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Sheet Fabrics with Biophysical Properties as Elements of Joint Prevention in Connection with First- and Second-Generation Pneumatic Anti-Bedsore Mattresses

Abstract
Textiles which have direct contact with the skin should have appropriate biophysical properties. There are especially high requirements of textiles used by hospitalised patients, who remain in bed in a prone position for a long time. The paper will present the results of the analysis connected with designing sheet fabrics with biophysical properties aimed at creating an appropriate surrounding for the patient's body. In the textile selection the following elements will be analysed: composition (hydrophilic fibres - cotton; hydrophobic fibres - polypropylene fibres and their spatial distribution), the product's weave and construction (embossed fabrics and satin fabrics). The paper will present the following results of laboratory research examining hygienic comfort under the following categories: vapour permeability, air permeability and water absorption. The paper will also present the results of their assessment when confronted with the results of the application research carried out in hospitals. The application research was carried out at the Department of Anaesthesiology and Intensive Care Medicine, Barlicki Clinic of the Medical Academy of Łódź and at the Department of Rehabilitation, Łask Hospital.

Key words: *woven fabrics, sheets, cotton fibres, polypropylene fibres, fabrics, weave, long-term prone position, bedsores, prevention.*

Introduction

The quality of textile products plays an ever greater role in human life. Especially high demands are made of textiles used by hospitalised patients, who remain prone in bed for a long time. It is especially important to maintain a proper microclimate between the body and the product in the case of permanently immobile people. The body's constant temperature is maintained as a result of thermoregulating system activity. Even minor deviation from the normal temperature of skin and body can cause discomfort. It is said that in the state of thermal-physiological comfort the human skin temperature is 33-35°C, with zero liquid perspiration [1,2]. Textiles can be a serious obstacle in carrying away the heat and perspiration produced by the body in patients who lie prone for extended periods. The problems especially concern the sheets with which the patient's skin is in direct contact, and on which significant pressure is exerted. In order for the skin temperature to remain between 33-35°C, the skin can produce up to 1000 cm^3 of perspiration an hour [2]. To ensure proper comfort, the textiles should transport the water vapour which results from perspiration away from the body to the outside at a similar speed. When free removal of perspiration is impossible, it condenses on the skin and within the structure of the sheet, which results in the formation of chafes, increases the probability of skin abrasions, and thus of bedsores [3,6]. Thus the sheets should have proper biophysical features. Important parameters of this type of textile which influence the creation of an appropriate climate around the patient's body are as follows:

- the ability to carry away perspiration from the skin surface conditioned by water vapour permeability, and
- air permeability [3,4,5,7].

In order to minimise the results of such skin damage as abrasions, chafes and red marks, the selection of fabrics for producing sheets is associated with the following structural parameters:

- appropriate selection of fibres,
- appropriate weave of the fabric, and
- distribution in space of fibres in the fabric [3,4,5,8].

Different kinds of fabrics have been used in hospitals world-wide. Unfortunately, in general they do not fulfil the high requirements set by users. The aim of our investigation commenced at the Institute of Textile Architecture, Łódź, Poland, was to develop sheets which could be positive verified by laboratory and application tests.

The Subject of the Research

The subject of the research was fabrics designed by us, and produced from fibres with widely divergent water affinity and weaving structures. This leads to the production of layer structures which simultaneously have diverse spatial distributions of particular fibre types throughout the fabric. The following yarn types were used to produce the fabrics:

- from hydrophilic fibres - a cotton yarn of 20x2 tex (raw, white colour), and
- from hydrophobic fibres - a yarn made of polypropylene fibres of 30x2 tex (white colour).

While designing the fabric structure, special attention was paid to the spatial distribution of hydrophobic and hydrophilic yarns. It was assumed that the layer of the hydrophobic (polypropylene) fibres,

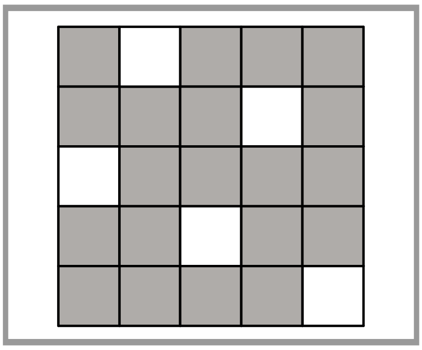

***Figure 1.** The 4/1 (3) weave structure of the satin fabric 1 (sample 1).*

due to their low water absorbing capacity determining its fast transport, should have direct contact with the patient's body, whereas the layer made from hydrophilic fibres (cotton) with high water absorbing capacity, should upon the above assumptions border on the surface of the anti-bedsore mattress. Double-layer constructions of fabrics with the satin weave and embossed structure were designed. This resulted from the assumption of a continuous and point-based contact of the hydrophobic fibres' layer with the patient's body, and from the use in hospital conditions of various types of anti-bedsore mattresses.

The satin weave fabric

The 4/1 (3) five-thread satin weave (Figure 1) popularly used in sheets was applied [9]. On one side of the fabric there are warp coverings, and weft coverings on the other. Long pleats of warp yarn create a homogenous, smooth and soft surface of the sheet. The hydrophilic fibres (cotton) yarn was used as warp, the hydrophobic (polypropylene) fibre yarn was used as weft.

The embossed fabric

The embossed fabric produced with a weaving technique is characterised by a three-dimensional, regular and ordered structure (Table 1). The double-layer character of the fabric was achieved as a result of using hydrophobic, polypropylene fibres in the upper (embossing) warp and hydrophilic (cotton) in the lower (basic) warp. Hydrophilic (cotton) yarn was used as the weft.

The scheme of the location of the hydrophobic and hydrophilic layers with reference to the patient's body and the surface of the mattress is presented in Figure 2.

The embossed fabrics make contact with the patient's skin in a point-based way. This point type of contact eases both air penetration and the abstraction of water vapour and carbon dioxide, which provides the skin with oxygen more efficiently.

The convexities and concavities characterising the embossed fabric can be programmed according to their height, width and density of distribution in the weaving process. With the use of this possibility, two variations of embossed fabric with a smaller (2a fabric) and larger (2b fabric) surface (which differentiate the type of the patient's body) make contact with the sheet surface. The contact depends on the coefficient of crimp of the upper warp, which is respectively
- 15.2% for fabric 2a, and
- 42.8% for fabric 2b.

The symbols and characteristics of the fabrics examined are presented in Table 2.

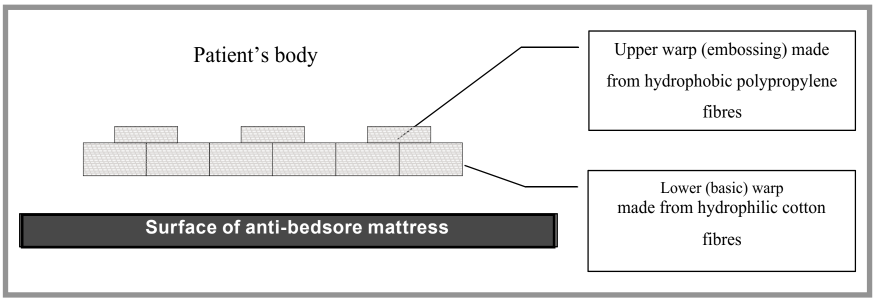

Figure 2. *The schematic presentation of the structure of the embossed fabric made with the use of hydrophobic and hydrophilic fibres and of their location with regard to the patient's body and the surface of the anti-bedsore mattress [3].*

Table 1. *Characteristics of the embossed fabric construction.*

Woven fabric onstruction 1/1 weave (samples 2a and 2b)	Upper warp (embossing)		Lower warp (basic)	Weft
	Coefficient of crimp 15.2%	Coefficient of crimp 42.8%		
Type of yarn	polypropylene yarn		cotton	cotton

Table 2. *The symbols and characteristics of the fabrics examined.*

Kind of fabric	Construction type	Raw material	Symbol of the fabric
Special designed fabrics	satin weave 4/1 (3)	polypropylene fibres cotton	1
	embossed fabric with a smaller coefficient of crimp (15.2%)	polypropylene fibres cotton	2a
	embossed fabric with a larger coefficient of crimp (42.2%)	polypropylene fibres cotton	2b
Traditional sheet fabrics	plain weave 1/1	cotton	3

Methods

Laboratory investigations of the indices characterising the fabrics' biophysical features, in comparison with traditional sheets used in hospitals (1/1 plain weave 1/1, cotton, sample symbol 3), were carried out for the sheet fabrics described above. The results of their assessment were confronted with the results of the application research carried out in hospitals.

Laboratory investigations

The following physiological indices, which are important from the point of view of minimising the skin damages, such as chafes and abrasions, and of assuring proper hygienic and physiological comfort, were assumed to be the basis of tests carried out of the following fabric's physical properties:
- vapour permeability,
- air permeability,
- water absorption.

The enumerated physiological indicators were assigned on the basis of the measurement techniques specified in the Polish Standards (PN -71/P-04611, PN-EN ISO 9237:1998, PN-72/P-04734). The following number of samples for every kind of fabric were tested carrying out the measurements of:
- air permeability - 10 samples tested,
- vapour permeability - 4 samples tested, and
- water absorption - 5 samples.

The research was carried out in the Laboratory of the Textile Research at the Institute of Textile Architecture, Łódź.

Application research

The application research was carried out at the Department of Anaesthesiology and Intensive Care Medicine, The Barlicki Clinic of the Medical Academy of Łódź, (Barlicki hospital) and at the

Department of Rehabilitation, Łask Hospital. Twelve sheets were tested (three series of three of the designed types of fabrics, and three traditional sheets). The application research lasted six months.

The research at the Department of Anaesthesiology and Intensive Care Medicine, Medical Academy of Łódź, was carried out under the guidance of Prof. Wojciech Gaszyński and Andrzej Wieczorek, MD. The users were patients with a high degree of immobility and unconscious people with a tendency to periodical or permanent swelling of soft tissue, i.e. the patients with a special risk of chafes and consequently of bedsore formation. Hence the sheets were used as the elements of joint prevention in connection with first- and second-generation pneumatic anti-bedsore mattresses. The working of the first-generation pneumatic anti-bedsore mattresses consists in achieving the change of the point of support in time, and thus in liquidating too long-lasting pressure and insufficient blood flow in the tissues situated between the bone points and the surface of the bed. This is achieved by alternate filling (once an hour) with air of the two multi-chamber systems built into the mattress made of plastics. The basic shortcoming of the systems when traditional sheets are used is insufficient draining of moisture and body fluids, which then accumulate in the sheet between the patient's body and the mattress surface which is impermeable to water. This can lead to formation of chafes and epidermis maceration, and in consequence to bedsores. The second-generation mattresses demonstrate better application qualities, as they have an enlarged area of support due to the application of a flexible system of chambers modelling on the patient's body, as well as highly efficient air pumps and micropore system on the surface facing the patient.

The application research at the Department of Rehabilitation, Łask Hospital, was carried out under the guidance of Katarzyna Krekora, MD and Elżbieta Bittner-Czapińska, MD. The users were very immobile, prone patients unable to stand up, as well as patients passively seated on the bed, spending about three hours a day being rehabilitated and nursed. The patients were included in the group of those at special risk of chafes and consequently of bedsore formation. The sheets were used together with standard rehabilitation mattresses.

Analysis of Results

The analysis of the results was carried out in two aspects:

- as the evaluation of the degree of physiological indicators obtained for particular constructions of the designed fabrics. The results of the laboratory research are illustrated in Figure 3, which presents the level of three indicators assumed for evaluation;
- as the evaluation of the structure parameters of sheet fabrics (in the doctors' opinion) as the elements of coordinated prophylactics in connection with mattresses used in hospitals.

The evaluation of the level of physiological indicators obtained for the designed fabrics

The samples examined differed greatly as regards the air permeability indicators. In case of the produced sheet fabrics the embossed fabrics have the highest, practically comparable, value of the indicators (samples 2a and 2b), whereas the value of air permeability for the satin weave fabric is the lowest, half of the value for the classical sheet fabric (sample 3).

The values of vapour permeability are relatively similar. The maximum difference reaches about 10% (sample 1 and 2b). From the examined fabrics we can distinguish the embossed fabric with the average coefficient of 3.35 (sample 2b).

The differences between the values of water absorption for the designed fabrics are significant. The classical sheet fabric has the highest value of this indicator (sample 3). It can thus be concluded that the factor determining the water absorption of the fabric is its composition, i.e. the percentage share of hydrophilic fibres. The fabric's weave is of secondary importance, and conditions water and moisture distribution in the fabric's structure.

The evaluation of the structure influence on the biophysical features of sheet fabrics in doctors' opinion

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The evaluation concerned the influence of the designed fabrics on the patients' skin surface, tendency to abrasions, epidermis maceration, and bedsore formation, as well as the application qualities of the fabrics during regular usage. No allergenic features and no allergic reaction were observed in case of any of the fabrics used. In the case of the patients lying on the first-generation pneumatic anti-bedsore mattresses, excessive accumulation of moisture was periodically observed for samples 1 (satin fabric) and 3. This effect was not observed when the second-generation pneumatic anti-bedsore mattresses were used. Imprinting of the fabric's texture and folds of the fabric on the skin of the patients with swollen soft tissues was observed in the case of samples 2a, 2b and 3. Nevertheless the disturbance was observed to be most intense when first-generation anti-bedsore mattresses were applied. The changes were most visible in case of the embossed fabric (sample 2b), and least so in the case of the classical fabric (sample 3).

From the clinical point of view, it would be most beneficial to associate the embossed fabrics (samples 2a and 2b) with the first-generation pneumatic anti-bedsore mattresses (unconscious patients). However, in the case of major swellings, the best solution would be to apply an embossed fabric with the lower coefficient of crimp (sample 2a), due to less intensive imprinting of the fabric's texture on skin, and in other cases an embossed fabric with higher crimp coefficient (2b sample) due to better skin drying.

When much more expensive second-generation pneumatic anti-bedsore mattresses are used, (unconscious patients with defective flow in peripheral tissues), it would be most beneficial to apply satin fabric (sample 1). A complete lack of imprinting of the fabric's texture on skin was observed, and the skin was dried by the air supplied from the mattress through the micropore system.

During a regular exploitation cycle, no damage to the fabrics was observed. However, the dimensions of the sheets changed after their washing and disinfection. In the case of sample 1, the dimensions shortened by 6-8%; sample 2a shortened by 9-12%, 2b by 7-9%, and 3 by 9-14%.

Department of Rehabilitation, Łask Hospital

The subject of this evaluation was the influence of the designed fabrics on the surface of the patients' skin, tendency to abrasion, epidermis macerating and bedsore formation, as well as the application qualities of the fabrics as evaluated by conscious, permanently immobile patients lying on classical mattresses. In the

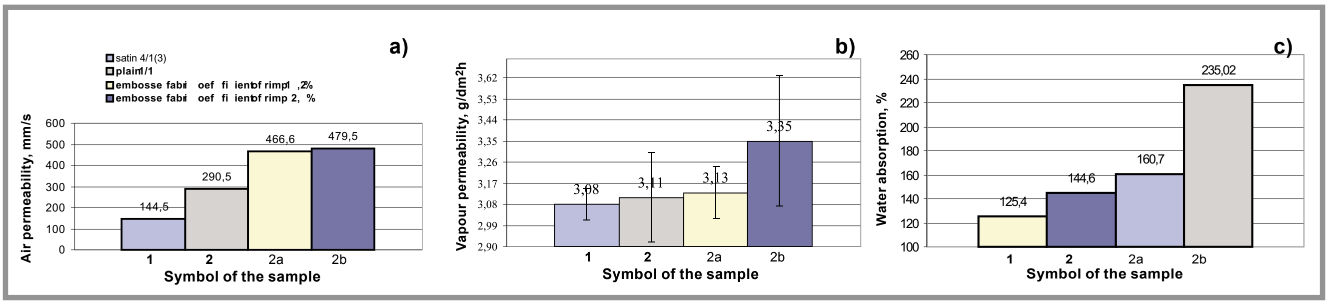

Figure 3. *The influence of the structure parameters of the designed fabrics (weave, type of raw material and its spatial distribution) on their biophysical features; a) air permeability coefficient of variation 2%, standard deviation 2%, b) vapour permeability; average values and error limits, c) water absorption, dispersion of results 2%. Fibre percentage in the fabrics: 1) cotton 60%/polypropylene 40%, 2a) cotton 64%/polypropylene 36%, 2b) cotton 54%/polypropylene 46%, 3) cotton 100%.*

case of a satin sheet (sample 1), excessive accumulation of moisture on the patients' skin was observed. The patients evaluated the sheet as draining perspiration poorly, and in consequence giving a wet and cold impression. Sheets made of embossed fabrics 2a and 2b were described by the patients as soft to the touch, pleasant and warm. Even after a long period of usage they were still evaluated positively by the patients. Moreover, the patients could feel the embossing of the fabric, which according to them was stimulating for the skin. Sheets made of the embossed fabric with the coefficient of 42.8% (sample 2b) were described as softer than those made of the embossed fabric with a lower coefficient of crimp of upper warp (sample 2a). Their permeability and draining of perspiration were evaluated positively, even more so in the case of sheets 2b with the embossed fabric and the coefficient of 42.8%). The sheets made of the embossed fabrics (samples 2a and 2b) did not get damp. The patients using them perspired less. The imprinting of the embossed fabric's structure on the skin soon disappeared without increasing any tendency to abrasions and epidermis macerating.

From the clinical point of view, it would be most beneficial to join sheets made of the embossed fabrics (samples 2a and 2b) with a standard hospital bed (better skin drying, softer and more pleasant to the touch according to the patients). The satin sheet (sample 1), in relation to regular cotton sheets (sample 3), received the lowest mark from the perspective of its biophysical characteristics. In the process of a regular exploitation cycle, no damage to the fabrics was observed.

Conclusions

- The spatial distribution of hydrophilic and hydrophobic raw materials in the product's structure, and their appropriate location with regard to the patient's body (the hydrophobic fibre layer in direct contact with the skin, and the hydrophilic fibre layer carrying away moisture from the body to the outside) is critical in ensuring proper hygienic-physiological comfort to people under special risk of chafes and consequent bedsore formation.
- The complexity of the surface, resulting from the coefficient of crimp of the polypropylene yarn in the embossed fabric construction, improves the product's bio-physical qualities . The relief surface is crucial in free vapour penetration through the concavities of the weave and its fast transport. As the coefficient of crimp of the polypropylene yarn in the embossed fabric increases, the values of vapour and air permeability as well as water absorption increase.
- The poorly developed surface of the satin fabric, despite its double-layer character (the hydrophobic fibre layer in direct contact with the skin, and the hydrophilic fibre layer carrying away moisture from the body to the outside), reduces the capacity of fast moisture transport and causes water to accumulate on the patient's skin, which can result in the skin macerating.
- Joining sheets made of embossed fabric with first-generation anti-bedsore mattresses to the so-called small area of support yielded good results. Using this type of sheet facilitated moisture draining, and thus improved skin drying through constant air flow in the concavities of the embossed fabric structure.
- Joining sheets with the second-generation mattresses with the so-called enlarged area of support yielded the best results for the satin weave fabric. This ensured effective water draining, the feeling of dryness and warmth, and facilitated modelling of the mattress according to the shapes of the patient's body. The process of skin airing through the layer of polypropylene fibres was intensive because it was supported by the system of micropores situated on the mattress's surface facing the patient.

Editorial note:

The problems described in this paper were presented were at the 1st International Conference, EasyTex 2002 - Clothing and Textiles for Disabled and Elderly People, Tampere, Finland, 16-17 June 2002.

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