Towards the design of simulators of medico-surgical gestures – An instrumental childbirth delivery simulator

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Context of medical training

- Learning from the patient poses ethical problems due to risks linking to the training
- So currently, the medical training is based on the observation rather than practice
- But the dexterity of surgical instruments requires practice!

**Question:** How learning medical gestures efficiently without any risk for the patient?
Contribution of new technologies

One solution is to propose new learning simulators based on Virtual Reality, combining:

- A **numerical simulation** reproducing the behavior of organs during their interactions with each other and with medical instruments
- A **haptic device** reproducing the sensations perceived during the gesture
- A **didactic software** offering adapted scenarios for learning (notion of scores, progression, evaluation)

HelpMeSee - cataract  HRV - dental  Lap Mentor - laparoscopy

Comparable approach to simulators for airplane pilots
Interests of medical learning simulators based on Virtual Reality

- **Learning without risk for the patient:**
  - "Never the first time on the patient" – French High Authority of Health (HAS) - 2012 report

- **Multiplication and targeting of situations encountered**
  - Usual situations, rare situations

- Improvement of the knowledge of the gesture to be made
- Improvement of the reasoning to be done during the gesture
  - to better understand / acquire / own it

- **Acquiring the necessary dexterity** to handle the instruments before the first time on the patient
Context of medical training at gestures of childbirth

- Acquire the right gestures for forceps extraction during childbirth
  - Understanding of the gesture to be made
  - Do not damage the tissues of the parturient and the fetus

- Dare to do this to limit caesareans

- Delicate context
  - where the parturient is conscious, where the husband is present
A childbirth simulator based on VR
[SAGA project (ANR-12-MONU-0006)]

A 3D simulation in real time

LIRIS, lab. TIMC-IMAG, CAOR ARMINES

Lab. Ampère, CAOR ARMINES

Haptic device

All4Tech, HRV, LSE, Lyon Sud maternity, midwifery school of Grenoble (France)

Didactic software
A necessary multidisciplinary approach

1- To analyze and understand the gesture and its learning to highlight the relevant components of the simulator

2- To develop relevant and progressive scenarios for learning

3 – To evaluate the contribution of the simulator for learning

To develop a numerical simulation reproducing the behavior of the organs during the gesture in real time

To elaborate a haptic device restituting the real sensations of the gesture

To validate the different parts of the simulator

Development of simulators for medical training

Computer Science

Robotics

Medical

Didactic
Scientific issues

- Simulate and visualize behavior of organs in real time
  - Simplify the models (geometric / biomechanical) while ensuring an adequate realism for the training
  - Evaluate errors related to the approximation of the numerical model (comparison with the real is difficult)
- Propose an adequate haptic device rendering tactile sensations
  - Felt tested by obstetricians
- Ensure the stability of the complete solution
  - Numerical model, haptic interface, interaction between components
Scientific issues

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Goal of the numerical simulation

- To simulate the descent of the fetus during childbirth
- To simulate the deformation of the head due to uterine pressions / forceps

The goal is to communicate the forces applied on the head and its position to the haptic device... and reciprocally...

[Buttin 2013]

BirthSim, Ampère lab.
The pipeline for medical simulations

Medical images
Anatomy
Organs

Segmentation

Geometrical models
With high resolution

Constitutive laws and
mechanical properties

Numerical simulations
High precision
High computational cost

\[ \text{Solving with the Finite Element Method} \]

\[ \begin{align*}
\text{div}([\sigma]) + f_{\text{ext}} &= \rho \ddot{u} \\
[M]\dddot{U} + [D]\dot{U} + [K]U &= F
\end{align*} \]
Challenges for training simulators

- We have:
  - to be fast! (and stable…) for interaction with haptic device
  - to be enough accurate to reproduce realist physical behavior

We have to find the adequate compromise between accuracy and execution time

A lot of simplifications  |  accuracy of biomechanical behavior  |  Complex simulations

Training simulator  |  Planification of operations  |  Physiological acknowledgement

[Buttin 2013]  |  [Collins 2014]  |  [Li 2008]

Real time  |  execution time  |  Several hours of computation

[Li 2008]
The complete childbirth simulator

[SAGA project (ANR-12-MONU-0006)]
Difficulties and limits

- The difficulty lies in the fact that one should not learn to do the intervention on the simulator / to use the simulator
- But the simulator must allow **to learn the "real gesture"**
- We must succeed in making sure that the simulator helps
  - to appropriate the gesture
  - to analyze the situations encountered
  - to acquire the dexterity of the gesture

"We have to learn how to operate a real patient and not to operate the simulator."
- **At shorter terms for medical simulators: "specific patient"**
  - Training before risky operations
  - Pre-operative diagnosis / prediction to assess risks
  - Help during the intervention

- **Case of the childbirth simulator**
  - Better understanding of the forces involved during childbirth
  - Limitation of the number of caesareans by daring to use forceps
  - Prediction of risky delivery in terms of damage for the parturient
  - Improvement of the medical care of prolapse

- **Expected interests of such simulators**
  - Acceleration of the learning process
  - Improvement of physiological knowledge
  - Implementation of new methods of gesture evaluation
  - Setting up new gestures
Conception of a childbirth simulator

SAGA project’s team
Our approach to obtain real time

- Simplication of the meshes (less nodes)

- Simplication of the constitutive law of organs

  - **Pelvis**: Hooke - $E = 23$ Mpa, $\nu = 0.3$, $\rho = 1\ 000$ kg/m$^3$

  - **Abdomen**: Néo-Hooke - $C10 = 5$ kPa, $\rho = 2\ 500$ kg/m$^3$

  - **Uterus**: Néo-Hooke - $C10 = 30$ kPa, $\rho = 950$ kg/m$^3$

  - **Fetus**: Néo-Hooke
    - Skin: $C10 = 130$ kPa, $\rho = 400$ kg/m$^3$
    - Skull: $C10 = 75$ kPa, $\rho = 950$ kg/m$^3$
    - Body: $C10 = 70$ kPa, $\rho = 950$ kg/m$^3$
Our approach to obtain real time

- Put boundary conditions
Simulation of fetal descent in real time

The descent of the fetus is involved by forces (abdominal, uterine contractions) applied on the uterus

[Buttin 2013]