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EVALUATION OF THE ACTUAL MEDICAL PROCEDURE REPLICATION QUALITY BY NOVELTY TRAINING PHANTOM FOR INTRAVENOUS INJECTIONS THROUGH MEASUREMENT OF FORCE PROFILES

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***Abstract**: The purpose of this research was to determine the values and profiles of forces during the penetration of phantoms for intravenous puncture training with a needle. The results showed that the developed training phantom design more accurately represents the real surgical situation than existing solutions on the market. The two-element design of the phantom allowed for the replication of real tissue behaviour during puncture, as the walls of artificial blood vessels offered greater resistance during needle penetration. The developed phantom is economical, reusable, and allows for precise replication of a specific surgical situation, making medical personnel training more efficient and resulting in increased patient safety.*

Keywords: Force profile, Medical phantom, Intravenous injection, Medical training.

1. Introduction

All medical procedures performed on a patient's body require the physician to have excellent motor coordination. Training is necessary for the doctor to become proficient in a particular procedure. In many cases, this obviously causes certain technical problems, as there is a lack of training subjects which are - in case of intravenous punctures - human or animal bodies. To fill this gap and facilitate the training of medical personnel in this topic, specialized training devices are being manufactured (Davda e*t al*., 2018)(Selame *et al.*, 2021). Classical training devices (phantoms) of this type available on the market are solid plastic mass blocks with channels serving as blood vessels. This solution does not accurately reflect the actual surgical situation (Tan *et al*., 2021). Real tissues are a system composed of many elements, and artificially reproducing their mechanical properties is not a trivial task (Gzik-Zroska *et al*., 2016) (Wolanski *et al*., 2017). For this reason, work was carried out to develop a new type of surgical trainer for learning to puncture blood vessels. In order to best simulate the behaviour of tissues during puncture, a two-element design of the trainer was chosen: phantom blood vessels were made separately and then embedded in plastic mass in a form. 3D FDM printing technology was used for creating forms from ABS

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plastic. After the phantom was created, the force profile during the puncture of the phantom was determined and compared to the phantom commonly available on the market.

2. Purpose of research

The aim of the research was to determine the values and profiles of the forces occurring during the penetration of phantoms for the training of intravenous puncture with a needle. The second part of the research involved similar measurements taken on a classical training phantom for comparative purposes.

3. Methods

3.1. Measuring method

The data was collected using a simple device for measuring the force during needle penetration in a trainer. Medical needles used during actual medical procedures were used for this purpose. The force measuring element is a load cell, the signal of which, after amplification, was measured using an analogue-to-digital converter that is part of the peripheral devices of a single-chip microcontroller of the ATMEGA328p type. The system was calibrated to measure force directly in newtons. The data was transmitted to a computer during the measurement cycle and saved in its memory for analysis.

Measurements were made using a needle with a diameter of 0.9 mm $^{+}/_{-}$ 0.02 mm. The diameter of the needles provided by its manufacturer was verified by a series of micrometric measurements.

To avoid the impact of losses of needle sharpness during phantom penetration, a new needle was used for each measurement.
At the time of measurement, the ambient temperature was 21°C $^{+}/_{-}$ 1 (69,8 °F) and the relative humidity was 60 % $^{+}/_{-}$5 %.

3.2. Phantom

In these studies, a prototype of a phantom was used that was produced as a result of work carried out by the team (Fig.1).

The walls of artificial blood vessels and the main elements of the constructed phantom were made of two different plastic masses with desired mechanical parameters. The mechanical properties of both plastic masses were selected in such a way as to replicate real conditions, i.e. the walls of phantom vessels have a higher hardness than the surrounding material. In the design of artificial blood vessels with bifurcation, dependencies found in real blood vessels, including Murray's law, were maintained (Wolanski *et al.*, 2020). The dimensions of the phantom are 90 mm x 50 mm x 25 mm, and the diameter of the artificial blood vessels is approximately 5 mm.

As a comparative material phantom of simpler construction was used (analogous to commercially available devices). It did not have a two-element structure: the artificial vessels were only cavities in the main body of the plastic mass and do not have walls with a different structure.

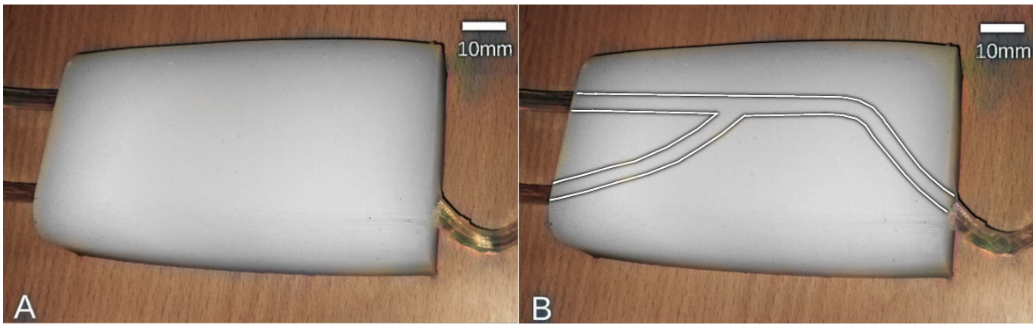

Fig. 1: A Prototype of the phantom; A - general view, B - with the outlined artificial vessel.

4. Results and Analysis

The measurement results are shown in Fig. 2 and Fig. 3. respectively for classical and prototypical phantom.

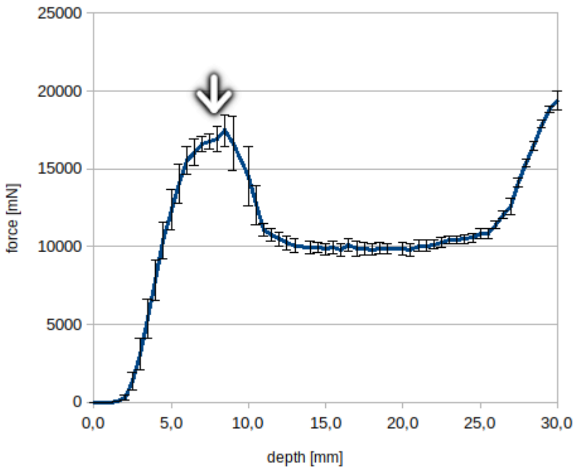

Fig. 2: Force profile; classical phantom, 0.9mm dia. needle; arrow: increased resistance during puncture of the upper surface of the phantom; vertical bars: standard deviations.

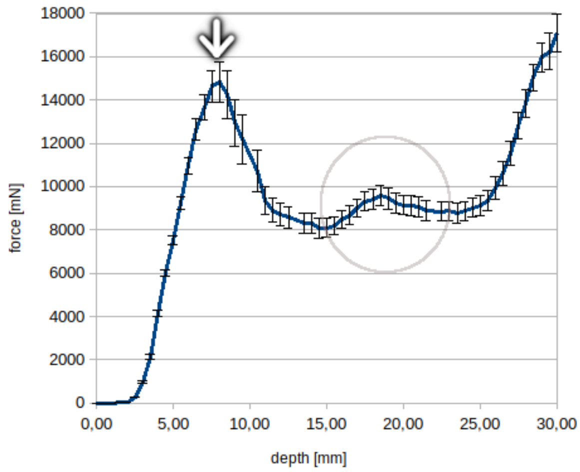

Fig. 3: Force profile; phantom prototype, 0.9mm dia. needle; arrow: increased resistance during puncture of the upper surface of the phantom; circle: increased resistance during puncture of the artificial blood vessel; vertical bars: standard deviations.

In both case, the needle was inserted into phantoms to a depth of 30 mm $^{+}/_{-}$1 mm. The results were averaged for 50 measurement series. It was noted that pseudotissue sometimes caused problems with single measurements at certain depths. When determining the described relationships, the averaged results from at least 8 proper measurements out of 10 were taken into account. As a measure of the dispersion of results, standard deviations were determined for each population of samples (marked on figures).

5. Conclusions

Analyzing the obtained data, it is possible to observe a local increase in the force value (average 17.5 N $^{+}/_{-}$0.9 N and 14.8 N $^{+}/_{-}$1.0 N for classic and prototype, respectively) at moment of phantom surface puncturing. Afterwards, the force value remained relatively constant during the penetration of phantom internal. The applied force started to increase significantly at a depth close to 30 mm (>25 mm), that is, after reaching the opposite wall of the phantom.

As can be seen, in the case of a classical phantom, there is no change in force during puncturing by the needle of an artificial blood vessel (Fig. 2, the area of the graph between the depths of 10mm and 25mm). This is a clear disadvantage of this solution because the walls of real blood vessels offer noticeably greater resistance during their piercing than the surrounding tissues which are useful feedback for physicians or nurses. This situation was successfully replicated in the case of the phantom prototype (Fig. 3, circle).

In conclusion, it can be stated that the developed training phantom construction much more accurately represents the real surgical situation than solutions available on the market. This makes it possible to train medical personnel more efficiently, which directly results in increased patient safety. The developed phantom is economical, reusable and allows for precise replication of a specific surgical situation for the patient; personalized medicine is one of the main directions of advanced healthcare models, which is an additional argument in favor of further research on this problem.

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