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Textiles Preventing Skin Damage

Abstract
The use of designed and created fabrics characteried by the specific placement of hydrophobic and hydrophilic fibres in their structure was tested, together with their various contact with the user's skin (due to the fabric surface). The fabrics were used to manufacture a bed sheet of the type used in hospitals for chronically immobilised people, who are particularly prone to bedsore skin damage. Their preventative effect on bedsore skin damage was analysed with respect to the etiology of their beginnings, focusing on so-called internal and external factors. As for the external influences, (in the model system exposed), the effect of the bed sheet used on the stream of heat and humidity transport from the patient's body outside was tested. As regards the internal conditions, blood flow disorders were tested in different areas of the patient's body threatened with bedsore skin damage using the impendance plethysmography method.

Key words: *woven fabrics, hydrophobic fibres, hydrophilic fibres, hospital sheets, bedsore skin damages, heat transport, humidity transport, blood flow, impedance plethysmography method.*

Introduction

It is commonly known that bedsore skin damage is a frequent nursing problem; those caring for the chronically ill and immobilised are often faced with it. An important external factor that initiates bedsore skin damage, but which is often disregarded in any considerations of bedsore etiology, is the disorder of the average skin temperature and humidity fluctuations, which is not only connected with the thermoregulation of the organism under conditions of prolonged immobilisation but also with the properties of the anti-bedsore base.

In the case of chronic immobilisation, the effectiveness of heat distribution in thermoregulation processes is conditioned not only by the pace at which sweat is emitted and other external conditions but also by the efficiency of the blood system functioning, on which heat transport from muscles to the skin depends.
The etiology of bedsore skin damage mentioned above, which is additionally connected with the impact of pressure from the bad-base, influences of our assumptions in the designing of a specific base on which chronically immobilised patients will lie. One of the base elements is the bed sheet material. The properties of bed sheet – layers in close contact with the skin – are connected with the type of fibres used, their spatial distribution in the structure of the material and with the character of contact with the ill person (point-based or continuous). A these factors are of significance in the prevention of bedsore skin damage. Hydrophilic fibres with various abilities of water sorption,t different physical microstructure, and mechanical durability as well as hydrophobicity with various structure and elasticity were used for manufacturing the sheets. The layer of hydrophobic fibres was located close to the skin of the chronically immobilised person. These factors should force the various distribution of heat and humidity in the disturbed thermoregulation processes and their influence the surface blood flow in areas that are at risk of bedsore skin damage.

This research was to prove that the structures of the fabrics designed, while modifying the microclimate close to the skin of a chronically immobilised person and the pressure impact on the skin tissue, by the point-wise material contact, can bring about an improvement in blood flow in places at higher risk of bedsore skin damage occurrence. Both these phenomenn should improve the comfort of the patient.

Characteristic of the tested material

As test material, two types of fabrics differing significantly in their construction were considered:
- satin weave fabric, selected due to the assumption of the continuous contact of the hydrophobic fibre layer with the patient's body
- fabric embossed by the process of weaving, the selection of which was due to the assumption of the point-based contact of the hydrophobic fibre layer with the patient's body

Characteristics of the fabric structures were as follows:
- The types of fibres used:
  - Hydrophilic fibres: cotton fibres and man-made cellulose fibres of the lyocell type
  - Hydrophobic fibres: polypropylene fibres and polyester fibres
- The following yarn structures were used:
  - Non-spindle yarn from hydrophilic fibres – cotton and fibres of the lyocell type
  - Yarn twisted from hydrophobic – polypropylene fibres
  - Texturised yarn from hydrophobic - polyester fibres
- The following fabric structures were used:
  - Principal satin weave of 4/1 warp with a leap (3),
  - Fabric embossed by the process of weaving, with a convexo-concave relief on the surface in plain weave 1/1,

As for the position of the fabric and the body of the user, the following is assumed:
- The layer that has direct contact with the body, ensuring a feeling of warmth and dryness (diffusion-convective layer), is made from hydrophobic fibres placed in the covering layers of embossing warp thread (in the case of embossed fabric construction during the weaving process) or in covering warp layers (in the case of fabric of satin weave) (***Figure 1***);
- The bottom layer, transporting moisture from the body outside, (sorptive layer) is made from hydrophilic fibres

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placed in warp covering layers of the principal warp thread (in the case of fabric embossed during the process of weaving) or in weft covering layers (in the case of fabric of satin weave) (***Figure 2***)

Research methods

For all of the fabrics of satin weave and embossed during the weaving process as well as that commonly used in hospitals bed sheets, which is made from cotton and of plain weave, the following tests were conducted:
- physiological - hygiene parametres,
- conditions of model simulating usage,
- heat and humidity transport,
- embossed fabric behaviour in usage conditions simulated,
- local blood flow tests in places at high risk of bedsore occurrence among chronically immobilised patients in clinical conditions.

Tests of selected physiological-hygiene parameters were carried out: water-absorbance, and air and steam permeability, in accordance with the procedures described in the following norms: PN-72/P04734 [2], PN-EN ISO 9237:1998 [3] and PN-71/P-04611 [4].

Model tests of the stream of heat and humidity transport in the fabrics were carried out according to the instructions on the Permetest device made by Sensor Co. [5] for three assumed temperatures of the heating panel: 35.5 °C, 36.6 °C and 39.5 °C, which reflect the three states of temperature of the human organism: lost heat, neutral temperature and fever. The model tests also included establishing such parameters as the overall heat-transfer coefficient k in W/m^2K and index of relative water steam permeability p_p in %.

Model tests of the embossed fabric behaviour in the usage conditions simulated were evaluated with the use of a self-established measuring method simulating real usage conditions, which is based on the regulations used in the biomechanics of the human movement system [6] (***Figure 3***). In the tests the deformation of convex fabric fragments under the load programmed was evaluated based on the observation of the macro topography of its surface and macro topography of its cross-section along yarn made from hydrophobic fibres. Images were recorded

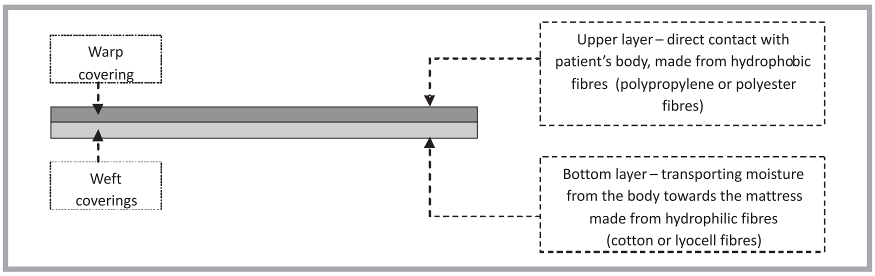

Figure 1. *Structure of a fabric of satin weave made from hydrophilic fibres.*

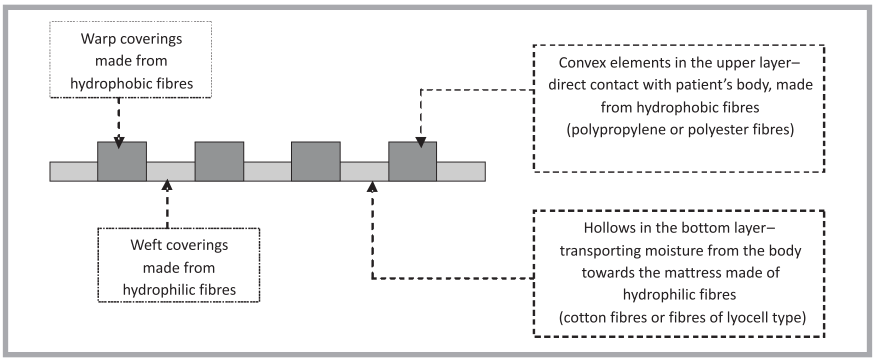

Figure 2. *Structure of a fabric embossed during the process of weaving from hydrophilic and hydrophobic fibres shown in the model depiction.*

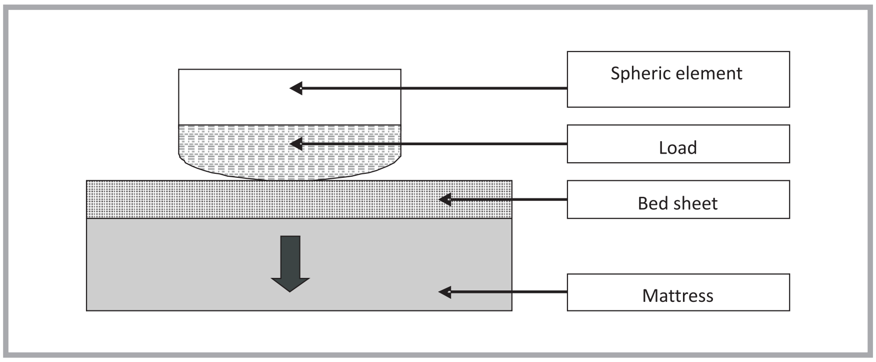

Figure 3. *Schematic draft of the simulation of real usage conditions of the fabric under the load programmed, complying with the mass and topography of the tested body area of a patient chronically immobilised in a horizontal position.*

Table 1. *Characteristics of the design fabric variations, polyester (PES), polypropylene (PP), Lyocell (CLY), Cotton CO).*

Fabric symbol	Type of fabric weave, coefficient of crimp of embossing warp,	Type of material used in warp yarn / Linear density, (I +II) tex		Type of material used in weft yarn / Linear density of yarn, tex	Mass per square metre of fabric, g/m2
		I Basic warp	II Embossing warp		
1W	satin 4/1(3)	PES / 44/f48		CO / 25	169
2W	satin 4/1(3)	PP / 29,5x2		CO / 25	195
3W	satin 4/1(3)	CO / 25		CO / 25	160
4W	satin 4/1(3)	PES / 44/f48		CLY / 25	173
5W	satin 4/1(3)	PP / 29,5x2		CLY / 25	197
6W	satin 4/1(3)	CLY / 25		CLY / 25	165
7W	plain 1/1, 42%	CLY / 25	PES / 44/f48	CLY / 25	167
8W	plain 1/1, 42%	CLY / 25	PP / 29,5x2	CLY / 25	182
9W	plain 1/1, 42%	CO / 25	PES	CO / 25	166
10W	plain 1/1, 42%	CO / 25	PP / 29,5x2	CO / 25	185
7Wm	plain 1/1, 14%	CLY /25	PES / 44/f48	CLY / 25	162
8Wm	plain 1/1, 14%	CLY / 25	PP / 29,5x2	CLY / 25	174
9Wm	plain 1/1, 14%	CO / 25	PES / 44/f48	CO / 25	182
10Wm	plain 1/1,	CO / 25	PP / 29,5x2	CO / 25	173

using a Canon Power Shot A620 device to observe any possible changes in the structure of the convex fabric fragments on the basis of micro topography observation of the yarn cross-section (longitudinal and lateral) with respect to deformations of yarn made from hydrophobic fibres. Images were taken using a scanning electron microscope - JSM-5200LV.

In tests of local blood flow changes in places at high risk of bedsore skin damage occurrence at normal and higher body temperatures, the impendance plethysmography method was used. A special agreement of the Commission of Bioethics at the Medical University of Łódź was obtained: No RNN/134/03/KB. Tissue blood flow measurements were made according to the procedure described by a Niccomo device, made by the German company Medis, so as to evaluate the hemodynamic parameters using the method of impendance cardiography with an attachment for plethysmographic measurements [7]. On the basis of the plethysmographic curve, drawn using the impendance plethysmograph, the following hemodynamic parameters were evaluated: pulse wave amplitude (Pampl), systolic slope (Pslope), crest time (CT) and propagation time (PT) – measured from the beginning of the R wave in ECG to the beginning of the plethyzmograph systolic slope.

Research was carried out for six groups of people, in which the following were established:

- Four major groups of people with a neutral temperature:
  - Group 1 - created from 14 people whose average age was 60 - hospitalised during the time of the test – with no relevant limits in their ability to move;
  - Group 2 - created from 12 patients whose average age was 62 - chronically immobilised after an ischemic stroke – using an embossed bed sheet;
  - Group 3 - created from 10 patients whose average age was 61 - chronically immobilied after an ischemic stroke – using a bed sheet of satin weave;
  - Group 4 - created from 11 patients whose average age was 60 - chronically immobilised after an ischemic stroke – using a traditional cotton bed sheet of plain weave;
- Two subgroups of people with a higher body temperature:
  - Subgroup 2a - comprising 4 patients with an average age of 60 - chronically immobilised after an ischemic stroke and in a subfebrile state (average body temperature was 38.2 °C) - using an embossed bed sheet;
  - Subgroup 3a - comprising 3 patients with an average age of 59, chronically immobilised, after an ischemic stroke (average body temperature: 37.9 °C) – using a bed sheet of satin weave.

For groups 1, 2, 3 and 4, tests were carried out once a day for seven days between 7 and 8 in the morning, after at least seven hours of night rest in an air-conditioned hospital room which had a temperature of 21 °C and humidity of 55%. Plethyzmographic evaluation of the local blood flow in groups 2a and 3a was made on the third day of tests between 8am and 8pm in the same temperature and humidity conditions. The tests were performed by the same person. From the tests, patients with significant heart diseases and/or disseminated sclerosis were excluded.

Details of the methodology of all the tests are described in a PhD dissertation [1].

Discussion of research results

Quantity measurement of heat transport through the fabrics tested points to its obvious dependence on the spatial development of the fabric structure. The spatial development of embossed fabric causes a decrease in the amount of heat transported from the body to the environment, resulting in the accumulation of a great amount of heat between the layers of the skin and the fabric surface.

During the cooling stage of the organism (the weakening state), it is recommended to maintain the highest possible amount of heat in the organism, therefore it is beneficial to apply fabrics that are characterised by the lowest value of heat transfer coefficient. This condition can be fulfilled using embossed fabrics that have non-spindle cotton yarn in both the main warp and weft and texturised yarn made from polyester fibres in the embossing warp (***Figure 4.A***). Such a bed sheet may be recommended for people chronically immobilised at an elderly age as their ability to control their cardiovascular system is limited, thus there is greater loss of heat from the skin (so-called chronic hypothermia limitation). This remains in accordance with references included in publications [8 – 16].

At the moment of the thermoneutral state of the organism (neutral temperature), it is recommended to maintain the correct amount of heat in the organism. Fabrics that are in direct contact with human skin should also present an appropriate level of heat insulation. It is beneficial, therefore, to apply fabrics characterised by a relatively low heat penetration coefficient value. The lowest values of coefficient k in the model fabric tests at a temperature of 36.6 °C were obtained for embossed fabrics that have non-spindle yarn made from fibres of the lyocell type in their main warp and weft, and yarn twisted from polypropylene fibres in the embossing weft.

At the moment of the organism overheating (fever state), it is recommended to quickly remove excess heat produced from the organism to the environment. In order to do so, it is advisable to use fabrics that are characterised by high heat penetration coefficient values. The highest values of coefficient k during the model tests at a temperature of 39.5 ºC were observed for fabrics with an undeveloped spatial structure (satin fabrics), which have warp covering layers made from texturised yarn of polyester fibres and covering layers made from non-spindle cotton yarn. A homogenous and smooth fabric surface causes an increase in the amount of heat transported from the body to the environment.

Fabric materials with physiological properties beneficial for patients who are chronically immobilised should effectively carry the excess of humidity from the skin's surface to the external environment. In cooled (physiological discomfort), thermoneutral (physiological comfort) and overheated states (physiological discomfort), the human organism produces a certain amount of sweat that is transported through the skin to the environment. Fabrics that have direct contact with a human body should be highly permeable to both steam and sweat.

In the model tests, carried out considering three different temperature states of an immobilised person (35.5 ºC, 36.6 ºC and 39.5 ºC), the highest values of relative steam permeability were characteristic for embossed fabrics with a higher percentage of the coefficient of crimp

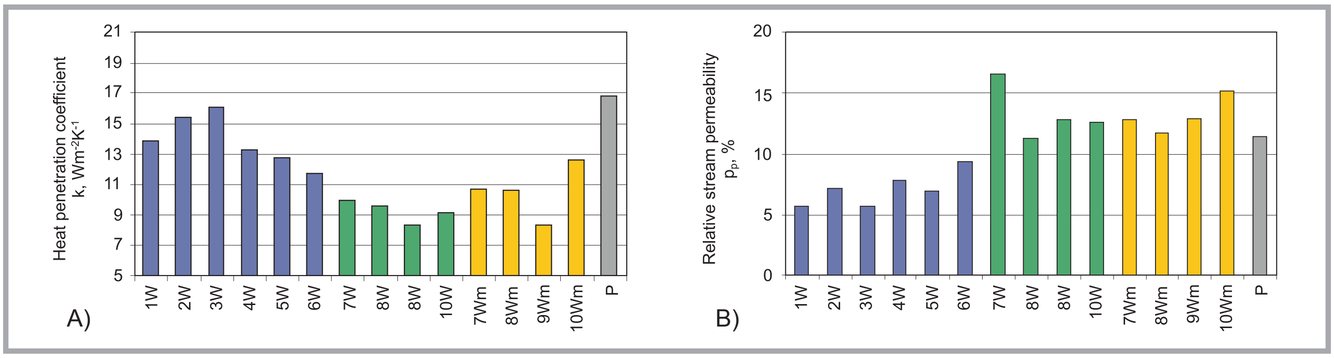

Figure 4. *Comparison of average values of: (A) heat penetration coefficient k in W/(m2K) and (B) relative value of steam permeability p_p in % for the teste fabrics at an assumed temperature T = 35.5 °C. Legend: 1W – 6W fabrics of satin weave; 7W - 10W embossed fabrics made using the weaving method, coefficient of crimp threads into embossed warp - 42%; 7Wm - 10Wm fabrics embossed using the weaving method, coefficient of crimp threads into embossed warp - 14%; P - cotton bed sheet of plain weave.*

threads in the embossing warp (***Figure 4.B***), which may be explained by the fact that the sculptured surface of the fabric sticks to the skin, and the more porous inter-thread structure of embossed fabrics causes more effective moisture transport than the homogenous and more filled structure of fabrics of satin weave.

The spatial development of embossed fabrics necessitated the carrying out of durability tests of their spatial shape in usage conditions and after maintenance in hospital conditions. On the basis of the model tests, it can be assumed that embossed fabrics keep their spatial shape after the load has been removed. The durability of the spatial shape varies for fabrics with different synthetic fibres (polyester, polypropylene etc). Embossed fabrics with polyester fibres show a greater stability of spatial development than those with polypropylene fibres, which stems mostly from the fact that polyester fibres are more elastic (the highest elastic strain) but also from the specific structure of the yarn (texturised yarn) [17, 18] (***Figures 6 and 7***).

The conclusions from the metrological and model tests carried out, simulating usage conditions of the fabrics designed with respect to their usefulness as a bed sheet used in closed health care, confirmed the announcements presented in publications [19 - 40], which were also confirmed by the evaluation of local blood flow changes in the place at high risk of bedsore occurrence among chronically immobilised patients, for whom an impendance plethysmograph was used. The register of the plethysmograph curve described with four hemodynamic parameters, i.e. pulse wave amplitude (Pampl), systolic slope (Pslope), crest time (CT) and propagation time (PT) is useful when the blood flow disorder is monitored, which occurs among patients immobilised for a prolonged period of time.

The analysis of the hemodynamic parameters tested proves that local blood flow disorders around tissue threatened with prolonged external pressure greatly de-

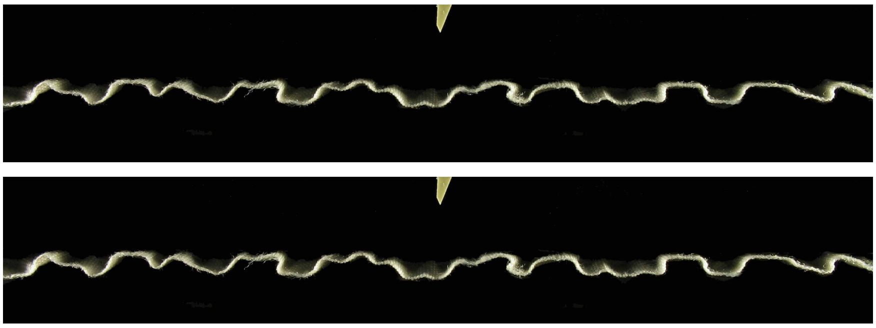

Figure 6. *Evaluation of the deformability of convex fragments of embossed fabric on the basis of observation of the macro topography of its cross-section along yarn made from hydrophobic fibres in the embossing warp before and after the activity of the load programmed. The photo presents an image of the fabric cross-section along texturised yarn made from polyester fibres (PES) in the embossing warp (for sample 9W) before (the upper cross-section) and after (the lower cross-section) the activity of the programmed load.*

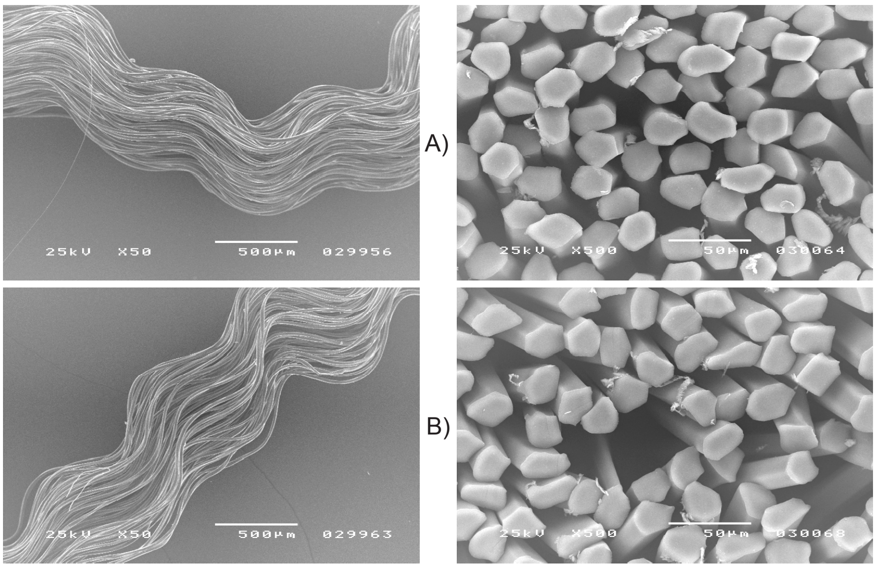

Figure 7. *Evaluation of the changes in the structure of convex fragments of embossed fabric on the basis of the micro topography of a cross-section - longitudinal and lateral for yarns made from hydrophobic fibres in the embossing warp - before and after the programmed load. The photo presents a longitudinal and lateral image of a yarn cross-section made from polyester fibres (PES) in the embossing warp (sample 9W) before (A) and after (B) the programmed load.*

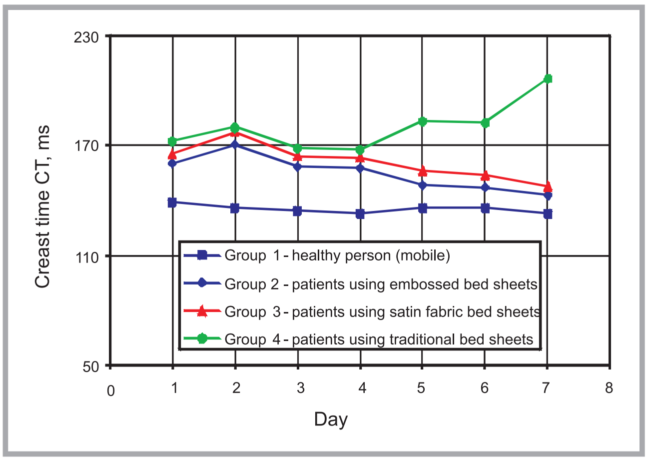

***Figure 8.** Graphic presentation of the dependencies observed for groups 1, 2, 3 and 4 comprising people with a normal body temperature with respect to the CT parameter selected in ms.*

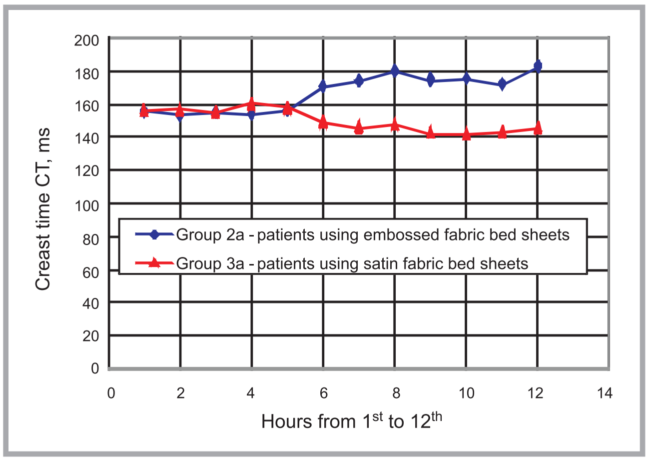

***Figure 9.** Graphic depiction of the dependencies observed for groups 2a and 3a of people with a higher body temperature concerning the CT parameters selected in ms.*

pend on the contact of the skin with the surface.

In the tests carried out on groups of patients with a normal body temperature using a bed sheet made from the test fabrics, significant statistical differences could be observed in the changes in blood flow in the area of bedsore skin damage occurrence. Significant disorder progression in the local blood flow was observed in the group of patients who used a generally available cotton bed sheet of plain weave. For this group of patients, it was noted that during the time of observation, blood flow disturbances in the area threatened with skin damage occurrence limited the time of observation, for ethical reasons, to seven days only. On the fifth day a significant lowering of the Pampl parameter and a prolonged CT time were observed, and on the seventh day a significant lowering of the Pslope parameter was noticed. The results described support the sudden acceleration in local blood flow disturbance in the area at high risk of bed sore occurrence. Further confirmation of the unfavourable character of intravessel changes is the PT propagation time result: On the sixth day of the test, the PT propagation time was significantly prolonged in comparison with the other groups of patients tested. Such behaviour of the PT parameter is connected with the relevant blood flow limitation.

On the other hand, among the patients using a bed sheet made from the fabrics designed, fundamental changes were registered around the fifth day of use. In that time, in both groups of patients using a bed sheet made from embossed and satin fabrics, a significant increase in the Pampl parameter was observed, together with a shortening of the CT time. On the seventh day of the test, a noticeable increase in the Pslope parameter was detected. Such a direction in plethysmographic changes points to the normalisation of blood flow,which occurred after a non-significant collapse in hemodynamic balance in the test area on the second day. It needs to be emphasised that on the last day of the test, a particularly significant increase in the values of Pampl and Pslope parameters was noticed as well as a shortening of the CT time for the group of patients using a bed sheet made from embossed fabric, which is different to what occurred in the group of patients using a bed sheet made from fabric of satin weave. It is worth mentioning that throughout the whole time of the observation, the value of the propagation time PT for both groups tested did not change significantly.

In both groups of patients (using beds sheet made from embossed fabric and those of satin weave), no significant difference was noted for the PT parameter in relation to the PT parameter determined for people with a full ability to move – that is, those who were not bed-ridden. This fact confirms the effective protection of local blood flow by the bed sheet made from the fabrics tested, particularly embossed fabrics (***Figure 8***).

Due to the fact that in the model tests of the fabrics used significant differences in the transport of humidity and moisture at a temperature of 39.5 °C were noted, there were additional clinical tests conducted on two groups of ill people with a higher body temperature. From the model tests it is clear that in a subfebrile state, moisture transport occurs more efficiently in a bed sheet of satin weave. A twelve-hour observation of two groups of patients revealed a significant increase in hemodynamic parameters – Pampl, PSlope and the shortening of the CT time at the seventh hour of the subfebrile state in the group of patients using a bed sheet of satin weave, which is different from what occurred in the group of patients using an embossed bed sheet. No significant changes in the PT parameter were noticed. Such a direction of changes in plethysmographic parameters points to a more beneficial normalisation of blood flow in the test area for the group of people with a subfebrile state using a satin bed sheet (***Figure 9***).

From the comparison of the clinical tests, a conclusion can be drawn that disturbances in thermoregulation which lead to an increase in body heat (a subfebrile state) significantly modify the unfavourable microclimate close to the skin of a patient chronically immobilised and also accelerate conditions in which bedsore skin damage occurs. This suggests a significant increase in the values of hemodynamic parameters – Pampl, PSlope and CT for the groups of people using a bed sheet made from the test fabrics, which is different from what occurs for patients who are fully mobile and not bed-ridden. Disturbances in the local blood flow in the groups of patients tested appear at the very beginning of their immobilisation (on the second day). Test results show that the local blood flow disturbances noticed at the beginning of immobilisation together with the accompanying temperature and body moisture rise modify skin damage processes. A similar view, while testing physiological implications of the organism at the early stage of inactivity, was expressed in publications [41-62], which is connected with the limitation of muscle tissue activity and progressive rheological blood disturbances.

The clinical tests confirm the usefulness of the fabrics designed regardless of the character of their contact with the patient's body – continuous (fabric of satin weave) and point-wise (fabric embossed during the weaving process). According to one of the publications [63], the main reason for bedsore occurrence among people chronically immobilised are creases and accidental waves on the bed sheet. Accidental fabric deformation seems to change the character of blood flow in the subcutaneous layer, from laminar to turbulent. The latter, by radically slowing down the blood stream in vessels, limits the metabolism of surrounding tissue, thereby increasing the changes connected with their anoxia. Thus, bedsore skin damage is more likely to occur. However, in the case of a structure with programmed convex elements appearing periodically (embossed fabric), the physiological reaction of the local vessel system seems to be more complex. An appropriately designed geometry of the fabric surface and the flexibility of its convex elements, as proven by the tests, cause adaptive vessel deformation in the subcutaneous layer; while not limiting blood flow, it can be beneficial to the maintenance of laminar blood flow. It seems that the most important role here is played by the density of the convex elements of the embossed fabric, which is beneficial for laminar blood flow in vessels that are under evenly spread pressure. On the basis of this, it can be claimed that the design and point-wise character of the contact between the surface and body is particularly beneficial from the point of view of blood flow dynamics in small vessels in the subcutaneous layer.

Final conclusions

On the basis of the tests carried out, conclusions can be drawn of both a general and detailed nature. The general conclusions may be reduced to the following statements:

1. The types of fabrics designed and created in this study present preventive activity in relation to skin damage among people chronically immobilised, resulting from beneficial heat and moisture transport from the patient's body outside, which is the most significant external factor in the etiology of bedsore occurrence.
2. Results of blood flow tests of the local vessel system among people chronically immobilised in the place at high risk of bedsore occurrence were objective confirmation of the preventive activity of those fabrics, as compared with the critically disturbed blood flow tested among people using an old-fashioned bed sheet.
3. The preventive anti-bedsore activity of the fabrics tested depends on the degree of fabric surface development, which determines the type of contact with the user's body (continuous or point-based), and on the temperature state of the chronically immobilised person:
   - For patients who lose heat or whose temperature is neutral, it is favourable to use fabrics with a well spatially developed surface (embossed fabric),
   - For patients with an increased body temperature e.g. a fever, it is more favourable to use smooth surface fabrics (satin weave fabric).

Detailed conclusions are as follows:

1. Fabrics containing the following materials are the most favourable variations for the following:
   - Patients who lose heat – fabrics made of the yarns of cotton fibres and texturised polyester fibres,
   - Patients with a neutral temperature – fabrics made of yarns of lyocell and polypropylene fibres
   - Patients with fever – fabrics made of yarns of cotton fibres and texturised polyester fibres.
2. The fabrics designed and produced maintain the durability of the structure under a load in usage conditions i.e. the patient's body weight.
3. The fabrics designed and produced maintain an unchanged structure after washing and sterilising processes recommended for hospital conditions, with the use of modern washing devices.

Editorial note:

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- *The study material was evaluated and prepared at the Textile Architecture Institute, Łódź (currently the Textile Institute, Łódź) as part of a Young Researcher's Grant: No 7 T08E 032 19, financed by the Polish State Committee of Scientific Research between 2000 – 2002Statutory works were realised between 2002-2005.*
- *A summary of the PhD dissertation [1] was included in the Scientific Exercise Books of the Technical University of Łódź (in press).*

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