BIOMECHANICS – EXPERIMENTAL DETERMINATION OF CRITICAL FORCE NEEDED FOR CANNULA TO BE TORN OUT

HALO Tomáš¹, FRYDRÝŠEK Karel¹, ČEPICA Daniel¹, KOPELÉNT Michal², FOJTÍK František¹, PLEVA Leopold³

¹VŠB – Technical University of Ostrava, Faculty of Mechanical Engineering, Department of Applied Mechanics, 17. listopadu 2172/15, 708 00 Ostrava, Czech Republic, e-mail: tomas.halo@vsb.cz, karel.frydrysek@vsb.cz, daniel.cepica@vsb.cz, frantisek.fojtik@vsb.cz

²VŠB – Technical University of Ostrava, Faculty of Materials Science and Technology, Department of Non-ferrous Metals, Refining and Recycling, 17. listopadu 2172/15, 708 00 Ostrava, Czech Republic, e-mail: michal.kopelent@vsb.cz

³University Hospital Ostrava, Department of Trauma Surgery, 17. listopadu 1790/5, 708 52 Ostrava, Czech Republic, e-mail: leopold.pleva@fno.cz

Abstract: The aim of this paper is to determinate critical (tearing) force. This force is needed to be caused, for cannula and its securing fixation (in this case by tapes), to be torn out from patient's body, (i.e. applications in medico-surgical branches). To determine this quantity, experimental approach was used, in which for more realistic approach real human cutis (skin) was used. Data acquired from this experiment may be later used in designing of a device for automatic winding of infusion tubes etc. Measurements were performed on porcine and human skin.

KEYWORDS: Biomechanics, Human, Cannula, Transfusion, Cannula fixation, Infusion tubes, Safety, Tearing force, Skin (cutis), Measurements

1 Introduction

This paper deals with problem in hospitalization of patients (biomechanics, medical problem). In the case of tearing out cannulas (i.e. application of infusion hoses for patients in a hospital or at home), the cannula is taped in place with tape (i.e. securing fixation). In our case, infusion hoses are placed on patient's forearm. A medical term cannula is a tube that can be inserted into the body, often for the delivery or removal of fluid or for the gathering of data. The anatomical interaction between mechanical circulatory or respiratory support and the patient is achieved by specially designed cannulae. For more information see references [1] to [5] and Fig.1 and 2.

During a treatment in a hospital or at home etc., if the cannula is pulled (ripped, torn) out from a vein of a patient, by accident or intentionally, it may lead to serious consequences or even exitus if not checked in time or correctly replaced. In order to ensure the safety of patients and make the patients have a good rest during liquid infusion, the cannulae and infusion hoses must be correctly proposed and designed.

Cannulae are usually with a trocar (needle) inside. The trocar punctures the cutis in order to get into the intended space. Many types of cannulae exist; see Fig.2.

Figure 1 Intravenous cannulations

Figure 2 Intravenous cannulae

The goal of this paper is to determine the minimum force needed for a patient to pull on an infusion tube with cannula at its end to tear it out from vein (biomedical requirement). And also, to specify safe force to be pulling on an infusion tube from automatic winding device to keep the tube outstretched, but not to pull too strong (reliable tool for safe and effective treatment).

There is a lack of information about cases of patients tearing cannulas out of their skin (cutis). Therefore, it is important to do research, measurements and development in this area.

2 Experiment on Porcine Skin (Cutis)

First idea for the experiment was to use porcine body with skin. Porcine body (i.e. fat back with skin) is easy to buy at the butcher shop. However, problem was that the porcine skin, even after proper preparation was still too oily, therefore the securing tapes didn't hold, and cannulas themselves are quite easy to pull out; see Fig. 3 and 4. Therefore, the continuations of our measurements were performed on human skin, see the following text of this article.

Figure 3 Cannulation on porcine cutis

Figure 4 Pig body with chosen part for experiments on porcine cutis

3 Experiment on Human Skin (Cutis)

The main element holding cannulas in place are the securing tapes, or in some cases the cannulae can be sewn onto patient's skin, see Fig. 5, but this was not the case of this experiment.

Figure 5 Sewn on cannula

To measure the force an S2M/100N load cell developed by HBM was used, see Fig.6. This load cell is capable of measuring forces up to 100 N, which was big enough range for this experiment.

Figure 6 S2M/100N load cell

On each side of the load cell (Fig. 6) was screwed in steel ring, which served for infusion tube to be tied around on one side, and to be pulled on the other side.

For more realistic approach, the experimental measurements were done several times in several anatomic directions on human forearm. For each of seven directions were done two measurements. Anatomical directions are shown in Fig. 7, 8. The cannulas were put on human cutis and taped in place.

Figure 7 Anatomical directions applied in measurements (Right hand)

Figure 8 Anatomical directions applied in measurements (Right hand)

The measurements on humans were performed without inserted cannulae (i.e. infusion hoses were only taped – no intravenous cannulation). According to the medical ethics, there were no intravenous incisions during human measurements (i.e. *benefice a non malefice*).

The original measurements of pulling forces were based on general anatomical directions of infusion hoses with cannulae “similar” to patients with infusions in a hospital; see Fig. 1, 7 and 8.

The measurements were performed at VSB – Technical University of Ostrava (Faculty of Mechanical Engineering, Department of Applied mechanics, Ostrava, Czech Republic) in cooperation with University Hospital in Ostrava & University of Ostrava (Ostrava, Czech Republic).

4 Experiment preparation

Figure 9 Measurement under 45°

To begin with the experiment (measuring) itself; see Fig 9 and chapter 3, proper preparation of human skin (cutis) and all other equipment was needed. According to medics,

the steps showing the procedure of intravenous cannulation (Tegaderm I.V. tape) are shown in pictures below; see Fig 10 to 15.

Figure 10 Skin preparation (shaving, disinfection etc.)

Figure 11 Cannula placed on skin (no incision)

Figure 12 Cannula taped in place (Tegaderm I.V. tape)

Figure 13 Connected infusion hose

Figure 14 More securing tapes

Figure 15 Fixed cannula with tapes

In the pictures above is shown the way, in which the preparations for experimental measurements were done. First step included shaving skin from any excess hair which could affect the stickiness of securing tapes; see Fig. 10. Then a cannula was placed on prepared skin; see Fig. 11, as said before, there was no incision because of ethical reasons. In Fig. 12 the cannula was taped in place by the main securing tape, and after that an infusion hose was connected and some more securing tapes were added. The last tape was used to guide the infusion hose on the forearm in a way, where the hose does not fold, which could cause the infusion to stop flowing through the cannula.

5 Results

The result diagrams show measurements, i.e. dependencies of loading force on time, until the cannula is torn out or infusion tube is detached (i.e. interrupted infusion).

Note: For maximal measured forces from graphs 1-14 (i.e. evaluation), see Table 1.

Graph 1 Measurement in palmar direction
(max. force 29.5 N)

Graph 2 Measurement in palmar direction
(max. force 19.12 N)

Graph 3 Measurement under 45° angle
(max. force 34.98 N)

Graph 4 Measurement under 45° angle
(max. force 31.87 N)

Graph 5 Measurement in distal direction
(max. force 22.47 N)

Graph 6 Measurement in distal direction
(max. force 21.52 N)

Graph 7 Measurement in lateral direction
(max. force 48.46 N)

Graph 8 Measurement in lateral direction
(max. force 35.47 N)

Graph 9 Measurement in medial direction
(max. force 23.51 N)

Graph 10 Measurement in medial direction
(max. force 39.52 N)

Graph 11 Measurement in proximal direction
(max. force 53.30 N)

Graph 12 Measurement in proximal direction
(max. force 50.39 N)

Graph 13 Measurement in dorsal direction
(max. force 45.92 N)

Graph 14 Measurement in dorsal direction
(max. force 34.84 N)

Measurement	Direction of force	Max. Force [N]	Average [N]
1.	Palmaris ^[Graph 1] ^[Graph 2]	29.50	24.31
2.		19.12	
3.	45° ^[Graph 3] ^[Graph 4]	34.98	33.43
4.		31.87	
5.	Distalis ^[Graph 5] ^[Graph 6]	22.47	22.00
6.		21.52	
7.	Lateralis ^[Graph 7] ^[Graph 8]	48.46	41.97
8.		35.47	
9.	Medialis ^[Graph 9] ^[Graph 10]	23.51	31.52
10.		39.52	
11.	Proximalis ^[Graph 11] ^[Graph 12]	53.30	51.85
12.		50.39	
13.	Dorsalis ^[Graph 13] ^[Graph 14]	45.92	40.38
14.		34.84	
Maximum		53.30	51.85
Minimum		19.12	22.00
Median		34.91	33.43
Average		35.06	35.06

Table 1 Measured data

CONCLUSION

From measured data, See Table 1, we can determine that the minimal and maximal force required for the cannula to be torn out or the securing tapes to be ripped apart is in interval 19.12 N to 53.30 N. Maximum force required for cannula to be torn out is in proximal direction because in this case, the securing tape prevents detachment of tubing from cannula. Therefore the tensile load must exceed resistance of securing tape. This result can be affected by the fact, that the measurements were done using the same tape (Tegaderm I.V. tape) without changing it for every measurement done. However, we can consider these

measurements sufficient and reliable enough because the securing tapes held well enough the whole experiment.

From this we can determine, that the infusion tubing is going to detach from cannula first, which means that the force to be used in auto winding device should be big enough for infusion tubing to be stretched, but not to disturb the tubing itself.

$$F = \frac{F_A}{k_s} = \frac{35.06}{5} \doteq 7 \text{ N} \quad (1)$$

To make sure the winding force **F** does not cause ripping the tubing out and allows the patient to move freely, average force **F_A = 35.06 N** (see Tab. 1) should be lowered by safety factor **k_s = 5**.

The acquired data fill the information gap in this topic and give us enough information for the construction of self-winding device etc.

To further this experiment, the winding device should be constructed, and more experiments should be done to test whether the calculated winding force is good enough. If not, the safety factor can be adjusted accordingly.

ACKNOWLEDGEMENTS

This work has been supported by The Ministry of Education, Youth and Sports of the Czech Republic from the Specific Research Project (SP2019/100) & by projects No. CZ.02.1.01/0.0/0.0/17_049/0008441 "Innovative therapeutic methods of musculoskeletal system in accident surgery" and CZ.02.1.01/0.0/0.0/17_049/0008407 "Innovative and Additive Manufacturing Technology" (provider Operational Programme Research, Development and Education, European Union and Czech Republic).

REFERENCES

- [1] Frydrýšek, K., Halo, T., Čepica, D., Fojtík, F. "Pulling out of Infusion Hoses (measurement report)", VSB – Technical University of Ostrava, Faculty of Mechanical engineering, Department of Applied Mechanics, pp. 1 – 20, **2019**.
- [2] Halo, T. "Biomechanika - Samonavíjecí infuzní hadičky (Biomechanics - Automatic Roll-up Infusion Hoses) ", unpublished bachelor thesis (written in Czech language), VSB – Technical University of Ostrava, **2019**, head of thesis Karel FRYDRÝŠEK
- [3] Frydrýšek, K., Čepica, D., Halo, T. "Stochastic Loading of a Sitting Human", Strojnícky časopis - Journal of Mechanical Engineering 69 (2), pp. 97 – 110. **2019**. DOI: 10.2478/scjme-2019-0020.
- [4] Frydrýšek, K., Dvořák, L. "Biomechanics - Testing of Mechanical and Utility Properties of Bottles for Redon Drainage", Engineering Mechanics 2017, ISBN:978-80-214-5497-2, ISSN: 1805-8248, Svratka, Czech Republic, pp. 318 – 321, **2017**.
- [5] Čech, R., Horyl, P., Maršálek, P. "Modelling of Two-Seat Connection to the Frame of Rail Wagon in Terms of Resistance at Impact Test". Strojnícky časopis – Journal of Mechanical Engineering 66 (2), pp. 101 – 106, **2016**. DOI: 10.1515/scjme-2016-0024