Wetting Behaviour of Surgical Polyester Woven Fabrics

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To ensure the prevention of viruses and microorganisms exchange in surgical theatre textiles must be biocompatible, comfortable, and also be able to provide a sterile field for both the patient and the working team. Wettability is one of the most important properties for surgical textiles because it enables to evaluate a barrier effect of a fabric against particle-loaded liquid. Wetting behaviour for the series of polyester fabrics (including woven of microfilament yarns), aseptic and non-aseptic, used for surgical articles is investigated in the paper. Contact angle for the fabrics was measured by sessile drop method using the Drop Shape Analysis System G10/DSA10, produced by Krüss Optronic GmbH. Distil water and salt solution (NaCl 0.9 %) were used as test liquids. Analyzed surfaces of all investigated fabrics can be considered as water-repellent. For aseptic fabrics with salt solution as a contact liquid, measured contact angles are a little bit smaller than with distil water. Time-dependent wetting behaviour of aseptic fabrics P4, P6, P8 and T1 was also investigated with the same contact liquids. The influence of gravitation force: at certain instants and of drop size on the contact angle is discussed. It is shown that all investigated fabrics are found being highly hydrophobic, especially the fabrics made up of microfilament yarns. Possibility of self-cleaning effect of the fabrics is discussed.
Keywords: surgical gown, drape, polyester woven fabric, microfibre, wettability.

1. INTRODUCTION

Textile related materials are very important in all aspects of medicine. Due to constant improvements and innovations in both medical procedures and textile technology the annual growth of medical textile products during the last two decades occurred at a compound annual rate of $10 - 15$ % [1]. Various types of textile items including protective and hygiene products as surgeon's gowns, caps and masks, patient drapes and cover cloths have been developed and widely used in hospital operating theatres. Textiles in various forms are also used for implantation, e.g. sutures, artificial joints, vascular grafts, etc.

To be used in surgery, textiles must be biocompatible, comfortable, and also be able to provide a sterile field for both the patient and the working team [2, 3]. On the other hand, they must be strong enough and abrasion resistant to withstand all the mechanical impacts that occur during the surgery.

It is crucial to ensure the prevention of viruses and microorganisms exchange in surgical theatre. The fabric should not let liquid and solid particles pass through easily, so they should be waterproof.

Wetting behaviour determines the resistance of flow and the sorption of liquid on the fabric surface. It is one of the most important properties for surgical textiles because it enables to evaluate a barrier effect of a fabric against particle-loaded liquid.

Wetting behaviour for the group of polyester woven fabrics, used for surgical articles, is investigated in this paper.

2. THEORETICAL CONSIDERATION

Wetting of textile fabric can be explained on a basis of physical phenomenon for the system solid-liquid-air (or gas in common case). Spherical surface shape of a drop of liquid laying at equilibrium on a smooth homogeneous solid surface is dependent on the relation between the interfacial tensions (γ): solid-air (γ_S), solid-liquid (γ_{SL}), and liquid-air (γ_{LA}) (Fig. 1). The last two quantities are not directly measurable. Ratio between these quantities at phase of equilibrium is described by Young-Dupré equation [4]:

$$\gamma_S - \gamma_{SL} = \gamma_{LA} \cdot cos\,\theta , \qquad (1)$$

where θ is a contact angle of a liquid droplet on a given surface. The difference $\gamma_S - \gamma_{SL}$ has been termed the "wetting tension" or "adhesion tension" [5, 6].
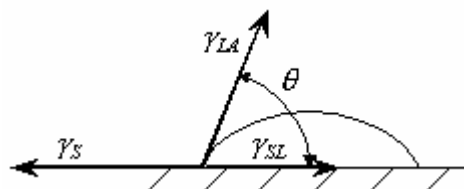

Fig. 1. Equilibrium state of a drop of liquid laying on the smooth solid surface

Wetting is the displacement of a solid-air interface with a solid-liquid interface. Solids with large γ_{SA} are more easily wetted compared to those with low γ_{SA}. In the latter, water tends to form hemispherical droplets with a high contact angle [6].

Textile fabrics or even single fibres are nonideal solid surfaces. Wetting of fabric surfaces are very sophisticated processes complicated by surface roughness, heterogenity,

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Table 1. Structure characteristics of fabrics

Fabric	Weave	Parameters of the yarn						Parameters of the fabric	
		Linear density, tex		Diameter, mm		Number of filaments		Number of yarns per 1 cm	
		warp	weft	warp	weft	warp	weft	warp	weft
P1	Plain	9.2	9.2	0.09	0.09	35	35	58.0	33.0
P2		10.4	9.3	0.10	0.09	36	36	61.3	36.5
P3		12. 9	17.4	0.11	0.13	88	288	60.5	30.3
P4		20.5	9.2	0.14	0.09	285	138	58.5	31.5
P5		9.4	8.5	0.09	0.09	112	102	45.6	37.0
P6		10.7	20.2	0.10	0.14	338	160	57.2	31.3
P7		9.5	9.4	0.09	0.09	36	36	67.4	35.8
P8		16. 8	14.9	0.12	0.12	582	61	55.0	33.4
P9		9.6	14.3	0.09	0.11	36	100	60.3	89.0
T1	Twill	9.9	19.9	0.10	0.14	161	325	73.0	59.0
T2		9.5	12.6	0.09	0.11	69	206	45.8	36.2

diffusion of liquid into the fibre, and the capillary action of the fibre assembly [5 – 10]. Therefore the experimentally measured (apparent) contact angle for the real fabric-liquid system can differ considerably from the true contact angle, described by the equation (1) for an ideal system. Some direct contact angle measuring methods for textiles have been proposed [8, 11].

In the theory of wettability contact angle of 0° means complete wetting, and a contact angle of 180° corresponds to complete non-wetting. The latter means that the material is hydrophobic and has little or no tendency to absorb the liquid that tends to spread on its surface into discrete droplets. For real fibre systems, in fact, it is more correctly to visualize that when the contact angle approaches zero, wettability has its maximum limit.

Liquid penetrates most deeply into the pores between yarns in the dynamic situation – when drop of liquid is falling onto the textile fabric. The ability of liquid to withdraw from the pore also depends on the contact angle at their interface.

3. EXPERIMENTAL

Series of polyester woven fabrics used for surgical gowns manufacturing was taken for the investigation. The fabrics differed in yarn structure as well as in main fabric structure characteristics (Table 1). As it is seen, some of the investigated fabrics are woven of microfilament yarns. The series of fabrics was divided into two groups: the fabrics of one group were supplementary sterilized to become aseptic. The fabrics of another group were "as received", i. e., non-aseptic.

Contact angle was measured by sessile drop method using the Drop Shape Analysis System G10/DSA10, produced by A. Krüss Optronic GmbH [12]. The basic instrument of the system – Contact Angle Meter G10 is presented in Fig. 2.

The sample stage of the instrument can be precisely adjusted along all three axes using precision drives. Drop image contrast is optimized using the variable intensity illumination. A zoom objective of the microscope allows the drop image to be shown at the maximum size possible. The optics can be tilted by up to 2° to achieve the best
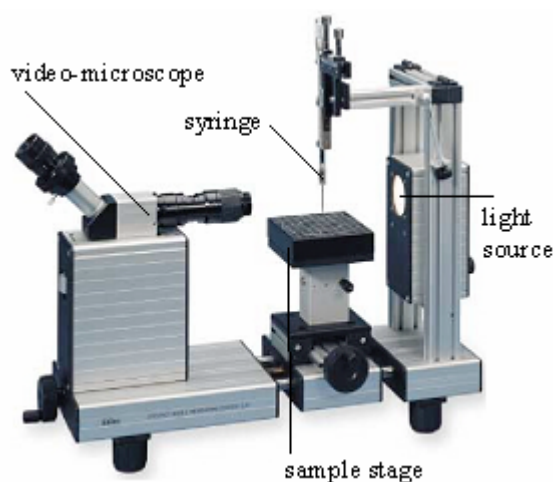
Fig. 2. Contact Angle Meter G10

angle of view. It is especially important for such rough and uneven surfaces as textile fabrics.

Instrument is equipped with a micrometer driven syringe and a mechanical stage. Dosing system uses a syringe controlled by a stepper motor to produce drops at a controlled flow rate. These ensure that the liquid drop is dosed exactly and positioned reliably for measurement.

Windows™ software is used to process images acquired by the video camera and digitizing card of the DSA10 system. Software uses a special algorithm to define the drop boundary reliably. Images of sessile drops are fitted to yield contact angle data. Contact angles are measured at the tangent lines to the surface and the mean value $\theta = (\theta_1 + \theta_2)/2$ is calculated (Fig. 3).

Fig. 3. Tangent lines at the borders of the drop

Distil water and salt solution (NaCl 0.9 %) were used as test liquids. The diameter of the drops ranged between

2 – 5 mm. Within this range the contact angle was almost independent of the drop size.

Contact angles for the investigated fabrics, measured at few seconds after the drop is put down from the syringe (an average value of 5 – 6 measurements) are presented in Table 2.

As the measured contact angles are much bigger than 90°, the analyzed surfaces of the fabrics can be considered as water-repellent. Air is enclosed in the textile-water (or textile-salt solution) system and this enlarges the water/air interface while the solid/water interface is minimized. On this rough "low energy" surface, the water gains too less energy through adsorption to compensate for any enlargement of its surface. Thus spreading does not occur; the liquid (water or salt solution) forms almost a spherical drop that can easily roll on a surface of the fabric. It could be said that contact angle of the drop depends almost entirely on the surface tension of the water (salt solution). As it can be seen, for aseptic fabrics the contact angles with salt solution are little smaller than with distil water.

The fabrics P4, P6, P8 and T1, all of them woven of microfilament yarns, can be marked as having higher contact angles comparing to the rest. So, it is desirable to use microfibres in manufacturing the fabrics for surgical gowns.

On nonideal surfaces measured contact angle exhibits hysteresis, it decreases with time [6]. To reveal such time-dependent wetting behaviour the aseptic fabrics P4, P6, P8 and T1 were tested with distil water and salt solution. Average contact angles measured at different times after the drop is put down from the syringe, and the contact angle 95 % confidence limits are presented in Table 3. The results marked 0 min mean measurements made within 10 seconds after the drop is put down from the syringe.

It is obvious that within 30 minutes average contact angles decrease in time for both the distil water and salt solution. Drops of both liquids act in similar way. It should be mentioned, however, that after a certain time period drop of water (or salt solution) slightly flattened under the influence of gravitation force: at certain moments the contact angles increased and then started decreasing again.

The influence of drop size on the contact angle could be the reason of such facts. Due to high hydrophobicity of a textile material the surface area at the interface drop/textile does not change for a while. Thus the contact angle starts to increase. But after a while the system turns to equilibrium, the interfacial area increases, and contact angle decreases. So, the measured values actually are very dependent on a measuring instant. At one instant the contact angle may be bigger, and after a second it may become smaller. This could be an explanation of some incidental data variations.

In general all the investigated polyester fabrics show high hydrophobicity, especially the fabrics made up of microfilament yarns. In most of the cases contact angles of aseptic fabrics are higher than non-aseptic. The differences in measured contact angles when test liquid is water and salt solution are very small.

Due to their high hydrophobicity the investigated fabrics can be expected to possess certain self-cleaning effect, very positive with regard to surgical theatre. Such effect, or so-called *lotus effect*, is well known for leaves of the lotus flower. High water repellency of lotus leaves is mainly caused by epicuticular wax crystalloids which cover the cuticular surface in a regular microrelief of about $(1 – 5)\,\mu m$ in height [13]. Contaminating particles are picked up from the surface of the lotus leaves by water droplets or they adhere to the surface of the droplets and are then removed with the droplets as they roll off the leaves. The particle is removed from the surface of the droplet only if a stronger force overcomes the adhesion between particle and water droplet.

Thus surfaces that are rough on a nanoscale tend to be more hydrophobic than smooth surfaces because of the reduced contact area between the water and solid – e.g., in the lotus plant the actual contact area is only 2 – 3 % of the droplet-covered surface.

In the case of a water droplet rolling over a particle, the surface area of the droplet exposed to air is reduced and energy through adsorption is gained. On a given surface, this is the case if the adhesion between particle and surface is greater than the adhesion between particle and water

Table 2. Contact angles (θ) of liquid drops on the fabrics, and their coefficients of variation (v)

| Fabric | Distil water | | | | Salt solution | | | |
| | Non-aseptic fabric | | Aseptic fabric | | Non-aseptic fabric | | Aseptic fabric | |
	θ, degrees	v, %	θ, degrees	v, %	θ, degrees	v, %	θ, degrees	v, %
P1	128.5	1.3	127.5	0.8	125.1	1.7	121.6	3.5
P2	136.5	2.0	141.2	3.2	137.1	2.1	135.6	3.2
P3	131.1	2.5	142.2	3.0	126.5	1.8	137.3	3.8
P4	139.5	1.7	146.6	1.2	133.9	3.3	149.9	3.6
P5	132.7	2.8	138.9	3.4	133.6	2.2	136.9	2.3
P6	144.2	1.6	149.5	2.9	148.5	3.5	146.9	2.6
P7	133.4	2.2	144.2	1.6	133.0	1.5	142.6	2.5
P8	142.3	2.9	144.6	1.3	142.9	2.5	140.0	3.8
P9	133.9	2.2	134.0	3.8	134.6	1.8	133.6	2.4
T1	141.3	3.5	147.0	2.2	137.6	2.4	144.6	3.7
T2	129.1	2.2	137.2	1.6	130.3	2.0	134.4	3.0

Table 3. Wetting behaviour of aseptic fabrics in time

Fabric		Contact angle, degrees			
		0 min	10 min	20 min	30 min
P4	distil water	147 ±3	147 ±3	142 ±5	136 ±5
P6		156 ±6	151 ±4	149 ±6	149 ±9
P8		150 ±2	147 ±2	146 ±3	144 ±3
T1		143 ±5	142 ±7	136 ±4	136 ±4
P4	salt solution	148 ±3	144 ±4	142 ±4	138 ±4
P6		150 ±6	148 ±5	145 ±5	144 ±5
P8		138 ±5	133 ±4	126 ±6	112 ±18
T1		146 ±3	145 ±5	143 ±3	140 ±7

droplet. Due to the very small interfacial area between particle and rough surface, adhesion is minimized. Therefore the particle is "captured" by the rolling water or other liquid droplet and removed from the leaf or fabric surface.

4. CONCLUSIONS

Wetting behavior of the investigated polyester woven fabrics is very similar, despite the differences in structural parameters. All the fabrics are found being highly hydrophobic, especially the fabrics made of microfilament yarns. For aseptic fabrics with salt solution as a contact liquid, measured contact angles are little smaller than with distil water.

The contact angles of drops on polyester fabric surface decrease in time for both the distil water and salt solution, however, within 30 minutes the fabrics sustain considerably high hydrophobicity. Drops of both contact liquids act in similar way.

Due to their high hydrophobicity the investigated fabrics can be expected to possess certain self-cleaning effect, very positive with regard to surgical theatre.

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