Users Consideration on Haptics Interface in Spinal Anesthesia

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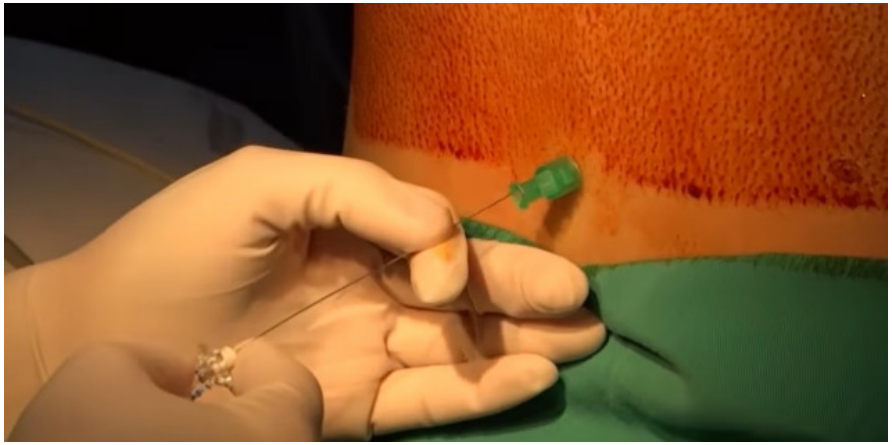
Anesthesia Training Importance

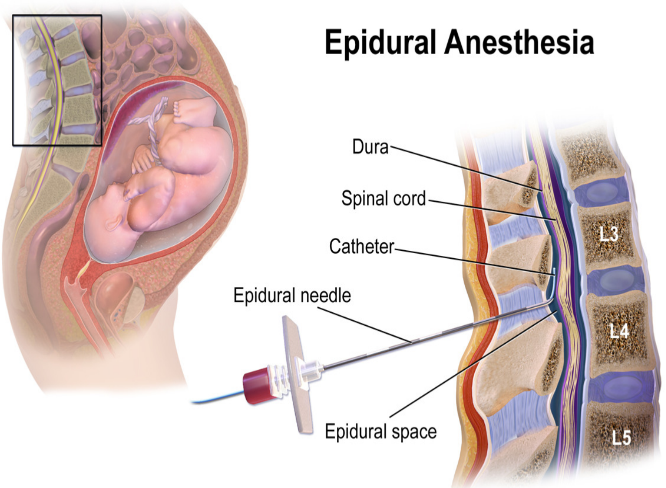
- Average anesthesia fail rate : 41% for Spinal and from 6% to 25% for Epidural anesthesia (these are the most used in obstetrics procedures like labor or cesarean) *.
- Both blind procedures, where the needle insertion is a critical step.
- Needle correct placement and location is related to the tactile perception and the difference of penetration resistance of tissues inside the body.
- Such a skill development and maintenance occurs through continuous practice**.**



* D. Tran, K. W. Hor, A. A. Kamani, V. A. Lessoway, R. N. Rohling, Instrumentation of the loss-of-resistance technique for epidural needle insertion, IEEE Transactions on Biomedical Engineering 56 (2009) 820-827.

Main Objetive

- Help on learning how to correctly identify (by the hand sensation) internal point where anesthesia should be administered using a virtual environment and haptic.



For instance : No invasion the *dura mater* tissue

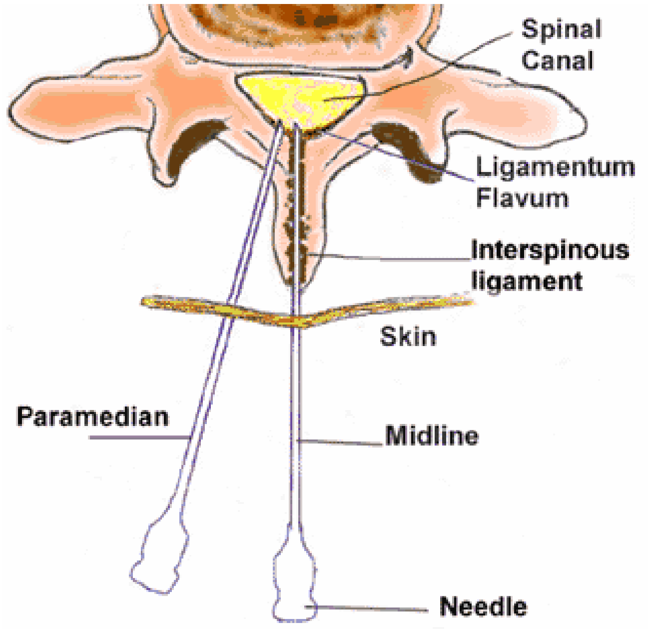
Needle insertion approaches

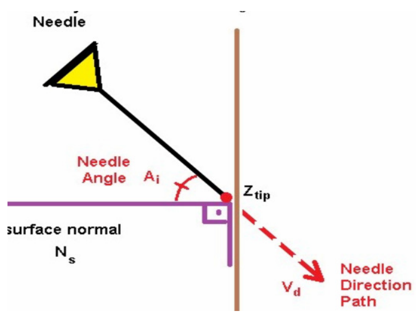
midline x paramedian.

Midline: needle insertion is perpendicularly to the skin;

Paramedian avoids the supraspinous and interspinous ligaments, so yellow ligament is directly reached after the muscle layer.

Midline approach usually does not pass through the muscle layer, is most used and difficult for physicians (better for patients).



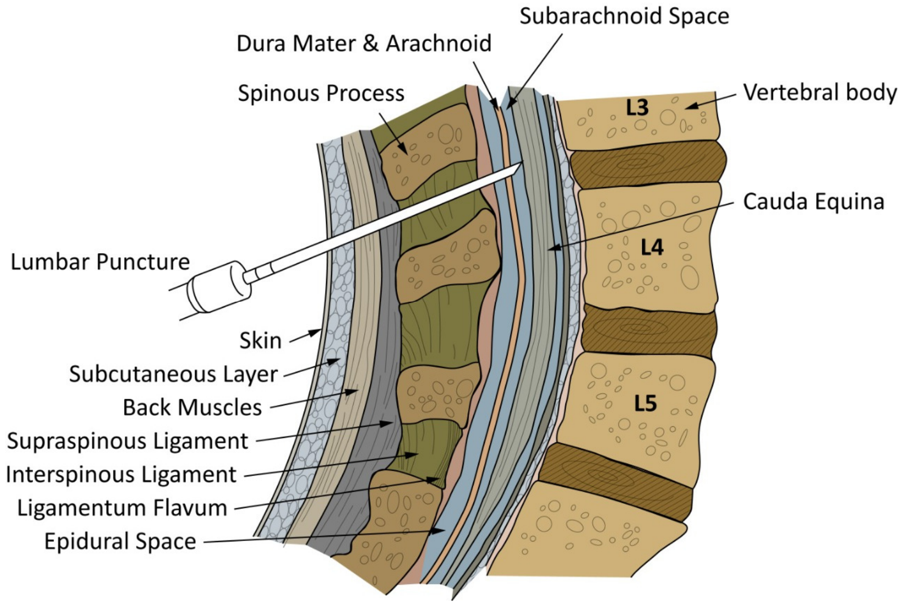


Challenge: simulation of hand feelings (tissue resistance with real needle)

- Identify the transitions between tissue layers :
  - Skin,
  - subcutaneous fat,
  - supraspinous ligament,
  - interspinous ligament,
  - ligamentum flavum,
  - epidural space,
  - dura mater,
  - arachnoid mater and
  - subarachnoid space for the Spinal (raquidian) anesthesia;

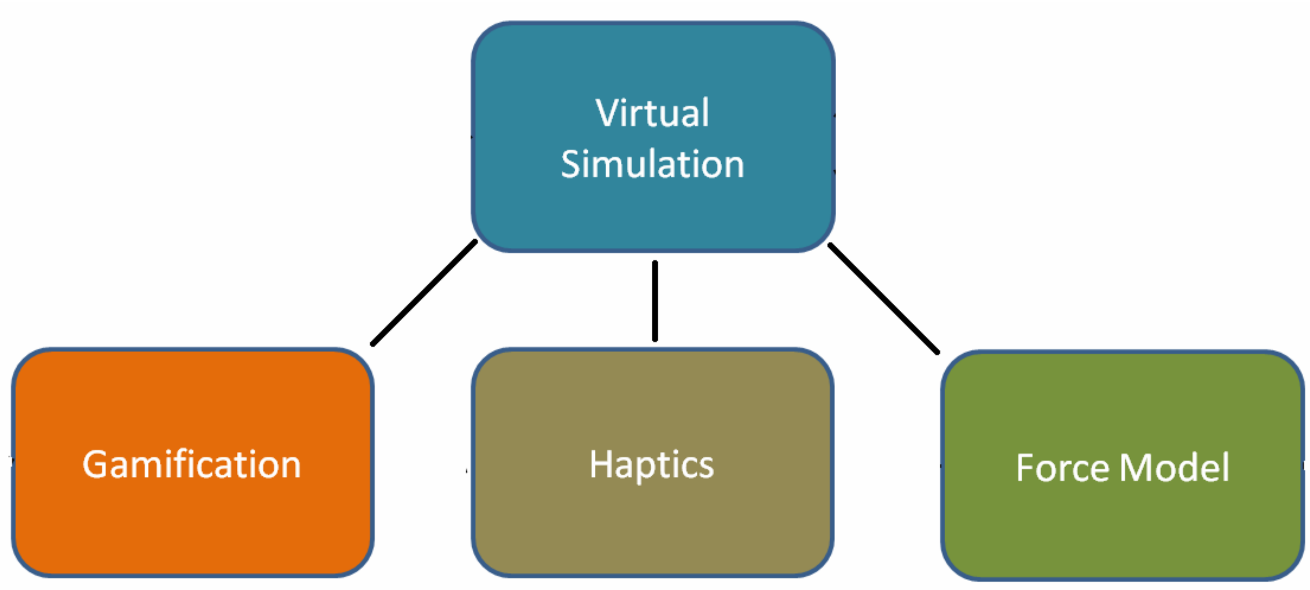
- Loss of resistance (LOR) on epidural space for the Epidural

- A "pop" sensation when perforating the dura mater



Spinal (9 tissues)
x
epidural (5 tissues)

Developed virtual simulators



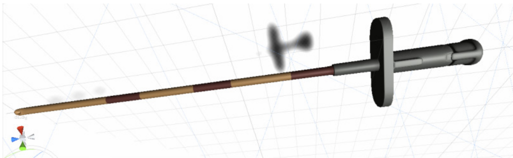
Unity3D engine was used for the development of 2 prototypes of a virtual simulator to spinal and epidural anesthesia training. Both with haptic feedback.

The force models

- Consist of 3 models:
- Model one - force along needle progression related to resistance of tissues against the needle insertion (based on real data* from experimental measurements).

Table 1. Human puncture forces and thickness of epidural lumbar region tissues

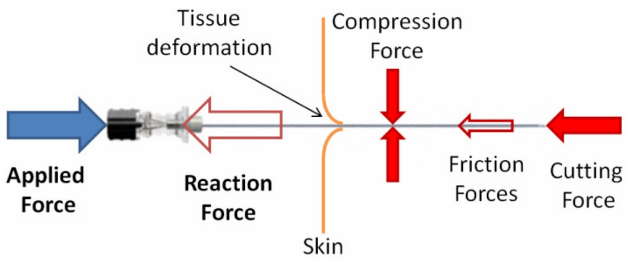
Tissue	Human puncture force (Newton)	Thickness (mm)
Skin	6.0372**	10.8
Fat	1.974	2.8
Muscle	4.354*	1.9
Interspinous Ligament	7.467	18
Ligamentum Flavum	12.1330*	7.4****
Epidural Space / Subdural Tissue / Dura-mater	2.437	8.6*****
Bone	8.0265******	-



*L. Holton, L. Hiemenz, *Force models for needle insertion created from measured needle puncture data*, Studies in health technology and informatics (2001) 180-186.

Resistance to needle progression

- Virtual internal behavior considers ***stiffness, friction and cutting forces*** for ***each tissue, and*** includes ***a represents the needle insertion stages before and after*** the puncture in each tissue.



The model proposed for the needle insertion **before** a tissue puncture is:

$$R_f = S_f = a_0 + (a_1 * \Delta d) + (a_2 * \Delta d^2) + (a_3 * \Delta d^3)$$

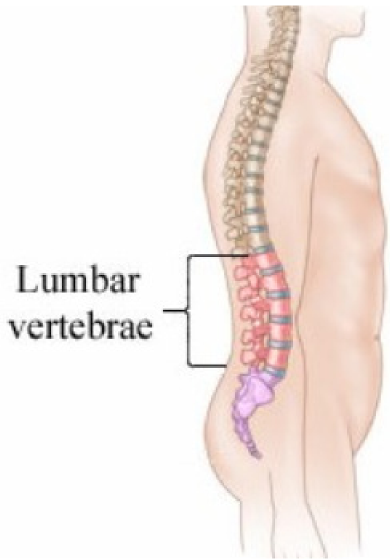
The *Δd* represents the needle displacement, calculated as the current needle tip depth (in millimeters) minus the depth of first contact location (on the skin). The constants a_0, a_1 and a_2 reproduce each tissue behavior before puncture.

Resistance to needle progression

- After a tissue puncture: Resulting force adds **Friction force** and **Cutting force**, and also considers different **tissue constants**, based on **biomechanical tissue properties**.
- The model used after a tissue perforation is:

$$R_f = F_f + C_f = ap_0 + (ap_1 * \Delta dp) + (ap_2 * \Delta dp^2)$$

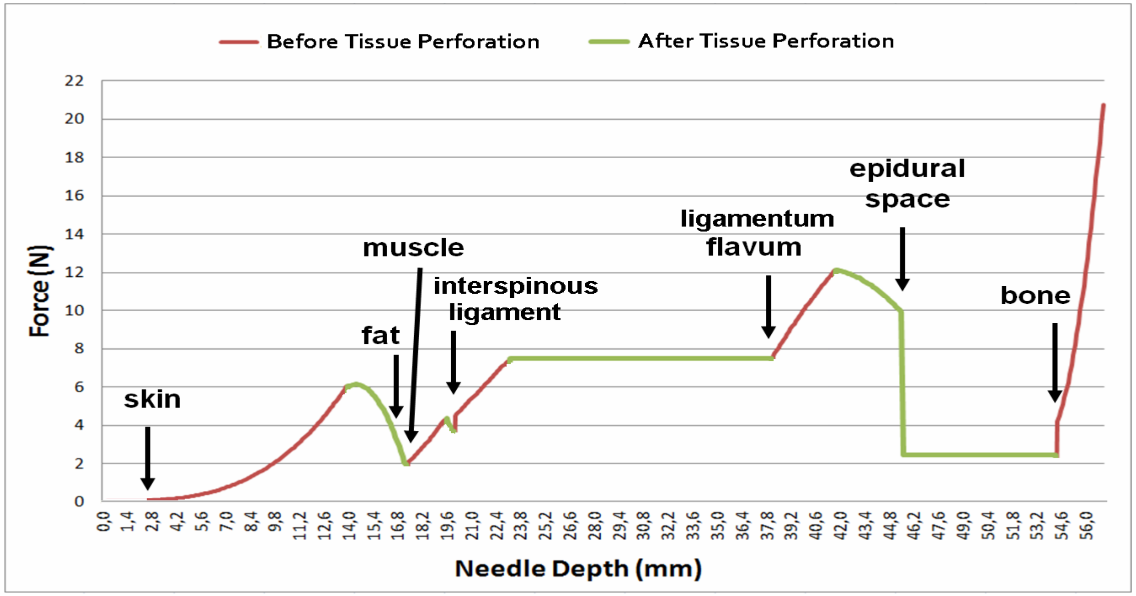
Δdp represents the needle depth after tissue puncture, being calculated as the current needle depth (in millimeters) inside the patient body minus the needle depth (in millimeters) where the current tissue was first punctured by the needle. The constants ap_0, ap_1 *and* ap_2 reproduce current tissue behavior after puncture.

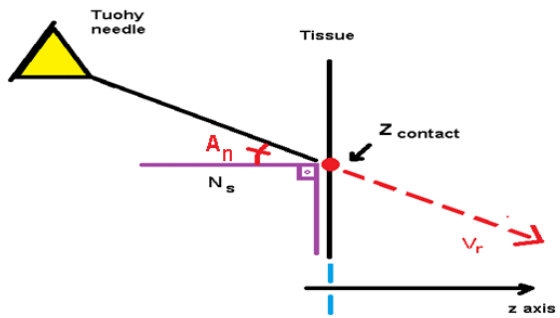


All constants were obtained from experiments of Holton & Hiemenz*.

Resistance to needle progression

- Used curves Force x displacement: ***representation of needle path from skin to bones before and after*** the puncture in each tissue*;

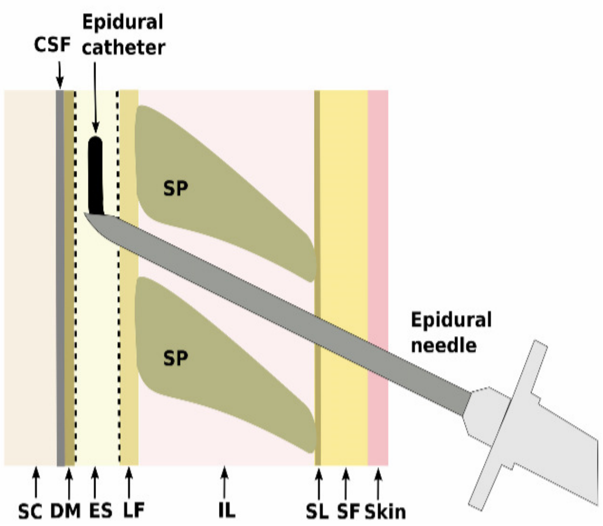


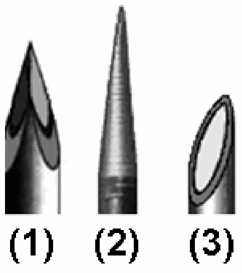


*A. Brazil, Epidural nerve block simulator using haptics and gamification, 2017

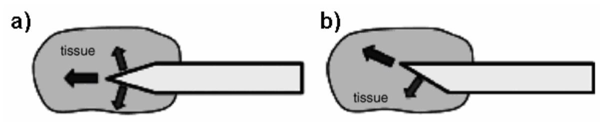
Developed virtual simulators

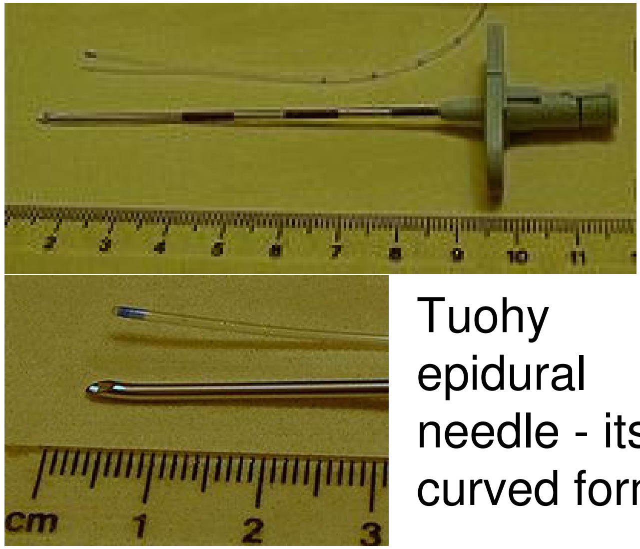
- Model two - ***calculates the axial force components due needle tip type used on training*** (symmetrical or asymmetric tips) in the virtual environment.



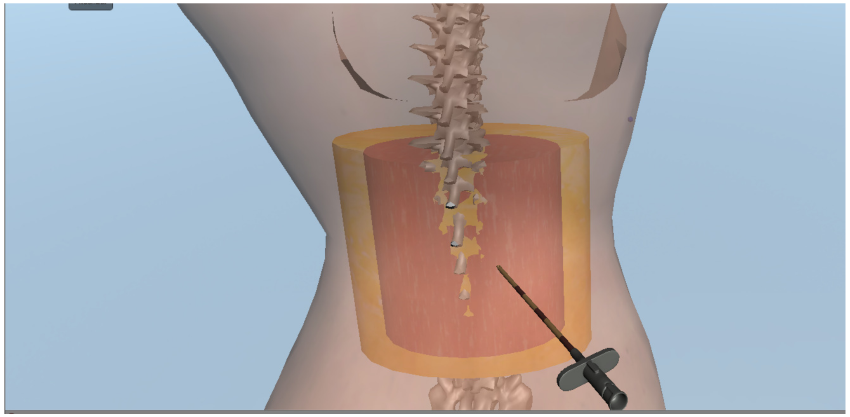


Tip types: Triangular (1), Coned (2), Beveled (3).





Tuohy epidural needle - its tip curved format

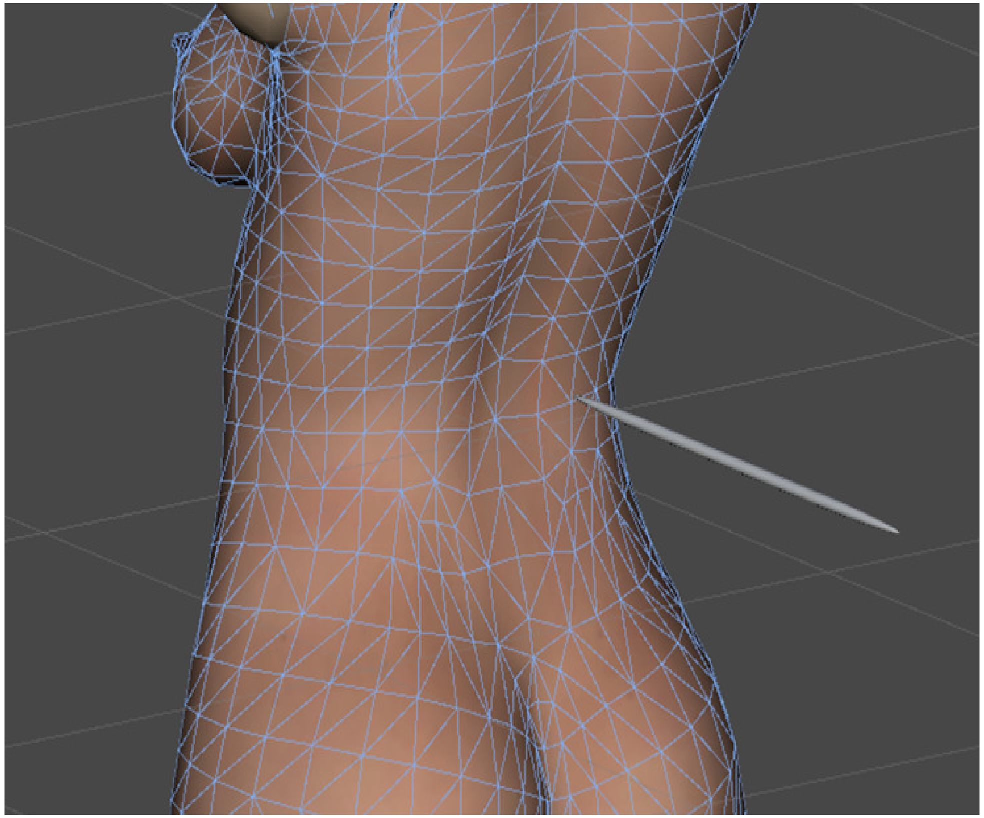


Developed virtual simulators

•Model three - thickness of tissues on the simulator, from input values of height, weight and data from **3319 parturient** (from **literature available data* of various gender and age)**.

***Data from 6 population groups:** 2009 Michigan-USA parturient, 1140 parturient from UK, 70 parturient from Singapore, 100 Indian parturients; 100 Indian males; 100 Indian non-pregnant females;120 Nigerian adults and 317 males and females from Ireland**.**

Developed equation



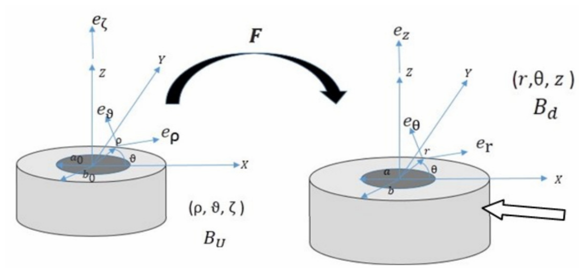
After statistic considerations* from **all the population groups**, a skin surface to epidural space distance **(SED)** as function of the **Body Mass Index (BMI) :**

SED = 2.52 + 0.11 BMI

Then each tissue is proportionally dimensioned

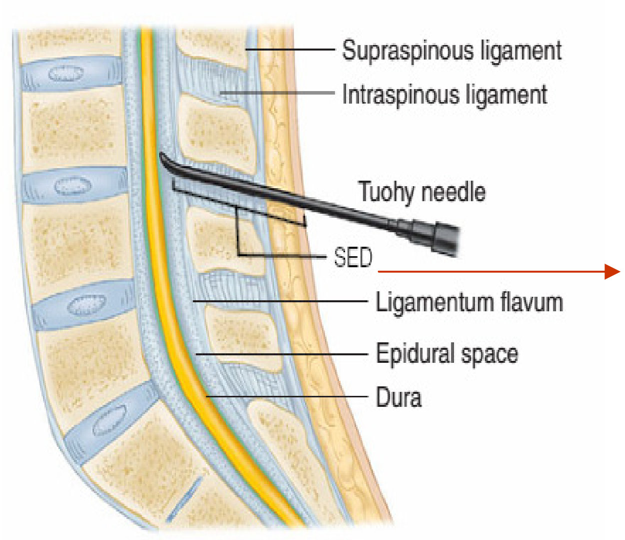
This added more realism when compared to previous works.

* R. Melo; A Conci; D Popovici; C Galhardo Jr, A proposal of general model for estimation of skin to epidural space distance on the parturient population , Annals of Anesthesia and Pain Medicine, 2020, 3(1): 1006.



Body model

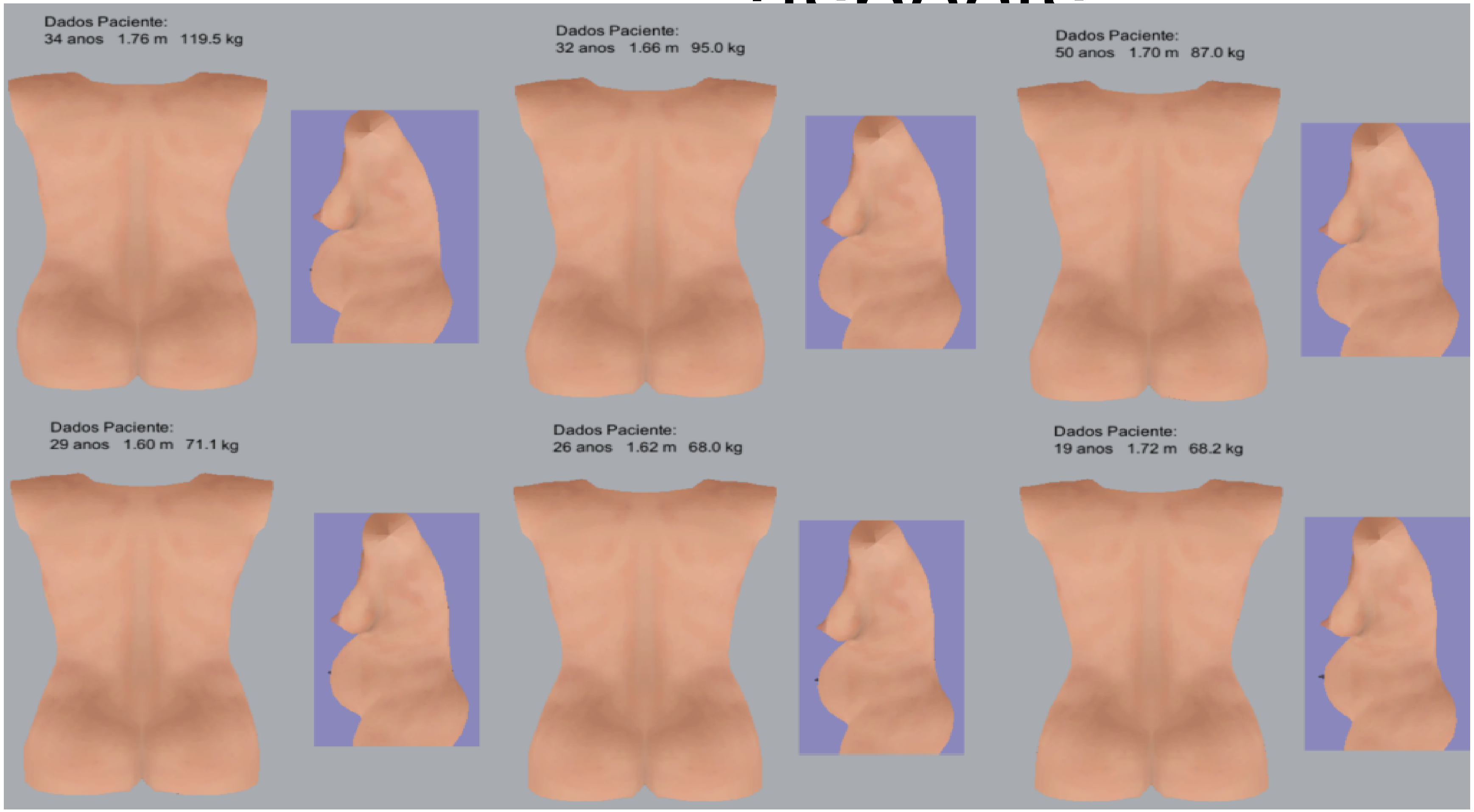
- Customizable body shapes, weights, and heights from the developed equation.
- 3D model of a **parturient** with variable mechanical properties and dimensions represented*



SED = skin to epidural space distance

*R. Melo; A Conci; *Modeling the basic behaviors of Anesthesia Training in Relation to Puncture and Penetration Feedback. In: IEEE Engineering in Medicine and Biology Society. Annual International Conference. . 2021*,

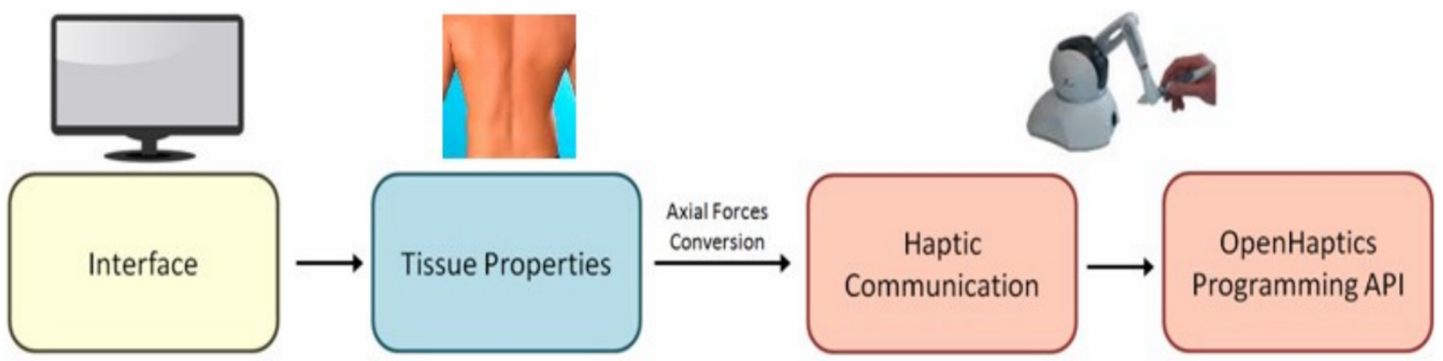
Example of external aspects



Equations for estimation layers depth based on BMI*

is crucial in these spinal and epidural anesthesia training.

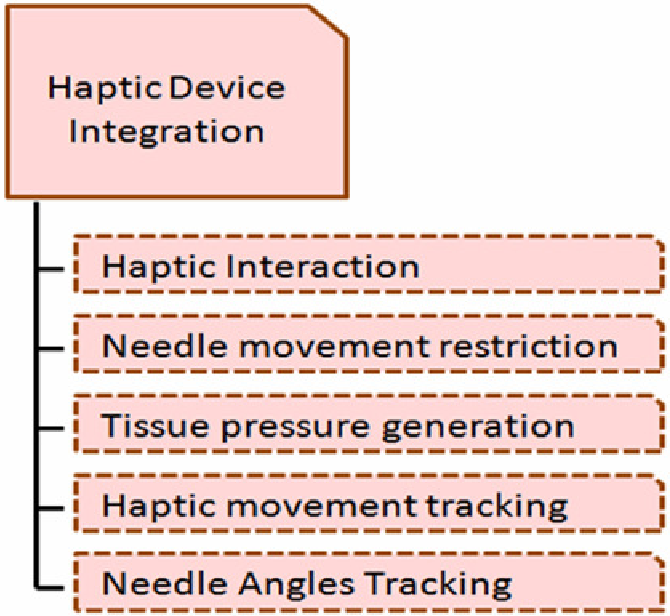
It allow to simulated multiples body for training.



*Body Mass Index

Integration with the haptic device

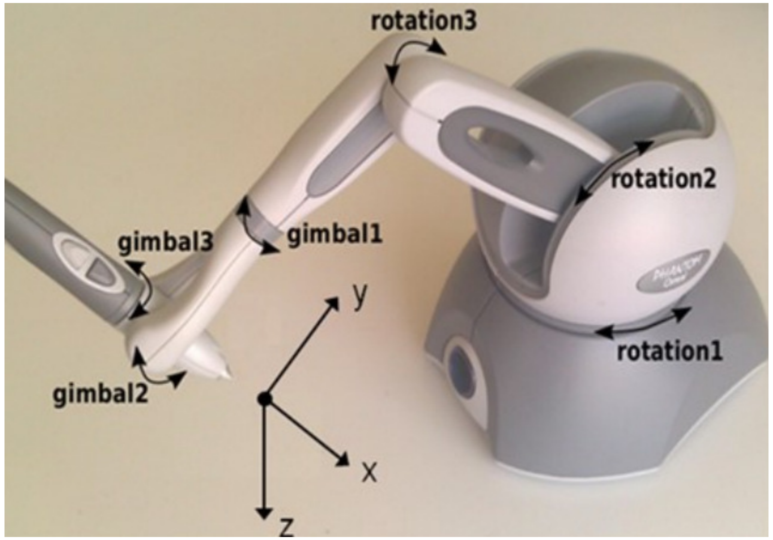
to control the needle movement when user manipulated



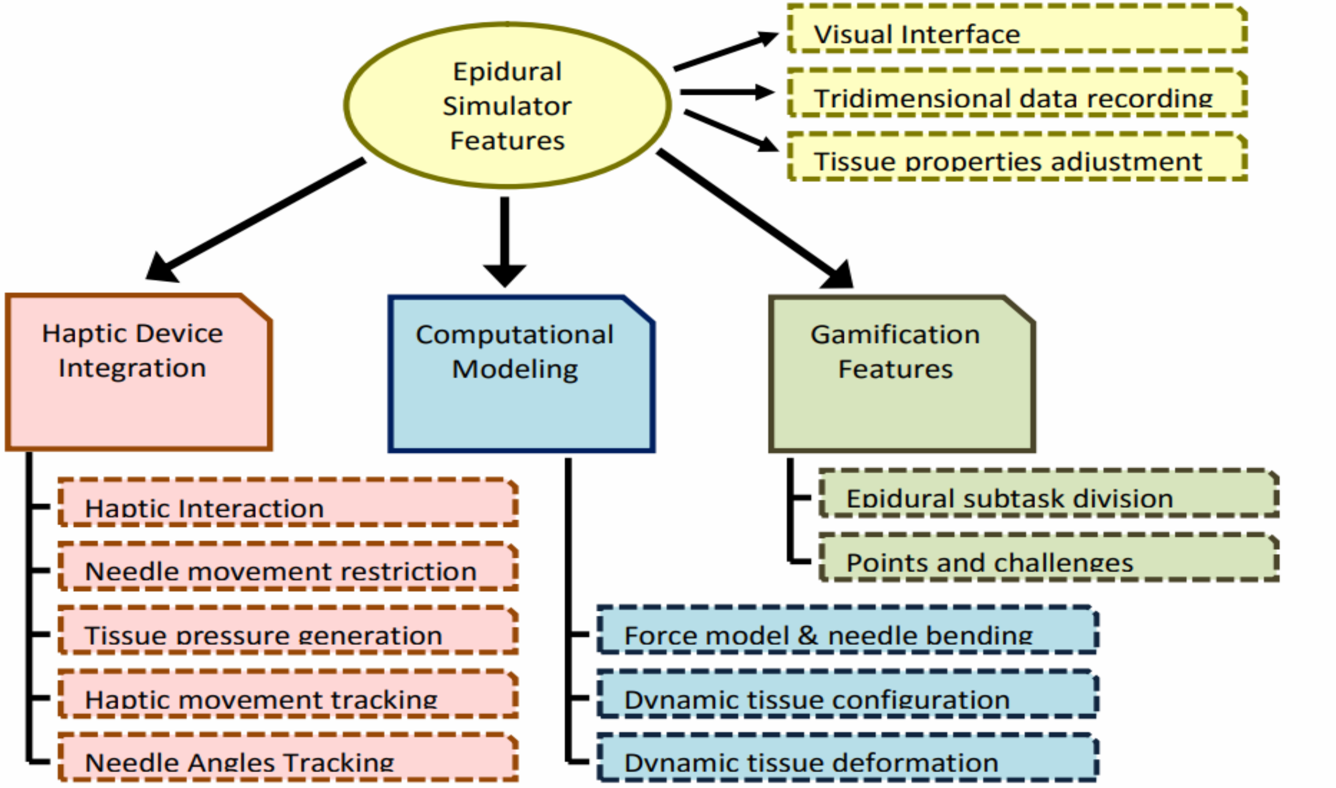
Integration of a haptic

Haptics are capable to reproduce movement restrictions and resistance forces generated by the developed models, provide physical feedback to **answer user movements**, emulating sensations and reactions from the by passed tissues (skin, fat, spinal ligaments, epidural space, dura-mater, etc.) as if those actions were executed **inside a body of a real patient**.

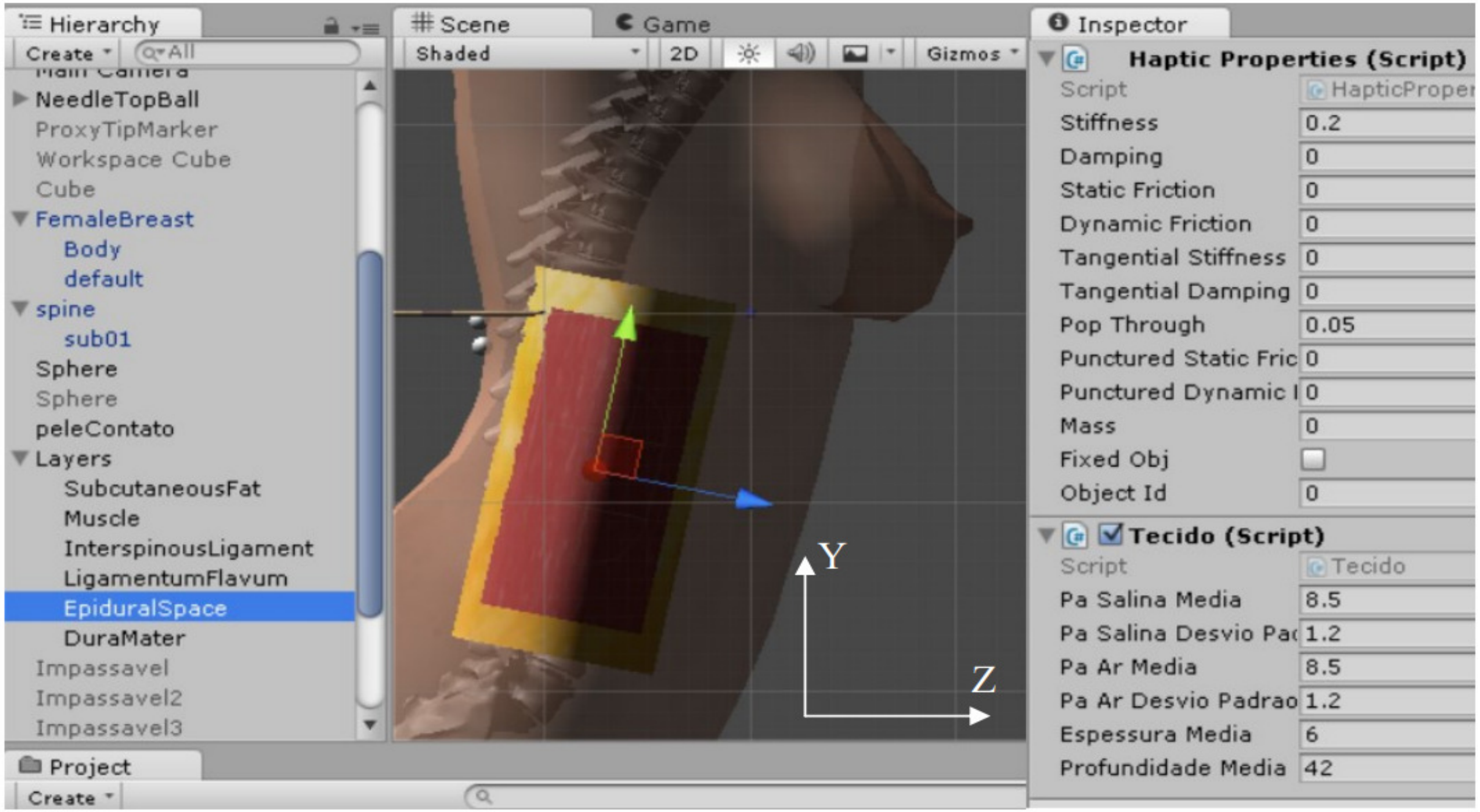
The haptic device used is capable of six (6) degrees of freedom (DOF), allowing translations and rotations on three axes (x, y, and z) and corresponding reaction forces.



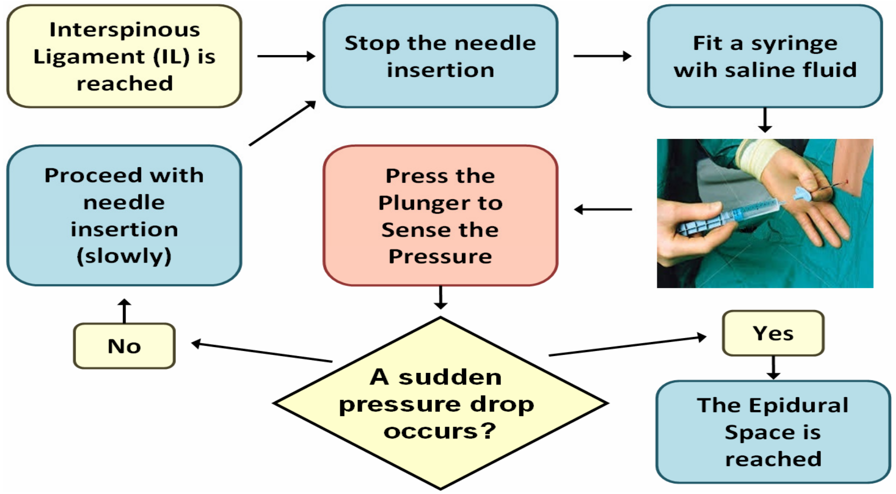
Complete project



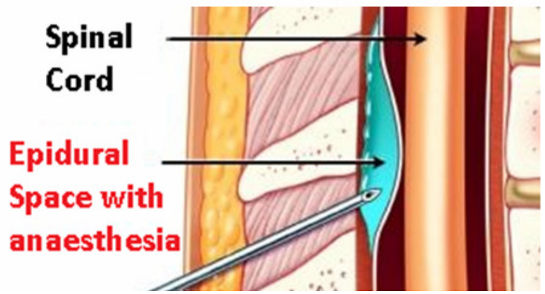
Setting properties for training



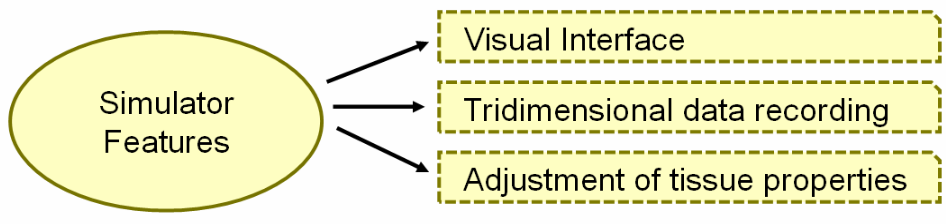
Loss of Resistance (LOR)



Injection of the anesthetic fluid in lumbar epidural space



Other details

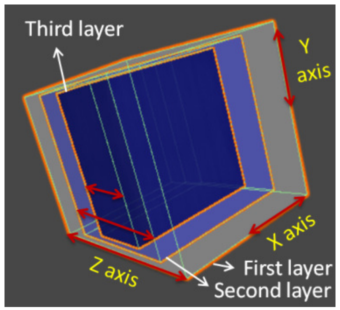


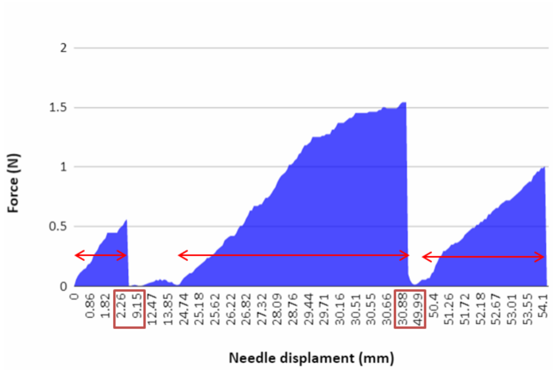
Performed Tests

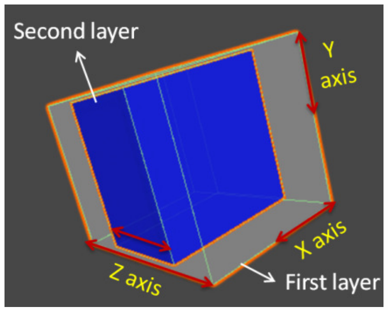
- Several tests were done.
- Some tests aimed to map the force model when applied in a virtual simulation environment with the goal of verifying the possibility of distinguishing different tissues (Pop and LOR sensations) .
- Other is relateed to the users oppinion about the system (this are here comented)

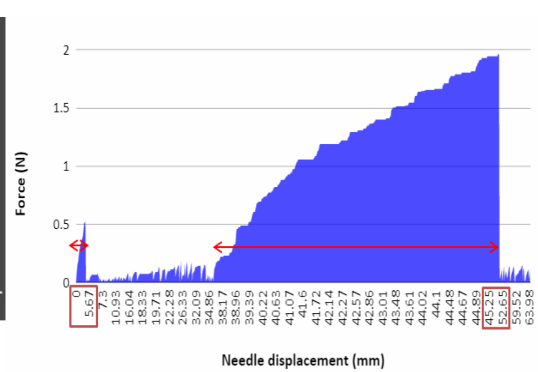
Layer transition identification by haptic handling

- 2 experiments on number of layer transition and hardness identification were applied to 12 volunteers (not reported in the paper*)
- 3 and 2 tissue layers are used.
- Intend: how many layers they can identify, the starting and ending points of each layer, and the resistance level or the felling against the motion inside each one.









* Details asked by one of paper reviewers

Questions

- 1 - How many layers can you feel after inserting the whole needle (for both experiments)?
- 2 - For experiment 1, sort the layers in descending order related to its resistance to puncture?
- 3 - For experiment 1, what is the starting point of each layer?
- 4 - For experiment 2, what are the start and endpoint (range) of the most resistant layer presenting a constant displacement keeping the pressure level?
- 5 - For experiment 2, what is the range presenting more restriction to the needle movement?

Answers Conclusions

- Q1: 11 volunteers (approximately 92%) answered correctly about Experiment 1. 12 volunteers (100%) were correct about two.
- Q2: 7 volunteers (58%) answered correctly for all layers. 10 volunteers (83%) were right about the least resistant layer and 9 volunteers (75%) were right about the most resistant one.
- Q3: 9 volunteers (75%) answered correctly for all layers. All were right about the second layer. 11 volunteers (approximately 92%) were right about the first one.
- Q4: 9 volunteers (75%) answered correctly.
- Q 5: 5 volunteers (42%) answered correctly. 1 volunteer (8%) missed the starting point. 7 volunteers (58%) missed the endpoint

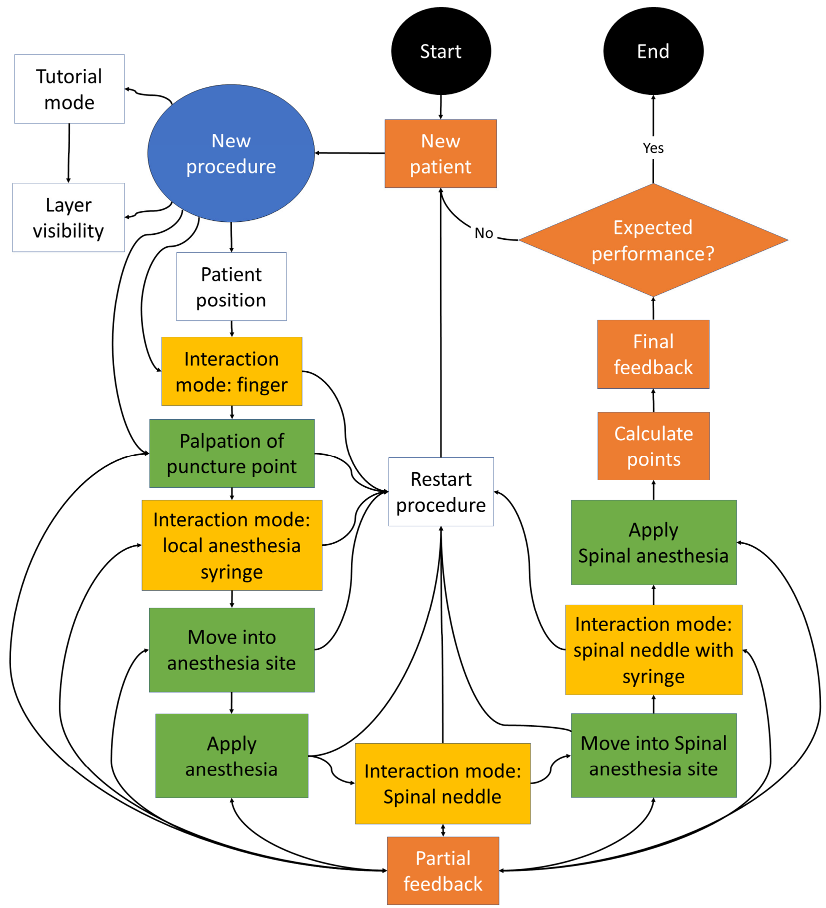
Current focus: Interactions

White boxes = optional functions.

Yellow boxes= interactions made through haptic buttons.

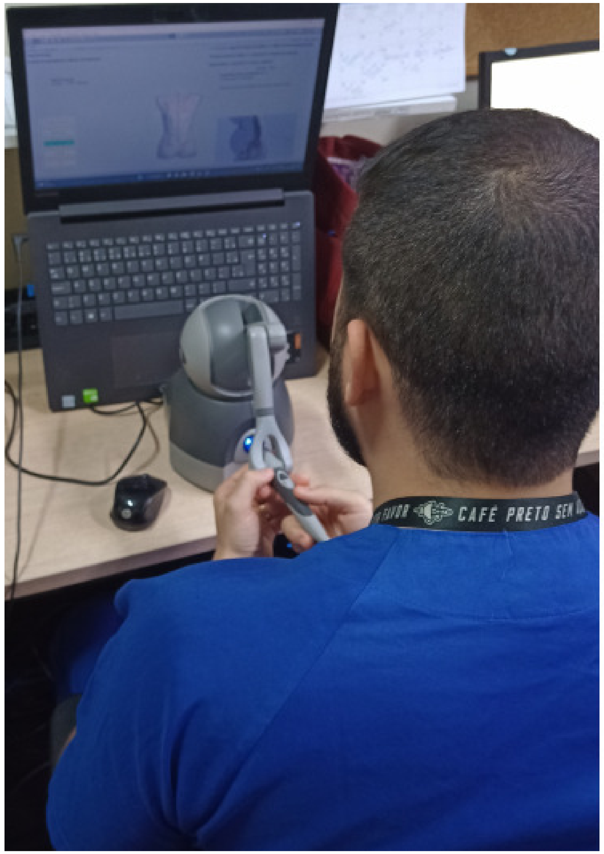
Green boxes= interactions with haptic feedback.

Orange boxes= user evaluations.



Users oppinion on haptic resources in the spinal simulator

- 2 experiments to evaluate the simulator environment implemented in C# language.
- It is related to tactile perception simulation promote by the haptic.
- 33 questions about the application to 2 groups : (62) students and (10) anesthesiologists
- Approval of Ethics Committee of Brazilian Ministry of Health: CAAE 23637019.5.0000.5243



Interaction users-program

Evaluation 1- To identify the opinion of students about the implemented application (62 volunteers).

Table 1. Median and standard deviation (SD) of beginner's grades about the implementation.

Statements	Median	SD
I would like use this system often.	4	0.9
I found the system complex.	2	0.8
I found the system easy.	4	0.9
I needed help to use this.	3	1.3
I think that the functions of it are well integrated.	4	0.8
I considered the system inconsistent.	2	0.7
I suppose that anyone will learn how to use it quickly.	5	0.6
I found the system cumbersome to use.	2	0.9
I felt confident using the system.	4	1.0
I needed to learn a lot of new things before I could use it.	2	1.7
The tutorial mode clarifies doubts about the actions to be executed.	4	1.1
Do you have any suggestions for changes in the interface? If yes, comment, please.	-	-

Results on interaction users-program

Evaluation 2- To consider opinion of experts about the haptic interface

(10 experts in anesthesia) . Table with results of our implementation and similar work

Our questions	Mean	SD	[14]	Mean	SD	Dif.
Does the palpation (to discover the point of needle insertion) improve the anesthesia?	2.6	1.2	-	-	-	-
Do the patient positions (sitting and lying down) meet the anesthesia needs?	1.9	1.4	-	-	-	-
Does the tutorial make it clearer how to use the simulator?	2.3	1.4	-	-	-	-
Is feedback (via texts) enough to improve your training?	2.5	1.3	-	-	-	-
Did you feel difference when penetrating each virtual tissue?	2.8	1.7	2	1.5	0.7	1.3
Is the control of the interaction with the haptic intuitive?	2.7	1.3	3	2.2	1.1	0.5
Are the patient appearances realistic enough?	3.3	1.3	5	2.0	1.1	1.3
Are the different views and transparency useful to understand the regional anatomy?	3.2	1.4	6	1.6	0.7	1.6
Did you feel more confident to perform anesthesia after this training?	3.9	1.5	7	1.9	1.1	2.0
Did you consider this environment useful for training?	2.3	1.2	8	1.5	0.7	0.7

Final Conclusions

- The current version shows that it is possible and viable to implement tissue resistance by haptic using the engine Unity3D with the Phantom Omni haptic device.
- The used force model can represent human hand sensation and needle movement restrictions inside a patient body (even the lost of resistance after tissue perforation). This enhances the simulation correspondence to reality.
- Needle angle with the skin can be modeled as well as the needle tip shape. Coned tips produce higher slopes, followed by beveled ones. The use of triangular tips results in lesser slopes. This can be justified by the number of cutting surfaces (triangular=3, beveled=1, coned=0) that contribute with tissue penetration. Needle diameter also significantly affects the sensations. These factors were included in the force model.
- The possibility of body and tissue properties adjustments based on BMI on prototype interface promotes a richer experimentation.
- Future works include validation with medical team in order to take more elements to improve physician experience into the interface and better appearance to user.

To see more:

https://www.youtube.com/watch?v=IVlRF9yuEJ0

https://www.youtube.com/watch?v=O_ZmZIkASuk

https://www.youtube.com/watch?v=NUXcgFU30_o

https://www.youtube.com/watch?v=mXOurEMrqi0

https://www.youtube.com/watch?v=6mT1r5ouMO4

https://youtu.be/g9RZRYId9ys
https://youtu.be/gGpJKjkVYWU .

Thank you!

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