



Pregnant Woman Model to Understand Injury Mechanisms in Case of Frontal Impact

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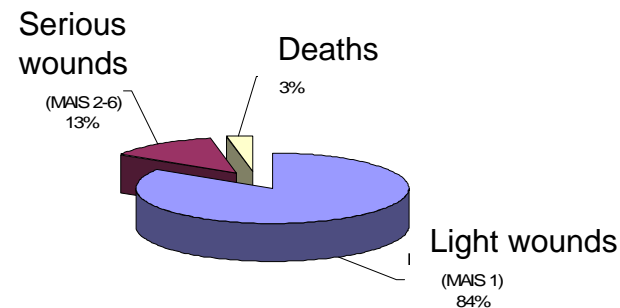
**Service de Gynécologie-Obstétrique, Hôpital Archet 2, 06202 Nice, France



1. Study context

Road Safety for pregnant women - Situation

- No Predictive Score, no Decision Algorithm
- More foetal loss than child aged 0-4 deceased during the same period*
- In the Rhône district, 302 road accidents involving pregnant women in the last decade



*Pearlman et al., 2000



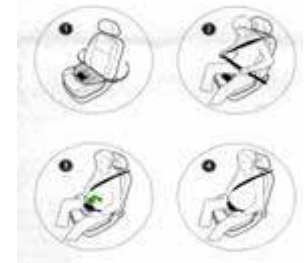
1. Study context

Road Safety for pregnant women - Situation

- Example of specific safety system

Validated with pregnant versions of ATD

Validation criteria : no negative effect on safety belt



- Existing Validation Tools (5th percentile Pregnant Women Models)



Undirect validation

Injury Mechanisms Analysis made difficult

Moorcroft et al.

Volvo Model

Acar and Van Lopik



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Study Objectives

- Development of a numerical model adapted for
 - injury mechanisms analysis
 - objective injury risk evaluation with biofidel uterus environment
- Direct validation with experimental crash tests
 - PMHS approach

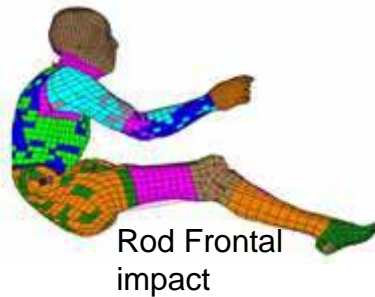
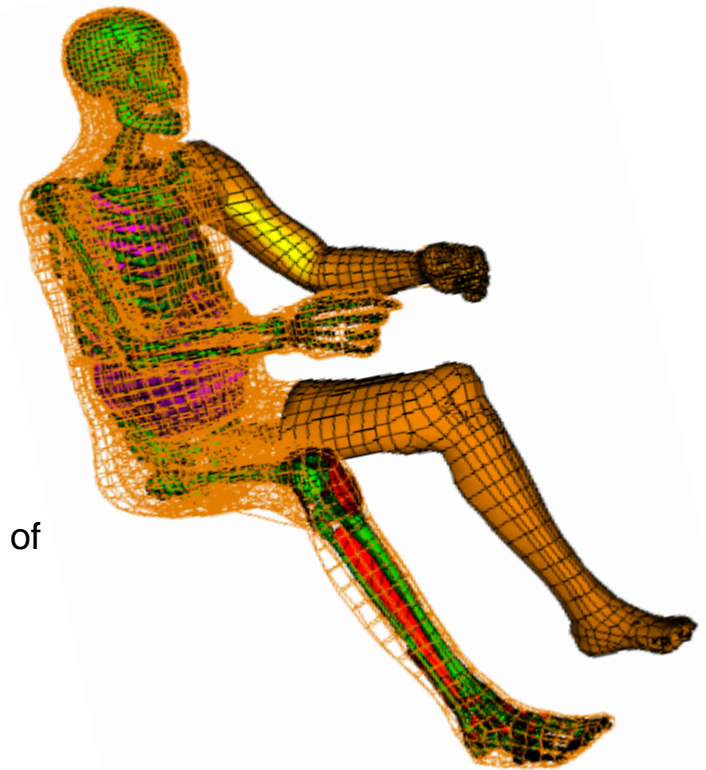




2. Numerical model Development

FE Human Body Initial Model

- The Radioss® HUMOS model
 - EC funded project (Coordinator: LAB PSA-Renault)
 - Accurate geometry definition in driving position (realistic lumbar configuration, and main soft tissues and organs)
 - Widely validated under impact conditions representative of car crash situations.



Rod Frontal impact



Oblique Abdominal impact



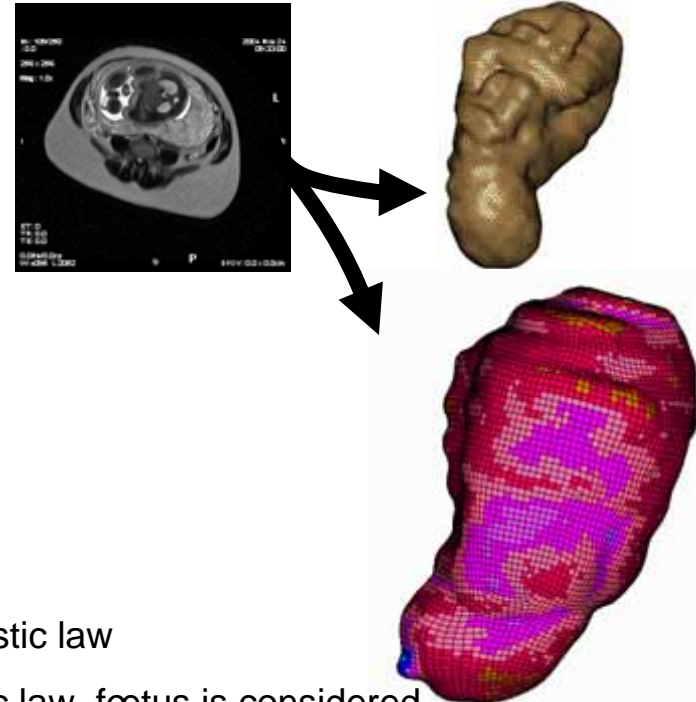
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2. Numerical model Development



Gravid Uterus

- Geometry acquisition
 - MRI images segmentation at full term
 - Uterus wall meshed with thick shells
 - Foetus and Amniotic fluid meshed with tetras
- Mechanical properties (literature)
 - Uterus Wall modeled with Kelvin-Voigt Visco elastic law
 - Ligaments and foetus are modeled with an elastic law, foetus is considered homogenous



Anatomical element	E (MPa)	ν	Viscosity coef. in pure shear	density kg/m ³
Uterus wall	0.566	0.43	20	1052
Foetus	10	0.4	x	1200
Ligaments	50	0.33	x	1000

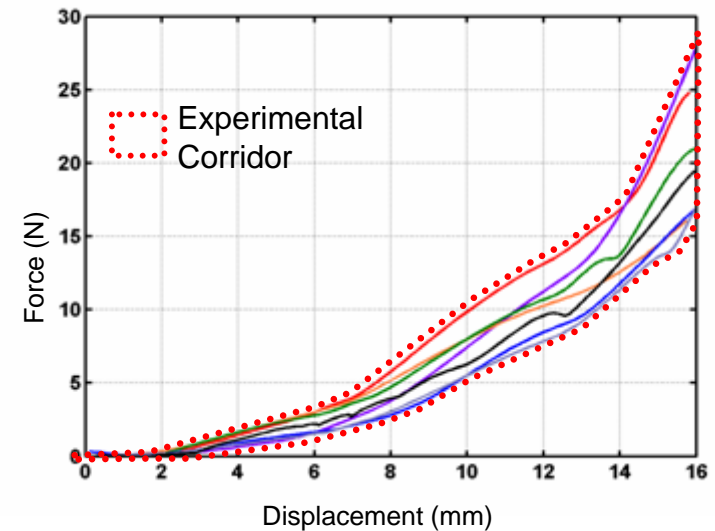
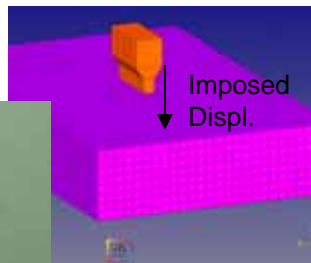
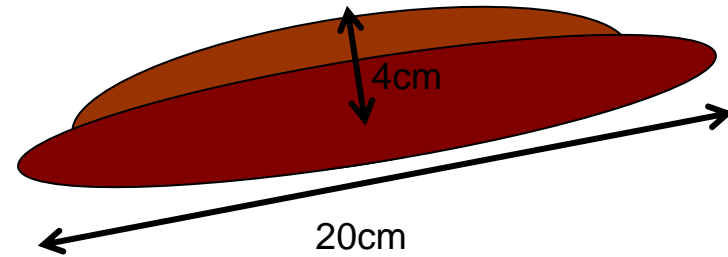


2. Numerical model Development



Placenta

- Geometry
 - generic definition (meshed with tetras)
- Indentation tests + Inverse Analysis
 - Manual indentation, 2 cycles are performed
 - Ogden hyper-elastic law is chosen for inverse analysis

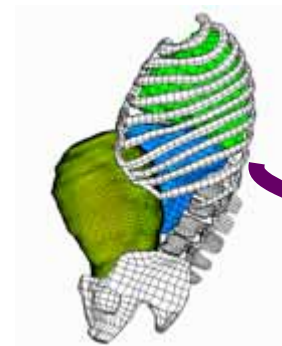


2. Numerical model Development

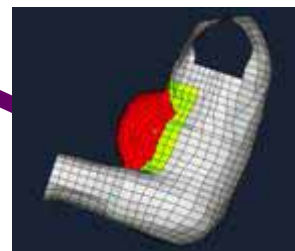
Coupling the models

• Humos model modifications

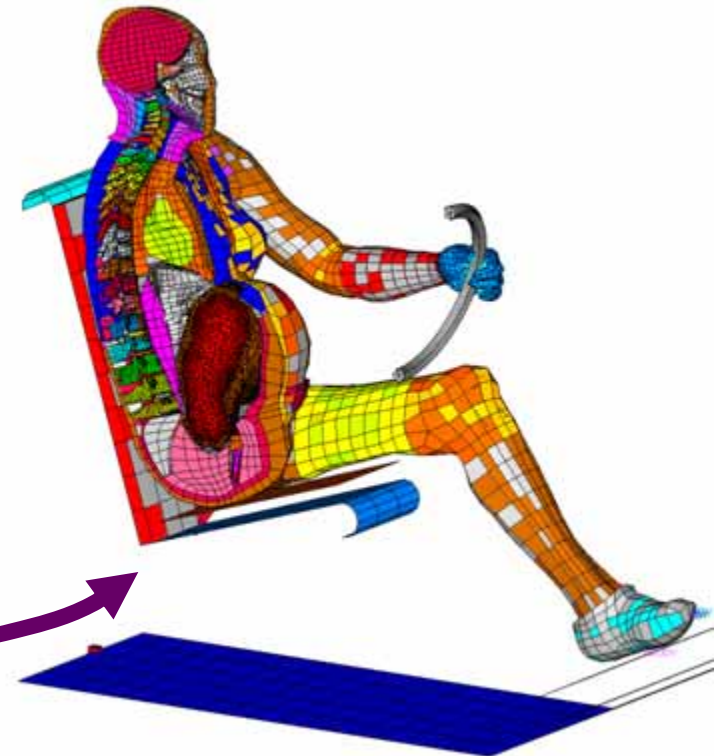
- Deformation of the thoraco abdominal anterior soft tissues
- Upward gravitation applied to abdominal organs (stomach, liver, spleen ..)
- Modification of the « Intestines » volume
- New interfaces definition between the uterus wall and its environment
- Uterus attachment modeled with utero-sacral ligaments definition



Uterus insertion



Initial Model modifications



Resulting pregnant woman model (sliced in sagittal plane)



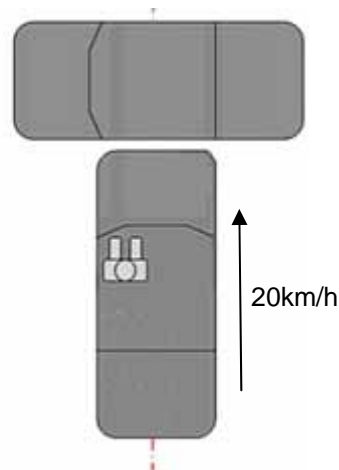
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3. Experimental tests



General protocol

- PMHS approach
 - The Pregnant woman model is a PMHS coupled to a physical gravid uterus
 - realistic mechanical environment for the gravid uterus
- Impact conditions
 - Frontal impact, 20km/h, compact cars



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3. Experimental tests



Physical Pregnant Woman Model

- Gravid Uterus
 - Silicone layer applied on a polystyren mould (geometry similar to numerical model)
 - Inclusion of a baby doll (47cm, 3kg) and model filled with water
 - Insertion in the PMHS by median laparotomy



Polystyren mould
(based on MRI previous segmentation)



layer of silicone
(SILASTIC®3481, Dow corning inc)





Instrumentation

- Sensors

3D accelerometers 50g
ENTRAN France

→on the Gravid uterus :at both extremities of
uterus, foetus

→on PMHS: Head, sternum, L5, right iliac crest

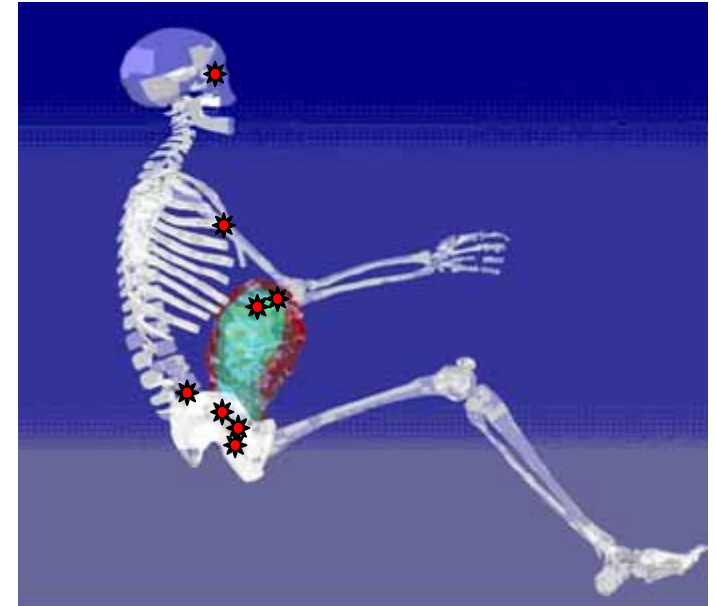
→at center of inertia of the moving car

- Computed data (uterus kinematics)

-Uterus cervix forward translation in the maternal pelvis

-Rotation of the uterus around the maternal pubis

3. Experimental tests

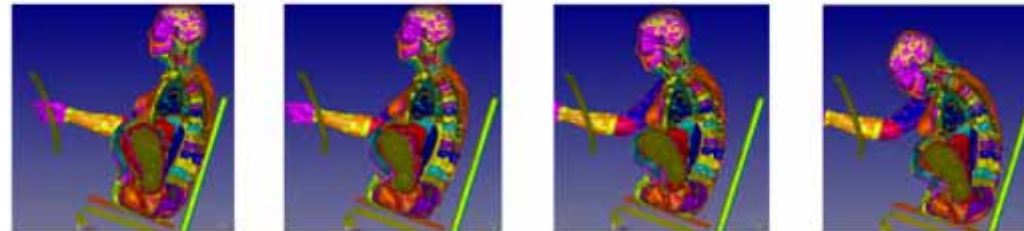


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4. Model Evaluation



Global Kinematics



0ms

50ms

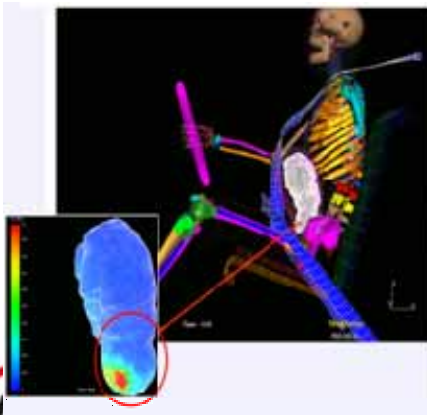
100ms

150ms

Forward shift
Abdominal belt loading
Foetus head compression

Uterus rotation
High strain level

Backward shift
Lower acceleration level

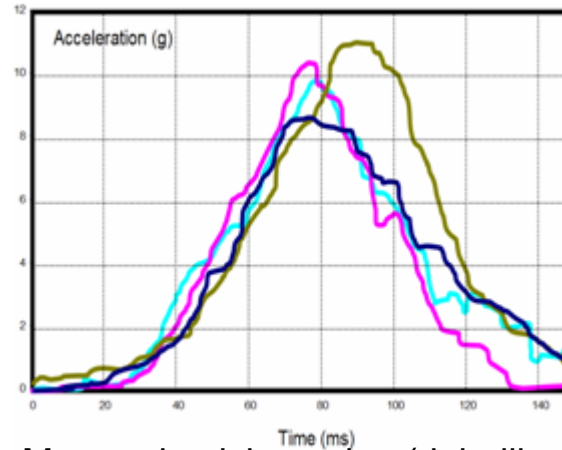


4. Model Evaluation

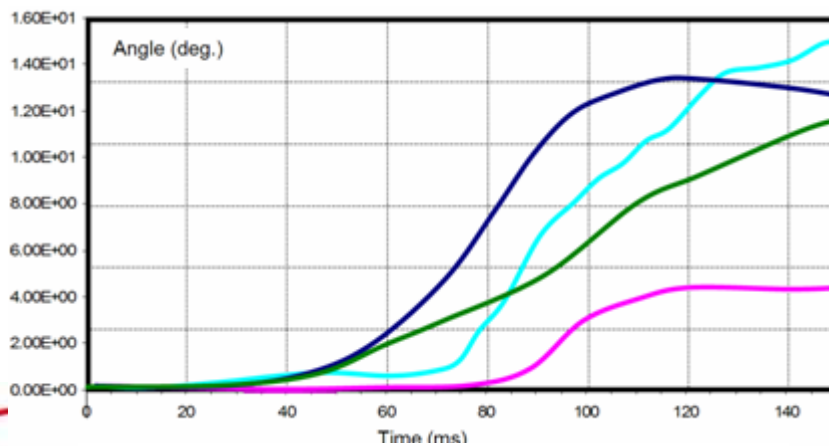
Gravid uterus Kinematics in the maternal abdomen



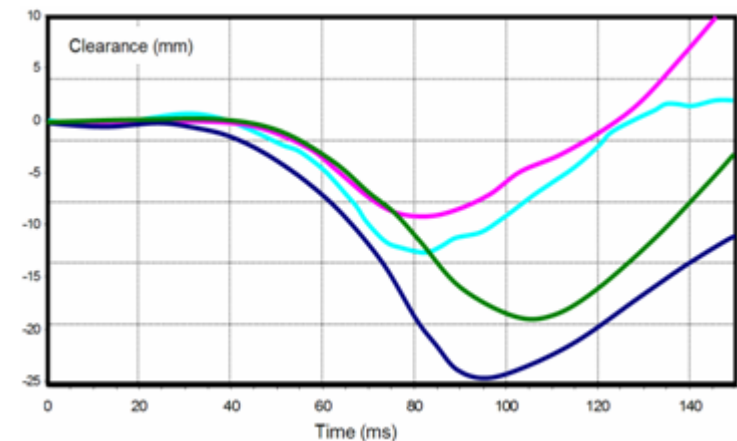
- Simulation
- Experimental curves



Maternal pelvis motion (right iliac crest)



Uterus forward rotation around the pubis



Cervix to pubis distance

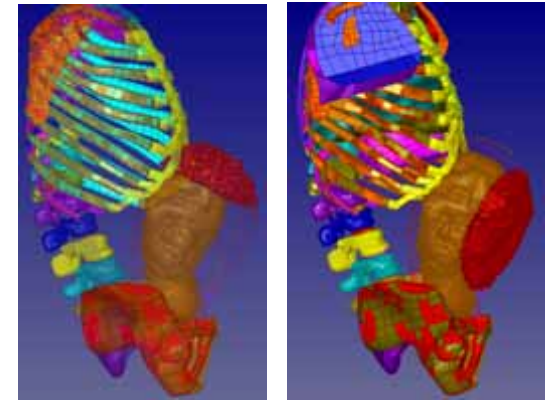
5. Application

Placenta injury risk according to its position

- The same frontal impact (20km/h) is simulated with 5 different placenta positions

The injury risk is given by $Ar = 1.12Ps-7$ *

(*Ar* is Adverse Foetal Outcome Risk and *Ps* the Peak Strain recorded on the uterus wall in the placenta region)



Placenta position	anterior	Posterior	Top	Lateral Right	Lateral Left
Max. Strain (%)	18	19.5	18	22	16
AFO risk (%) *	13.5	15	13	17.5	11

6. Discussion



- PMHS (Vs ATD) → direct validation, but problem of repeatability
- The FE approach in a realistic anatomic environment allows direct stress/strain levels measurement → Injury mechanisms
- Results illustrates the possibilities offered to
 - develop specific safety systems at the conception level
 - objectively evaluate the benefit on mother and foetus safety

But such systems will still need regulatory tests with ATDs (for rep.) ...

- Limitation 1: Mechanical properties (ex: Placenta/uterus attachment modeled with adhesive law)
- Limitation 2: Instrumentation of experimental tests should be extended (to force, pressure...)

6. Future work



○ Experiments

- Additional Frontal crash tests at 20km/h are needed
- Large scale Indentation tests on fresh placenta have started

○ Numerical Model

- Validation needs to be extended
- Mother morphology and foetus age will be included

○ A specific safety system will be developed using FE simulation and evaluated with PMHS and ATD tests

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