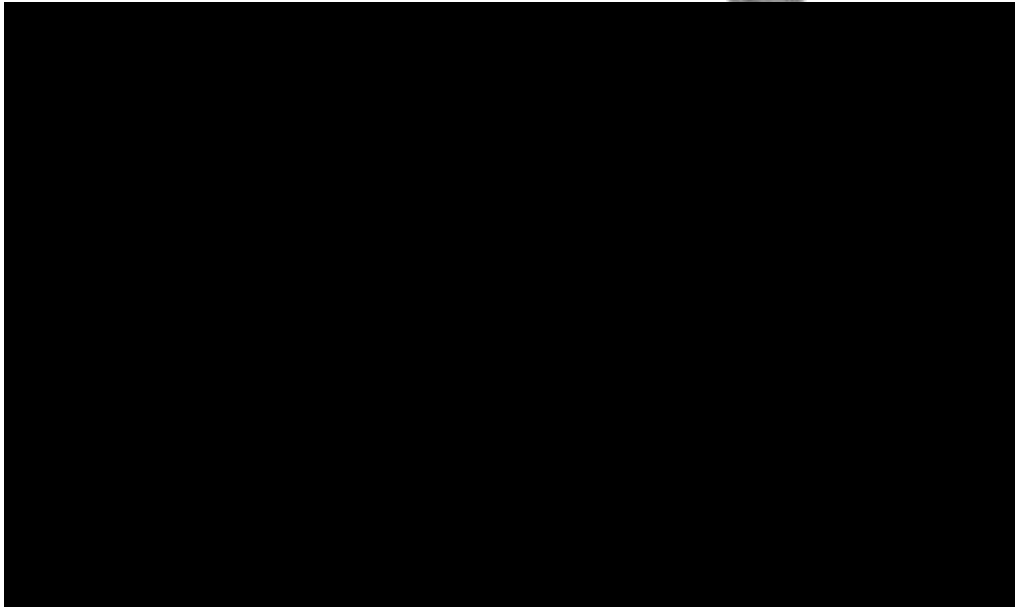


C | 3D model
AVIZO



A retenir

- Méthode manuelle = Chronophage
- Patiente unique
- Représentation géométrique mais inutilisable en EF



Autres outils et développements en cours

Pour diminuer le temps de réalisation, 2 possibilités:

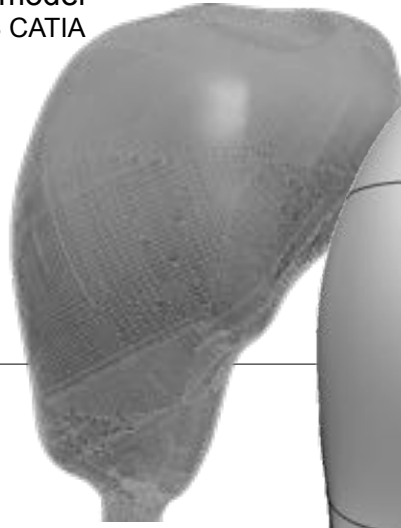
- 1- Sélection automatique (cf. cours du Pr. BRIEU)
- 2- Modèle personnalisé (Cf. partie 6 du cours)

Prendre des informations localisées sur IRM pour piloter un modèle générique
= personnalisation, morphing, paramétrage...

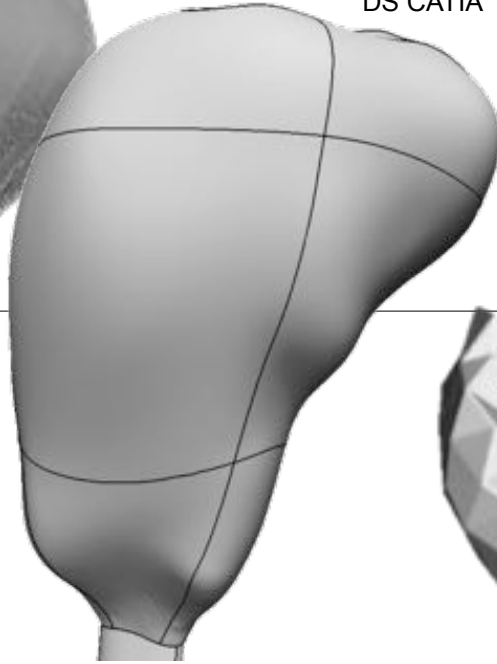
1 Introduction

Etapes de modélisation (Application sur le vagin)

C | 3D model
AVIZO + DS CATIA

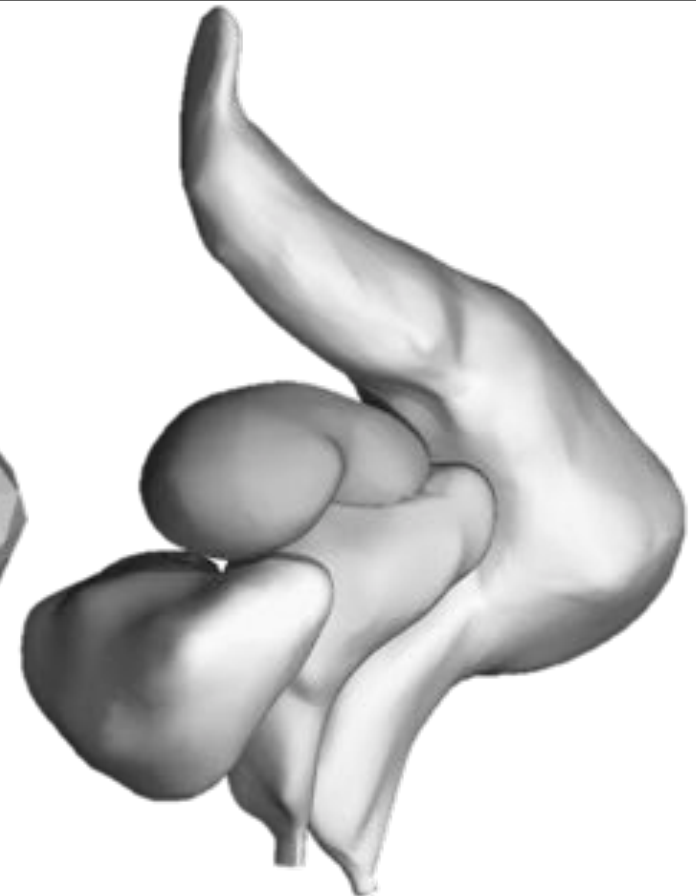


D | Surface
DS CATIA

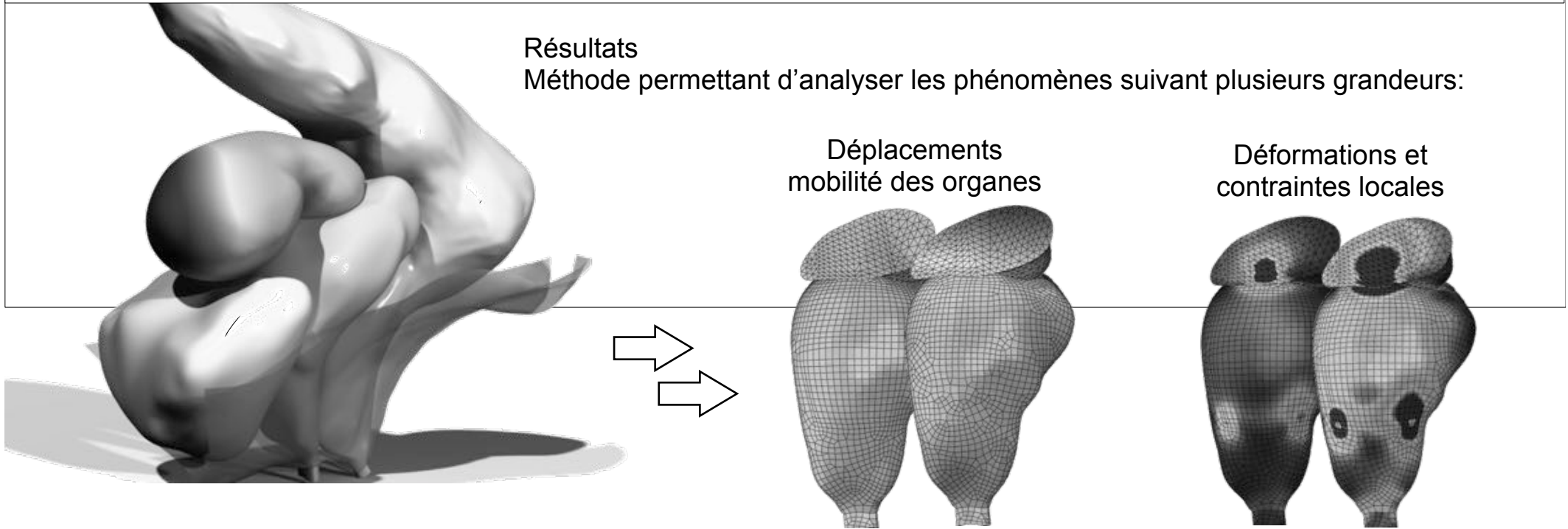


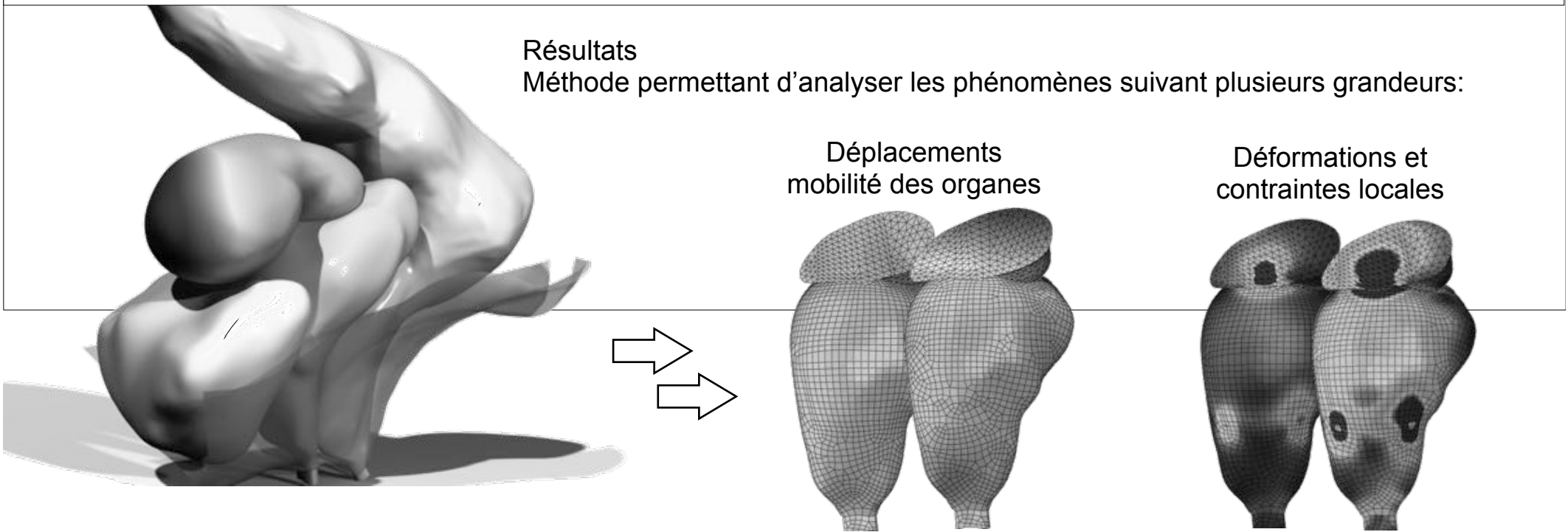
A retenir

- Méthode manuelle = Très chronophage
- Patiente unique
- Représentation géométrique utilisable en EF



**Quels types d'information pouvons nous analyser?
Quelles sont les applications possibles?**





Résultats

Méthode permettant d'analyser les phénomènes suivant plusieurs grandeurs:

Déplacements
mobilité des organes

Déformations et
contraintes locales

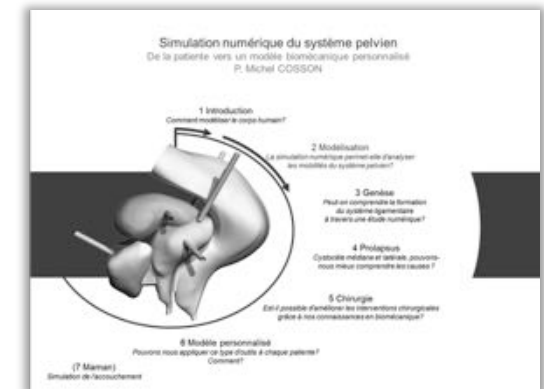
Partie 2 Construction d'un modèle EF
permettant d'analyser le rôle des systèmes de suspensions

Partie 3 Genèse du système ligamentaire:
analyse des zones de sollicitations (APEX niveau 1)

Partie 4 Prolapsus: Cystocèle médiane et latérale
influence de la géométrie et des propriétés mécaniques sur les mobilités pelviennes

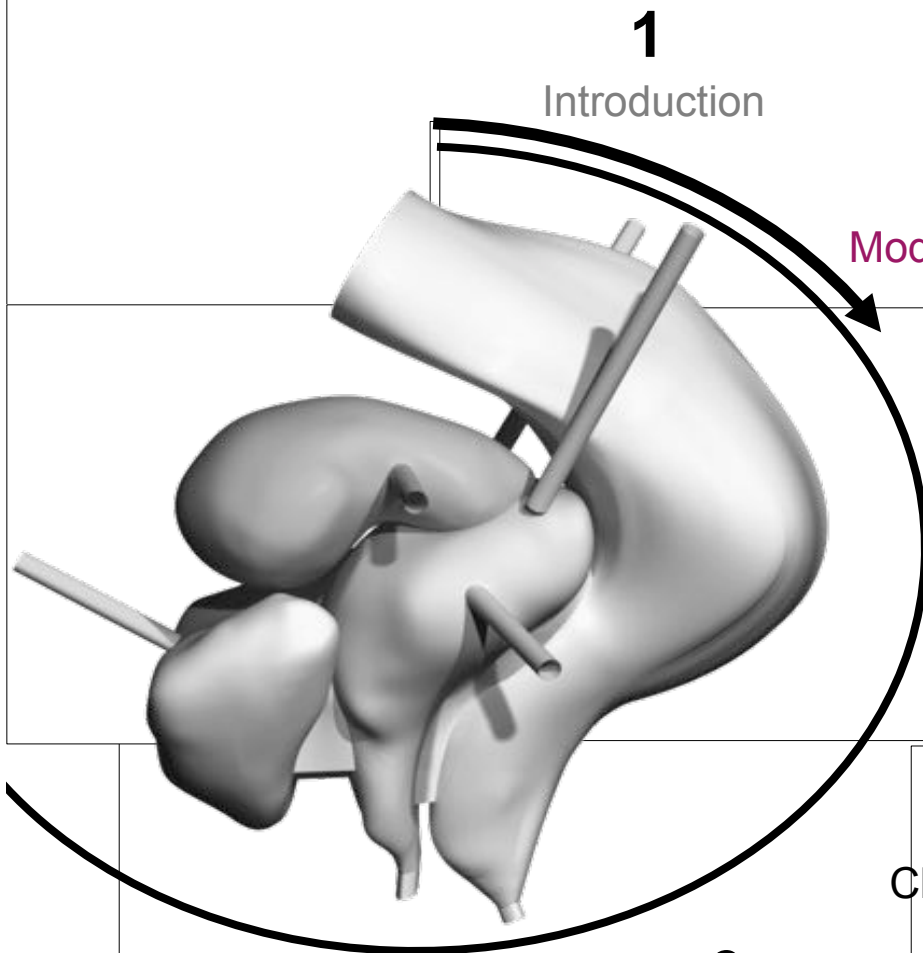
Partie 5 Chirurgie: La promontofixation
Améliorer les connaissances en terme de...

Partie 6 Paramétrage du modèle
utilisation de données morphologiques pour personnaliser le modèle EF





ReClip UE3 - Vendredi 07 novembre 2014 – 17h00/18h00
Applications des modèles biomécaniques pelviens
P. Michel COSSON, **Olivier MAYEUR**



1

Introduction

2

Modélisation

3

Genèse

4

Prolapsus

5

Chirurgie

8

suppléments

7

Maman

6

personnalisation



Question

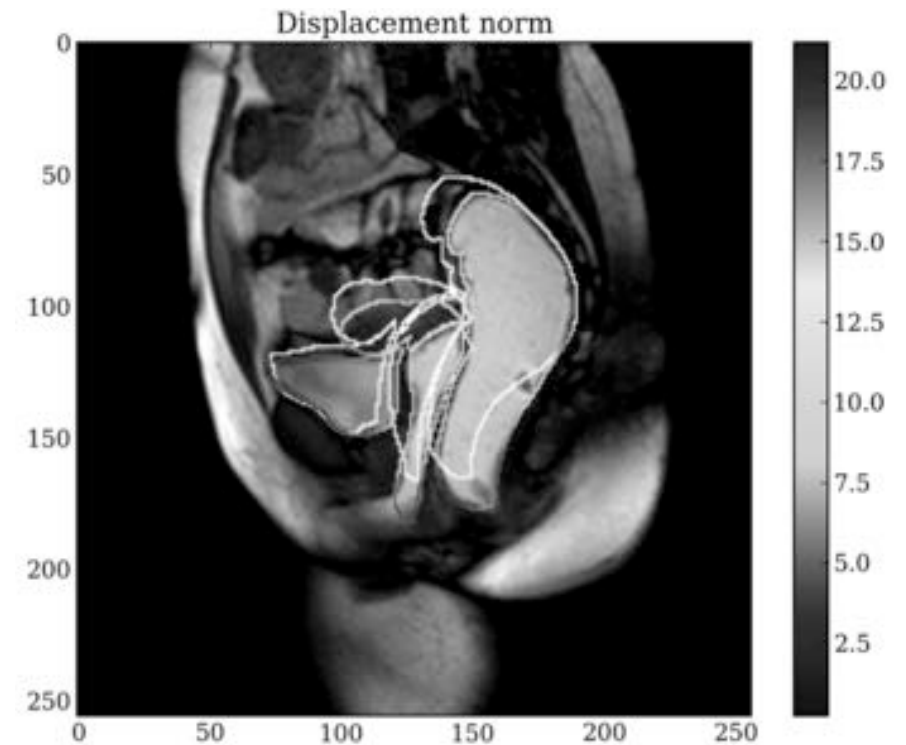
Comment modéliser le corps humain?

- Première étude dédiée à la compréhension des mobilités pelviennes
- Application à une patiente témoin

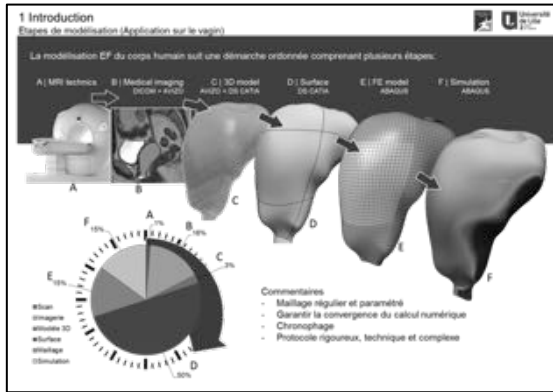
IRM dynamique



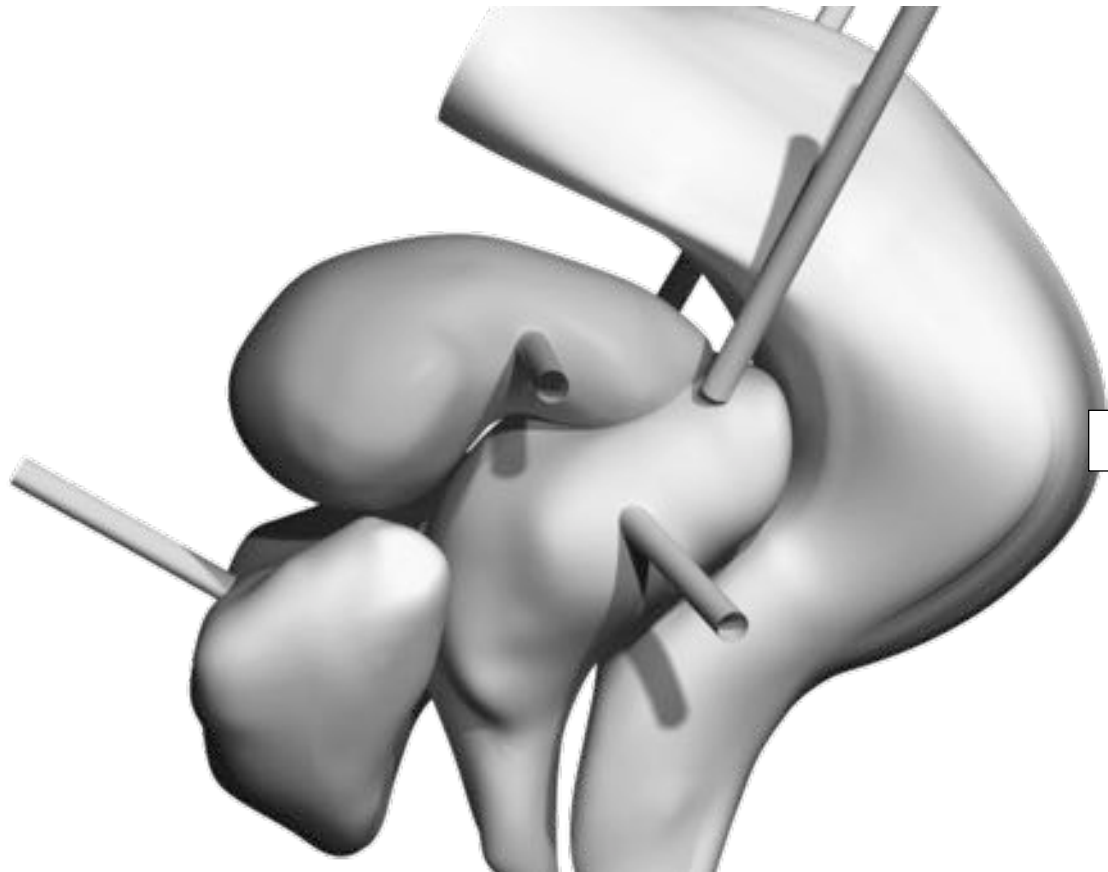
Illustration des mobilités
(comparaison étape initiale et finale)



Est-ce qu'une étude numérique permet de représenter ces mobilités et de comprendre les phénomènes mis en jeu?



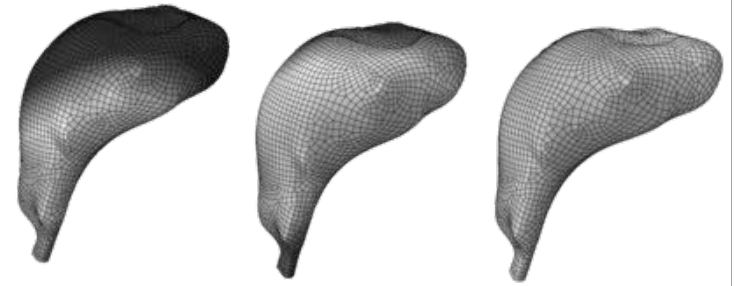
- Reconstruction de la patiente suivant le protocole de modélisation
- Travail réalisé en partenariat avec ingénieur et médecin afin de fusionner les compétences de chaque discipline (modélisation et cohérence anatomique).



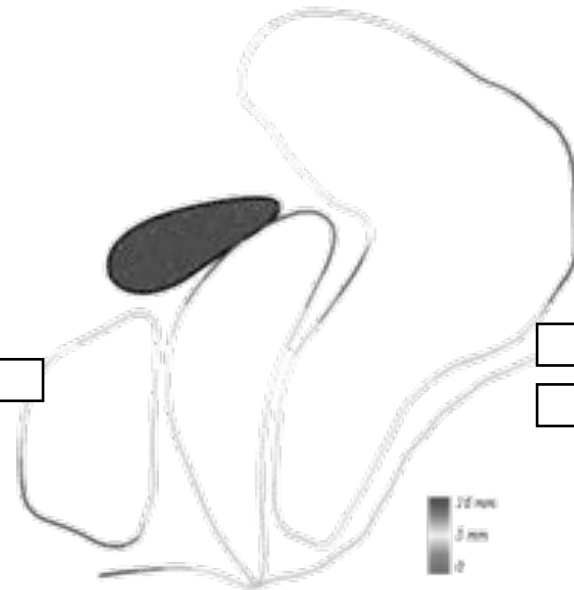
Objectifs

- Etudier les mobilités des organes
- Analyser l'influence des structures anatomiques
- Identifier les pressions
- Comparaison avec IRM dyn

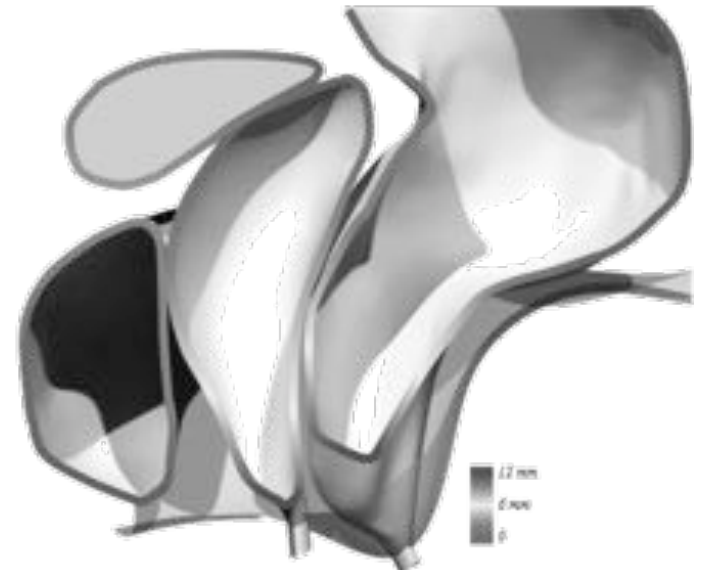
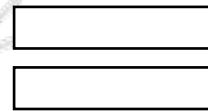
- Importance des ligaments et des fascias sur la mobilité
- Différence entre la simulation et l'IRM dynamique très faible
 - < 2 mm au col de l'utérus
 - < 5 mm sur les parois antérieures et postérieures du vagin
- Différence plus importante au niveau du plancher pelvien (nécessité de mieux représenter les muscles???)



MRI – Displacement norm



SIM – Displacement norm



Gap between MRI and SIM



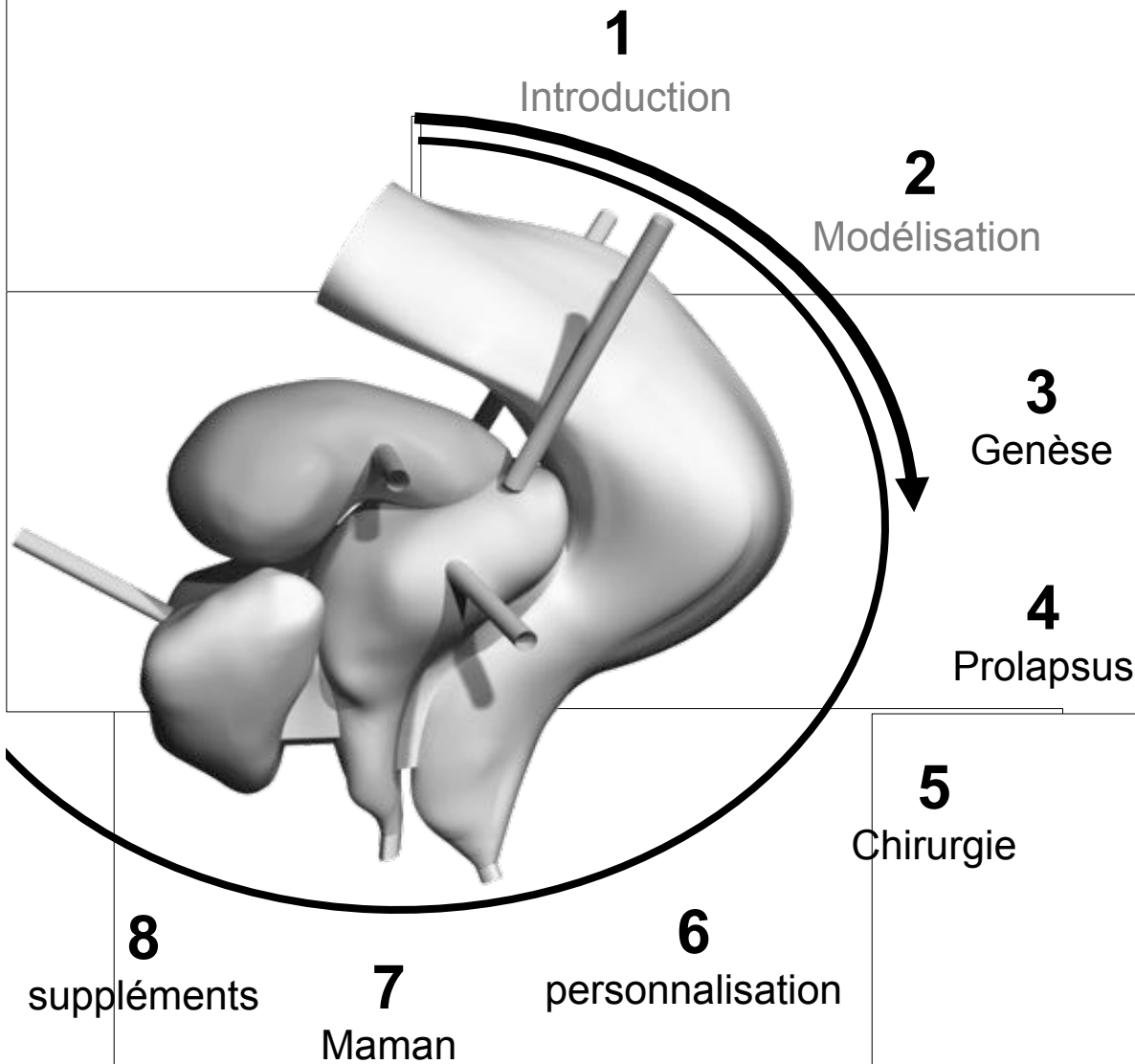
A retenir

Cette étude souligne l'importance de prendre en compte le système ligamentaire

Mais souvent mal compris/décrit + peu d'information dans la littérature + forte variabilité suivant l'âge...

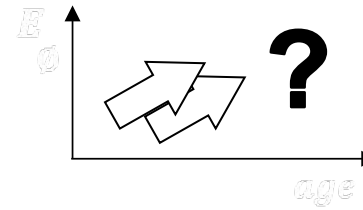


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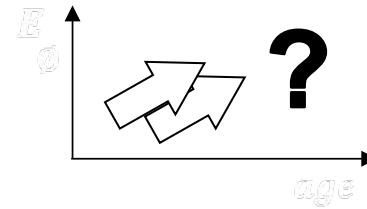
Question
La simulation numérique permet-elle d'analyser les mobilités du système pelvien?

- - Module d'Young des ligaments dépend de l'âge
Sujet jeune = similaire / Agé US augmente...
- Anatomie: présence +/- marquée suivant l'âge...
- Expérimental: augmentation des déformations...



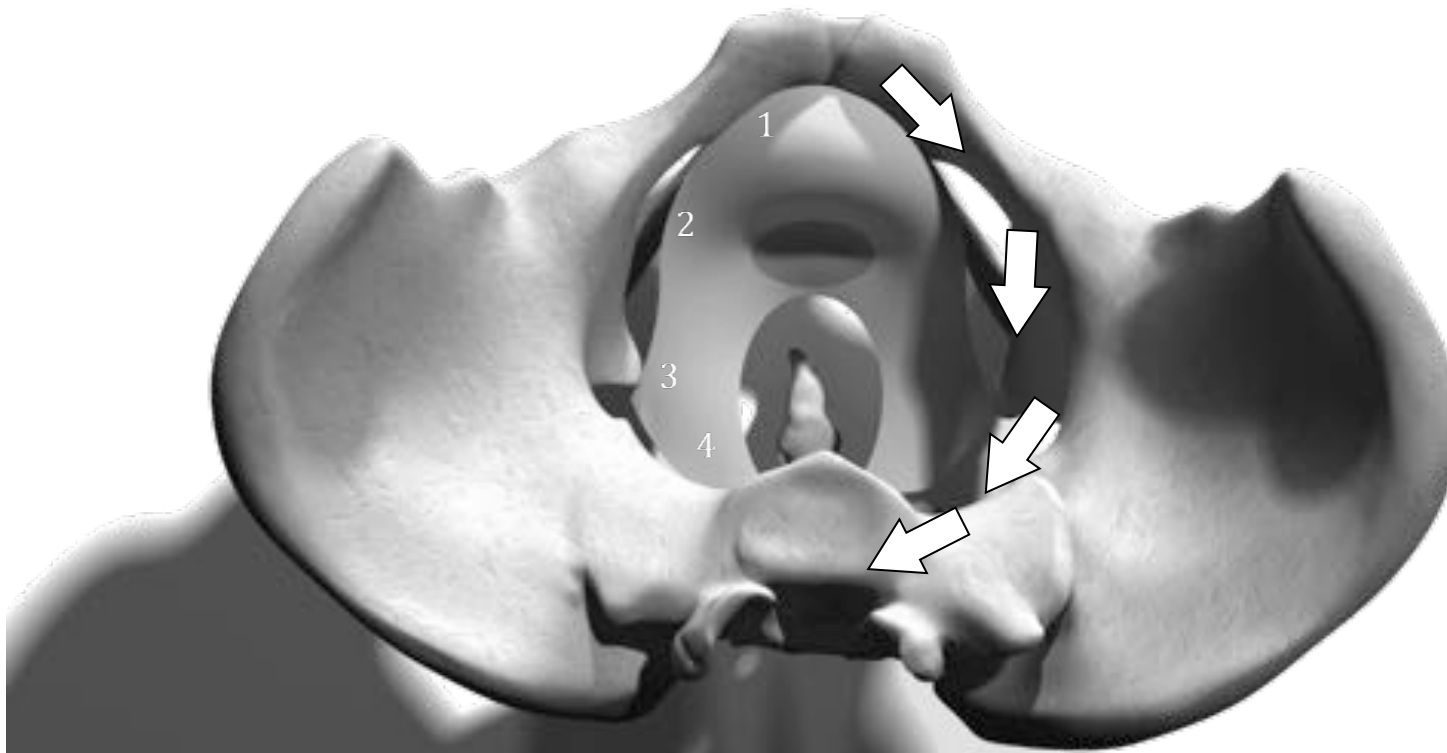
**Est-ce qu'une étude numérique
permet de comprendre les choses?**

- Module d'Young des ligaments dépend de l'âge
Sujet jeune = similaire / Agé US augmente...
- Anatomie: présence +/- marquée suivant l'âge...
- Expérimental: augmentation des déformations...



Est-ce qu'une étude numérique permet de comprendre les choses?

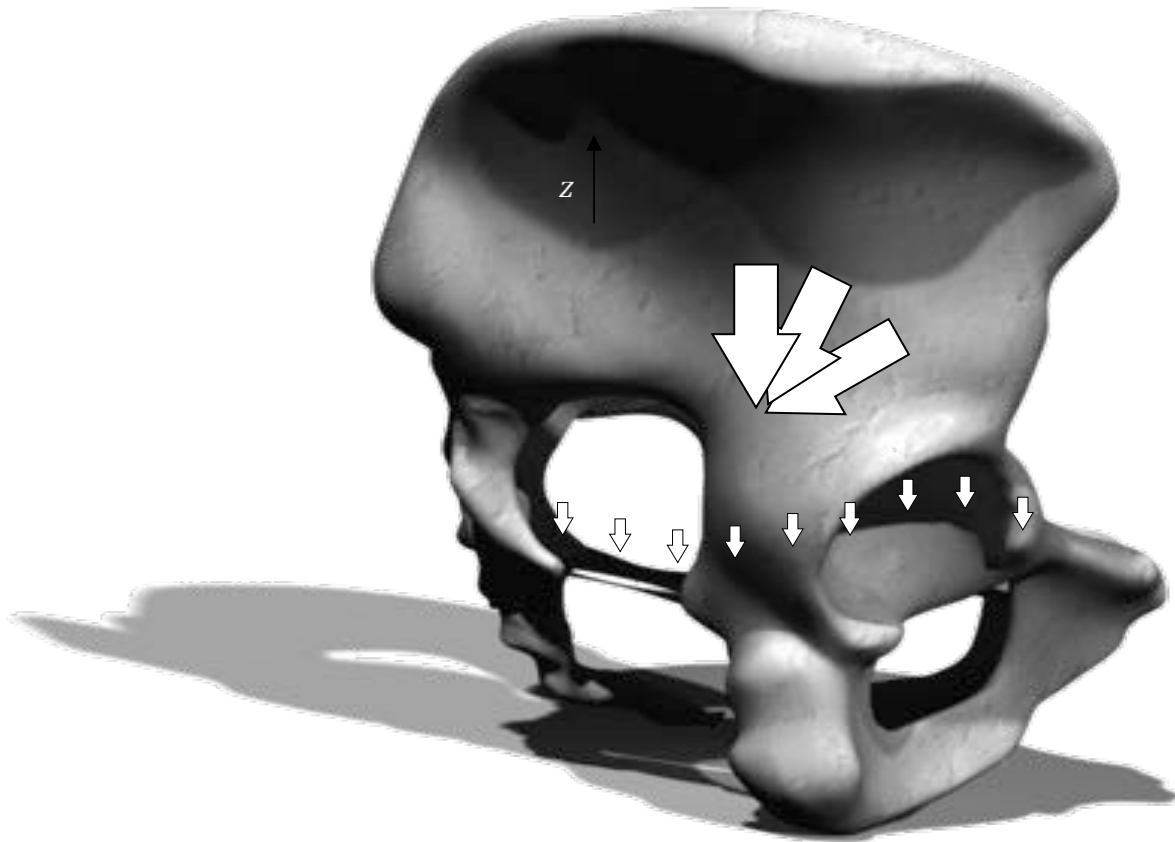
- Motivation**
Approche purement numérique pour comprendre:
Système pelvien > Paroi > répartition des charges
Modélisation de l'APEX niveau 1



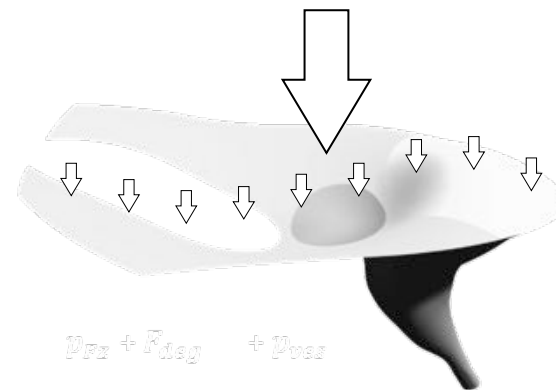
- Suspension de la paroi**
Trajet antéro-postérieur
(zones d'accroches)
- 1- Face postérieure du pubis,
- 2- Arcs tendineux, ATLA
- 3- Ligaments Sacro Epineux,
- 4- Sacrum

□ **Interaction / environnement**
Proposition de surface.

- a- Ouverture autour du Rectum
- b- Zone d'appui de l'Utérus
- c- Paramétrage au niveau de la vessie



Cas critique
Pression sur l'ensemble de la paroi
+ Pression plus importante autour de l'utérus
+ pression de la vessie



$$P_{Fz} + P_{deg} + P_{ves}$$

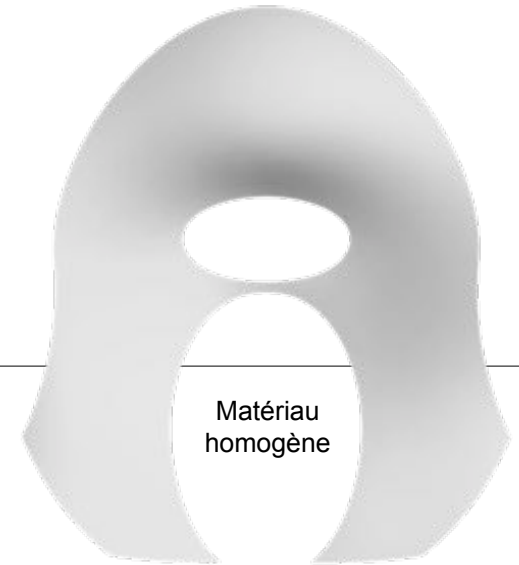
Matériau
 $\rho = 1000 \text{ kg.m}^{-3}$
 $E = 0,3 \text{ MPa}$
 $\nu = 0,45$

Objectifs

Mettre en évidence l'évolution du système ligamentaire

Identifier les zones les plus sollicitées (Déformations max.)

Illustration des déformations
Matériaux homogène



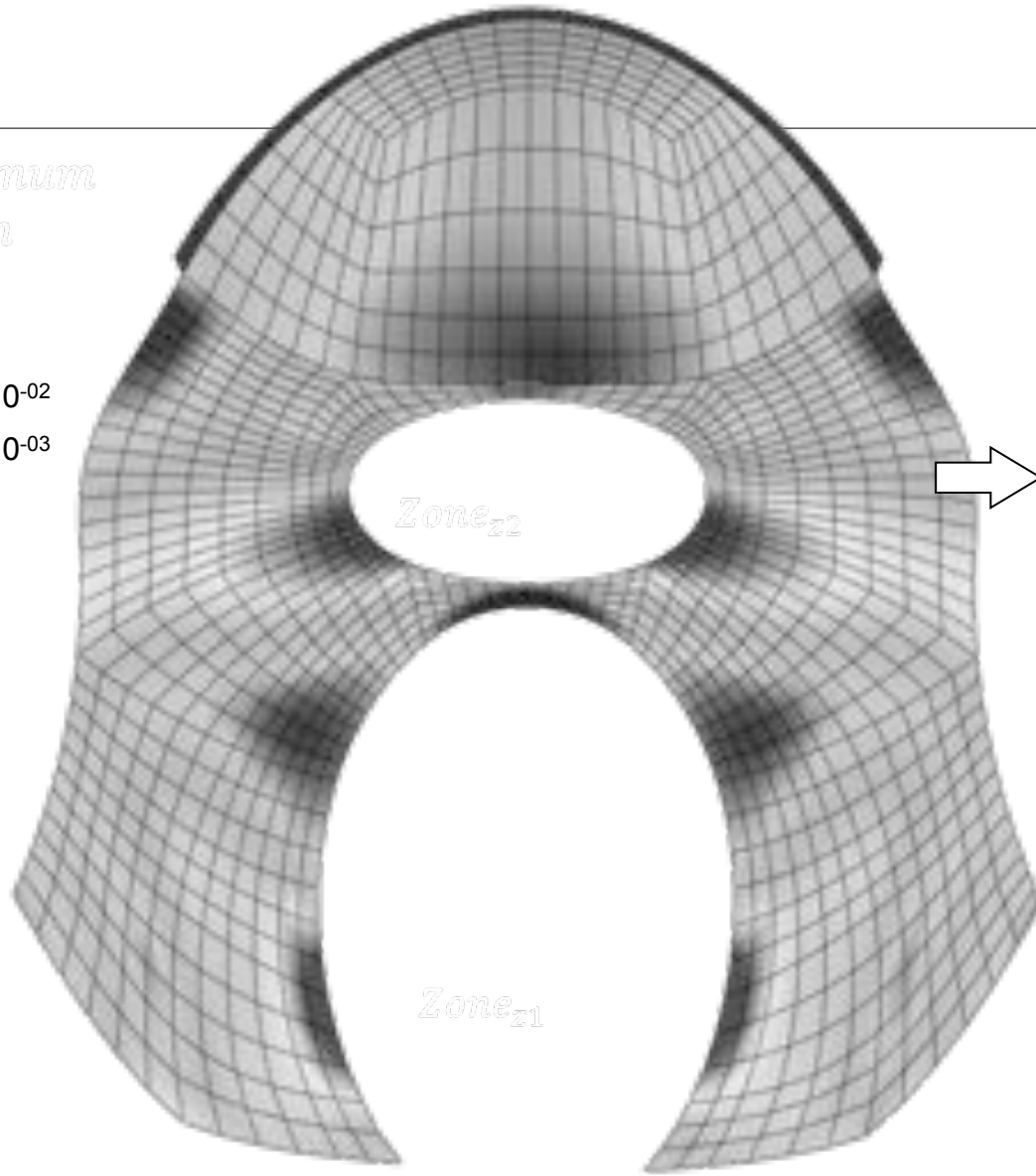
Maximum strain

ϵ_I

+1.10⁻⁰²

+5.10⁻⁰³

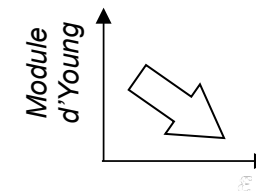
0

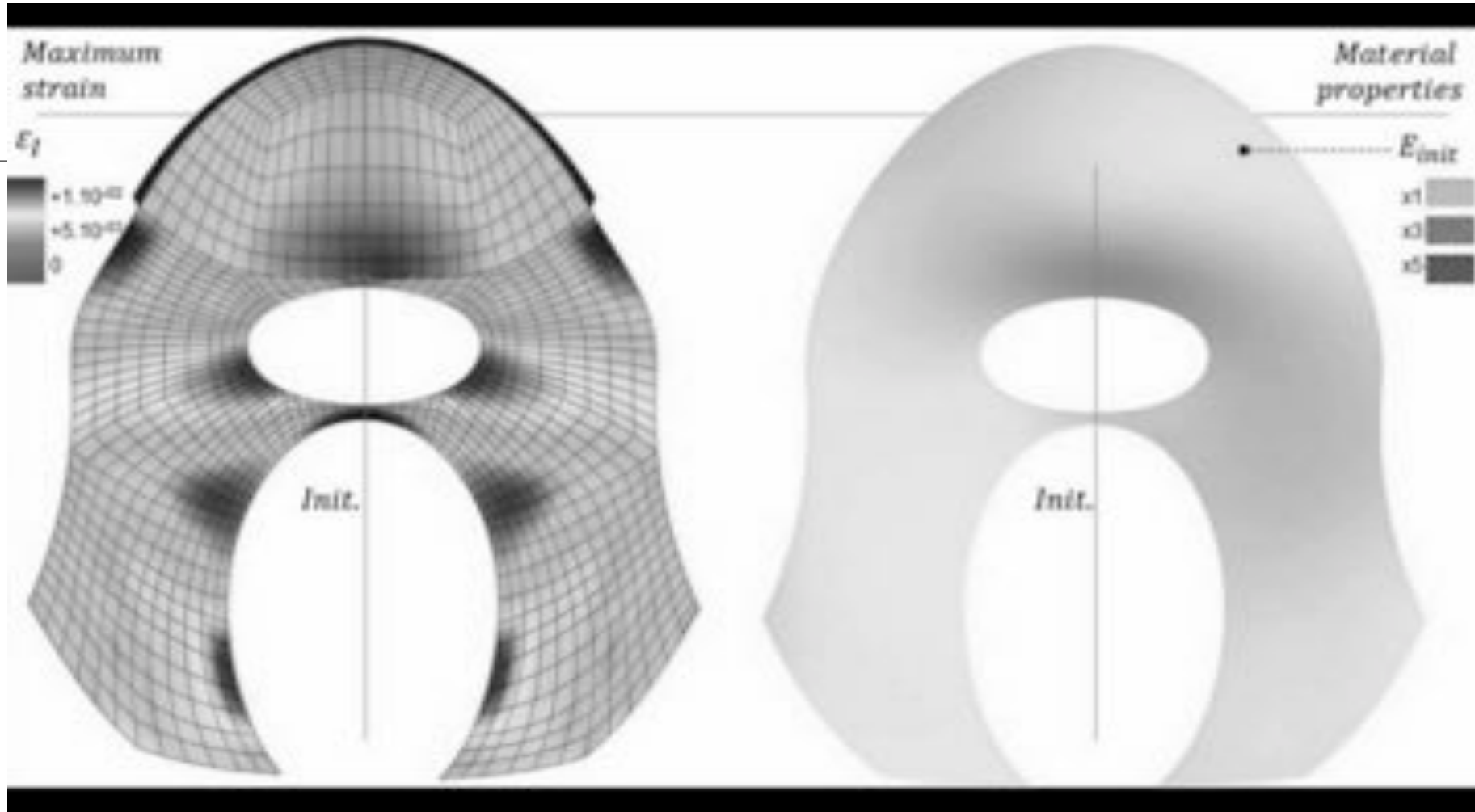


Apparition de 2 zones symétriques avec des déformations élevés.

Comment diminuer les déformations maximales dans les zones 1 & 2?

Augmenter numériquement la rigidité du matériau dans les zones les plus sollicitées.





Augmentation numérique de la rigidité du matériau dans les zones les plus sollicitées.

Illustration des déformations
Matériaux variable

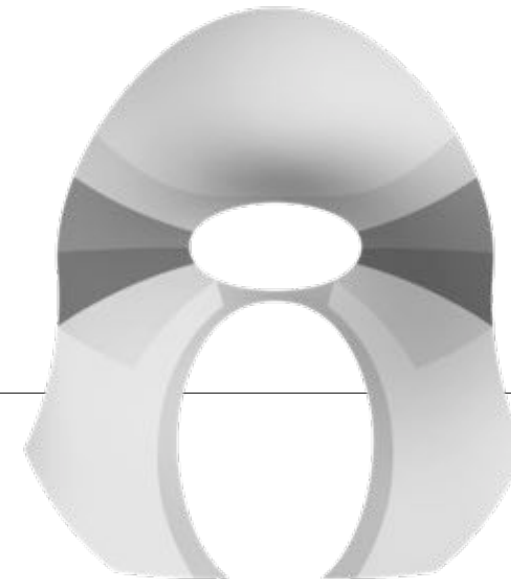
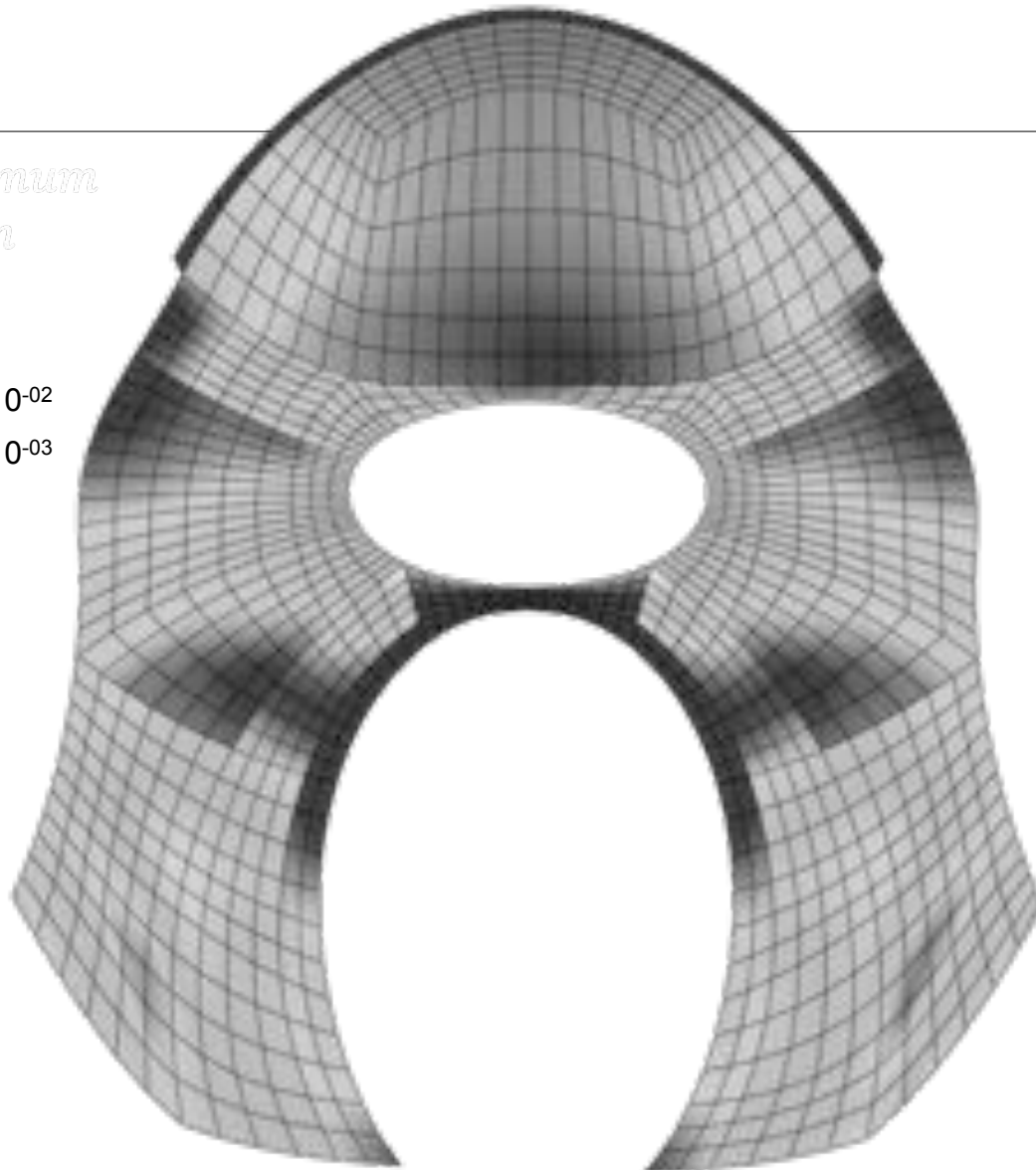
Maximum strain

ϵ_I

+1.10⁻⁰²

+5.10⁻⁰³

0



Conclusion

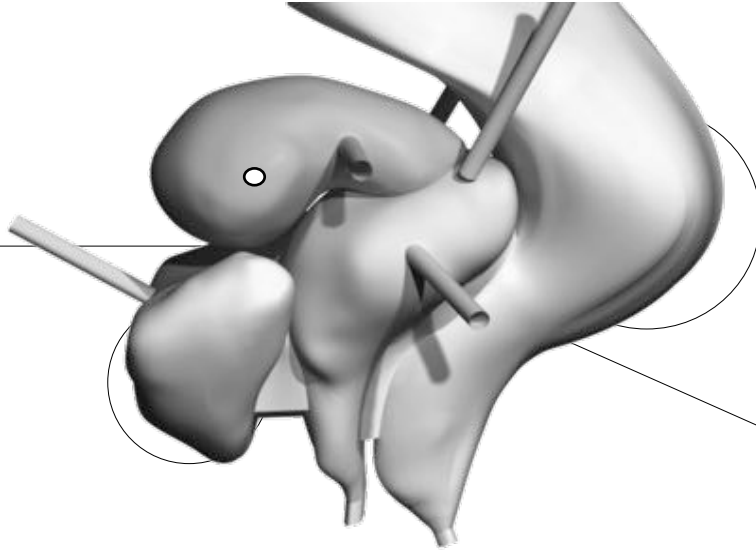
Les zones les plus sollicitées sont des zones où il y a présence de structure ligamentaire.

Adaptation/réponse des tissus...

L'homogénéisation des déformations (équilibre de la surface) permet de constater des modules plus importants

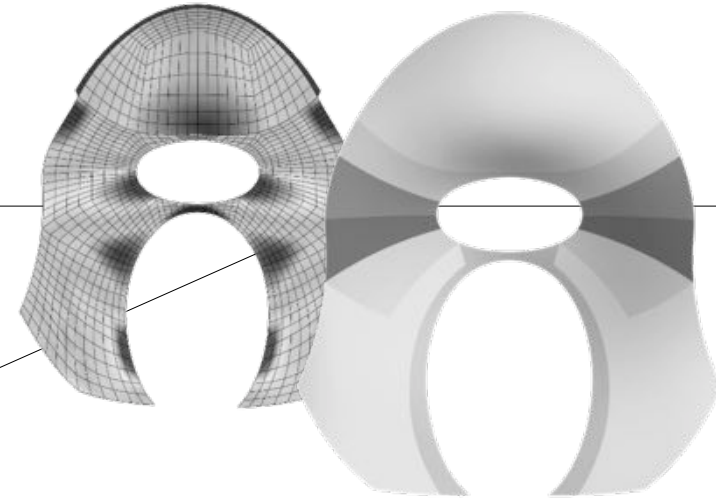
Partie 2

Rôle important du systèmes de suspension
Influence de la géométrie (Organes, Ligaments, Fascias...)

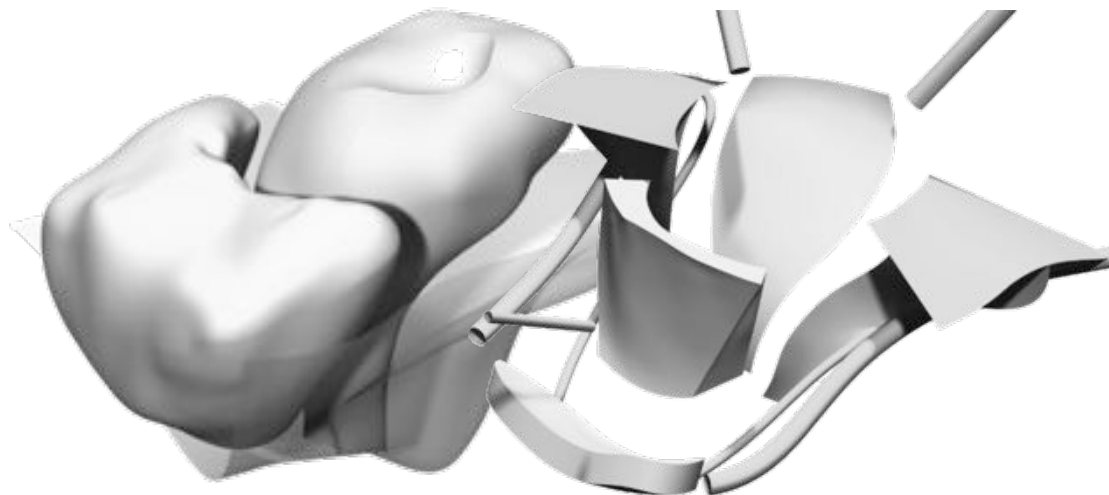


Partie 3

Matériau n'est pas homogène, cartographie...
Influence du matériau (différence de module, Jeune/vieux...)



Nécessité d'une représentation biofidèle des organes et des structures de suspension et d'une cartographie détaillée des matériaux

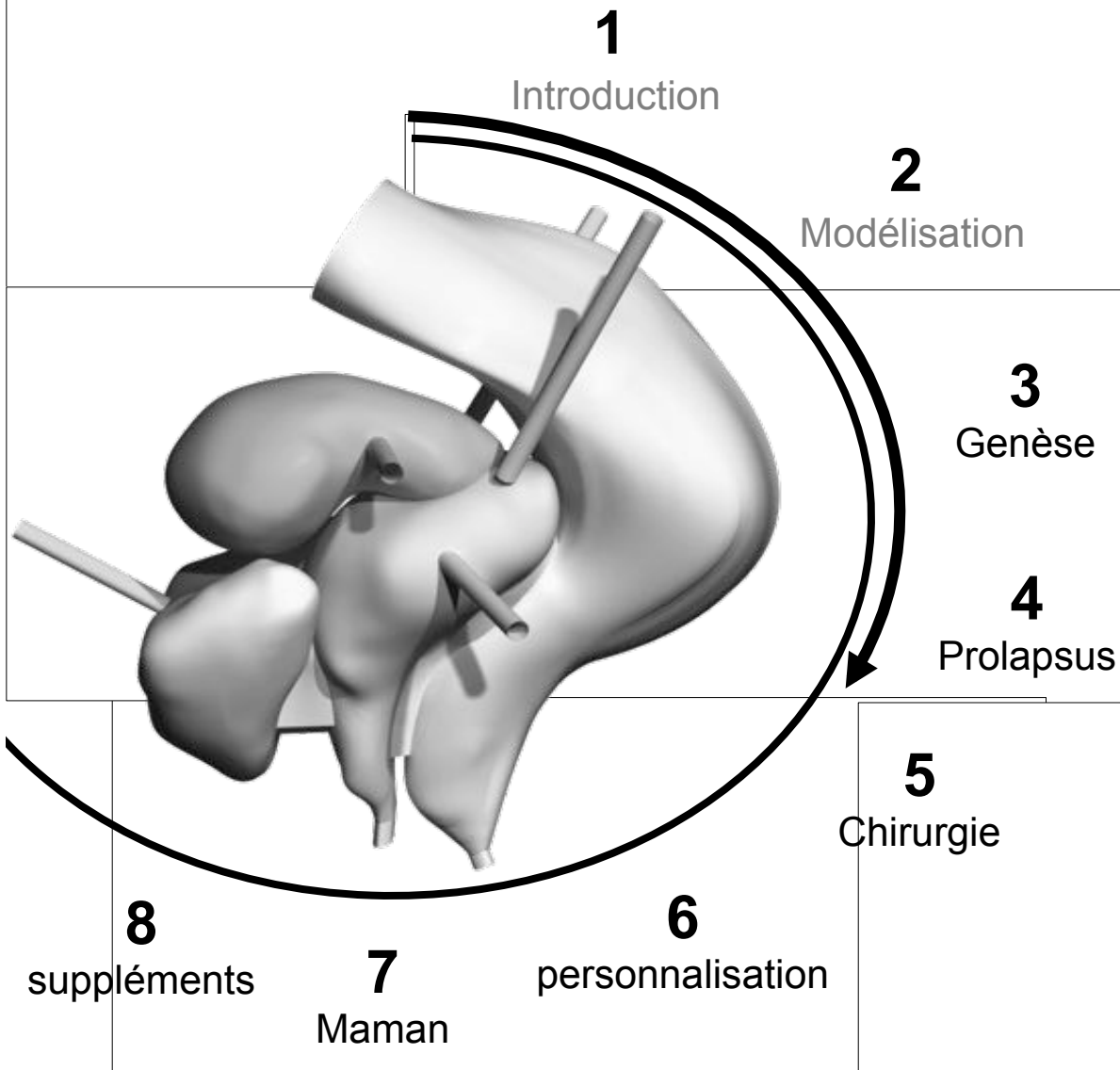


Partie 4: Prolapsus

Cystocèle médiane et latérale, pouvons-nous mieux comprendre les causes à l'aide de ce modèle?



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Question
*Peut-on comprendre la formation
du système ligamentaire
à travers une étude numérique?*

4 Prolapsus

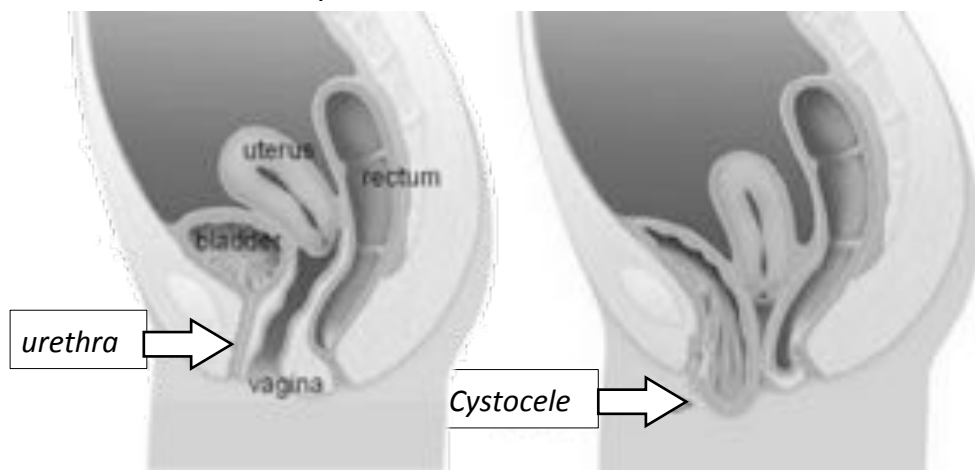
Introduction au cas d'étude: la cystocèle médiane et latérale



□ Main cause of failure

- complex physiopathology, linked to soft tissues, fasciae and ligaments.
- organ support system misunderstood or poorly described.

Normal anatomy



□ Median cystocele prolapse (MCP) occurrence

theory #1 [Petros 2008]

defect of fascia between bladder and vagina (FBV) is the most important cause of MCP.

theory #2 [DeLancey 2002, Chen 2009]

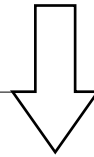
= theory #1 + paravaginal ligaments must be added to induce cystocele.

Which is the influence of the anatomical structures on the cystocele?

Does a numerical study help to understand the phenomenon involved?

Etudier l'influence de ces structures sur la mobilité revient à modifier leurs propriétés géométriques ou/et mécaniques

Suivant les théories #1 Petros et #2 DeLancey



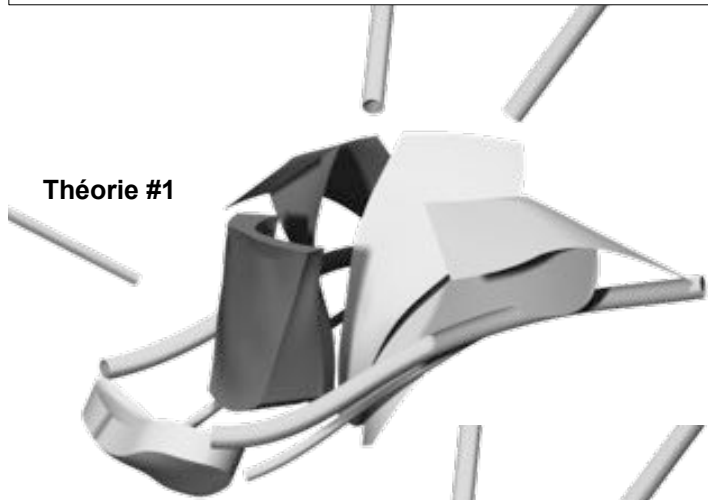
Cystocèle médiane

Cystocèle latérale

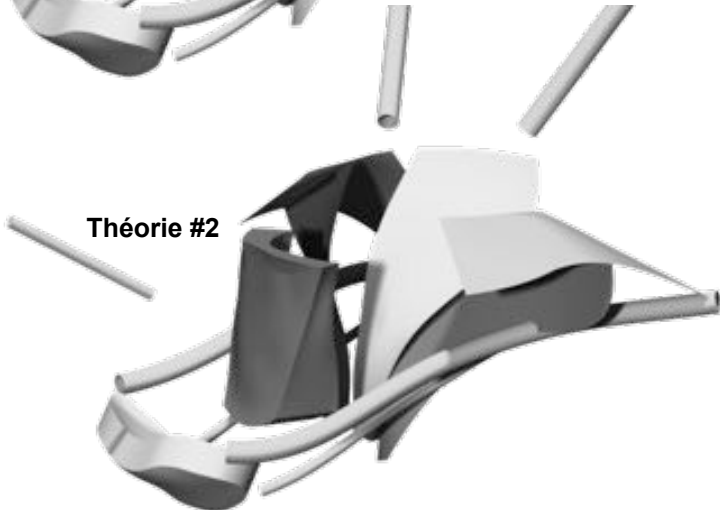
Modèles paramétrés permettant de modifier de xx%

- 1- le matériaux (*on modifie le module d'Young*)
- 2- la géométrie (*on allonge les structures*)

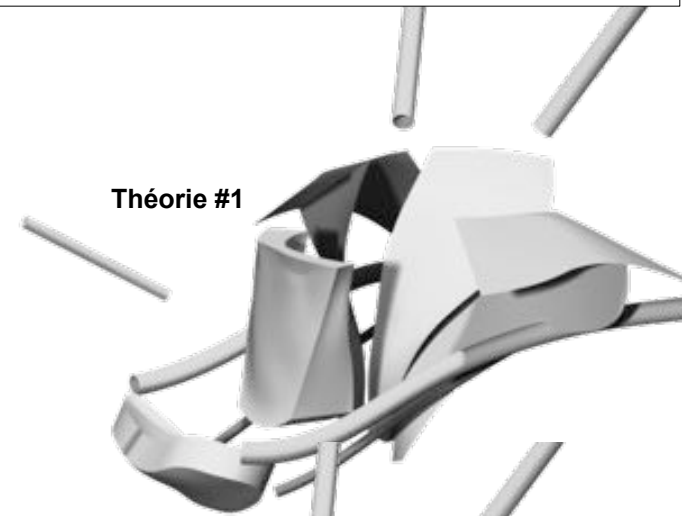
Théorie #1



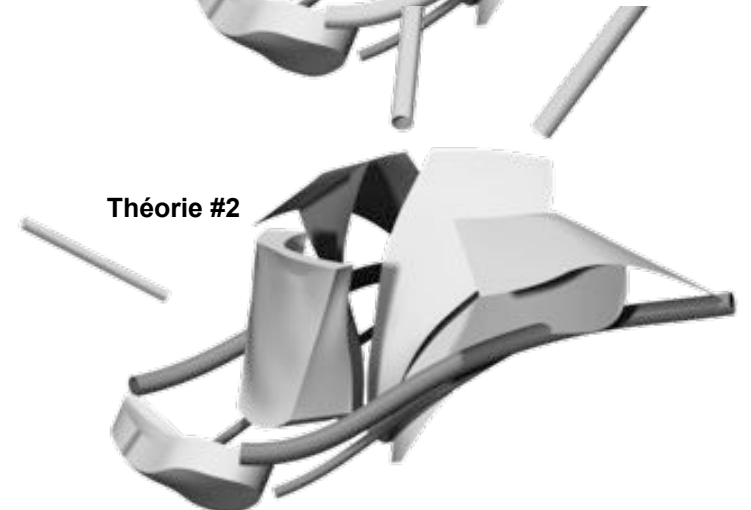
Théorie #2



Théorie #1



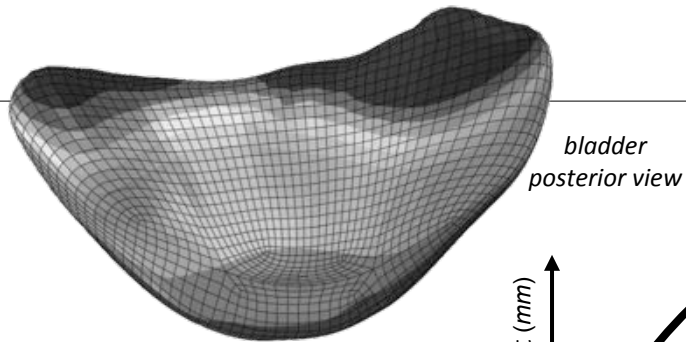
Théorie #2



Step #1 – Material properties influence

Initial simulation (young tissues)

Applied pressure to analyze bladder mobility

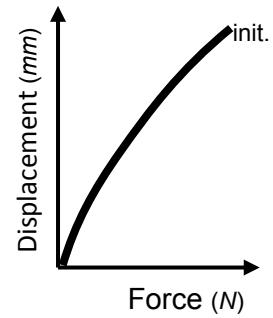


Displacement (mm)

2 mm

1 mm

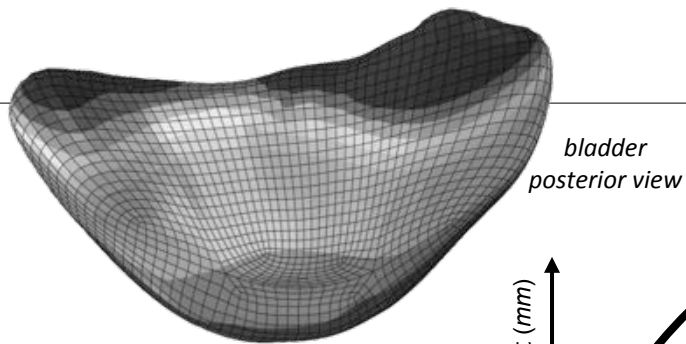
0 mm



Step #1 – Material properties influence

Initial simulation (young tissues)

Applied pressure to analyze bladder mobility



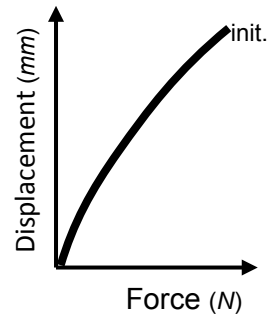
bladder
posterior view

Displacement (mm)

2 mm

1 mm

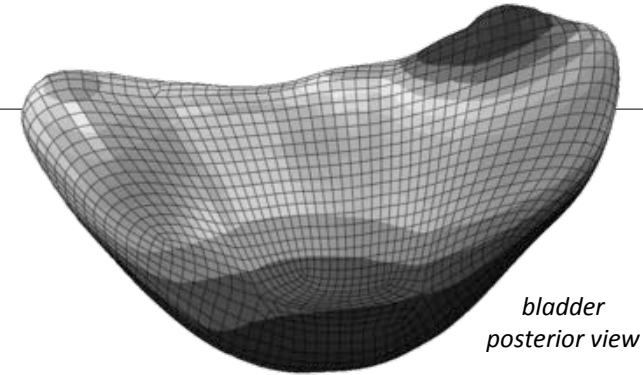
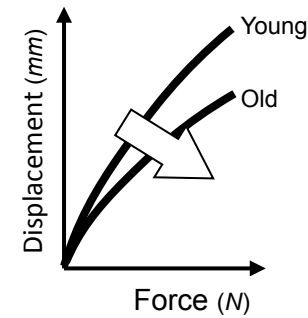
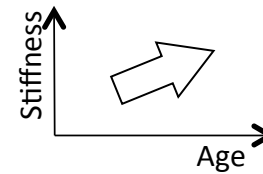
0 mm



Comparison

Simulation with old tissues Modulus increase with age.

[Chantereau, 2014]



bladder
posterior view

Displacement (mm)

2 mm

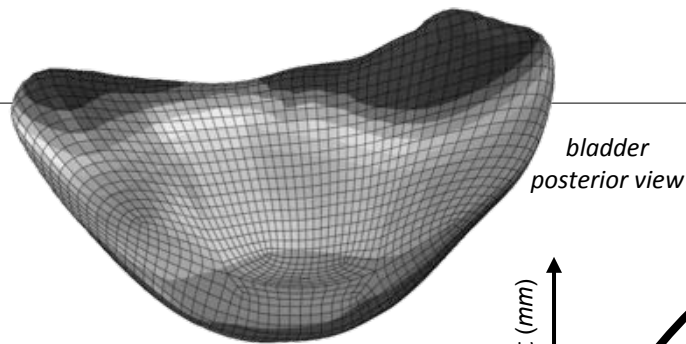
1 mm

0 mm

Step #1 – Material properties influence

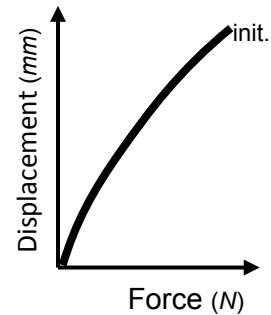
Initial simulation (young tissues)

Applied pressure to analyze bladder mobility



Displacement (mm)

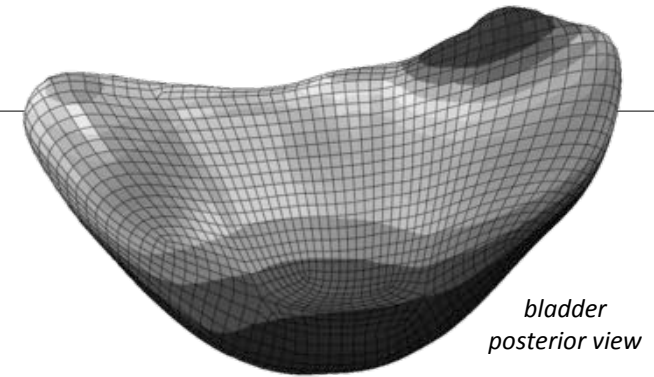
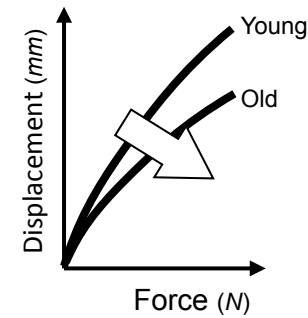
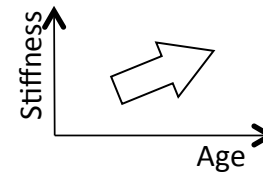
2 mm
1 mm
0 mm



Comparison

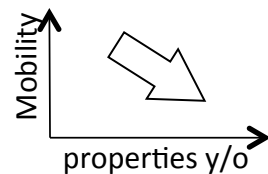
Simulation with old tissues Modulus increase with age.

[Chantereau, 2014]



Displacement (mm)

2 mm
1 mm
0 mm



Conclusion

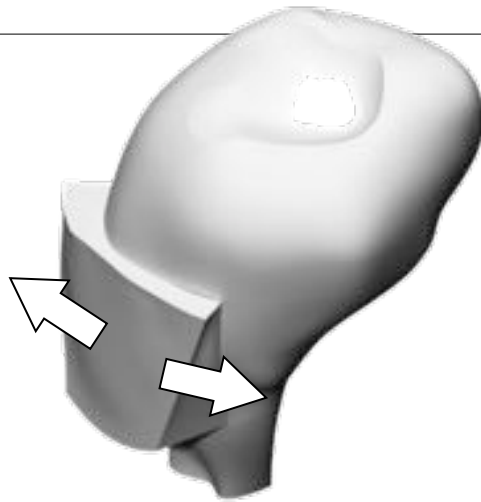
decrease in mobility between Y / O tissues

Material properties are not the cause of hypermobility
> interest to the geometry impairment.

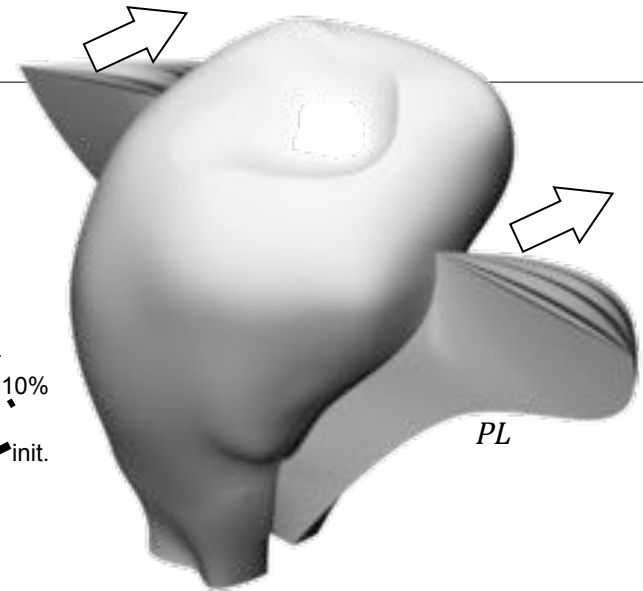
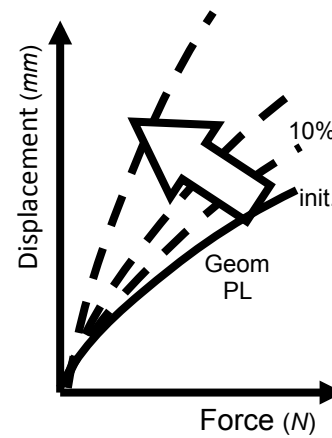
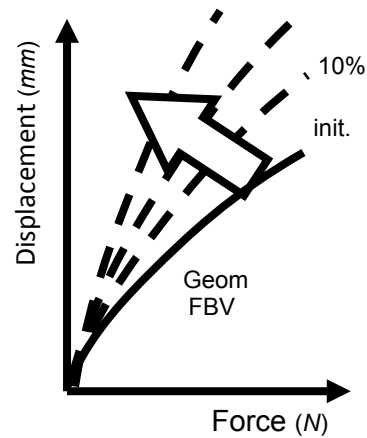
Step #2 – Geometrical properties comparison

The pathology occurrence is rather geometric, favoring evolution of structures following an increase of FBV and PL.

- Parametric model > percentage of impairment of FBV and PL geometry



Modification of Fascia geometry



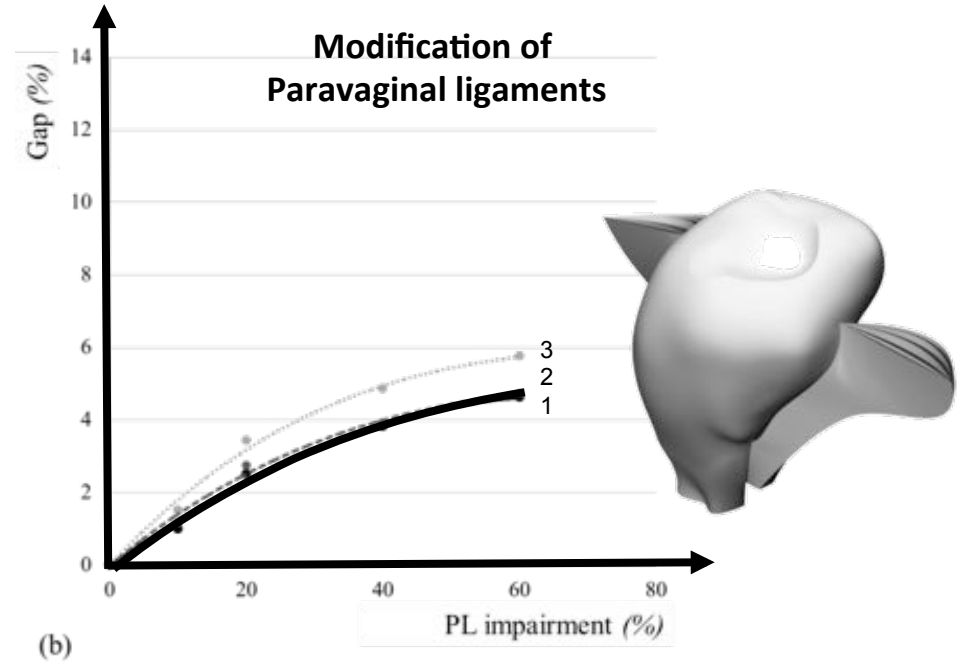
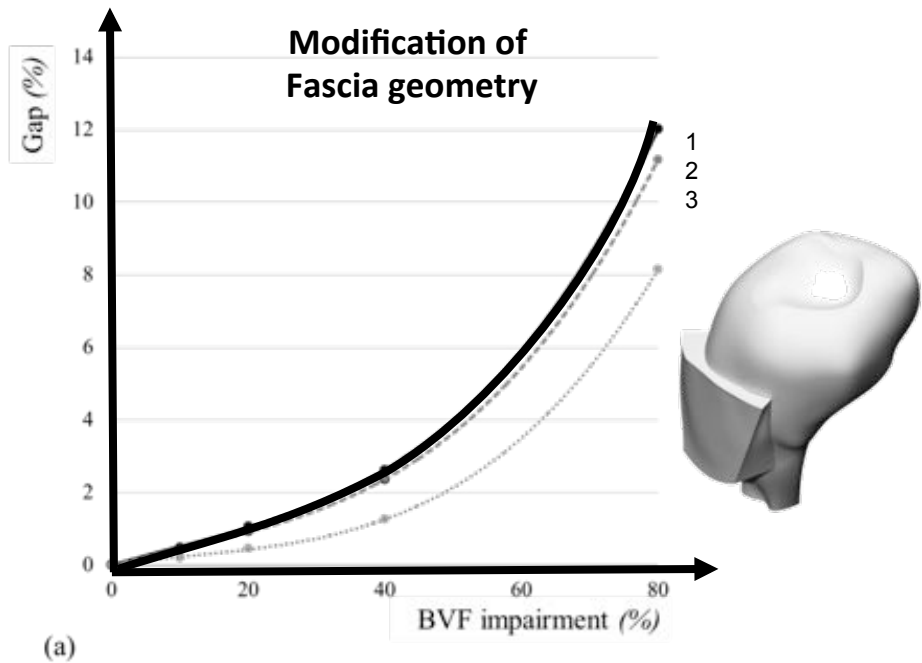
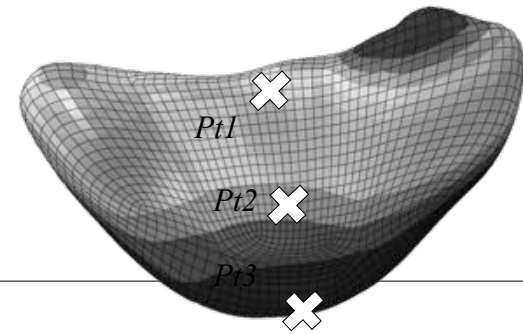
Modification of Paravaginal ligaments

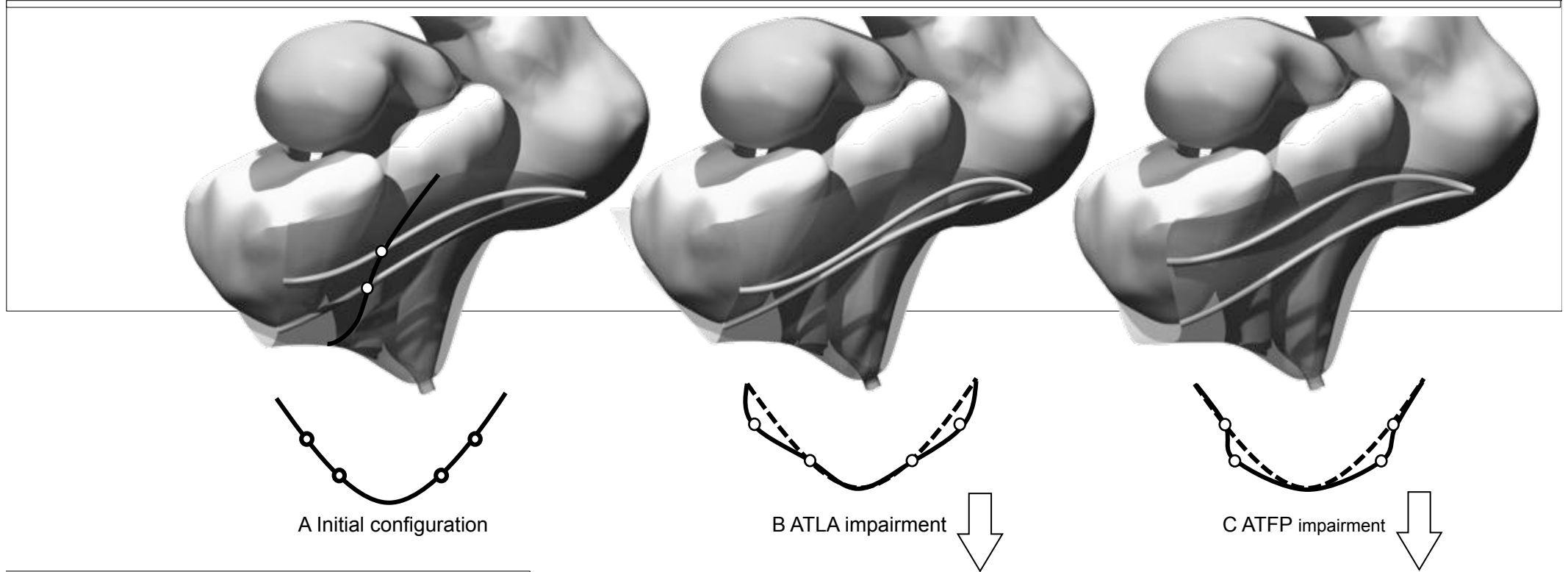
Conclusion

Geometrical impairment Increase the mobility of the pelvic system

Step #3 – Geometrical influence

The geometric changes correspond to 10, 20, 40 and 60% elongation for PL and equivalent evolution between 10 and 80% for the FBV.





A Initial configuration

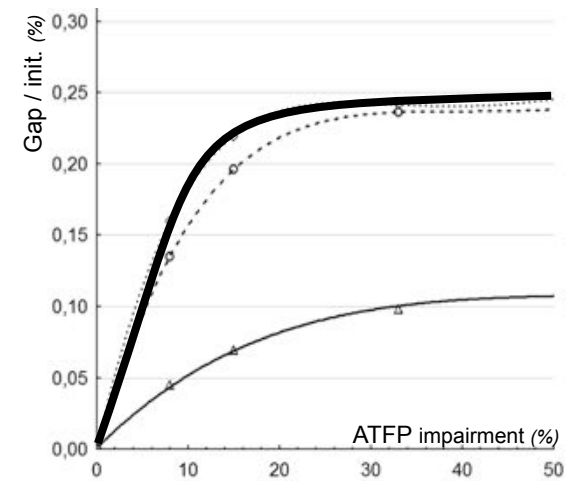
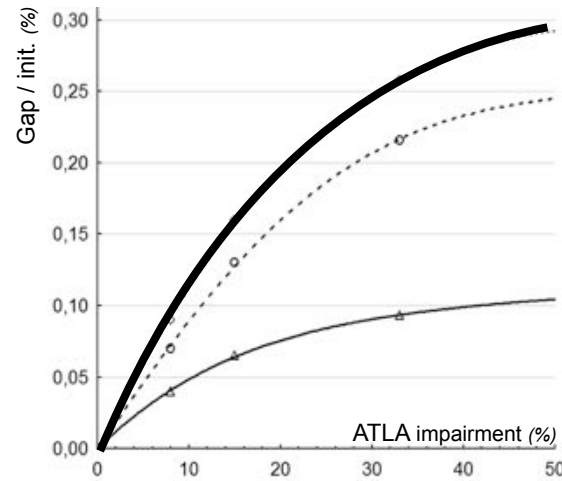
B ATLA impairment

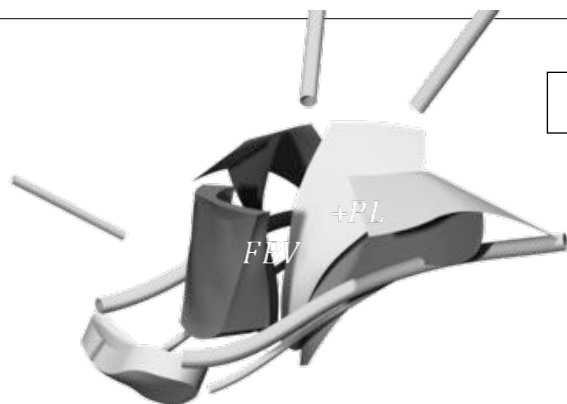
C ATFP impairment

Cystocèle latérale

Same study on the lateral cystocele occurrence:

- Step #1** Influence of material properties
- Step #2** Geometrical modifications (ATFP/ATLA)
- Step #3** analysis on bladder mobility



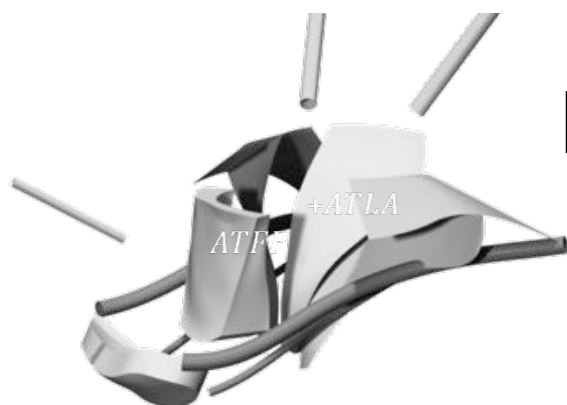
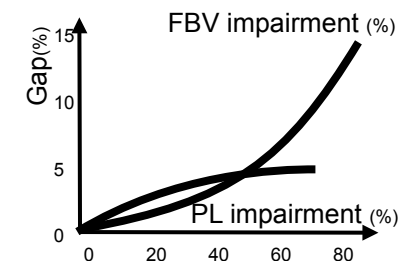


Conclusion - Median cystocele

FBV strong influence after 40% impairment
 PL different trend
 less pronounced after the 40%,

Before 40% Similar tendencies (theory #2)

After Fascia between bladder and vagina is more influent (theory #1)

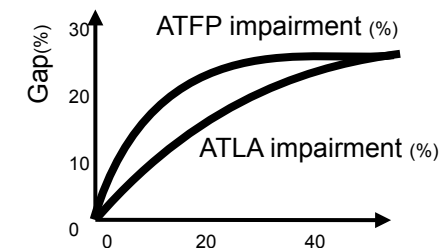


Conclusion - Lateral cystocele

ATFP strong influence before 20% impairment
 ATLA progressive trend before 40% impairment

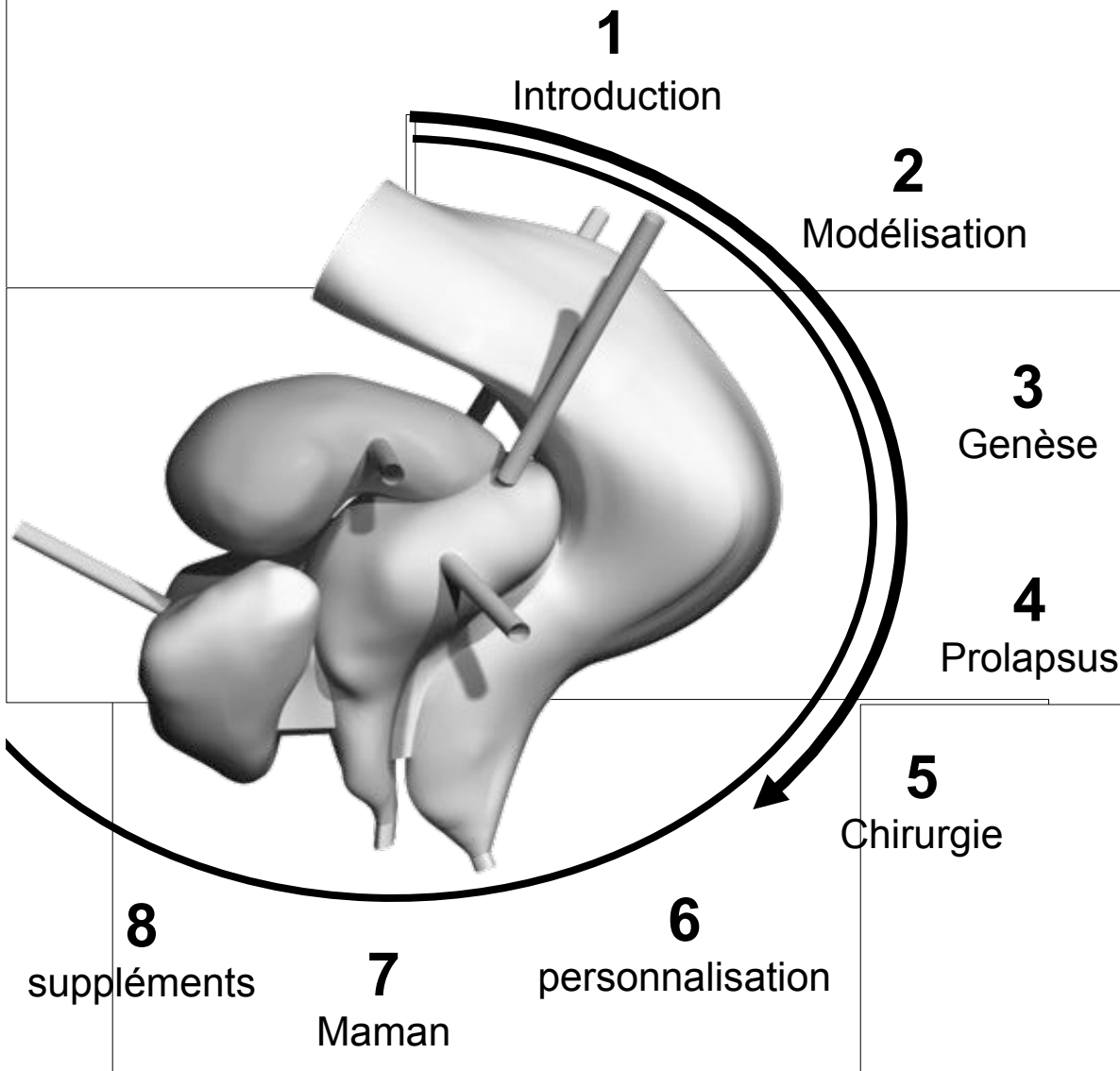
Similar if important impairment (theory #2)

Before 20% impairment ATFP > ATLA (theory #1)

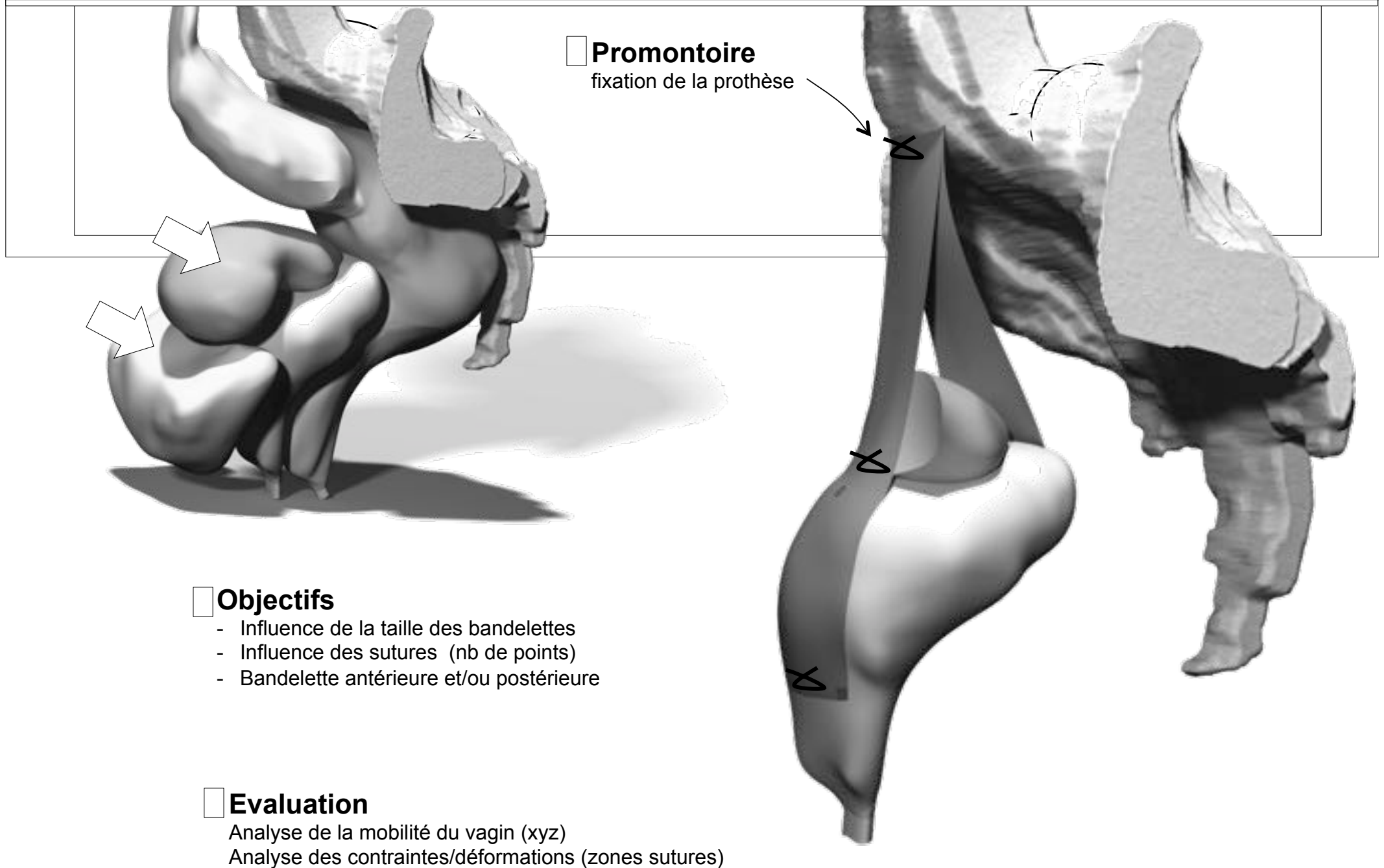


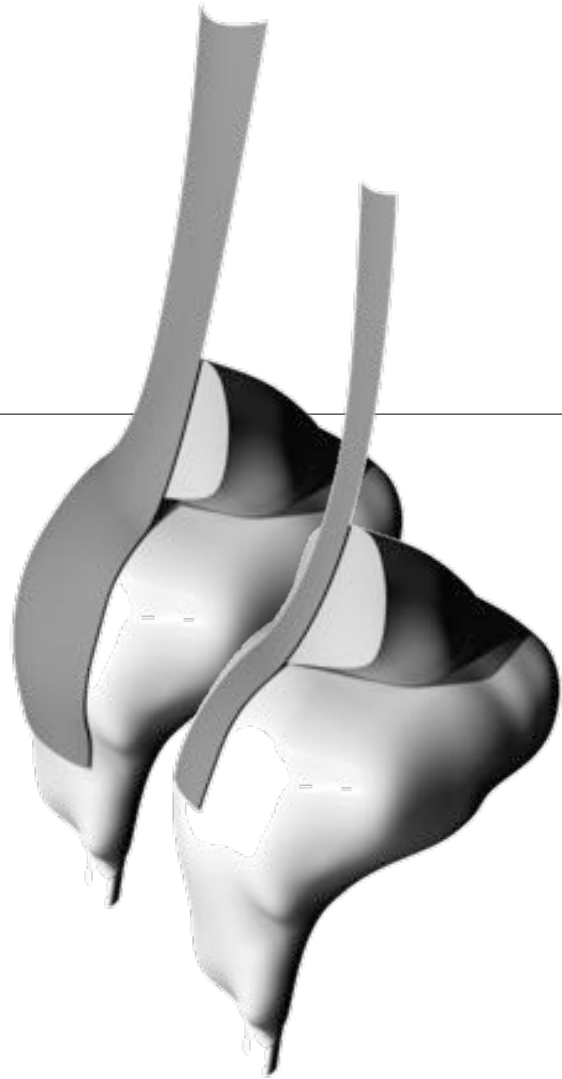


ReClip UE3 - Vendredi 07 novembre 2014 – 17h00/18h00
Applications des modèles biomécaniques pelviens
P. Michel COSSON, **Olivier MAYEUR**

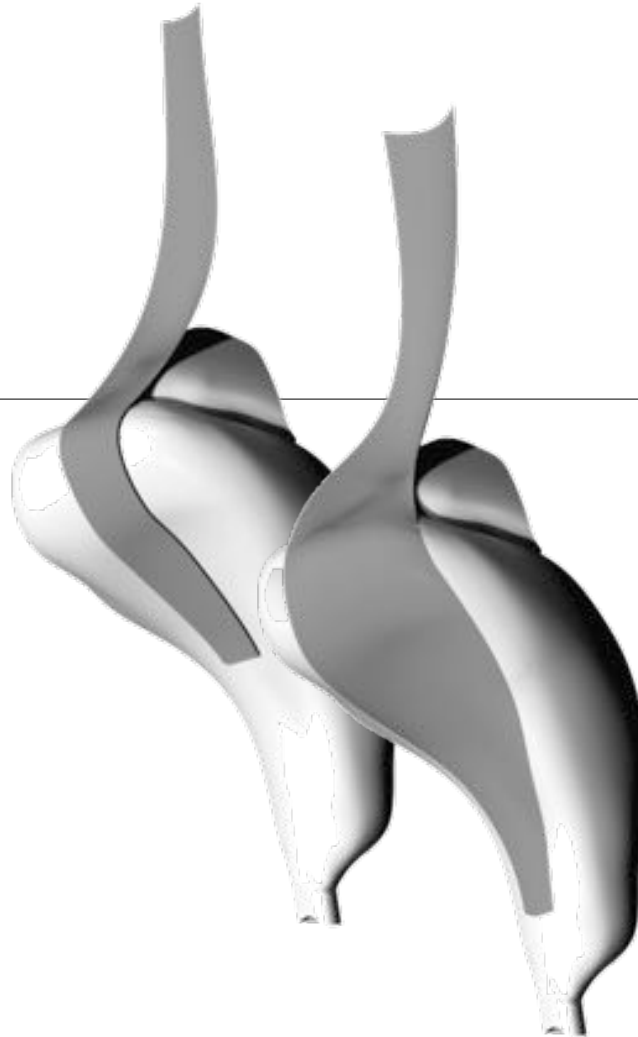


Question
Cystocèle médiane et latérale, pouvons-nous mieux comprendre les causes ?

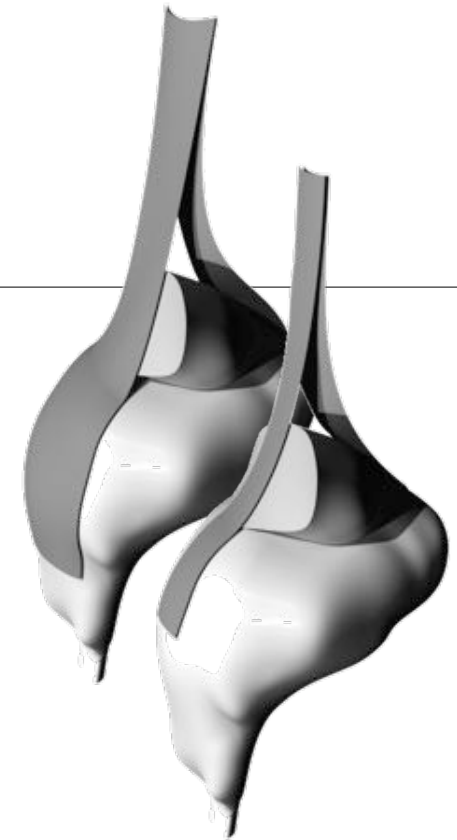




- Configuration #01**
Bandelette antérieure
- Grande vs petite
 - 2 vs 4 points (+1 col)



- Configuration #02**
Bandelette postérieure (idem)
- Grande vs petite
 - 2 vs 4 points (+1 col)

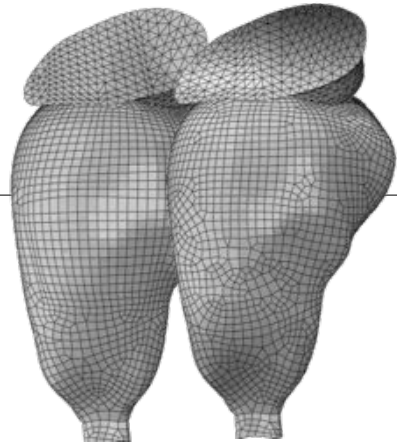


- Configuration #03**
Combinaison anté/post

Motivation

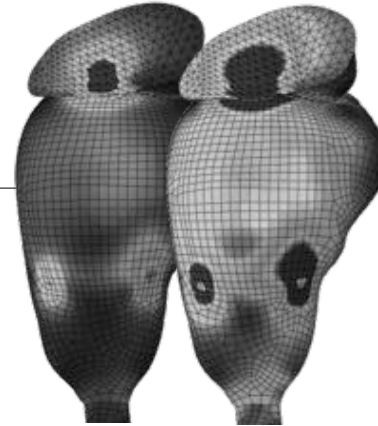
Numerical simulations to understand the influence of :

- anterior, posterior or coupled configurations,
- mesh size
- number of vaginal wall suture



Step #1

Comparison of pelvic organ mobility

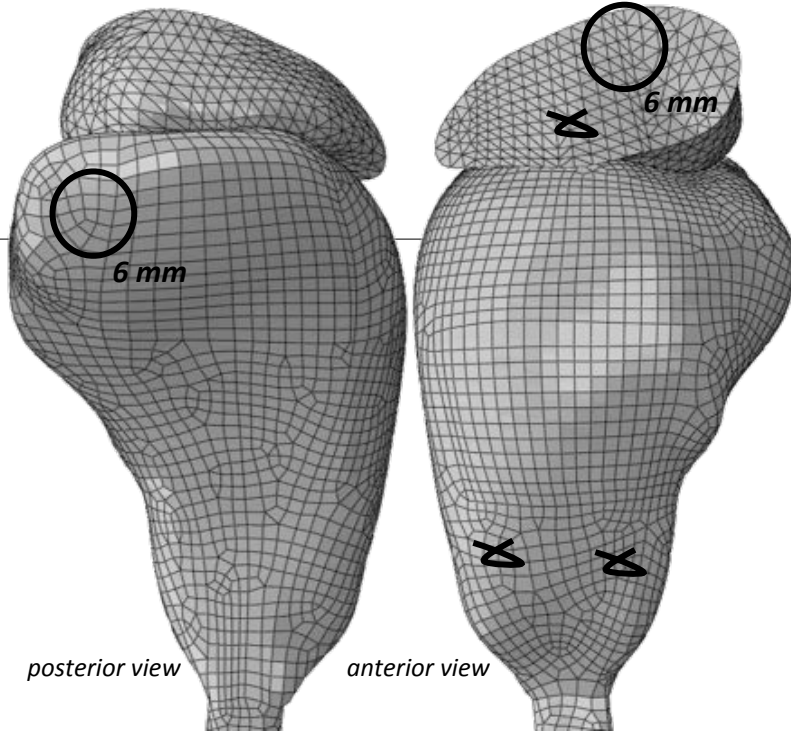


Step #2

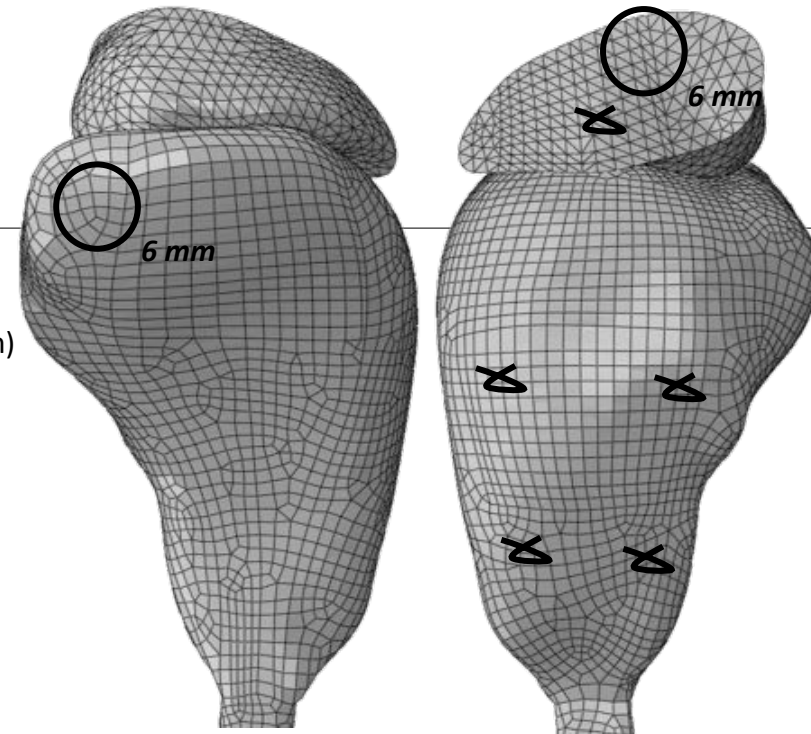
Analysis of suture stress

Comparison of pelvic organ mobility

Large Anterior Mesh (LAM3)
3 sutures



Large Anterior Mesh (LAM5)
5 sutures



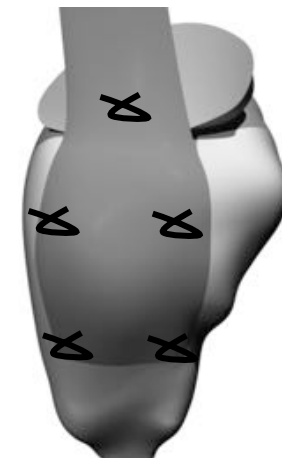
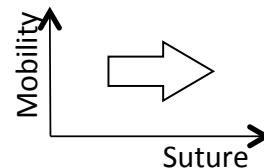
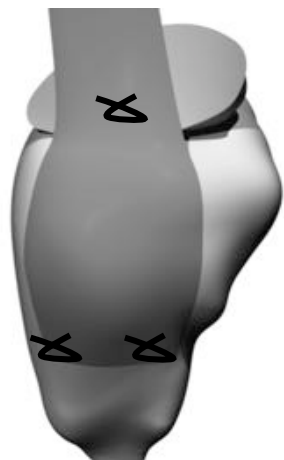
Displacement (mm)

- 12mm
- 10mm
- 8mm
- 6mm
- 4mm
- 2mm
- 0mm

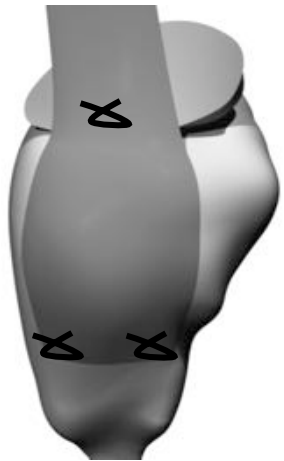
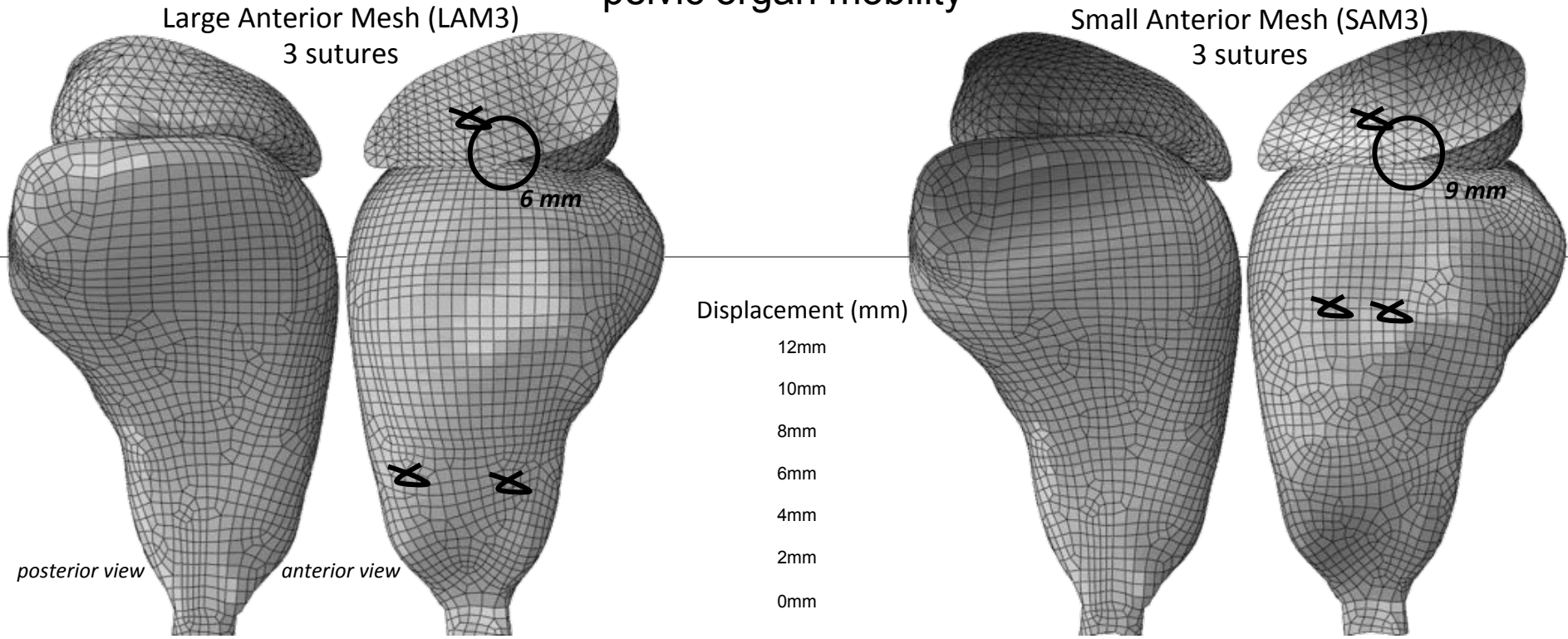
Observations

Equivalent displacements on the vaginal wall and cervix.

Suture number on the vaginal wall = no influence of the pelvic organ mobility (same loading condition and mesh type)



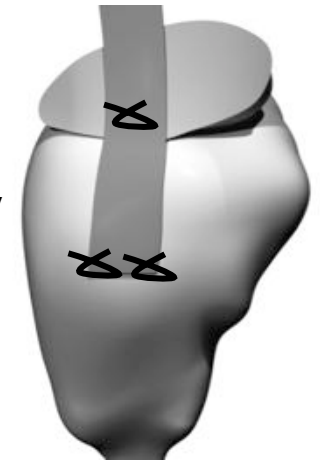
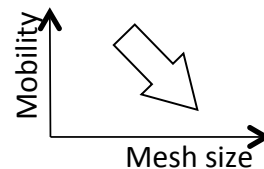
Comparison of pelvic organ mobility



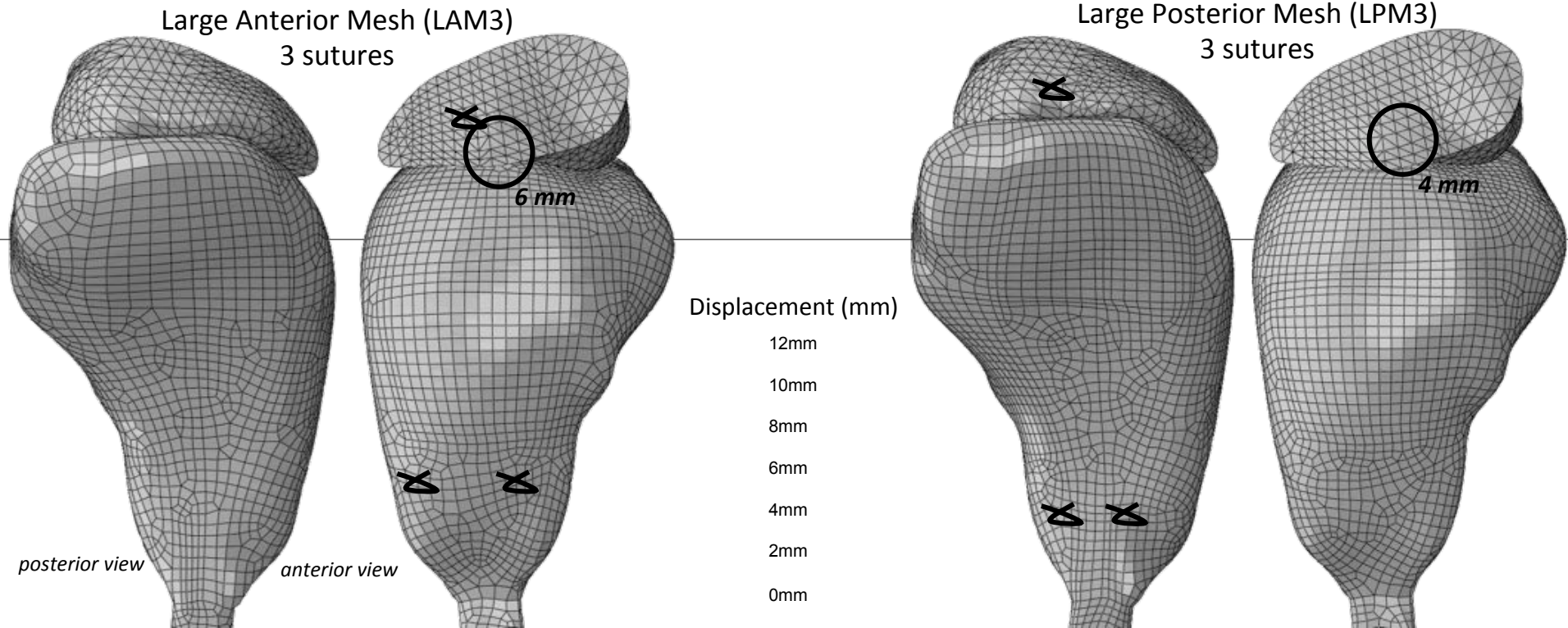
Observations

Increase of pelvic organ mobility with a small anterior mesh compared to a large one. 50% gap between the 2 configurations on the cervix displacements.

A largest mesh with spaced suture (better distribution) seems to reduce the vagina mobility



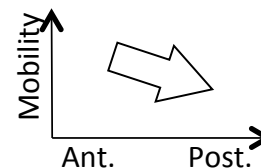
Comparison of pelvic organ mobility



Observations

Reduce mobility with a posterior mesh compared to an anterior one.
30% gap between the 2 configurations on the cervix displacements
(LAM 6mm / LPM 4mm)

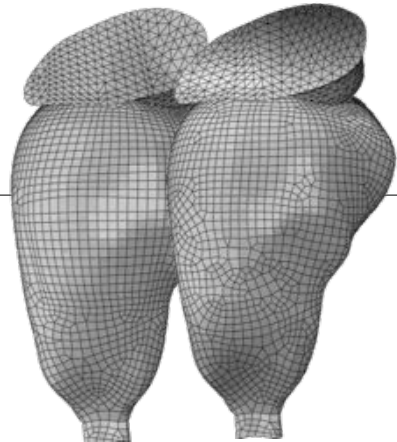
A posterior mesh seems to reduce the vagina mobility compared to anterior mesh
(same loading condition and size type).



Motivation

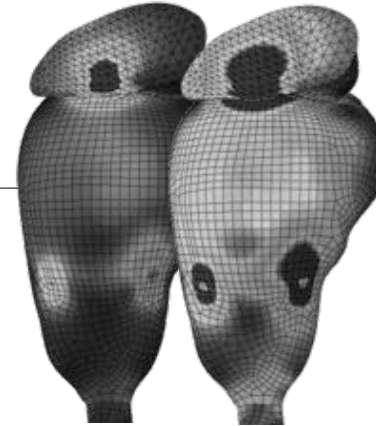
Numerical simulations to understand the influence of :

- anterior, posterior or coupled configurations,
- mesh size
- number of vaginal wall suture



Step #1

Comparison of pelvic organ mobility



Step #2

Analysis of suture stress

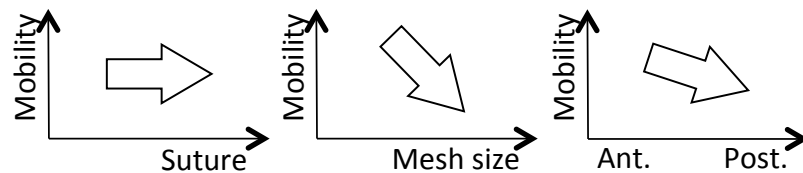
Conclusions

- No effect of the suture number

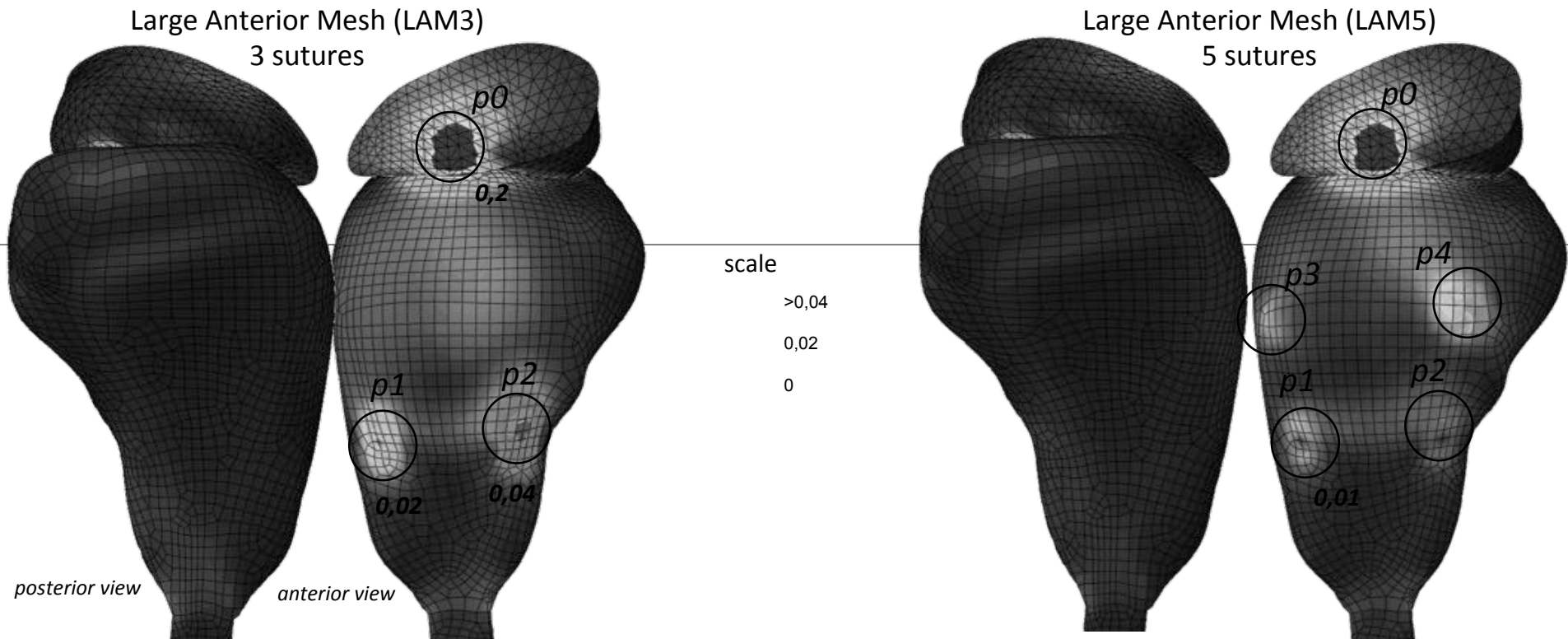
To reduce vaginal displacement

- Prefer large mesh compared to small one

- Relative influence of anterior or posterior mesh

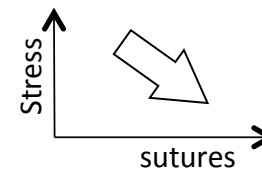


Analysis of suture stress



Observations

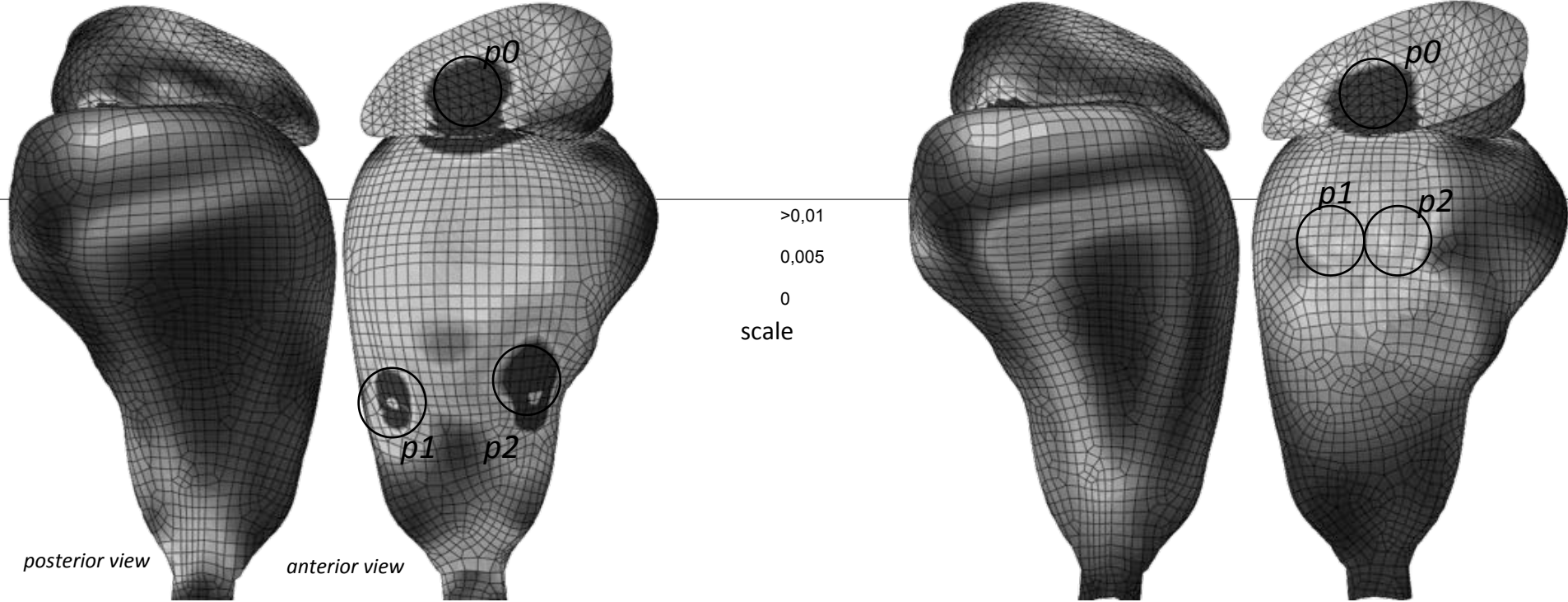
- stress is more important on the cervix suture
10x higher than the vaginal wall sutures
- Diminution of stress on the vaginal wall with added sutures
improvement of stress distribution (-40% max value)



Analysis of suture stress

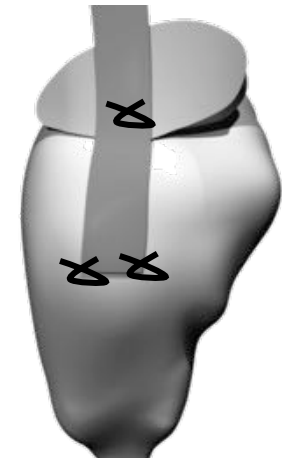
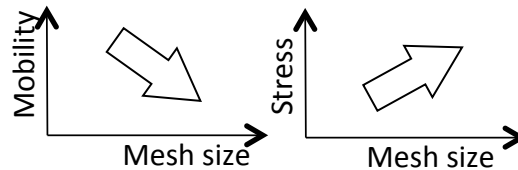
Large Anterior Mesh (LAM3)
3 sutures

Small Anterior Mesh (SAM3)
3 sutures



Observations

- The stress on vaginal wall is more important with a large mesh than small one.
decrease of 83% with SAM compared to LAM.
- The previous results show an increase of organ Mobility with a small mesh.
= It maintains more with large mesh = stress increase.



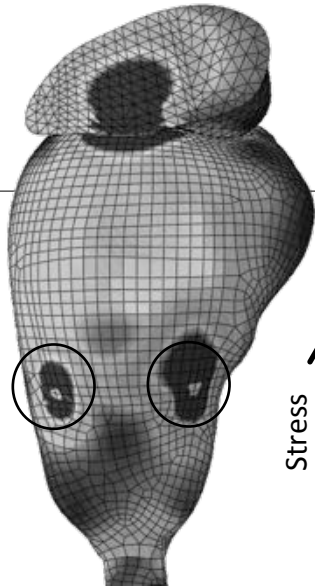
Analysis of suture stress

scale

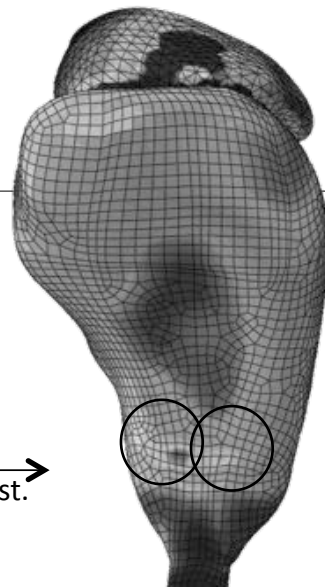
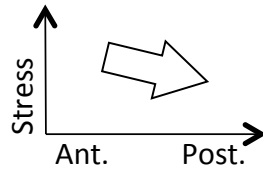
>0,01

0,005

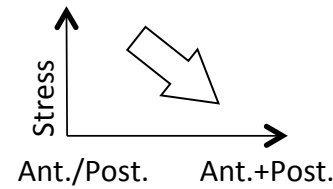
0



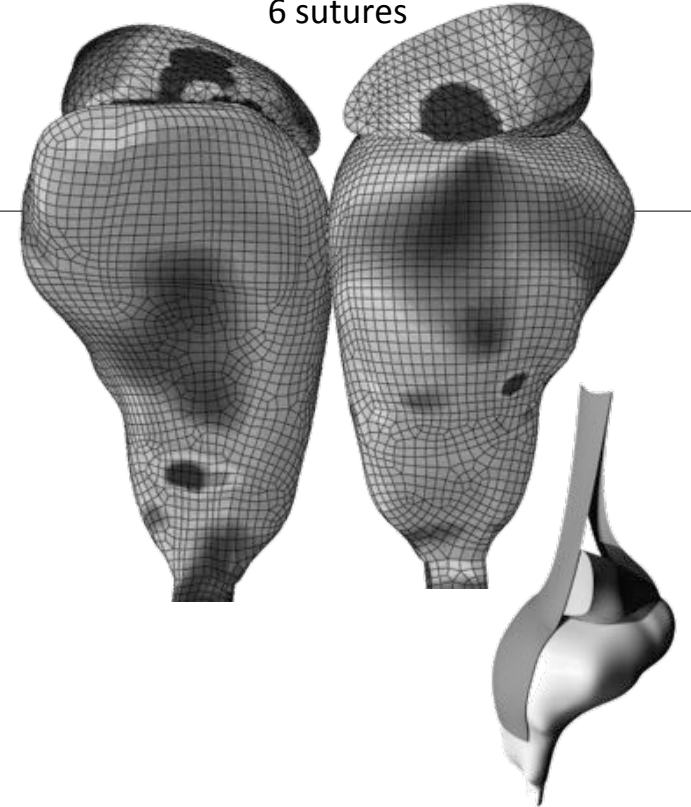
Large Anterior Mesh (LAM3)
3 sutures



Large Posterior Mesh (LPM3)
3 sutures



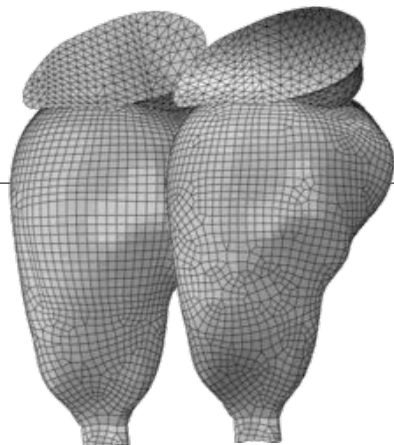
Merge configuration (Large Mesh)
6 sutures



Motivation

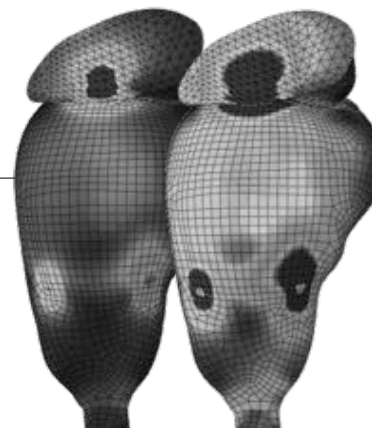
Numerical simulations to understand the influence of :

- anterior, posterior or coupled configurations,
- mesh size
- number of vaginal wall suture



Step #1

Comparison of pelvic organ mobility



Step #2

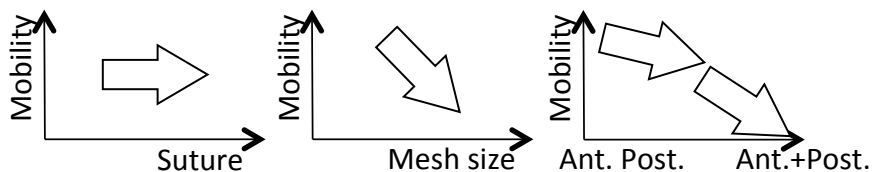
Analysis of suture stress

Conclusions

- No effect of the suture number

To reduce vaginal displacement

- Prefer large mesh compared to small one
- Relative influence of anterior or posterior mesh

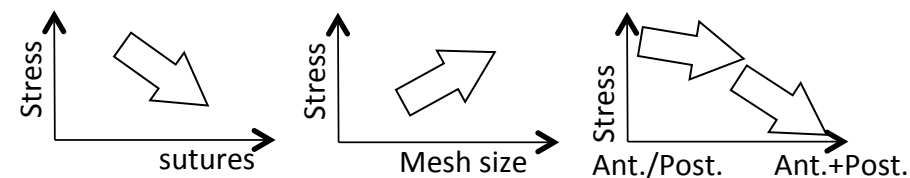


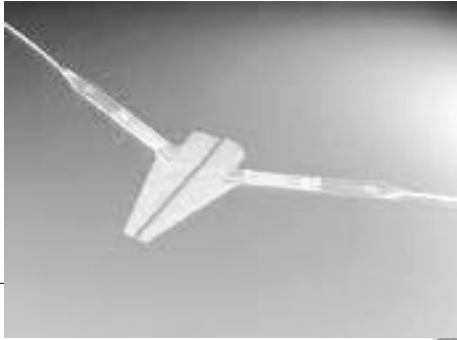
Conclusions

- Stress on cervix suture is higher than vaginal wall ones
- Added sutures reduce stress on vaginal wall

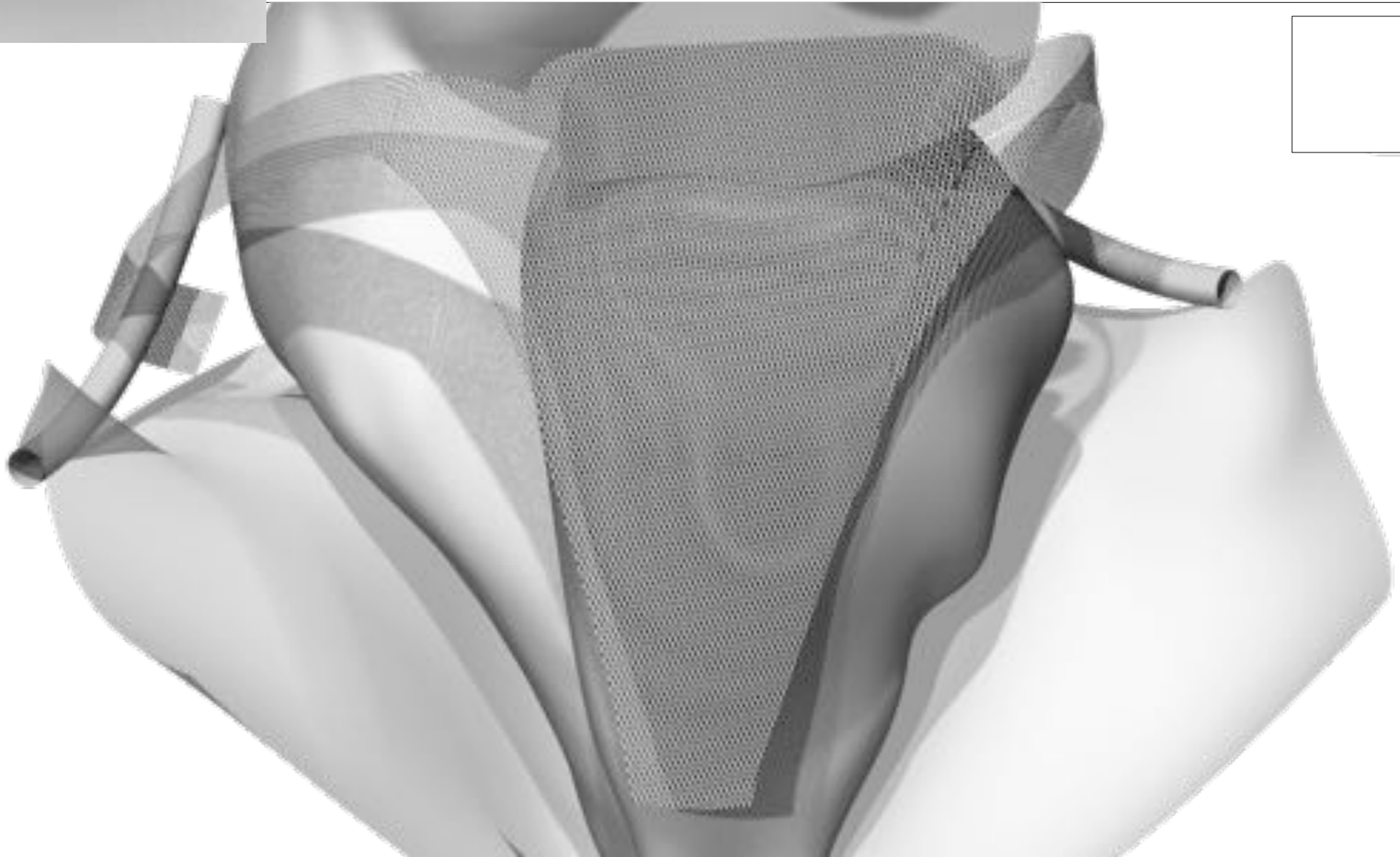
- Stress is higher with large anterior or posterior mesh (configuration with 3 sutures)

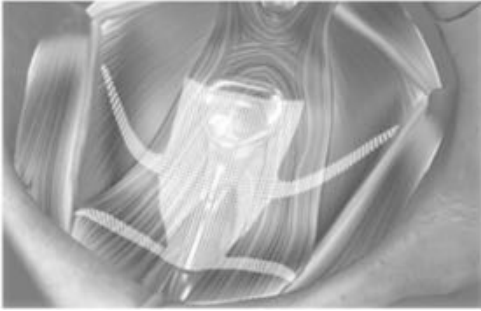
- Coupled configuration reduced the suture stress



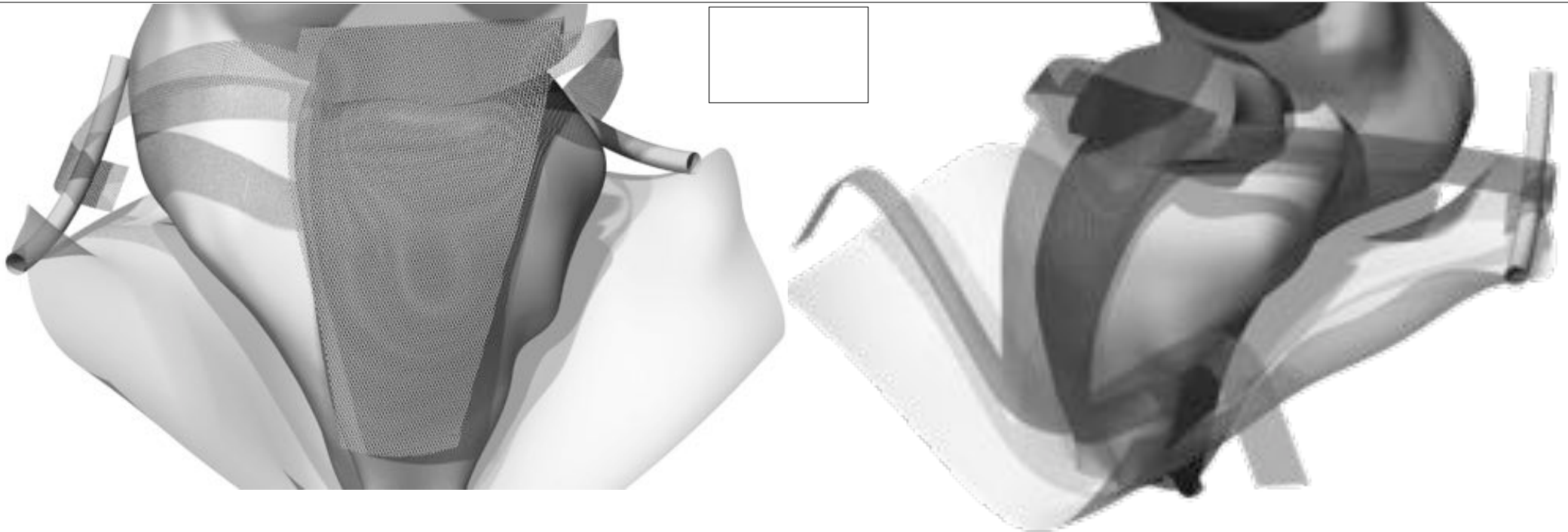


Etude en cours
modélisation de bandelette de type « uphold »



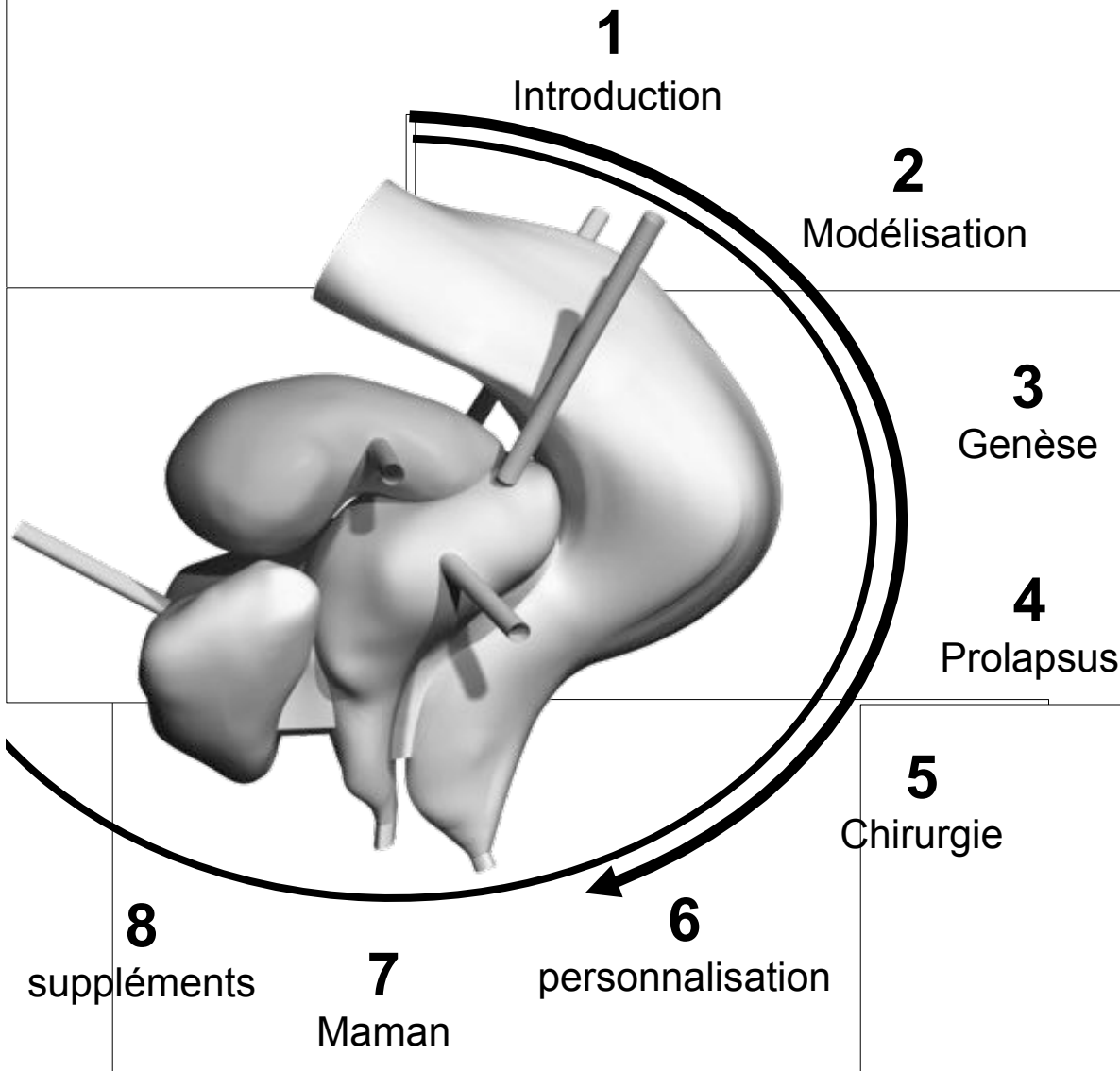


Etude en cours
modélisation de bandelette de type « elevate »

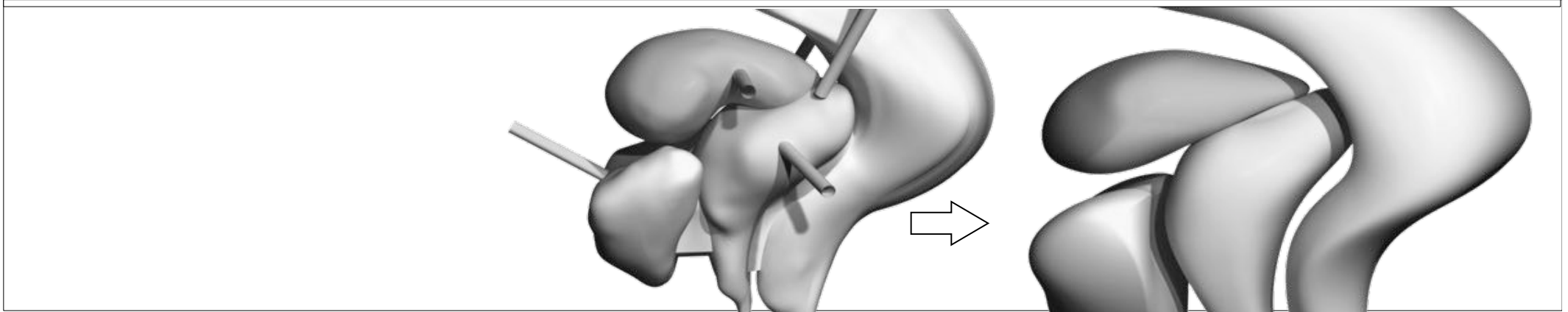




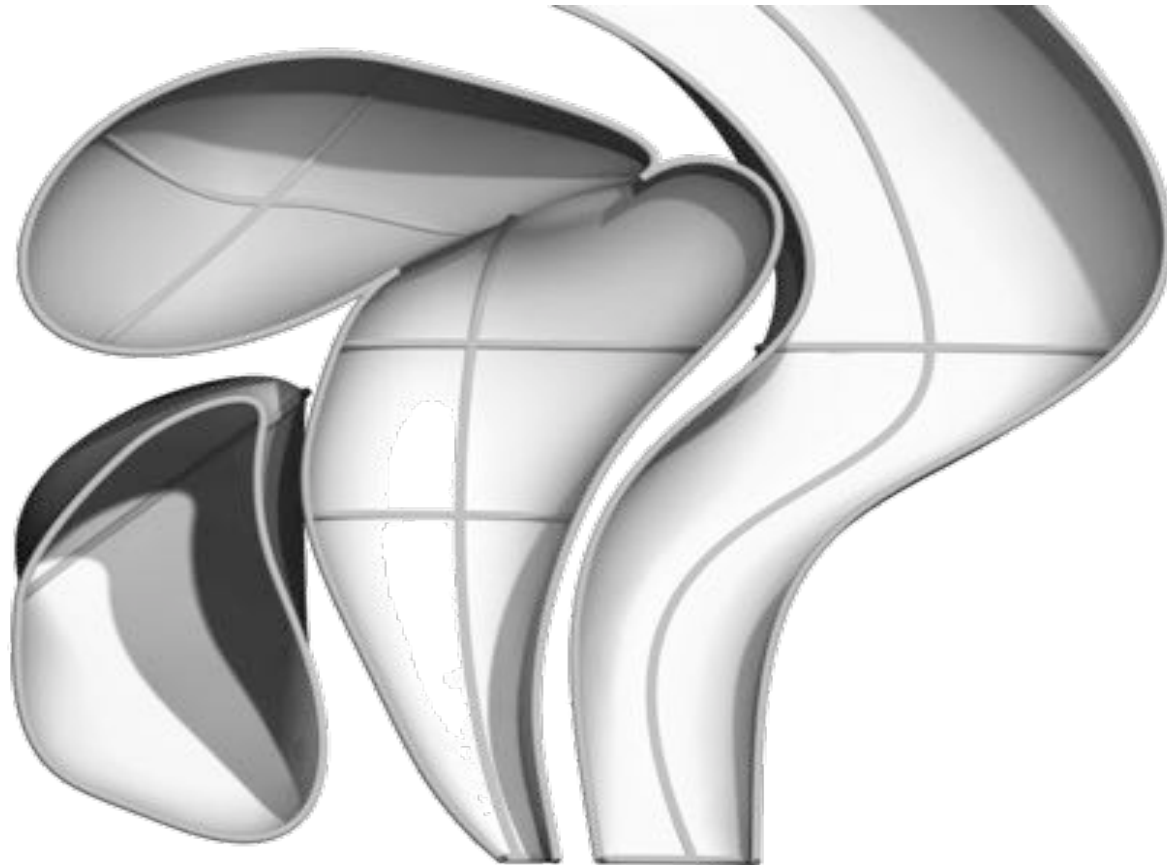
ReClip UE3 - Vendredi 07 novembre 2014 – 17h00/18h00
Applications des modèles biomécaniques pelviens
P. Michel COSSON, **Olivier MAYEUR**



Question
Est-il possible d'améliorer les interventions chirurgicales grâce à nos connaissances en biomécanique?

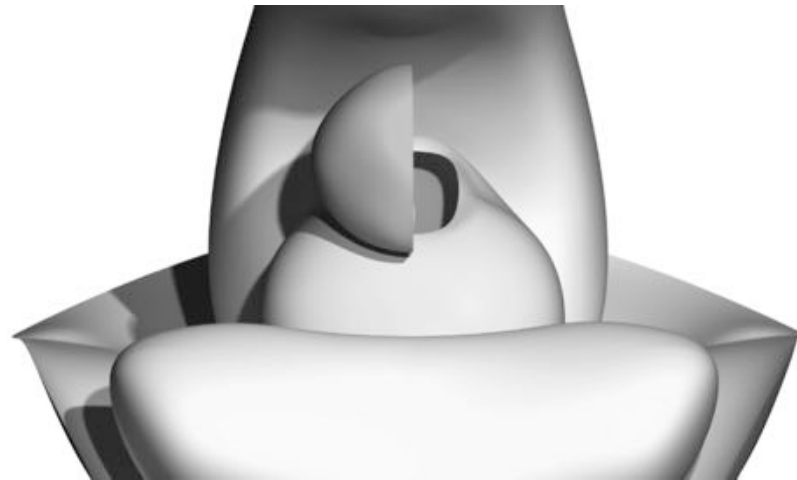
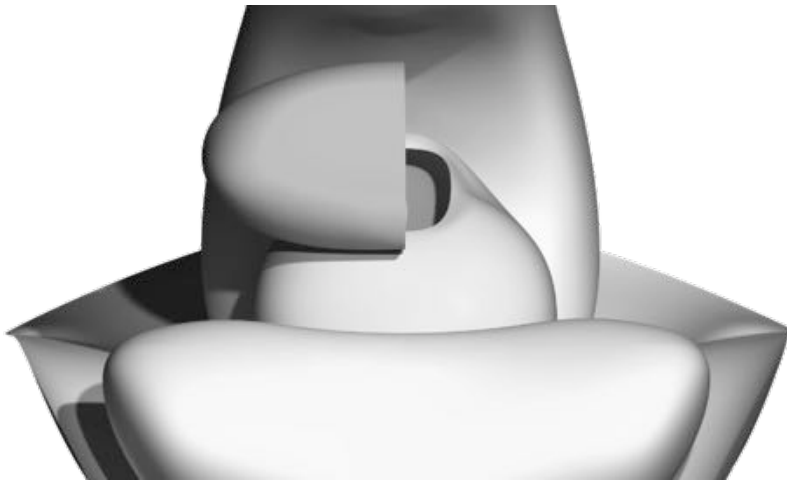
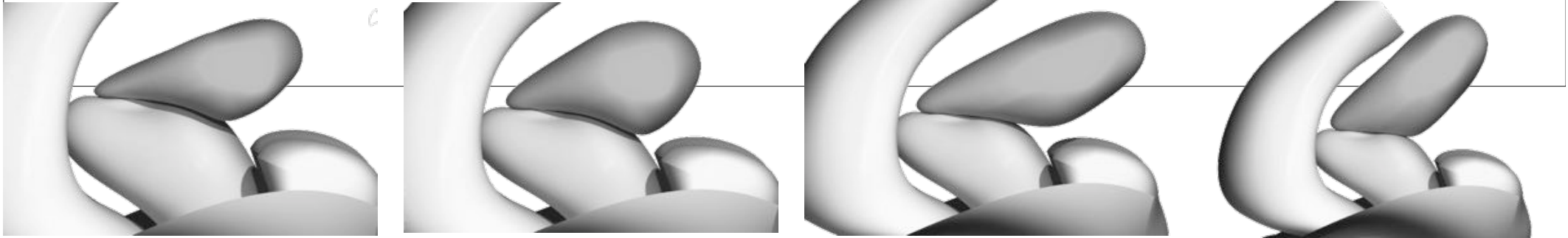


Pouvons nous appliquer ce type d'outils à chaque patiente? Comment?



6 Modèle personnalisé

Exemple de personnalisation de l'utérus

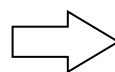


8 Suppléments

Introduction

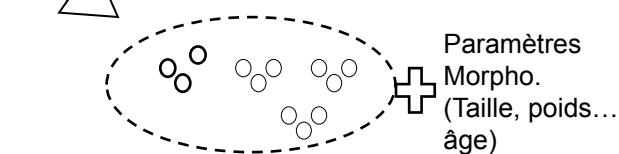
5 mesures

- PRP Distance proéminence-rétro-pulsion
- TM Distance transversale médian
- TM_{max} Distance transversale maximum
- SC Distance sacro-cotyloïdien
- θ_{sp} Angle euro-pulsion

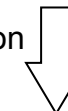


- PRP 112,7 mm
- TM 116,7 mm
- TM_{max} 120,9 mm
- SC 73,4 mm
- θ_{sp} 112,6°

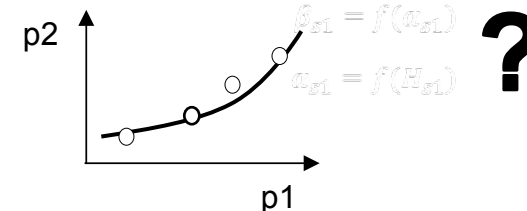
Base de données (x sujets, p)



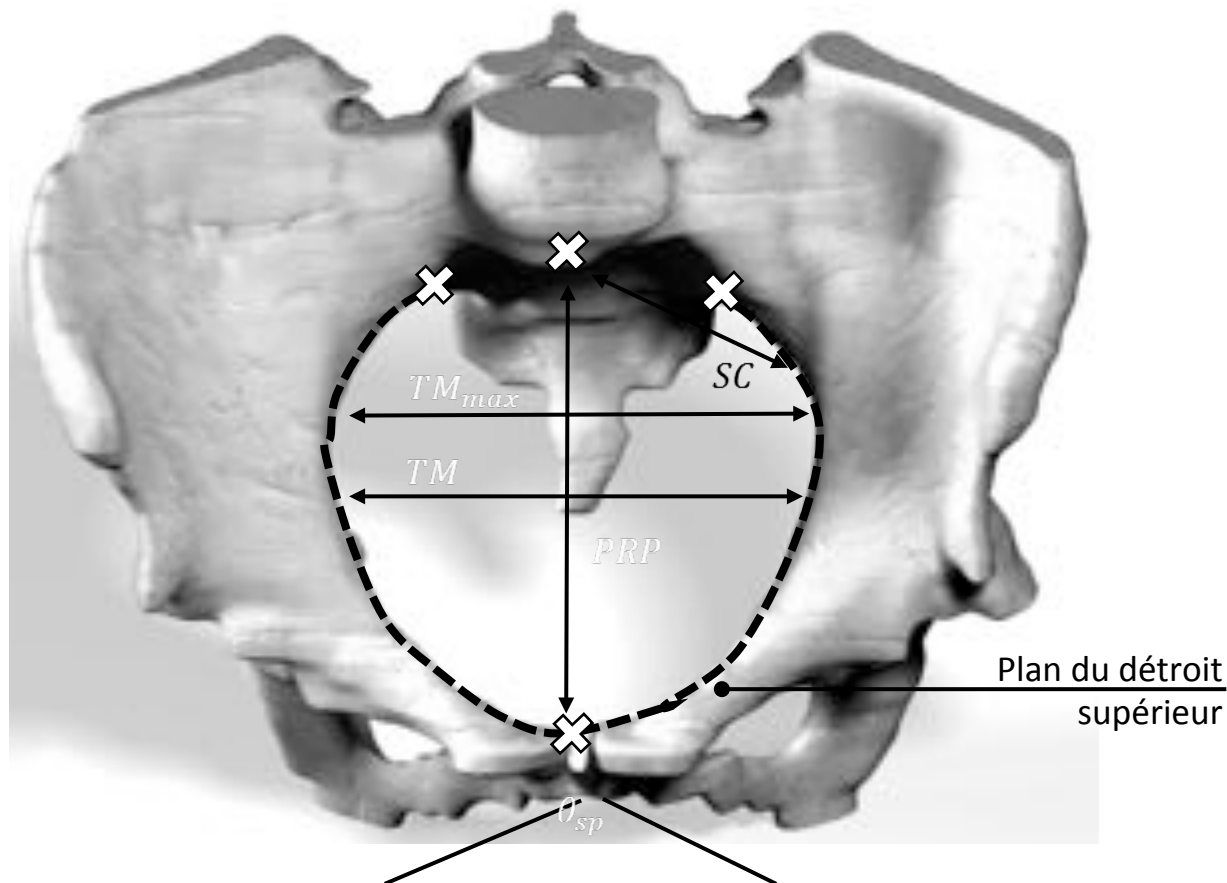
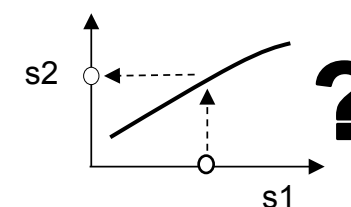
Matrice de corrélation



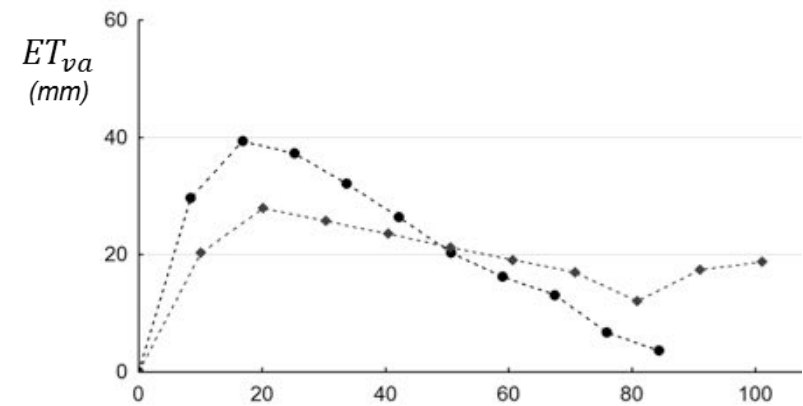
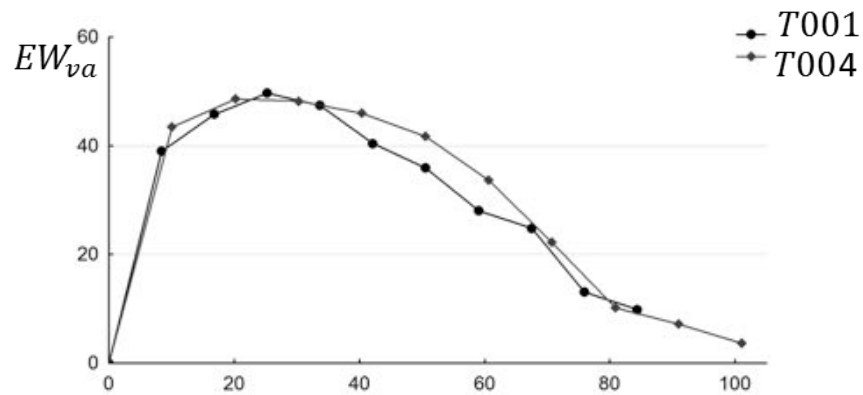
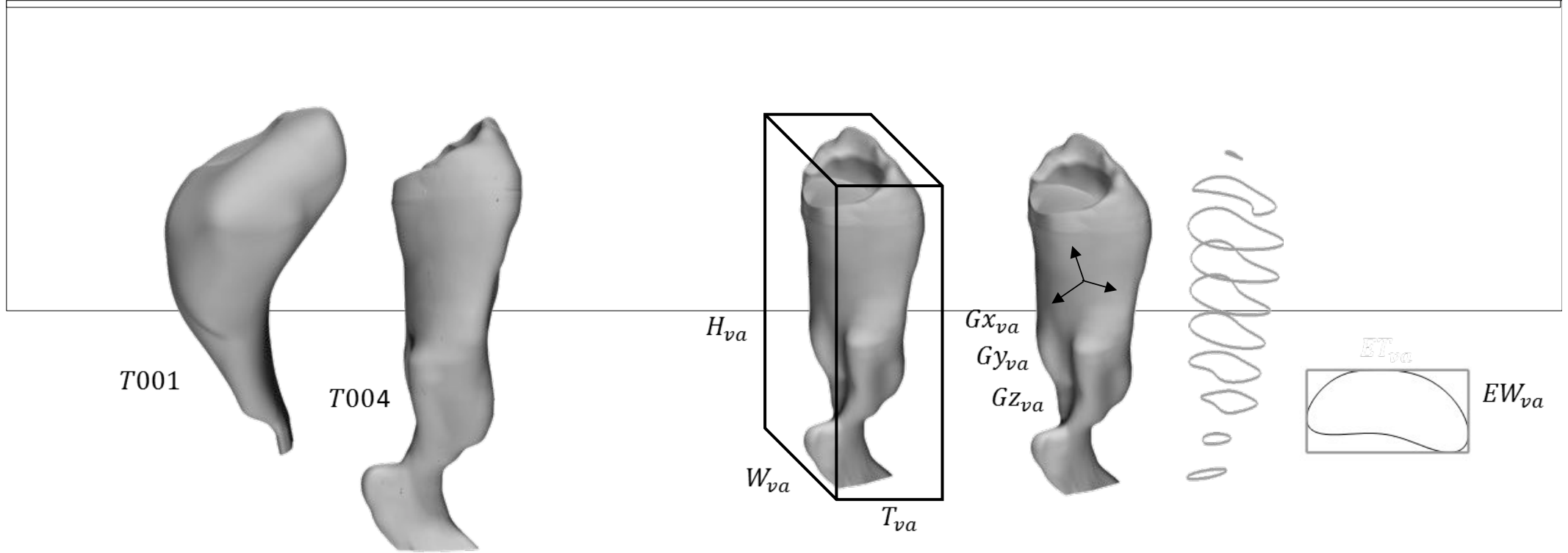
Relation intra-individuelle



Relation interindividuelle



Kamina, P.: Anatomie Clinique, To. 4, Paris: Maloine (2008)

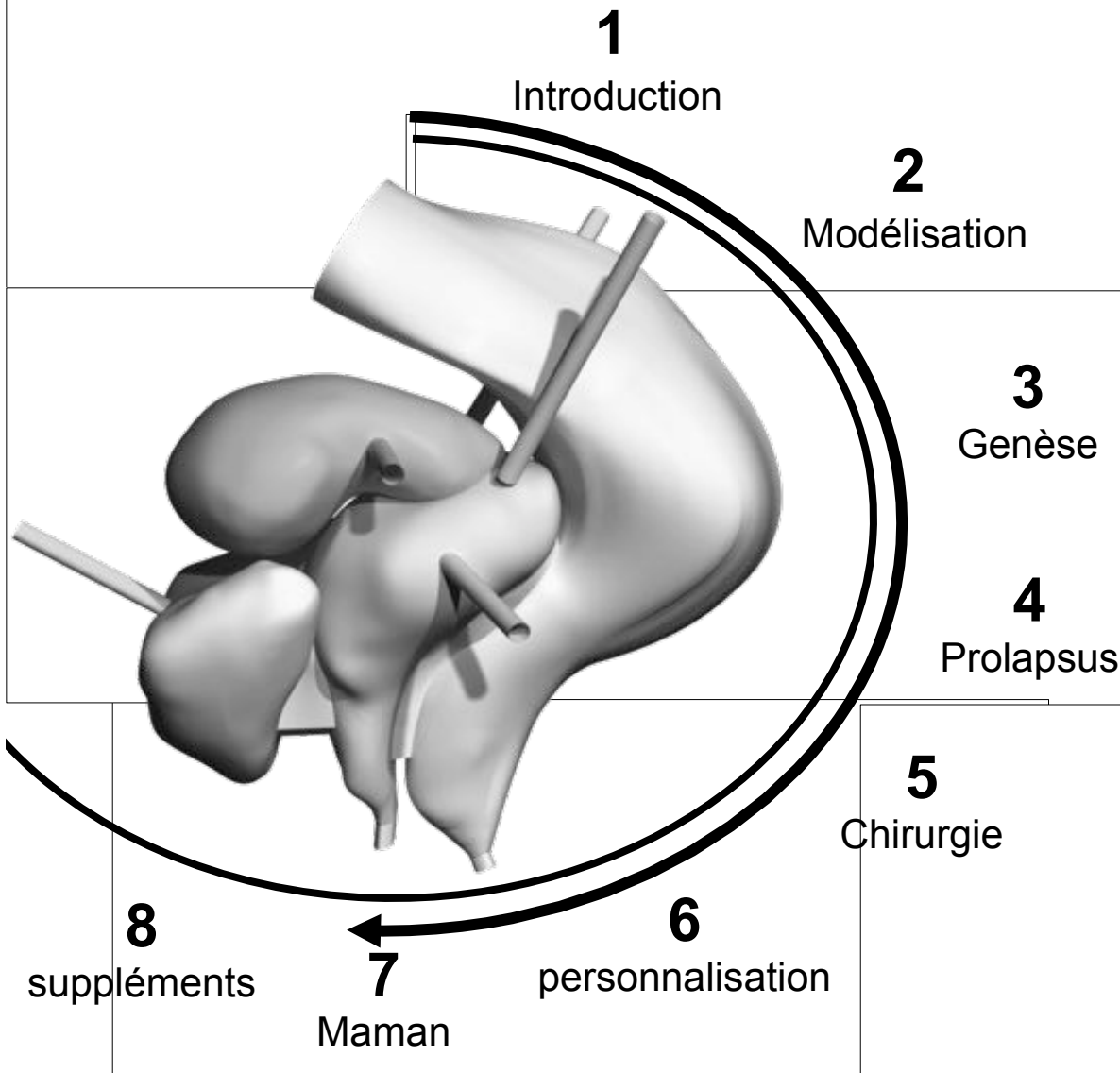


Première tendance: la largeur du vagin semble similaire
 Evolution fixe de la grand rayon de l'ellipse
 Possibilité de paramétré en fonction de la taille du vagin, sujet... (Augmenter cohorte)

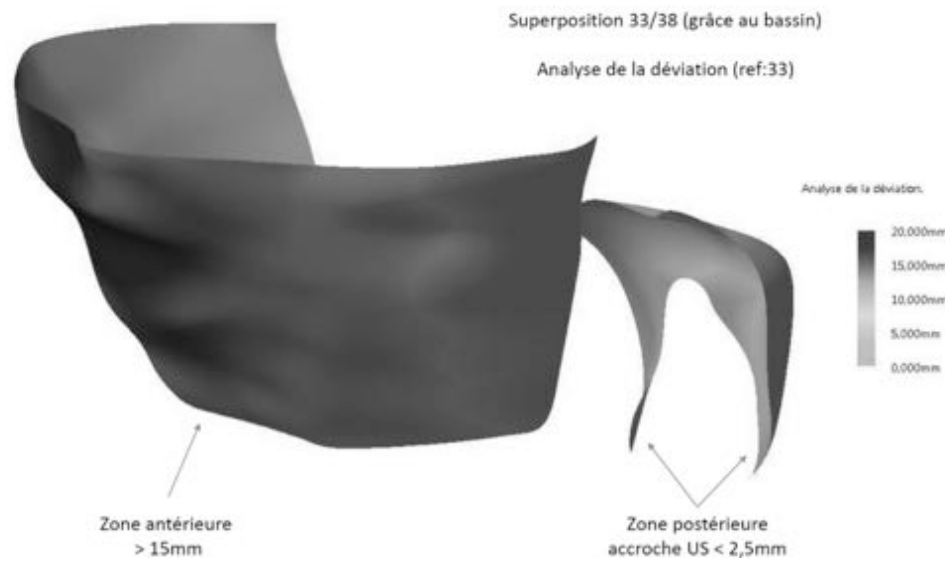
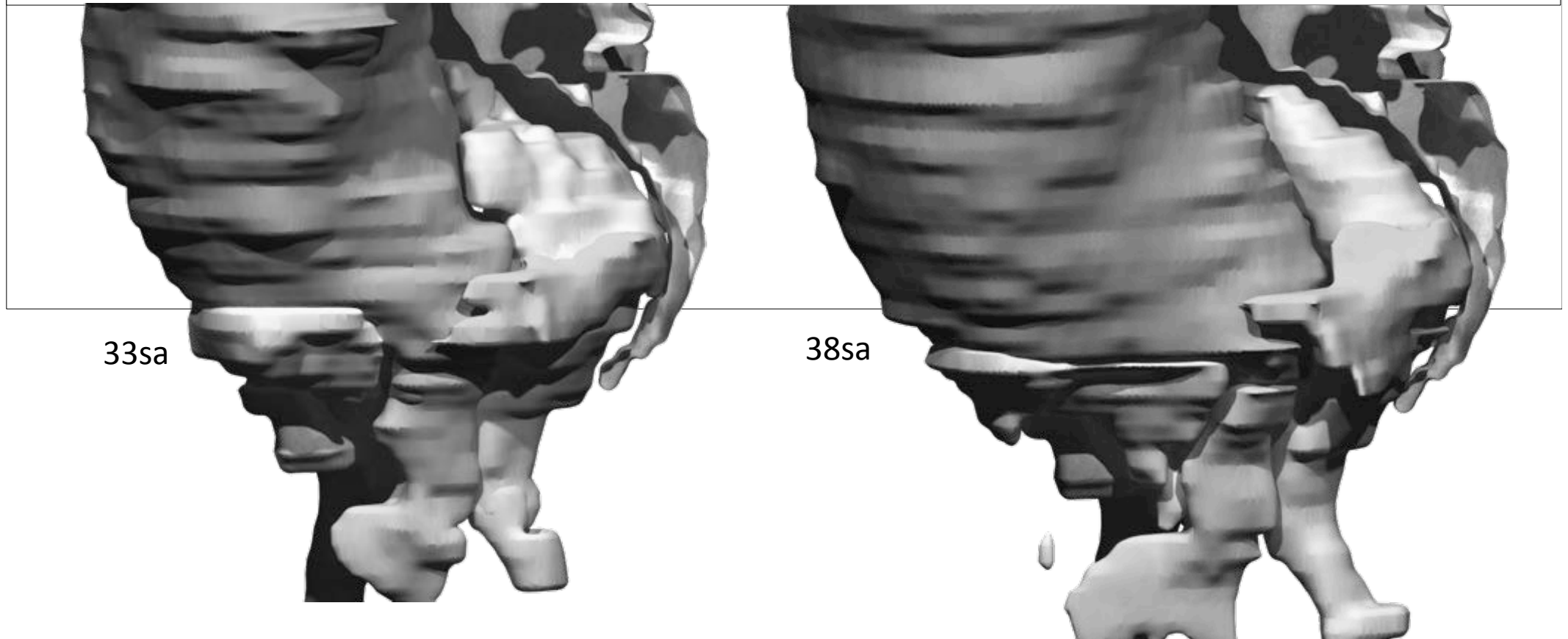
Résultats éloignés
 Voir pour normaliser suivant la longueur (%)



ReClip UE3 - Vendredi 07 novembre 2014 – 17h00/18h00
Applications des modèles biomécaniques pelviens
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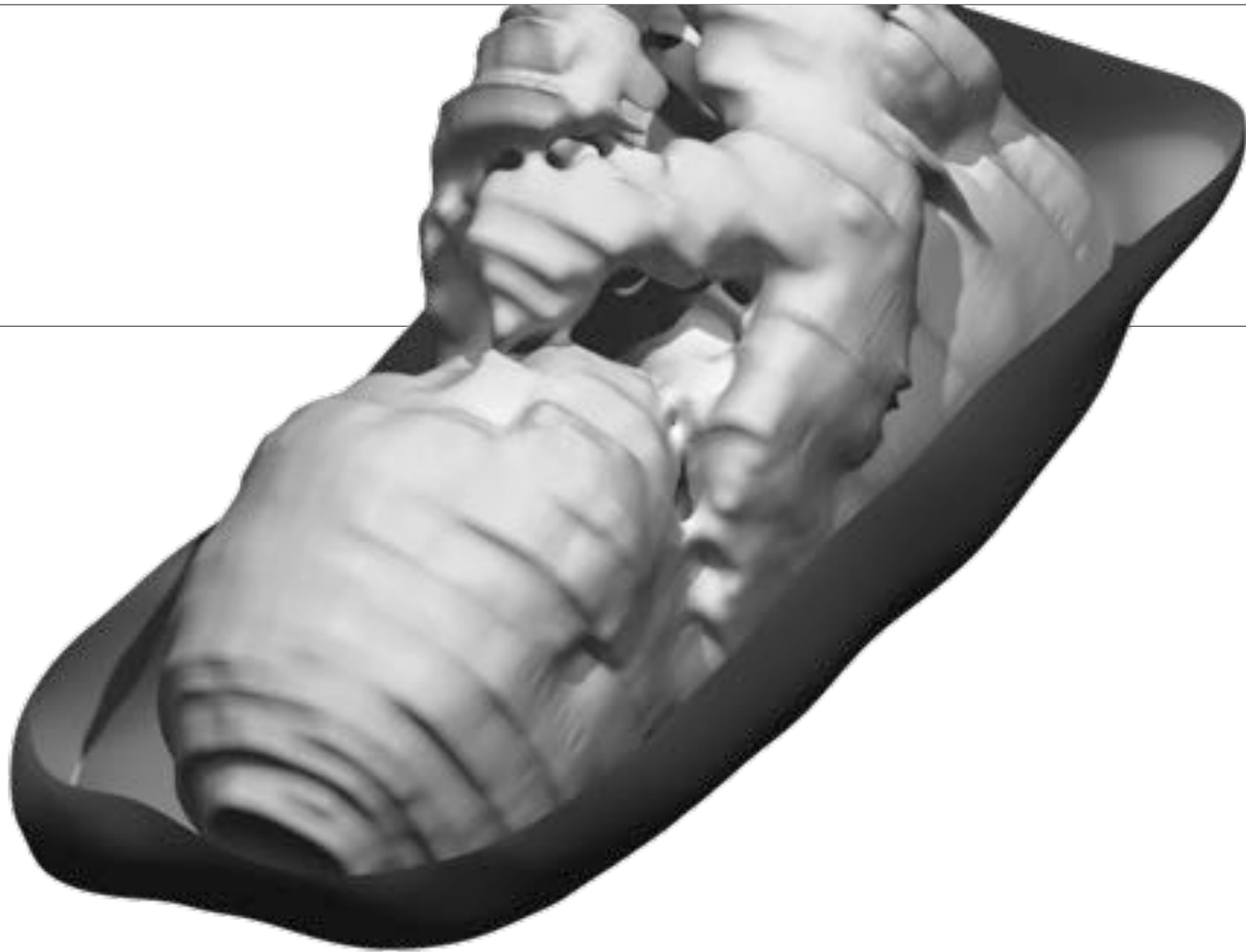
Question
*Pouvons nous appliquer ce type d'outils
à chaque patiente? Comment?*

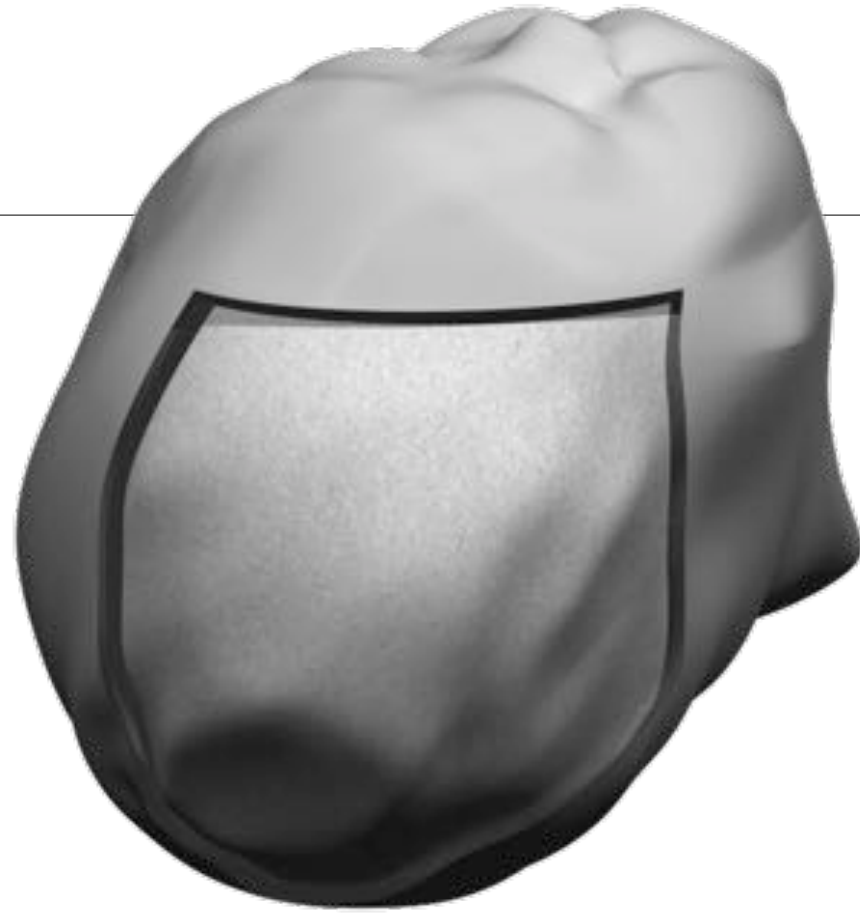
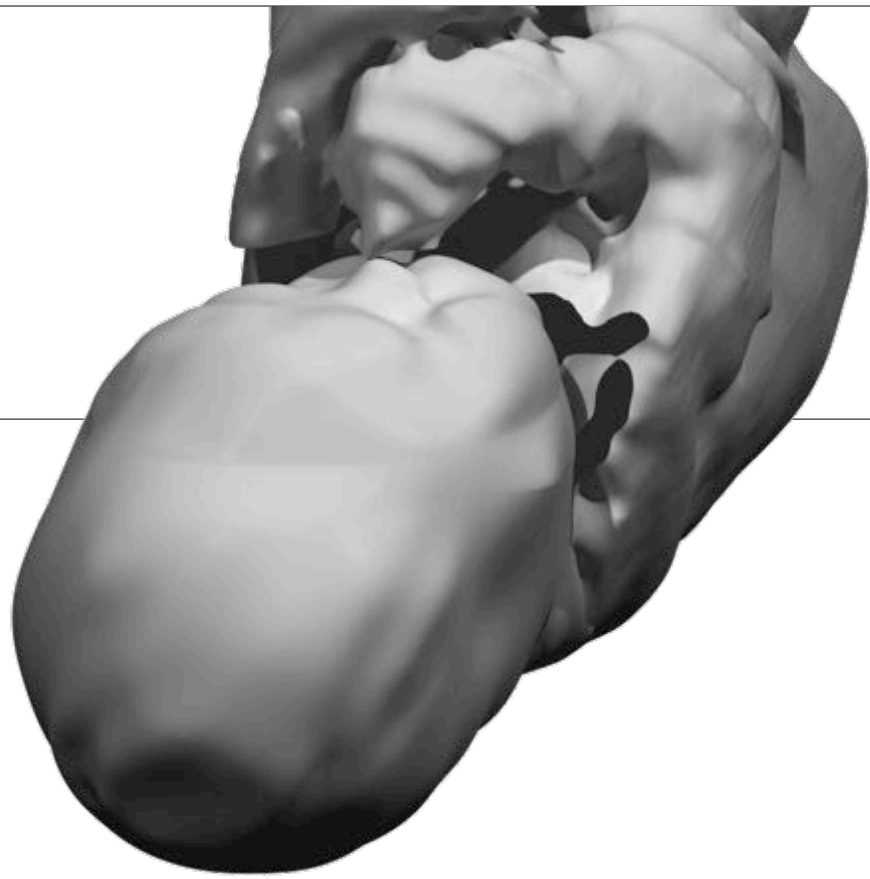
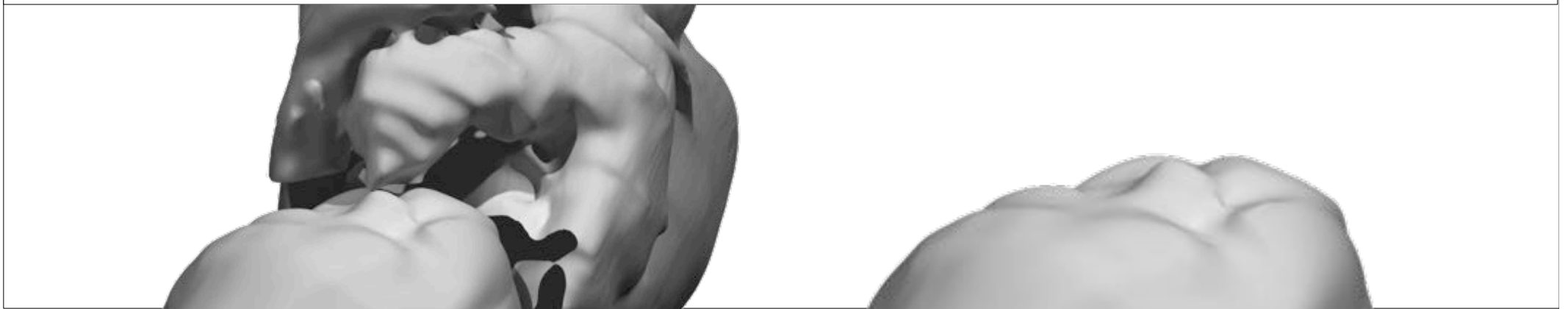


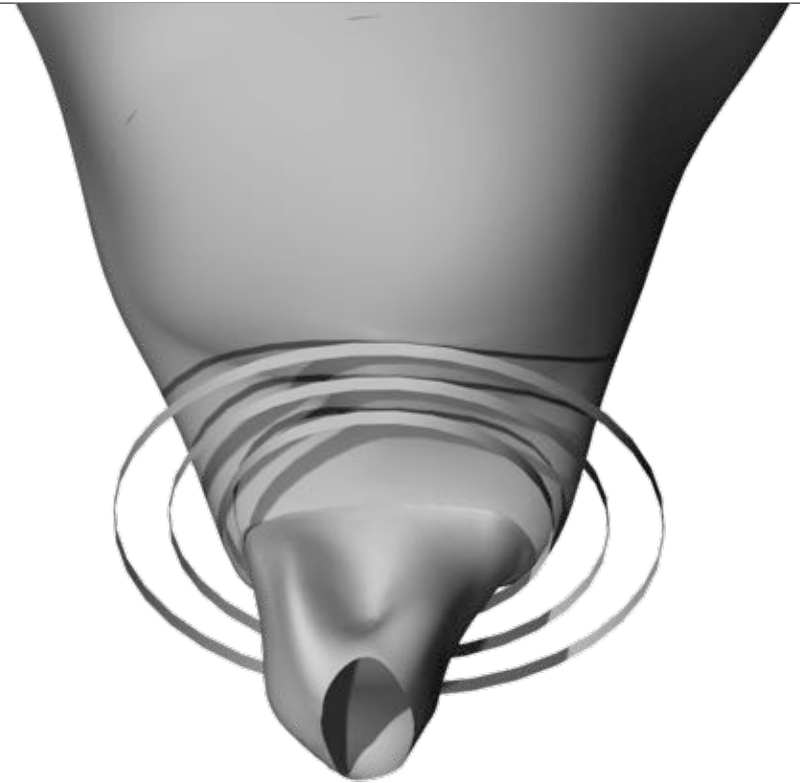
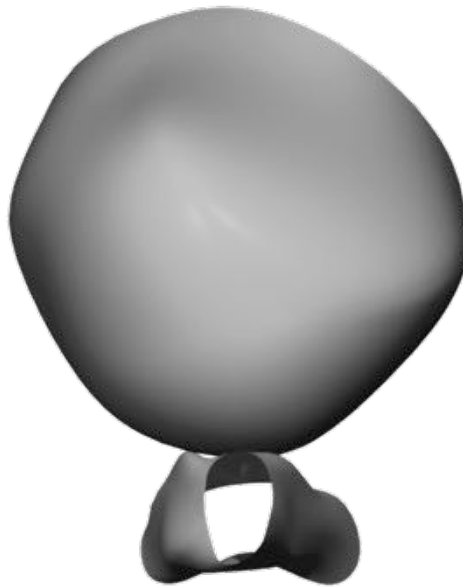














ReClip UE3 - Vendredi 07 novembre 2014 – 17h00/18h00
Applications des modèles biomécaniques pelviens
P. Michel COSSON, **Olivier MAYEUR**

*Protocole de reconstruction adapté
Maillage Eléments Finis paramétré*

*Modèle EF dédié à la compréhension des
mobilités du système pelvien*

*Analyse du système ligamentaire
Fonction/rôle des utéro-sacrés*

*Cystocèle médiane et latérale
Meilleure compréhension des causes
Influence de la géométrie et des
matériaux sur les mobilités*

*Chirurgie: Mobilité en fonction du nombre de
point de sutures, taille des bandelettes, type
d'opération...*

*Comparaison des contraintes aux sutures en
fonction de ces mêmes paramètres*

*Travaux en cours concernant la
personnalisation géométrique et mécanique du
système pelvien*

(7 Maman)
Simulation de l'accouchement