

COMPARISON OF THE USABLE PROPERTIES OF THE DEVELOPED GAUZE WITH COMMERCIAL COMBAT GAUZE

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Abstract

Massive hemorrhage is one of the most common causes of death on the battlefield. Hemorrhage can be controlled by combat gauze such as H&H compressed gauze and Compressed Gauze NAR. The aim of the research was to comparison of the usable properties of the newly developed gauze with the other medical devices having the well-known history of the use at real conditions. The new types of the gauze structure showing the complexed novelty in the design of the usable form of the combat gauze. The absorption capacity of the combat gauze plays the most important role in hemorrhage stopping applications. Thus, the presented research compared absorption under free soaking conditions, tested in laboratory environments, and absorption of artificial blood under simulated conditions. The results show that the newly developed 17-thread gauze has the improved properties with regard to maintaining fluid inside the gauze structure as well as the highest absorption capacity as compared in commercial comparison. Above allows to conclude, that the tested useable attributes of newly developed combat gauze indicate the promising in the possibility to use it in real conditions (after biocompatibility and clinical studies).

Keywords: Battlefield medicine, Combat gauze, Hemorrhage, Medical gauze, Personal security, Wound healing.

1. Introduction

As can be seen in the literature uncontrolled hemorrhage is the main reason of death on the battlefield [1, 2] and the second main reason after civilian trauma [3]. Heavy hemorrhage accounts for up to 40% of mortality after traumatic hurt. In contemporary battle, most injuries are piercing and mostly apply the limbs [1, 2]. Bleeding from limb wounds accounts for over half of all avoidable deaths on the battlefield. To stop bleeding, hemostatic gauzes are used. Death rate from hemorrhagic shock caused by heavy bleeding in a wound is preventable if action is taken upon instantly after injury. The most popular are Combat Gauze (CG; z-Medica Corporation; Wallingford, CT) [4, 5], QuikClot Combat Gauze (QCG) (Z-Medica, Wallingford, CT) [6, 7], Celox Gauze (Medtrade Products Ltd., Crewe, UK) [8]. These dressings contain an agent that promotes blood clotting like chitosan, alginate, fucoidan, hyaluronic acid, kaolin [9]. However, there is also a textile wound dressing gauze without any substance, which can also stop bleeding - medical gauze.

Medical gauze is a material intended for post-surgical wound applications or deep wound healing. It is made of fabric with specific loose open weave. The application of gauze helps to quickly wound heal. Gauze dressings can be medicated or impregnated with antiseptic or made for wound debridement - specifically in cases where the wound is large. The future solution in scope of the haemostatic materials will be implemented the pharmaceutical products, such as topical drugs, i.e. nonsteroidal, anti-inflammatory formulations [10, 11].

Wound dressings are materials that are alleged to support healing and guard the wound from further harm. The healing action, aside from the needs of effective dressing, also contains other important parameters such patient convenience and drain verification [12]. Wound healing contains an entangled sequence of cellular and molecular processes such as inflammation, cell migration, angiogenesis, temporary matrix synthesis, collagen deposition and reepithelization [13].

Wound dressings should be described by flexibility, applicability, hemostatic properties, good mechanical properties, water vapor permeability, good gas replacement capacity, improved blood flow, decreased infection chance [14-20]. It is well known that understanding the features of hemostatic dressings translates into their performance and allows you to determine all aspects related to the security of the use.

Gauze is a direct wound dressing and is intended to be in close contact with the wound, enabling it to heal. Cotton gauze is the most commonly used textile for wound management (mainly for cleaning purposes). It is effective in removing blood and exudate from the wound site. It is generally known that the main purpose of using gauze is to absorb and remove exudate from the wound, so as part of the work carried out, the most important criterion for choosing gauze was absorbency. Absorption is a very important factor that makes it possible to evaluate the effects of dressings used on abundant or moderately oozing wounds.

However, the development of gauzes and wound dressings with specific properties still remains a challenge for several medical applications. There is no comparison of absorbency for hemostatic gauzes. Therefore, a new gauze to control uncontrolled hemorrhages was developed, which is described in this article, and it was compared with commercial gauzes.

The main goal of the research was to compare the absorption behaviour of various types of medical gauzes considered for inclusion in the kit for dressing injuries, which constitutes equipment during performance of official duties by uniformed services, in comparison to the newly-designed product. Essential factors such as absorption under free soaking conditions and absorption of artificial blood were studied for the new gauze (Sample 1) and compared with commercial products. The results obtained in the study were used to indicate which of the tested gauzes should be recommended to equip the dressing kit.

The risk of the use of discussed materials is mostly connected with the absorption capacity as well as the reduction of the risk of leakage of the blood during the use. Taking into the account above, the estimation of this risk is needful on the early phase of the development with the validation using the equivalent medical devices having well-known history of the applications.

2. Materials and Methods

To compare the functional properties of the developed gauze, two commercially available combat gauzes (NAR, H&H) were used for comparative studies. Subsequently, tests were carried out using SEM and FTIR techniques. The sorption properties of the analysed materials and their surface mass were also examined during the research.

2.1. Newly designed form of the gauze

The newly developed 17-thread cotton gauze has an irregular arrangement of threads resulting in an increase of its absorbency. The process of fabrication of the new type of gauze was carried out in TZMO Tkalnie Żelów S.A./Poland. Additionally, due to the content of the project co-financing agreement, the proprietary rights to the subject of dissolution are vested in the Ministry of National Defense and cannot be presented.

2.2. Compression gauze - H&H compressed gauze

Cotton fluff bandage rolls manufactured by H&H Associates, Inc., USA. Measures 4.5"× 4.1 yds stretched. 6-ply, single use. H&H gauze is the perfection answer for a cohesive, simply to use, cotton roll up gauze intended for hurt packing and bandaging. Created of high-quality cotton, H&H compressed gauze can be applied to regulation hemorrhage in conjunctive with a compression bandage, applied as underlay gauze for hemostatic wound dressings or for bandaging smaller wounds. The H&H gauze is packed in a special dispenser that permits for controlled use and protects disused portions from impurity during application. Its small place requirement and rugged, stable vacuum-sealed packaging make it easy to match in individual first aid kits and medic sets [21].

2.3. Compressed Gauze NAR

The cotton 6-ply gauze with finished edges to reduce loose ends or lint is manufactured by North American Rescue, USA. Those gauze is made of cotton. Due to unique crinkle weave, it has good fluid absorption. Gauze has finished edges to reduce loose ends or lint. The application of gauze is to dressing wound and stop hemorrhage [22].

2.4. Fourier Transform Infrared Study (FTIR)

Infrared spectra of the tested samples were obtained within the range 4000-400 cm⁻¹ using Nicolet iS50 Spectrometer (Thermo Scientific, USA) and the ATR attachment equipped with a diamond crystal. The analysis was performed at the accuracy of wavenumbers reading for characteristic bands was $\pm 1\text{cm}^{-1}$ and the number of scans for baseline and spectrum collection was 32.

2.5. Electron Microscope Study (SEM)

SEM observations of the topography of the tested usable forms of the topical haemostatic agents were carried out using SEM Quanta 200 (FEI Co., Hillsboro, OR, USA).

2.6. Absorption under free soaking

The absorption under free soaking conditions of the tested medical gauzes was established according to the guidelines presented in EN 13726-1:2002/AC:2003. The standard prescribes a test liquid containing a 142 mmol sodium and 2.5 mmol calcium in the form of chloride salt. The solution achieved an ionic composition similar to human serum or wound exudate. The gauze was placed on Petri glass and the appropriate amount of the tested solution in composition mentioned-above was added (40-times higher than the mass of the tested sample). The tested system was heated to $37\pm 1^\circ\text{C}$ in a dryer (C-30W, WAMED, Poland) for 30 min. Then, the tested sample was hanged by one of its horns and left for 30 s. The final mass of the sample was estimated.

Absorption under free soaking conditions was determined as the average weight of the absorbed liquid per 1 g of the sample.

The results were expressed as the mean with standard deviation (SD), and assessed by a one-way analysis of ANOVA to demonstrate differences between groups. The PQStat (PQStat, Polska) for statistical analysis was used.

2.7. Surface density

The surface density of gauze was determined by three measurements of the sample's width and length. The surface density was determined based on the Eq. (1).

$$Mp = \frac{m_i}{(d \times s) 10^6} \quad (1)$$

2.8. Absorption tested under simulated conditions

Absorption tests under simulated conditions were carried out at the Police Academy in Szczytno/Poland. The results obtained in the course of the tests were used to verify which of the tested gauzes should be recommended to equip the dressing kit under development.

In order to ensure proper conditions for the implementation of the research, diagnostic tools were prepared: three bowls with a capacity of 300 ml each, 300 ml of artificial blood preparation with clots - 100 ml of liquid in each bowl (Fig. 1), samples of the three compared dressing gauzes marked accordingly: H&H Compressed Gauze, Nar Compressed Gauze, 17-thread Gauze (Sample 1) - each 100 cm long. Figure 2 describes the procedure of the test realization.



Fig. 1. Bowls containing artificial blood used in the examination.

All tested gauze had the same length of 100 cm and were marked accordingly.

The meter lengths of gauzes and 100 ml of artificial blood preparation were weighed with laboratory scale (RADWAG PS210/C/). The artificial blood preparation was heated to a temperature of 36.6°C in an ESCO laboratory bath.

The artificial blood preparation was prepared from water and powder containing Hydroxyethyl cellulose, called Simulaid's Blood Powder. This product is manufactured by the Nasco Healthcare Inc. (Simulaid's Blood Powder, USA) [23]. It is a commonly used product for the easy preparation of simulated blood. Usually used as a teaching aid to add a realistic feeling during first aid training.

In the present experiment, it was used as a coloured liquid simulating blood to make possible careful observation of the behaviour of various types of medical gauzes during free soaking in order to compare their absorption properties. According to the preparation instructions given by the manufacturer, the artificial blood is prepared in the following proportions: one sachet of powder weighing 172 g per 3.78 dm³ of water. In order to form clots in the artificial blood preparation, 1 dm³ of obtained liquid was poured into another glass and 5 g of powder (Simulaid's Blood Powder, USA) was added to it again. In this way, 1 dm³ of artificial blood preparation with clots was obtained. 3x100 cm³ (300 cm³) of this preparation were used for the experiment - 100 cm³ for each bowl.

The research started with placing the gauze samples into bowls with artificial blood. The samples of the compared gauzes soaked in the artificial blood preparation for 5 minutes, then were removed from the bowls and placed on a prepared test stand enabling accurate measurement of the absorbed fluid (laboratory stand, laboratory funnel, measuring cylinder).

Observations and measurements for the absorption of fluid and the maintenance of fluid inside the gauze were made 1, 3 and 5 minutes after the gauzes were removed from the bowls.

The flow diagram of the test realization procedure is presented in Fig. 2.

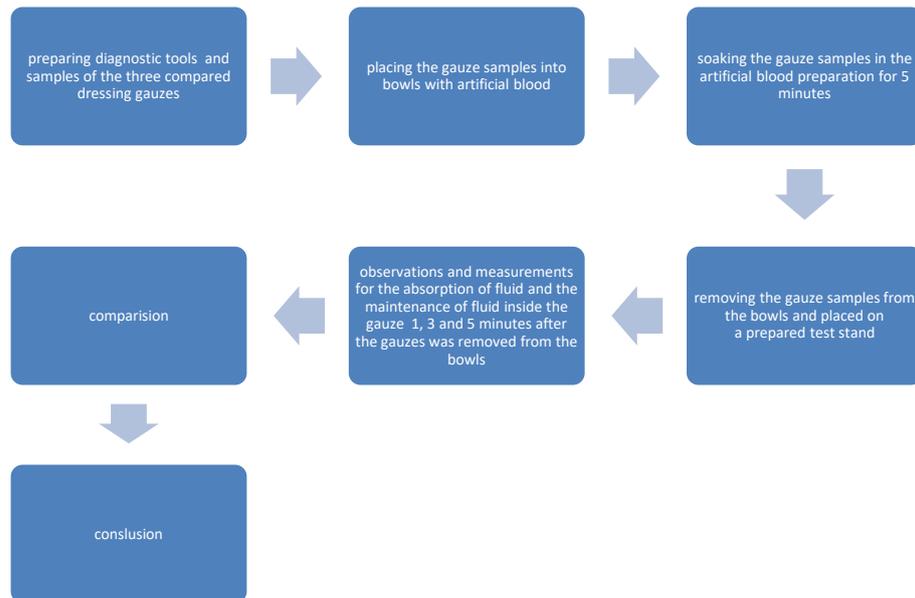


Fig. 2. Flow diagram of the test realization procedure.

3. Results and Discussion

3.1. Structural changes in medical gauzes - Infrared spectroscopy

At the presented FTIR-ATR spectrum shown, the mid-infrared range ($400\text{-}4000\text{ cm}^{-1}$) is included, which is the most widely used to provide information about the analysed sample. As reported by Nandiyanto et al. there are four regions in the mid-infrared spectrum:

- the single bond region ($2500\text{-}4000\text{ cm}^{-1}$),
- the triple bond region ($2000\text{-}2500\text{ cm}^{-1}$),
- the double bond region ($1500\text{-}2000\text{ cm}^{-1}$), and
- the fingerprint region ($600\text{-}1500\text{ cm}^{-1}$) [24].

Figure 3 shows that at the FTIR-ATR spectrum of all gauzes typical bands of cotton were observed. There were no differences between the samples. The hydroxyl (OH) groups at 3330 cm^{-1} were observed. The bands around 2898 cm^{-1} were correspondent to the symmetric and asymmetric stretching for C-H and have not separated as sharp peaks, which is a common phenomenon in the case of cotton. The absorption band at 1427 cm^{-1} was associated with the CH_2 symmetric bending of the cellulose [25, 26]. The band 1640 cm^{-1} was due to asymmetric carboxylate stretch, whereas in the range bands $1360\text{-}1314\text{ cm}^{-1}$ were relative to bending O-H in plane bending. Two bands 1160 and 1108 cm^{-1} were correspondent to asymmetric bridge C-O-C. Intense characteristic peaks at 1050 cm^{-1} were result of asymmetric in plane ring stretching and at 1040 cm^{-1} C-O stretching. The peak at 894 cm^{-1} indicated the presence of β -glycoside linkages between monosaccharides [27-29]. As expected, no changes in the FTIR spectra of the tested gauzes were detected after the separation of FTIR spectra.

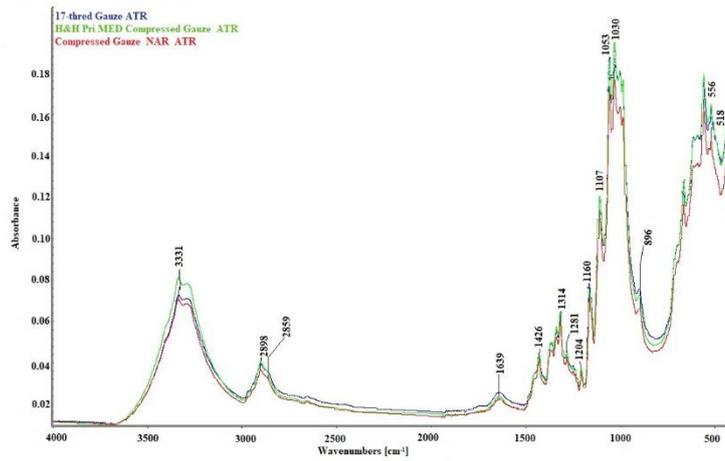


Fig. 3. Fourier transform infrared study (FTIR) spectra of the study gauzes.

3.2. Topography of the gauzes

Figure 4 shows the SEM microphotographs all three study gauzes.

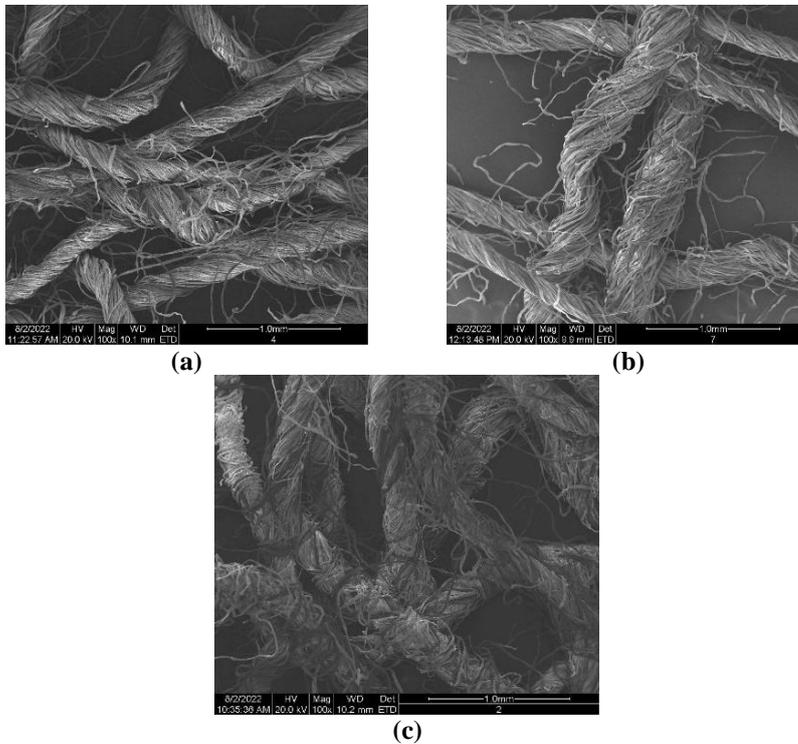


Fig. 4. Scanning Electron Microscope Study (SEM) microphotographs of study gauzes at magnification 100×, (a) Sample 1, (b) H&H compressed gauze, (c) Compressed gauze NAR.

By comparing the structures of the yarns used to produce the gauzes (Fig. 4), significant differences can be seen between the structure of the yarn used to produce gauze c) and the yarns used to produce the other two gauzes. Based on the presented SEM photos, it can be seen that a different spinning technique was used to produce the yarn used to produce gauze c) [30, 31]. Unlike the helical arrangement in the case of the yarns in gauzes a) and b), a weaker twist and the presence of wrapper fibres can be observed in the case of the fibres from compressed gauze NAR c). Since the yarn structure has a significant influence on the properties of the yarn, the presence of fibres aligned perpendicular to the fibre core, may affect the slightly lower sorption capacity of this gauze due to the hindered access of liquid to the fibres.

Furthermore the small-sized, empty spaces among the fibres were observed in SEM microphotograph of the study samples, resulting from the woven structure of the gauzes, Figs. 4(a), (b), (c). The smallest spaces can be observed for Sample 1. This may be because the gauze is woven more densely. Due to its structure, sample 1 can absorb more blood.

3.3. Absorption under free soaking conditions

Cotton gauze absorbs water very well and can be used to quickly absorb blood, plasma and other fluid from wounds. As described in the literature, the cleaning process of raw cotton affects its absorbency. Raja et al showed that depending on the cleaning method, a product with different absorption capacity can be obtained [32]. In the literature described that surface modification of gauze helps to improve the water absorbency and strength of it. Dai et al. [33] showed what elements can influence to the water absorbency of the cotton gauze. They described that it will be an amount and strength of the fibre, hydrophilic groups, physical structure and chemical structure.

Gauze developed by us has not any finish it has the highest value of absorption under free soaking conditions. The absorption capacity is strongly connected with the structure of the material as well as its surface density.

The absorption under free soaking conditions of the newly developed gauze (Sample 1), as well as the commercial gauzes (H&H PriMed Compressed Gauze and Compressed Gauze NAR) are shown in Fig. 5.

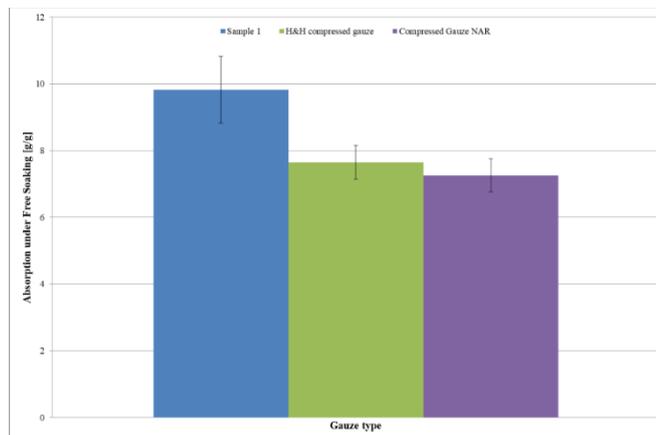


Fig. 5. Absorption under free soaking conditions of tested gauzes ($P < 0.05$).

The newly designed 17-thread gauze demonstrated the highest value of absorption under free soaking conditions in comparison of: H&H PriMed Compressed Gauze (lower by 22% as compared with Sample 1) and Compressed Gauze NAR (by approx. 26% compared with Sample 1), which suggests its greater desirability for applications related to stopping bleeding. P values <0.05 were considered as statistically significant. The observed phenomenon is connected with the structure of the newly developed woven products resulting from the technological process. Due to significantly enhance the surface of the material.

The highest value of absorption under free soaking conditions observed for Sample 1 significantly reduces the risk of uncontrolled bleeding and speaks in favour of its acceptance for implementation in a wide range of applications associated with stopping massive haemorrhage. This result is better even compared to [4], where Combat Gauze absorbed around 7.1 g/g, whereas Traumat Stat gauze 5.7 g/g.

In other research, Zielińska et al. [34] investigated the absorption under free soaking for various usable forms of the haemostatic topical agents: lyophilized powder, lyophilized foam and impregnated gauze. The highest values of absorption for the lyophilized foam were found being the approx. two times higher as compared with the impregnated gauze. However, the values of the absorption under free soaking for the impregnated gauze was approx. 20% lower as compared with initial gauze. Moreover, the impregnation of the gauze with the active formulation yielded in reduction of the studied parameters by approx. 20%.

Wiśniewska-Wrona et al. [35] tested the absorption on the free soaking for two forms of the powders containing fibrids made of the formulation of the chitosan and sodium/calcium alginate. The obtained parameter was approx. 10% lower related to the values obtained for the tested impregnated gauze. The tested parameters are important due to the estimation of the affinity of the material/formulation to the absorption of the amorphous elements of the blood during the first stage of the application. It effects on the blood clotting phase due to the rise in concentration of the natural clotting factors in place of the homeostatic topical agent applications [34].

3.4. Surface density

Surface densities of tested gauzes are shown in Fig. 6.

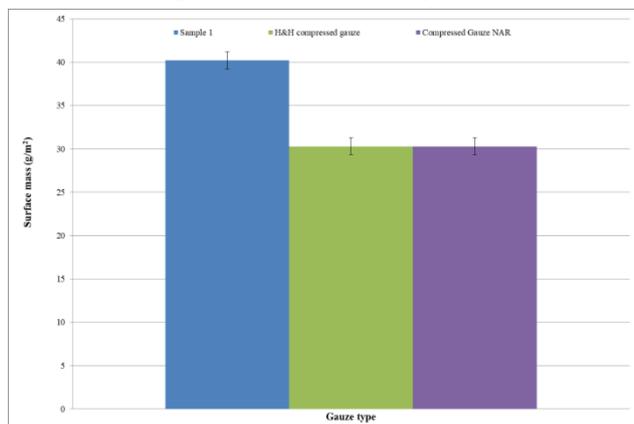


Fig. 6. The surface density of samples.

The H&H compressed gauze as well as Compressed Gauze NAR have similar surface density. The highest value for Sample 1 was found to be higher by approx. 10 g/m² as compared with other tested commercial gauzes. As described above, the values of surface density are directly connected with the absorption under free soaking conditions, and higher surface density promotes improvement of the absorption behaviour of the tested gauze.

3.5. Absorption

After soaking in artificial blood for 5 minutes and removal of the samples from the bowls and their placement on the laboratory stand with laboratory funnel and measuring cylinder, they were reweighed with laboratory scale (RADWAG PS210/C/). It was observed that none of the gauzes absorbed 100% of the preparation, but the differences in absorption occurred. The 17-thread gauze (Sample 1) absorbed the greatest amount of liquid: 104.5 g, which is 88.86% of the total fluid used in the experiment (Table 1).

Table 1. Differences in absorption of the tested gauzes after a 5-minute of free soaking in the artificial blood preparation.

Name of the item to be weighed	H&H PriMed Compressed Gauze	Compressed Gauze NAR	17-thread gauze	Artificial blood preparation
Mass of the tested items before soaking (g)	15.00	14.63	15.02	117.60
Mass of the tested gauzes after a 5-minute of free soaking in the artificial blood preparation (g)	107.89	110.33	119.52	x
Mass of the absorbed fluid in tested gauzes after a 5-minute of free soaking in the artificial blood preparation (g)	92.89	95.70	104.50	x
Percentage of fluid absorbed by gauze (%)	15.00	14.63	88.86	x

One minute after **gauzes** were removed from the bowl and placed on the laboratory stand with laboratory funnel, the leakage fluid from Compressed Gauze NAR was observed. The above phenomenon was not detected for the H&H PriMed Compressed Gauze as well as the newly-developed gauze.

After 3 minutes fluid leaked from both gauzes: Compressed Gauze NAR and H&H PriMed Compressed Gauze, but not from Sample 1. The same phenomenon was observed after 5 minutes. Detailed numerical and percentage specification of the amount of fluid leaking from the tested gauzes is presented in Table 2.

The observation of the gauzes impregnated with artificial blood preparation after just 1 minute from the end of the soaking period showed differences between the behaviour of H&H PriMed Compressed Gauze as well as Compressed Gauze NAR and the newly developed gauze (Sample 1). After 1 minute from the application of the artificial blood and their removal from the bowls, both of the tested commercial gauzes began to leak the preparation. After 3 and 5 minutes, these differences still persisted. The newly developed gauze: Sample 1 (17-thread Gauze) retained artificial blood in its structure without expelling it to the outside.

Table 2. Differences in the mass of the fluid leaking from the tested gauzes after 1 minute, 3 minutes and 5 minutes.

Name of the item to be weighed	H&H PriMed Compressed Gauze	Compressed Gauze NAR	17-thread gauze	Artificial blood preparation
Mass of the fluid leaking from the tested gauzes after 1 minute (g)	0.00	0.74	0.00	117.60
Percentage of fluid leaking from the tested gauzes after 1 minute (%)	0.00	0.77	0.00	x
Mass of the fluid leaking from the tested gauzes after 3 minute (g)	0.239	2.48	0.00	x
Percentage of fluid leaking from the tested gauzes after 3 minute (%)	0.26	2.59	0.00	x
Mass of the fluid leaking from the tested gauzes after 5 minute (g)	0.712	3.56	0.00	x
Percentage of fluid leaking from the tested gauzes after 5 minute (%)	0.77	3.72	0.00	x

4. Conclusions

The research results suggest that the newly designed gauze exhibits enhanced absorption behaviour, tested in both laboratory and simulated conditions, as compared with commercially available products. The absorption capacity is strongly connected with the structure of the material as well as its surface density. Based on the assumption that the hemorrhage preventing gauze is an absorbent dressing material used to control bleeding, the absorbency of the material should be the main criterion for choosing the optimal gauze. Therefore, when comparing the absorbency of the three gauzes subjected to research procedures, it is recommended to use the newly designed gauze, because it has the best properties with regard to maintaining fluid inside the gauze structure as well as high liquid absorbency. Because this research had to be conducted - the prototype of the hemostatic gauze is still under development, and its validation should be performed on a wider scale during preclinical in vivo tests and clinical studies.

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Nomenclatures

d	Length of the specimen, determined as an average of 3 analysis, mm
m_i	Mass of the specimen, g
M_p	Surface density, g/m^2
S	Width of the specimen, determined as an average of 3 analysis, mm

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