PROPOSAL FOR AN AUXILIARY DEVICE FOR LUMBAR PUNCTURE PROCEDURES

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Abstract. *The lumbar puncture is a procedure that aims to collect cerebrospinal fluid from the subarachnoid space within the spine for medical diagnostics. The procedure itself is delicate and needs to be carried out by a highly trained professional, relying on needle force feedback sensation. With the purpose of assisting the less trained professional, we developed an auxiliary device by embedding sensors to the puncture needle and providing visual feedback. This way medical students and beginner professionals can have a more reliable way of detecting the subarachnoid space within the spine.*

Keywords: *lumbar puncture, instrumentation, electronics.*

1. INTRODUCTION

Many clinical practices involve the insertion of a needle through body tissues. Lumbar puncture is a specially delicate procedure, as it is carried out in the lumbar section of the spine. Thus, it needs to be performed by highly skilled specialists. It relies on the ability of the professional to detect the slight changes of resistance during the needle insertion in order to correctly place the needle in its final position. As pointed by Busti and Kellogg (2015), this procedure can have various complications, such as intracranial hypotension, resulting in brain stem herniation, accidental puncture of important spinal structures, such as the aorta or vena cava and the spinal cord.

Nowadays there are many methods used in order to train medical students and beginner professionals to perform an epidural anesthesia and these methods can be adapted into lumbar puncture procedure training, given the similarities between both procedures. Usually, students use silicon models and human cadavers for training, but new ways of training, such as the use of simulations based on haptic feedback, have become increasingly common (Brazil et al, 2016).

The aim of this work is to provide visual feedback to the procedure as an alternative to the more imprecise “force sensation” method to aid trainees and inexperienced professionals.

1.1 Anatomy

As the puncture needle travels in the direction of the subarachnoid space, where it will collect cerebrospinal fluid, the force needed to perforate different tissues inside the spine changes with the needle depth. The sensibility to these changes is crucial for the professional performing the lumbar puncture to detect the arrival of the needle into the subarachnoid space. Figure (1) shows the different tissues traversed by the needle and where the subarachnoid space can be found.

The lumbar puncture described by Busti and Kellogg (2015) depends on the ability of the professional to feel a “pop” sensation when the needle punctures the *dura mater*, crossing from the epidural space to the subarachnoid space. In order to a professional to acquire this ability, a lot of experience and training is necessary.

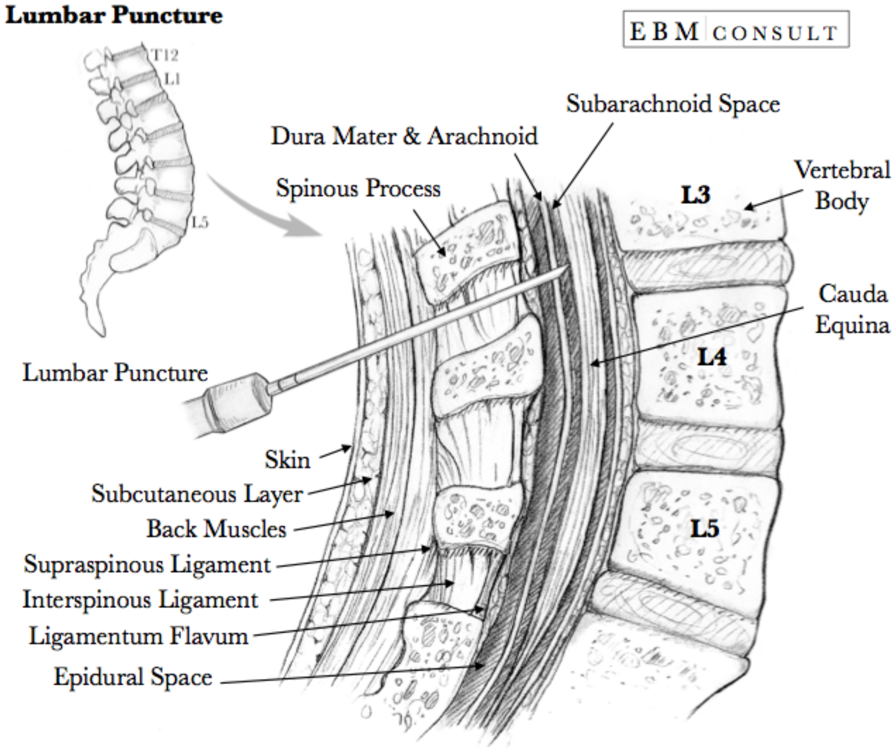


Figure 1: Cross section of the spine showing the different layers of the spine and which are crossed by a needle during the lumbar puncture procedure, Busti and Kellogg (2015)

2. LITERATURE REVIEW

There are numerous works exploring the identification of the epidural space by many methods. Because of the proximity of the epidural space and the subarachnoid space, the aim of the lumbar puncture procedure, these works can be used to estimate measurements up to the subarachnoid space.

A highly influential work for this research was carried out by Ravi et al. (2011), who measured the average depth of the epidural space in 120 adult patients, being 60 men and 60 women, with ages ranging from 18 years old to 70 years old. Ravi measured the correlation between the depth of the epidural space with age, height, weight, sex and Body Mass Index (BMI), finding that the correlation with BMI is more significant than the correlation with other parameters.

Table 1: Average depth of epidural space (mean ± standard deviation) correlated with patient sex and BMI, Ravi et al. (2011)

BMI(kg/m^2)	Men	Women	Total
18 - 25	44.14 ± 5.23	36.38 ± 4.75	40.00 ± 6.28
25 - 30	44.69 ± 4.27	41.50 ± 5.08	43.20 ± 4.86
30 - 35	49.23 ± 2.26	50.68 ± 3.75	49.95 ± 3.28
35+	57.38 ± 8.43	57.63 ± 1.51	57.50 ± 5.85

Correlation results with patient BMI and sex are displayed in Tab. (1). Figure (2) displays a visual representation of this data for better visualization.

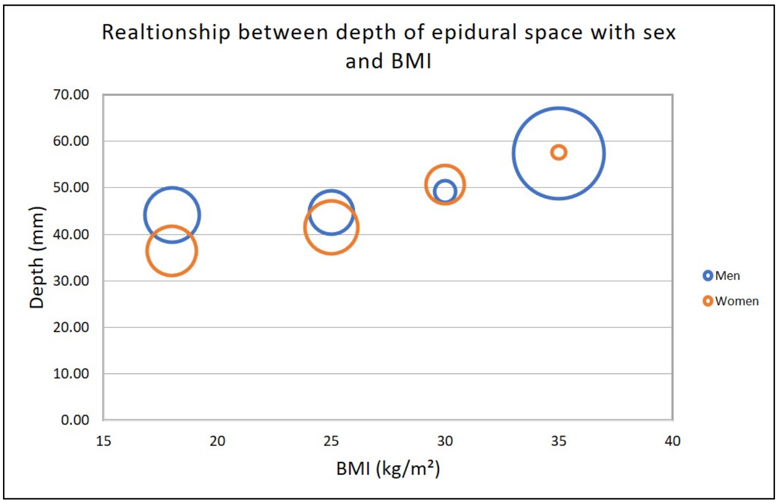


Figure 2: Visual representation of data pertinent to men and women (with standard deviation) obtained from Tab. (1)

Ravi observed that the depth of the epidural space significantly increases in patients with higher BMI, but not with age or height. Ravi concluded that, as expected, patients with higher BMI have their epidural space located deeper within their body due to a thicker fat layer beneath their skin. It is also to be noted that within patients with lower BMI, their sex seems to be relevant to determinate the depth of the epidural space.

By using simple linear regression based on the data illustrated by Fig. (2), Ravi found that the depth of the epidural space can be correlated to the patient's BMI by Eq. (1). This correlation can be used to estimate the depth of the epidural space in a patient given their BMI.

$$Depth\ (mm) = 17.7966 + 0.9777 \text{ x } BMI \tag{1}$$

The difference in force sensations felt by the doctor during needle insertion comes from the difference between tissue properties such as elasticity, viscosity, density and friction. The resulting forces are divided between 3 components: friction forces, resistance forces and shearing forces.

Holton et al. (2001) made observations of a Tuohy 18G 1.27mm needle force feedback during penetration in the Lumbar 2 vertebrae. Holton's aim was to produce a force model for a haptic-based simulation of an epidural anesthesia procedure, represented in Fig. (3). In his work, Holton validates important assumptions for the force model, such as the independence of the puncture force from the insertion speed and angle, for both skin and muscle tissues.

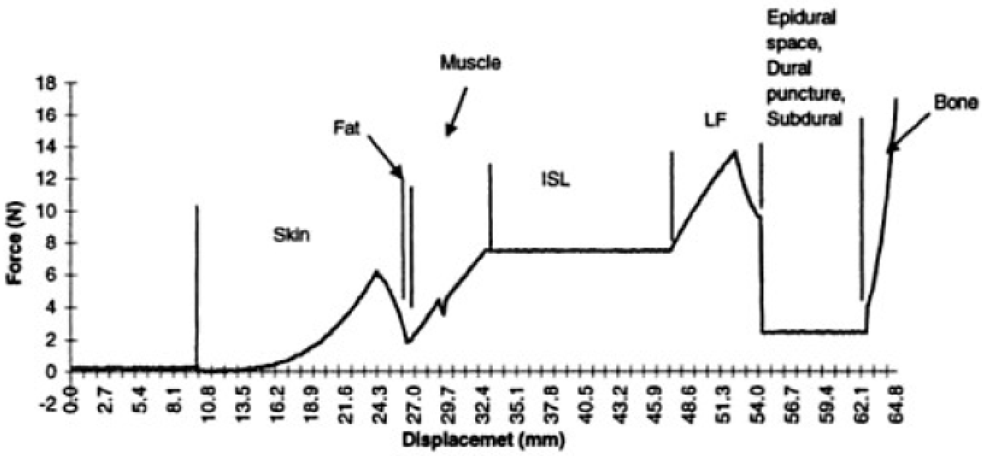
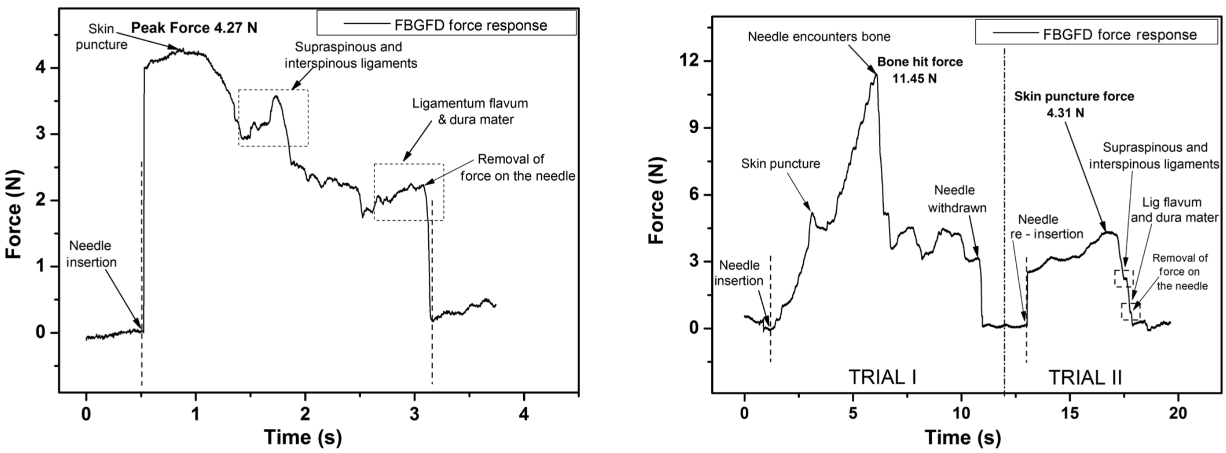


Figure 3: Force model for epidural anesthesia procedure simulation, based on a Tuohy needle insertion force-feedback, Holton et al. (2001)

Ambastha et al. (2016) used a fiber Bragg grating force device (FBGFD) attached to a Quincke 18GA 1.2mm needle to measure and record this force feedback. Some of their measurements are displayed in Fig. (4) and can be used as validation for the results of this research.



(a) Force feedback during a normal insertion with constant velocity.

(b) Force feedback for a failed procedure, indicating a force spike in which a bone was hit, with reinsertion of the needle.

Figure 4: Force feedback recorded using FBGFD during tissue penetration, Ambastha et al. (2016)

This data can be crossed with Ravi's data in order to predict when the needle is about to puncture the *dura mater* and enter the subarachnoid space (see anatomy: Fig. (1)).

3. OBJECTIVE

The purpose of this work and the device to be developed, is to aid medical students and beginner professionals to perform a lumbar puncture procedure by providing visual feedback displaying real-time force feedback and needle insertion depth on a touchscreen in form of a graph, mitigating the negative effects of the rudimentary "loss of resistance" technique.

4. METHOD

A suitable method to validate the accuracy of the measurements obtained by the auxiliary device would be running control tests where a specialised equipment would slowly insert the needle into custom-made silicone samples. The silicone samples were produced specifically to mimic, to a certain extent, the differences in resistance of the tissues inside the human spine.

For the silicone samples, 3 layers of different types of silicone mixture, with varying stiffness, were poured into 6 acrylic molds, fig. (5), using a 20mL syringe. The molds have a height of 50mm and internal and external diameters of, respectively, 34,45mm and 40,40mm.

Figure 5: Acrylic molds used to produce the silicone samples.

The result can be seen in Fig. (6). The pink layer has an average stiffnes compared to other layers. It has an average thickness of 8mm. The green layer is the softest layer and has an average thickness of 16mm. The black layer is the stiffest layer and has an average thickness of 18mm.

Figure 6: Samples with different layers of silicone.

The equipment used is an Instron machine with the needle attached under a moving platform, Fig. (7). This platform lowers the needle at a speed of 0,1 mm/s and takes measurements every 0,1 seconds. The equipment is used to accurately measure the loads at the base of the needle while it is inserted up to 40mm deep inside the previously produced silicone samples.

Figure 7: Testing equipment with the needle attached.

5. RESULTS

The graph in Fig. (8) shows the result of the control tests performed by the Instron machine. It is expected that the auxiliary device being developed displays similar results.

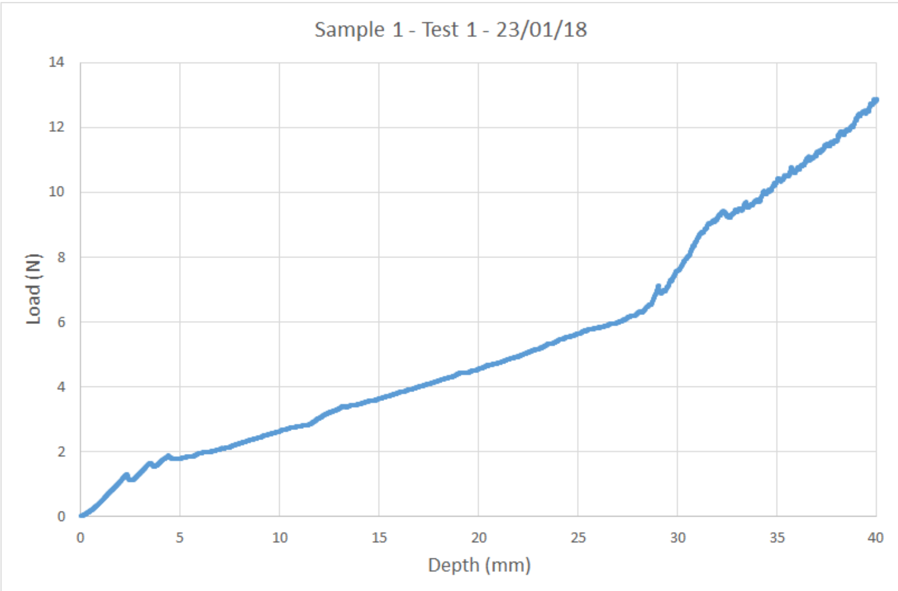


Figure 8: Control measurements taken by the Instron machine.

Preliminary results obtained with tests performed in the Instron test machine show that it is possible to infer the variable puncture resistance measuring the force and displacement of the needle. A device that measures these two variables have a big potential to help doctors to achieve a perfect puncture reducing pain and collateral effects.

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7. ACKNOWLEDGEMENTS

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8. RESPONSIBILITY FOR THE INFORMATION

The authors are the only ones responsible for the information included in this work.