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Computational modelling of hospital mattresses made from spacer fabrics

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ABSTRACT

The appearance of pressure ulcers is a very common occurrence, especially for people with limited mobility who are obliged to spend a long time prone on a support surface. Pressure ulcers in severe cases can cause damage to underlying muscle and bone. Damage to deeper tissues, tendons and joints may also occur. Serious complications, such as infection of the bone (osteomyelitis) or blood (sepsis), can occur if pressure sores progress. While the main strategy for dealing with pressure ulcers is centred around the interaction of patient and care-giver (manually changing the position of the patient every two hours in order to relieve pressure on critical body areas, examination of patient for signs of pressure ulcer formation) there are auxiliary approaches, such as the choice of a pressure relieving support surface. Currently, a variety of support surfaces exists. The criteria of choice are dependent on factors such as the medical history of the patient and economic. The emergence of 3D spacer fabrics as textile materials with good compression behaviour makes them suitable candidates to produce support surfaces that contribute to the prevention of pressure ulcers. In order to decide on their suitability, extended clinical trials involving actual patients must be performed. In the present paper, a computational methodology utilizing a tool widely used in the area of engineering, namely Finite Element (FE) Method, is proposed as a supporting tool for the preliminary evaluation of the suitability in terms of mechanical behaviour of certain 3D spacer fabrics, providing an insight of the deformation, stress and strain developed on the bodies (human body – mattress) as well as on their interface.

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Pressure ulcers, medical support surfaces, spacer fabrics, finite elements method

1. INTRODUCTION

Decubitus ulcers are associated with tissue necrosis, which is itself connected to several factors that include, but are not limited to, pressure, friction, shear, moisture and ischemia. Decubitus ulcers are not necessarily connected with the application of high pressure on a specific body area but can also be caused by the application of medium pressure which affects a body area continually for a long time. The appearance of decubitus ulcers is quite common. Epidemiological studies report frequencies of decubitus ulcer appearance ranging from 8.3% to 23% in European hospitals, 10.2% in UK based care units and 12.3% in care units located in the U.S.A. Estimations regarding the appearance and frequency of pressure ulcers, which are based on hospital surveys, differ a lot depending on the definition and stage of ulcers, the population of patients under investigation and care procedures. For home care situations the frequency of decubitus ulcers reaches 16.5% in the USA and Canada [1, 2, 3].

Populations under greater risk of developing decubitus ulcers include people of limited mobility and/ or limited sensory perception and people undergoing operations with durations counted in hours. In summary, high risk groups include the elderly, patients in intensive care units, patients with neurological problems, trauma patients (including spinal cord injury) and patients subjected to operations lasting several hours. [2, 4] Body areas with the greatest frequency of decubitus ulcer appearance are areas where body weight is concentrated over bony projections such as the hips, sacrum, heels and elbows [4, 5].

In order to decrease the possibility of decubitus ulcer appearance different support surfaces are being used. The support surfaces have particular specifications and aim to support the sensitive parts of the body and to redistribute the pressure as evenly as possible [2, 4, 6, 7].

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Support surfaces that are used for the prevention of decubitus ulcers belong to one of the following two categories [2, 4, 7].

1. Low-tech devices – They offer a support surface which adapts to the body curvature and distributes body weight across a large surface (pressure management). Low-tech devices include standard foam mattresses, alternative foam mattresses/overlays e.g. high specification foam, convoluted foam, cubed foam, viscoelastic foam. This category also includes mattresses/overlays which contain gel, liquids, fibrous materials and air.
2. High-tech devices – Dynamic systems that include:
   a. Mattresses/overlays of alternating pressure: patients lie on air-filled sacs that inflate and deflate sequentially to relieve pressure at different anatomical sites for short periods; these may incorporate a pressure sensor.
   b. Beds/mattresses/overlays air fluidised: warmed air circulates through fine ceramic beads covered by a permeable sheet; allowing support over a larger contact area.
   c. Beds/mattresses/overlays of low-air-loss: patients are supported on a series of air sacs through which warmed air passes
   d. Turning beds/frames: those function either by aiding manual repositioning of the patient, or by motor driven turning and tilting.

Strategies for decubitus ulcer prevention include systematic inspection of the dermal condition of the patient, moisturizing of the patient skin using appropriate creams, review of patient's diet and change of patient's positioning / posture by the health care providers according to a set schedule (usually every two hours) [2, 6].

Investigation of the ability of support surfaces to reduce the possibility of decubitus ulcer appearance is carried out either through measurement of the pressure applied to the patient body during the use of the support surface (interface pressure) or by controlled clinical trials that monitor the clinical course of patients when using the support surfaces under test. The non-invasive measurement of the interface pressure by placing a pressure sensor mat between the patient body area containing a bony prominence and the support surface provides an approximation of the pressure applied to a specific bony prominence. It is generally accepted that lower interface pressure means lower pressure applied on the surrounding tissues and capillaries [11]. A useful value that can be used as a guideline for a critical value of interface pressure is 32 mm Hg. This value has been used in the literature as an interface pressure limit. Exceeding this limit is possible to facilitate the appearance of decubitus ulcers [5, 8].

Clinical trials, while forming an inevitable stage of the development and production process of a medical device, also possess certain characteristics that can only be described as risks or burdens (to borrow some words used in the Declaration of Helsinki). First and foremost are the risks and burdens that are related to the test subjects, i.e. human beings either healthy or ailing. Further to the ethical considerations when working with human subjects there exist the monetary and time requirements for conducting clinical trials. According to DiMasi et al., [13] the estimated average out-of-pocket cost per new drug is US$ 403 million (2000 dollars). While the cost mentioned pertains to the development of new drugs and not medical devices as is the case in this paper, it can logically be argued that costs for the development of medical devices should be proportionally comparable to the costs for drug development [8 – 10, 12, 13].

Lately, the finite element (FE) method, which is a computational method popular in engineering, is used in order to computationally evaluate the developed pressure on the interface between the patient’s body and the support surface. The basic idea of the FE method is to segment a continuous 2D or 3D - space into smaller surfaces or volumes [14]. Its main advantage comes from the fact that one can simulate different anthropometric data and different base materials for the support surface in one FE model just by changing the geometry or the material properties. Yoshida et al. developed three different 2D FE models of human body, simulating male and female subjects, lying on a mattress. They monitored the interface stress distribution resulting from FE analysis and compared it to sensory results concluding that computational stress values are in accordance with sensory tests [15]. A FE simulation of human tissue and support device interaction has also been performed by Silber et al., Makhsous et al. and Levy et al., using the FE method focus on the pressure distribution on the anatomical area of the buttock. The first research group creates a 3D FE model at the area along with the support surface, while the second research group creates a 2D FE model [16, 17, 18]. Finally, Vassiliadis et al. [19] presented a preliminary study on the modelling of spacer fabrics used in the development of support surfaces.

Spacer fabrics, in the present study, are proposed as a technologically interesting textile alternative for the development of support surfaces that can help to the prevention of the medical condition of pressure ulcers. Their construction principle namely, fabric layers interconnected by a layer of monofilament yarns, provides them with characteristics such as good compression behaviour. This characteristic is affected by the overall composition of the fabric, the composition of the connecting fibres, the angle of the fibres and the number of connecting monofilaments per unit length. Furthermore, spacer warp knitted fabrics are characterised by high breathability (low water vapour resistance) allowing moisture to be guided away from the body which reduces the chances of skin maceration. Skin maceration causes greater friction between skin and sheeting material and between skin and skin (e.g. at skin fold areas). Greater friction in turn causes greater shearing forces that could lead to pressure ulceration [20]. The mechanical properties of spacer fabrics and their ability to manage the microclimate near the patient skin make spacer fabrics suitable for medical applications such as compression bandages and support surfaces for hospital beds and operating room tables concerning decubitus ulcers [21]. In 2009 Vassiliadis et al. [22] used the FE method in order to predict the micro and macro compression performance of typical spacer fabrics.

In the present paper, a methodology for the preliminary qualitative assessment of materials used for the construction of medical support surfaces (e.g. hospital mattresses), is presented. The methodology is based in the evaluation of the compression properties of the base material for the support surface with the combined use of experimental and computational procedures and the computational evaluation of the interface pressure developed on the human body while it is lying on such a support surface. The proposed methodology is implemented for the assessment of different spacer fabrics. For these purposes a generic setup for compression testing of spacer fabrics has been built, along with computational FE models in ANSYS® Workbench software which simulate the compressive behaviour of support surfaces made of these materials.

2. MATERIAL AND METHOD

In the present section, the proposed methodology is outlined followed by its implementation for the assessment of seventeen spacer fabrics with different technical characteristics.

The proposed methodology comprises of three distinct steps, one experimental and two computational ones. In the first step, a compression test is performed on specimens of each of the materials under examination. Then, computational modelling of each experiment is performed in order to inversely evaluate an equivalent isotropic elastic modulus for each material. Finally, one computational model for each material under investigation is built, consisting of a human body lying down on a support surface with the corresponding material properties of the base material is built. The outcome of the proposed methodology is a sorted listing of the tested materials with respect to various mechanical quantities, such as the maximum vertical displacement of the upper area of the support surface, the maximum developed pressure on the interface between the human body and the support surface etc.

2.1 Material

The materials under assessment for the use in the development of support surfaces are seventeen different warp knitted spacer fabrics. All spacer fabric samples were a mix of open and closed constructions, i.e. front and back side, either both open or both closed, or front side open back side, closed (open and closed refers to the presence or absence of significant openings in the structure of the outside layers of the samples). The thickness of the connecting monofilament in all cases was 0.2 mm. The yarns used for knitting the front and back sides had yarn counts of 1080 dTex or 600 dTex. The fabrics were all constructed with 100% polyester yarns, with variations on their construction parameters such as thickness and weight. The specimens had been produced on a Karl Mayer 3D warp knitting machine.

Figure 1 illustrates the appearance of two typical spacer fabrics as seen from the top and the side while, Table 1 presents the technical characteristics of all the spacer fabrics that were examined, as well as the specimen dimension that were used.

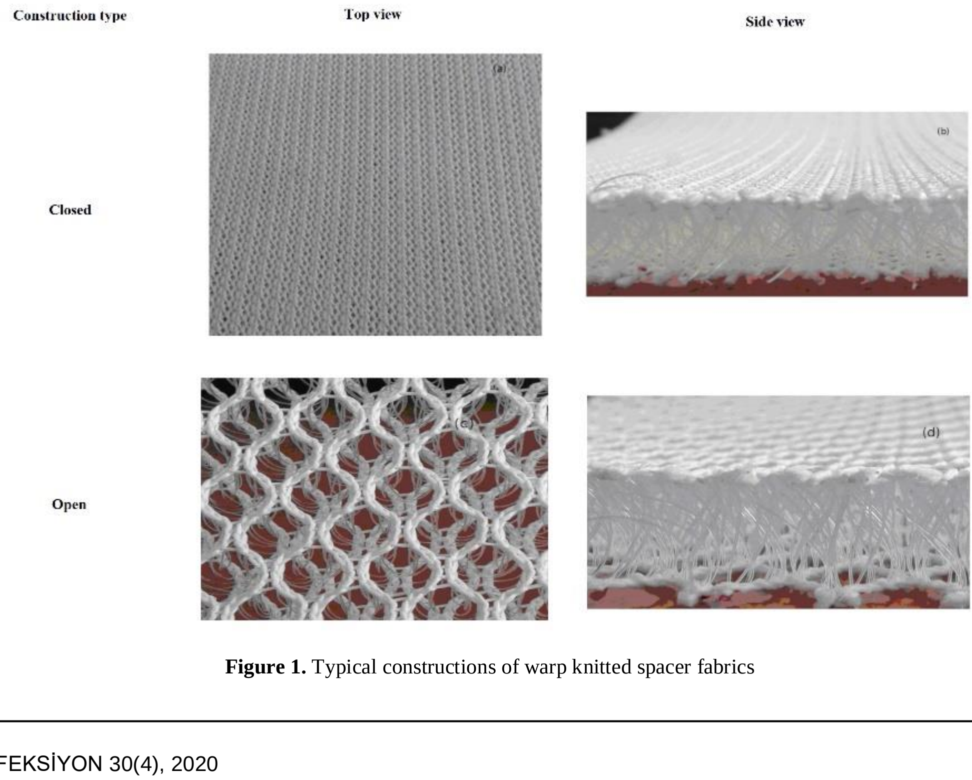

Figure 1. Typical constructions of warp knitted spacer fabrics

Table 1. Technical characteristics of the spacer fabrics

Sample	Thickness (mm)	Width (mm)	Length (mm)	Mass per unit area (g/m^2)
A1	10	202	300	510
A2	10	210	302	625
A3	10	215	304	1035
A4	11	205	310	430
A5	12	305	210	825
A6	12	300	212	980
A7	12	304	211	1100
A8	13	200	292	600
A9	8	204	293	490
A10	12	205	293	880
A11	12	205	295	1120
A12	10	207	293	850
A13	10	200	297	460
A14	10	209	290	500
A15	10	202	285	900
A16	10	150	200	1030
A17	10	150	200	535

2.2 Method

The spacer fabrics were experimentally tested in compression and their indentation under a known load was monitored.

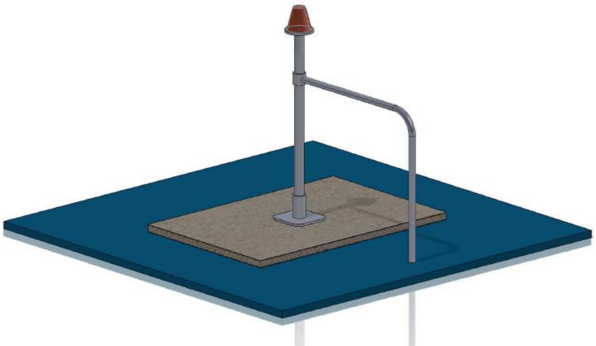

Figure 2. 3D representation of the experimental setup

Using the experimental setup presented in Figure 2, a weight (red volume) of 1300 g (12.753 N) was placed on the upper circular area of the setup acting on each spacer fabric sample through the square surface of area equal to 0.0025 m^2. This square surface was acting as an indenter, causing the vertical deformation of the fabric sample (brown volume) which was placed on a rigid surface (blue volume). The magnitude of the weight was chosen in order to prevent indentations higher than 80% of fabric thickness in any sample. For every spacer sample the resulting indentation was measured. Since the following computational modelling of the spacer fabrics was supposed to consider the materials as linear elastic, only one point on the force - displacement curve was considered. The applied force could not be directly converted to stress value since the axial force was not acting on the centroid of the cross section of the sample. This resulted from the fact that the cross – sectional area of the sample is larger than this of the experimental setup.

In order to retrieve the equivalent linear elastic modulus of each spacer fabric, the abovementioned experiment was computationally simulated using the FE method and an optimization procedure, with the objective of the minimization of the difference between the experimentally measured and the computationally evaluated vertical deformation, was implemented. For this procedure, all spacer fabrics were considered as isotropic and homogenous materials. Seventeen different FE models were built incorporating the exact geometrical dimensions of the samples as they are presented in Table 1.

The FE model simulating the experiment performed for sample 1 is, indicatively, presented in Figure 3. A square plate (green volume), simulating the square, load bearing, end of the experimental setup (25 x 25 mm^2), was loaded with a force of 1300 g (12.753 N). The square plate was placed on the top of the upper surface of the spacer fabric (grey volume). The vertical displacement of the lower surface of the spacer fabric has been constrained simulating the rigid surface below the 3D spacer fabric. Both volumes are segmented with 4632 hexahedral, 20-nodded FE.

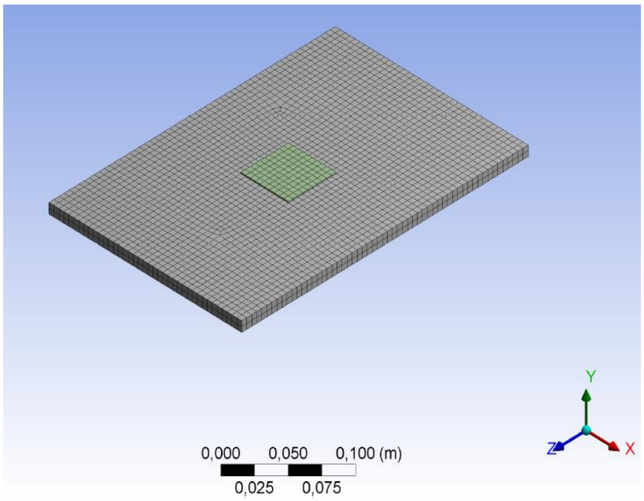

Figure 3. FE model of the simulation of the compression test of the spacer fabric

Next, the computed equivalent elastic modulus of each spacer fabric was used in seventeen FE models simulating a human body, [23] of exact geometrical representation, lying down on a mattress consisting in each model of one spacer fabric. This FE model consists of two solid bodies, one simulating the human body and one simulating a mattress of typical dimensions. The geometrical model of the human body corresponds to a male subject of height 180 cm and weight of 90 kg. As far as the elastic modulus of the FE belonging to the human body is concerned, a weighted average of the elastic modulus of soft tissue and bone has been considered. In more details, according to Mukherjee et al. [24] if flesh and bone are considered linear isotropic materials, they have elastic moduli equal to 6×10^4 and 2×10^{10} Pa respectively. The human body consists of 15% of bone while the rest is a type of soft tissue (dermis, muscles, fat, etc.). [25] Given that, the elastic modulus of the human body was considered 3×10^9 Pa and its Poisson ratio equal to 0.4. [26]

The model simulating the interaction of human body and the support surface consists of a total of 6966 FE, from which 3974 belong to the human body and are tetrahedral, 10-nodded FE, in order to represent the exact geometry of the body, and the rest are hexahedral 20-nodded elements and belong to the mattress. In Figure 4 the final FE model of human body and mattress is presented in an isometric view. For purposes of meshing simplicity, the face and the hands of the geometrical model of the human body have been removed not altering the final FE method results.

Between the human body and the support surface a rough contact was considered, and its status is presented in Figure 5. For the modelling of the contact 138 contact and 138 target quadrilateral FE have been used.

The performed analysis is static structural and as far as the loading is considered, in order to simulate the supine body posture on the mattress, gravity is applied while the displacement of the lower surface of the mattress is constrained in the vertical direction simulating the existence of a base for the support surface as it is presented in Figure 6.

In the FE method various results are available in order to monitor the performance of each setup. For the implementation of the proposed methodology, the results that are monitored in order to provide the listed sorting are (a) the vertical displacement of the upper surface of the mattress, (b) the equivalent stress, (c) the normal stress on Z-axis, (d) the shear stress on the XY plane developed on the human body, and (e) the status, (f) the pressure and (g) the frictional stress on the interface between the human body and the mattress.

3. RESULTS AND DISCUSSION

The presented results are divided in two sections: (a) the results of the first two steps of the methodology which lead to the computational evaluation of the equivalent elastic modulus of the seventeen samples of spacer fabrics and (b) the results of the third step which lead to the sorted listing according the suitability of the spacer fabrics for their use in the development of support surfaces.

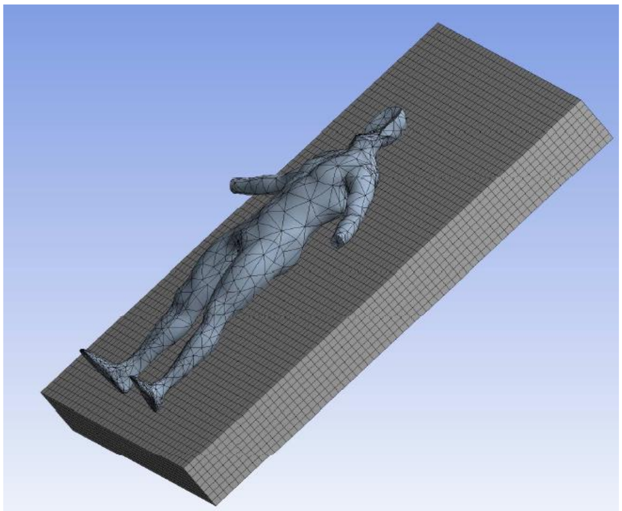

Figure 4. FE model of human body and mattress

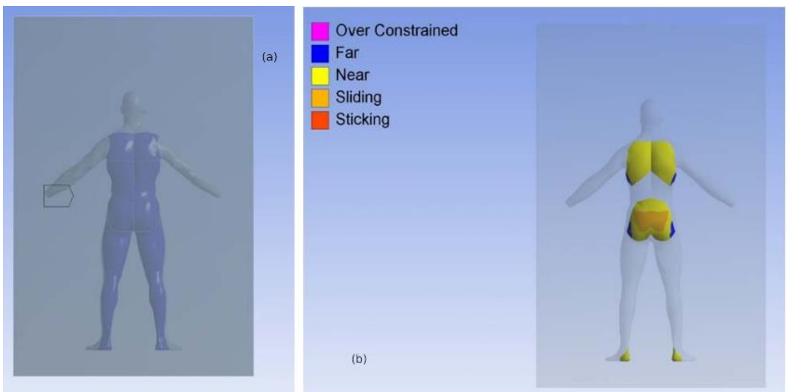

Figure 5. Contact areas and contact status between the human body and the support surface

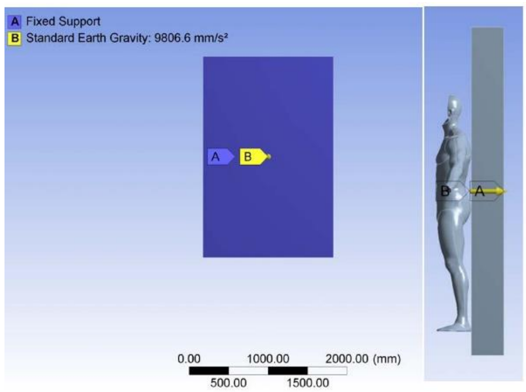

Figure 6. FE model boundary conditions

3.1 Computational evaluation of the equivalent elastic modulus of the spacer fabrics

The experimental results of the compression test performed in the first step are presented in Table 2 in terms of indentation and calculated elastic modulus under the constant load.

In Table 3 the measured density along with the evaluated equivalent elastic modulus of all the spacer fabrics is presented along with the error between the experimental and computationally calculated indentation on the vertical axis.

In Figure 7 the computationally evaluated vertical displacement is presented for samples A4 and A9 which have the maximum and minimum indentation and minimum and maximum computationally evaluated equivalent elastic modulus, respectively.

Table 2. Maximum indentation and calculated elastic modulus of each spacer fabric

Sample	Indentation (mm)	Calculated E (Pa)
A1	1.00	51012
A2	1.68	30364
A3	0.99	51527
A4	8.19	6851
A5	1.68	36437
A6	1.21	50590
A7	1.01	60608
A8	2.48	26740
A9	0.04	1020240
A10	0.35	174898
A11	1.04	58860
A12	0.94	54268
A13	1.43	35673
A14	0.12	425100
A15	1.15	56057
A16	1.21	44358
A17	0.91	42159

Table 3. Calculated density and computed elastic modulus for all spacer fabrics

Sample	Sample Density (kg/m^3)	Computed Elastic Modulus (Pa)	Error (%)
A1	51.00	32500	-0.19
A2	62.50	19250	0.09
A3	103.50	32500	-0.20
A4	39.09	4220	0.02
A5	68.75	22500	0.86
A6	81.67	32000	-0.34
A7	91.67	37750	0.29
A8	46.15	17000	0.30
A9	61.25	670000	2.19
A10	73.33	112500	0.37
A11	93.33	37500	0.45
A12	85.00	35500	-0.49
A13	46.00	23000	-0.92
A14	50.00	280000	0.71
A15	90.00	29000	-0.09
A16	103.00	20900	-0.08
A17	53.50	37500	-0.85

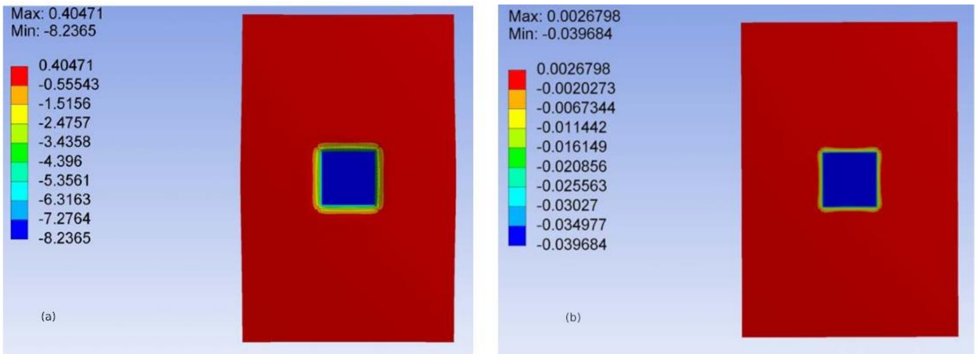

Figure 7. Vertical displacement of samples A4 (a) and A9 (b)

3.2 Computational evaluation of the base materials used as support surfaces

As mentioned above, in order to monitor the performance of all the spacer fabrics three different types of results are selected and presented below. The first group of results concerns the vertical deformation of the top surface of the mattress. In Table 4 the minimum and maximum values of vertical displacement are presented for all the samples.

Table 4. Vertical displacement of the upper surface of the mattress

Sample	Minimum Uz [mm]	Maximum Uz [mm]
A1	-41.07	-0.10
A2	-58.53	-0.36
A3	-41.47	-0.50
A4	-163.99	-0.25
A5	-51.03	-0.35
A6	-41.30	-0.34
A7	-36.46	-0.34
A8	-62.08	-0.17
A9	-4.45	-0.01
A10	-17.01	-0.07
A11	-37.25	-0.36
A12	-39.55	-0.34
A13	-52.02	-0.12
A14	-9.74	-0.01
A15	-38.51	-0.11
A16	-45.23	-0.47
A17	-47.04	-0.62

The maximum absolute value of the vertical displacement on the top surface of the mattress appears for sample A4 while the minimum one appears for sample A9. In Figure 8 the results of the vertical displacement in terms of contour are presented for these two samples. It is obvious that the body sinks further in the model consisting of the sample A4. The more the human body is sunk into the mattress the higher the interface area between the human body and the mattress is.

The second group of results concerns the stress distributions on the human body. In Table 5 these results are presented in terms of maximum/minimum absolute values.

Although the computational evaluation indicated that all spacer fabrics cause development of stresses in a similar way, the exact values of the mechanical magnitudes on the human body vary according to the spacer fabric used for the mattress. Sample A4 has the minimum value for the Von Mises Equivalent stress and the minimum values of Shear stress on XY plane, while sample A8 has the minimum value of Normal stress on Z axis. Figure 9 presents the contours of Von Mises Equivalent stress, Normal stress on Z axis and Shear stress on the XY plane for samples A4 and A8.

The maximum value of equivalent von Mises stress appears in the middle of the calves of the human body, while maximum Normal and Shear stress appear on the heels. This group of results is highly depended on the elastic modulus of the human body, so it can be only used if a full model of the human body is built with bones and soft tissue.

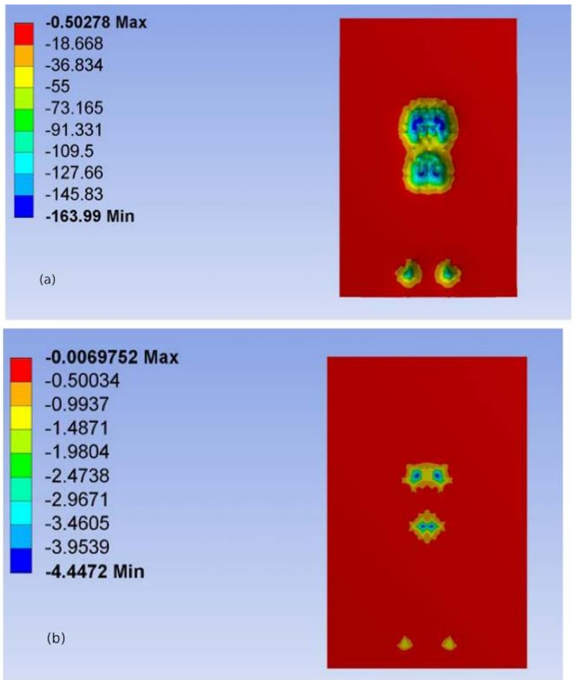

Figure 8. Vertical displacement of the upper area of the mattress for samples A4(a) and A9 (b)

Table 5. Stress results on human body

Sample	Maximum Von Mises Equivalent Stress [MPa]	Minimum Normal Stress on Z Axis [MPa]	Minimum Shear Stress on XY plane [MPa]	Maximum Shear Stress on XY plane [MPa]
A1	0.194	-0.057	-0.024	0.0194
A2	0.182	-0.049	-0.023	0.0195
A3	0.195	-0.057	-0.024	0.0193
A4	0.158	-0.085	-0.019	0.0169
A5	0.186	-0.051	-0.023	0.0194
A6	0.195	-0.057	-0.024	0.0194
A7	0.197	-0.060	-0.024	0.0195
A8	0.180	-0.047	-0.023	0.0199
A9	0.177	-0.051	-0.022	0.0181
A10	0.190	-0.054	-0.023	0.0184
A11	0.197	-0.058	-0.024	0.0194
A12	0.196	-0.057	-0.024	0.0195
A13	0.185	-0.050	-0.023	0.0193
A14	0.199	-0.054	-0.024	0.0190
A15	0.196	-0.058	-0.024	0.0194
A16	0.191	-0.054	-0.023	0.0192
A17	0.190	-0.053	-0.023	0.0190

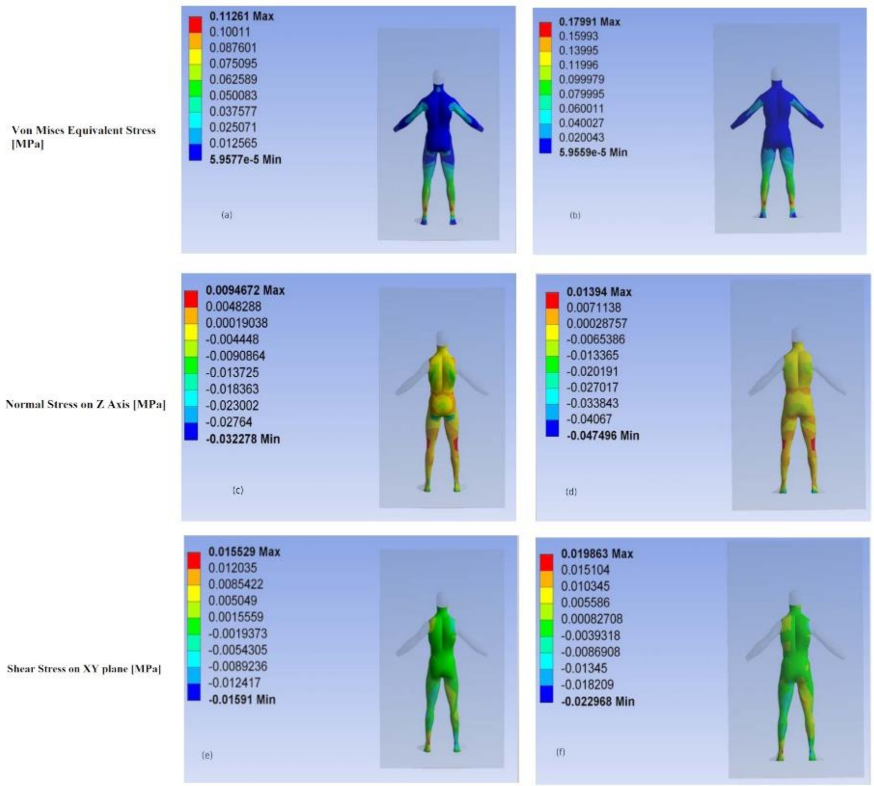

Figure 9. Stress contour of status, pressure and frictional stress on human body for samples A4 (a, c, e) and A8 (b, d, f)

In Table 6 the maximum values of pressure and frictional force on the interface between the human body and the mattress are presented.

Table 6. Maximum Pressure and frictional force on the interface

Sample	Maximum Interface Pressure [MPa]	Maximum Frictional Stress [MPa]
A1	0.0708	0.0163
A2	0.0539	0.0241
A3	0.0707	0.0162
A4	0.0865	0.0305
A5	0.0588	0.0150
A6	0.0707	0.0162
A7	0.0799	0.0156
A8	0.0514	0.0229
A9	0.0661	0.0138
A10	0.0749	0.0080
A11	0.0765	0.0156
A12	0.0732	0.0151
A13	0.0587	0.0182
A14	0.0750	0.0076
A15	0.0746	0.0163
A16	0.0650	0.0150
A17	0.0629	0.0154

The third group of results is presented in Figure 10, which concerns the area of the interface between the human body and the mattress. The contours of the interface pressure and the frictional stress for samples A8 and A14 that have the lower values of interface pressure and frictional stress respectively are presented. It is obvious that the areas of higher stresses are the areas of the calcaneus, the gluteus and the dorsum. As mentioned above the pressure threshold for non-developing pressure ulcers is considered the value of 32 mmHg i.e. 4266 Pa.

The maximum value of the pressure presented in Figure 10 is higher than the pressure threshold existing in the literature. On the other hand, the area of high pressure is very small, so it is interesting to see the percentage of contact area above this threshold.

3.3 Discussion

In this section the results of the preliminary qualitative evaluation of the seventeen spacer fabrics are going to be analysed proving the ability of the implemented methodology to produce useful sorted listings. Also, the proper interpretation and use of these listings is going to be discussed.

As far as the experimental results are concerned, the spacer fabric with maximum indentation under the load of 12.753 N is A4 with 8.19 mm while the spacer fabric with minimum indentation is A9 with 0.04 mm. In Figure 11 the experimentally measured indentation of each spacer fabric is presented as a percentage of its total thickness.

It is obvious that the most deformed sample is A4 while the less deformed are A9 and A14 with 0.5% and 1.2% of deformation. This means that A4 will have the lower elastic modulus, while A9 and A14 the larger. Observing Table 3 that correlation becomes clear. The rest of the samples show deformation ranging from 9 to 17%. In Figure 12 the values of the elastic modulus for every spacer fabric is presented. The samples are sorted according to the percentage of vertical deformation in the experiment from maximum to minimum.

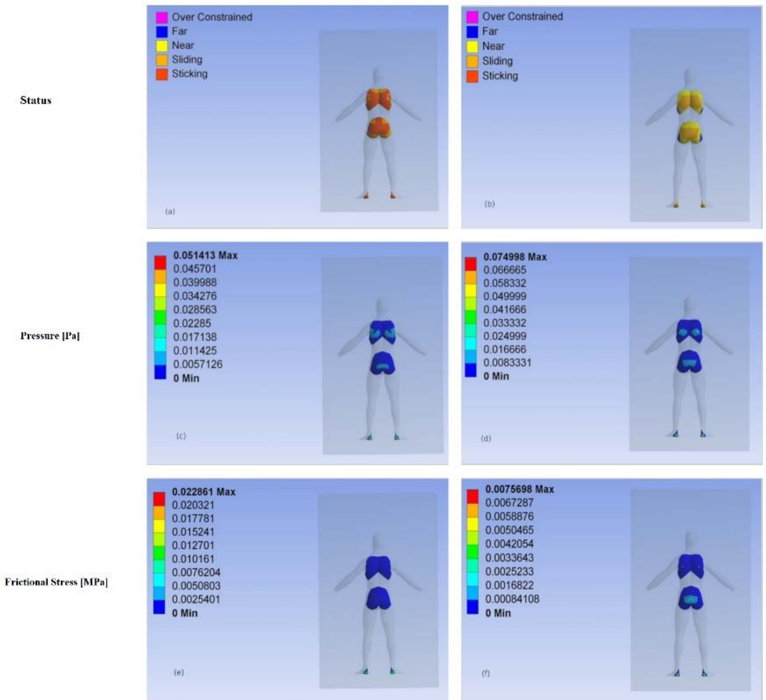

Figure 10. Stress contour of status, pressure and frictional stress on human body for samples A8 (a, c, e) and A14 (b, d, f)

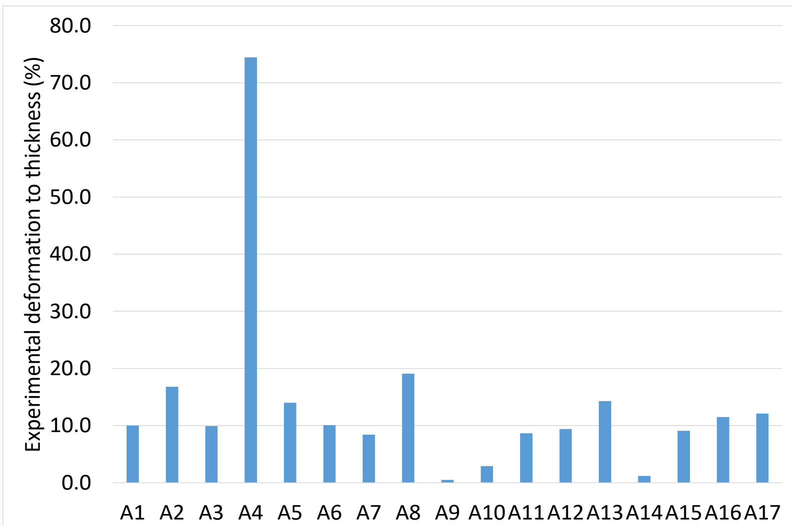

Figure 11. Experimental Indentation as a percentage of the total thickness of its sample

Most of the samples in Figure 12 (A13 – A7) have an elastic modulus in the range of (0.022 to 0.038 MPa). In Figure 13 the sorted listing of the samples used in the mattress according to their vertical deformation is presented.

In Figure 14 a sorted listing is presented. The spacer fabrics with the lowest percentage of area above the pressure threshold are A9, A14, A10, A7 and A11. For these samples the percentage under investigation is below the threshold under discussion. These samples represent also the samples with the lowest values of vertical deformation.

From the above results it appears that there is a strong correlation between the elastic modulus of the fabrics and the resultant stress on the human body. The specimens with lower vertical displacement had the greater elastic modulus and the smallest areas with pressure above the threshold. While this paper is indented to present a selection method for support surfaces, this finding illuminates an interesting aspect of the behaviour of the support surfaces on the human body providing a quantitative criterion.

The fabrics with best behaviour based on the lower pressure area are A9, A14, A10, A7 and A11. Thus, it is of interest to obtain more information about these samples. Figures 15 and 16 present the outside layer of the 3D fabrics and the connecting filament layer respectively, and at Table 7 the structural characteristics of the samples are presented as well.

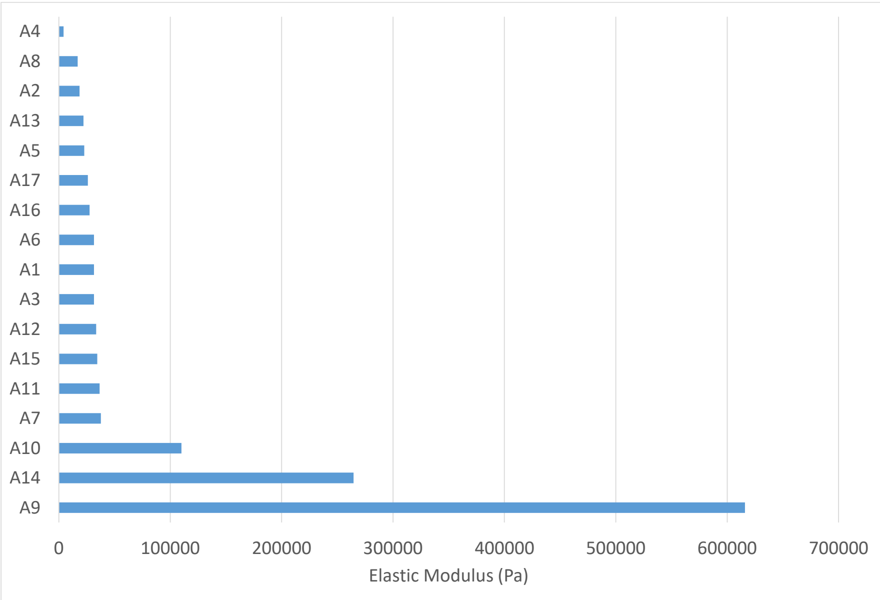

Figure 12. Computed elastic modulus per sample

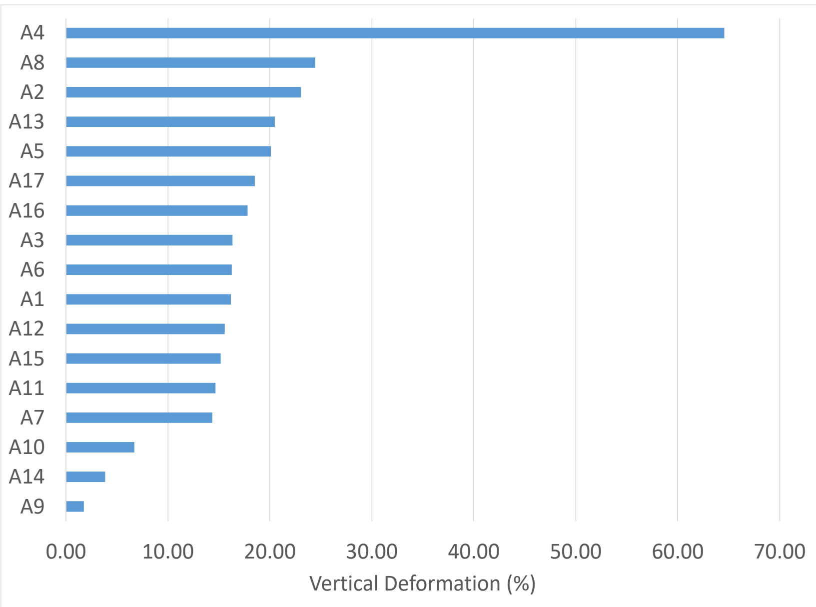

Figure 13. Percentage of the maximum vertical displacement of the top area of the mattress

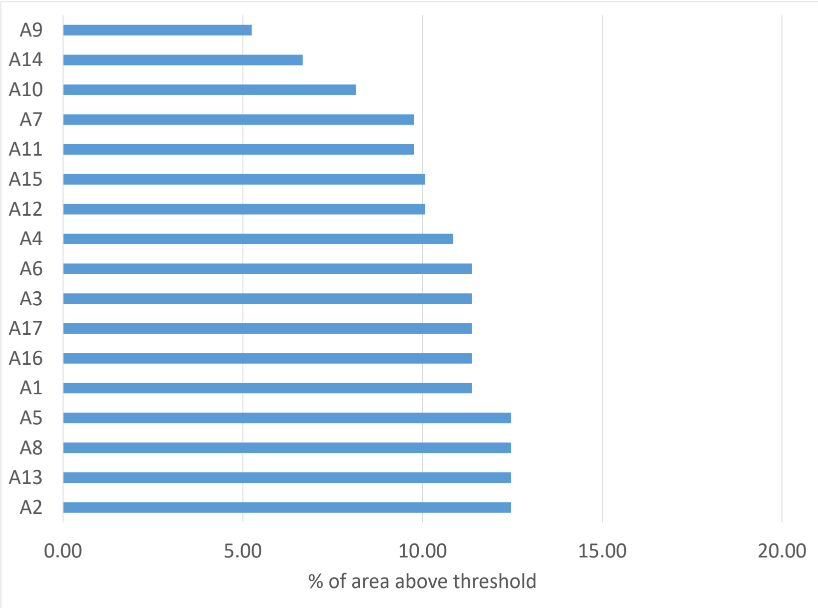

Figure 14. Area with pressure above threshold

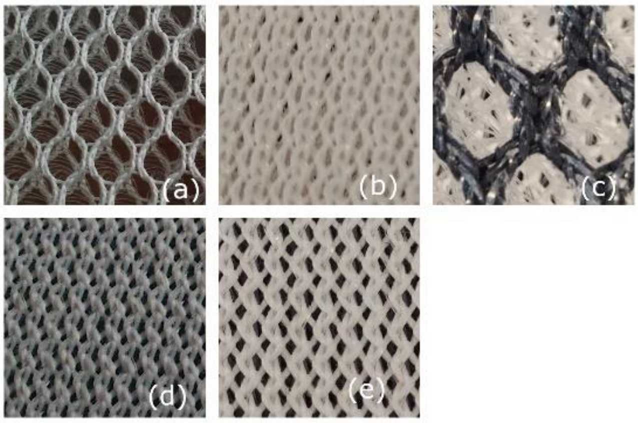

Figure 15. Outside layer of samples (a) A9, (b) A14, (c) A10, (d) A7, (e) A11.

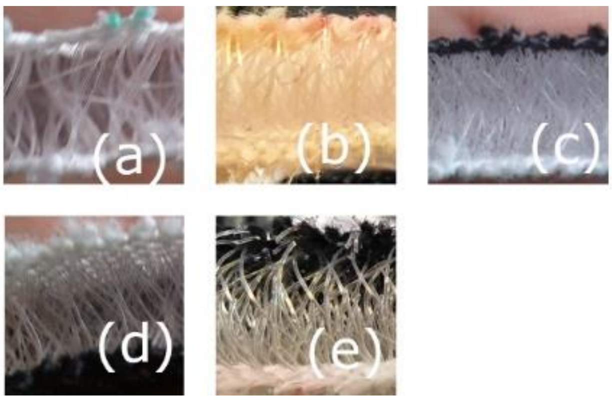

Figure 16. Interconnecting filament layer of samples (a) A9, (b) A14, (c) A10, (d) A7, (e) A11.

As can be seen, the specimens show an evident variability to their structural characteristics – i.e. a mixture of open and closed structures as well as a variety of the number of yarn loops on the outer surfaces of the samples. The relationship between this variety of structures and the elastic modulus of each specimen can be subject to future research.

Table 7. Structural characteristics of specimens with the lowest percentage of area above the pressure threshold

Sample	Yarn count (dTex)		Number of loops per 10 cm^2	
	Front	Back	Front	Back
A9	600	600	20x74	21x74
A14	600	600	66x54	66x52
A10	1080	600	28x32	60x50
A7	1080	600	36x27	70x34
A11	600	600	64x60	62x62

4. CONCLUSION

In the present paper a methodology for the preliminary assessment of medical support surfaces, based on simulation driven design is presented. This methodology can be used, before the clinical trial, and it involves FE modelling of the interaction between the support surface and the human body while lying down. The main advantage of the proposed methodology is that it can eliminate materials unsuitable for the use as primary material for medical support surface from the time consuming and costly stage of clinical trial. More specifically, in the present paper, this methodology has been used for the evaluation of different spacer fabrics suitable for support surfaces. The outcome of the proposed methodology is sorted listings of the candidate materials based on their properties and suitability for the specific use. This methodology can be a precious selection tool based on the mechanical performance of different materials, before creating the actual prototype support surface which must undergo through clinical trials.

A significant advantage of the proposed methodology is that it can be easily expanded to other materials and different body types or body positions because of the versatility of the FE method. Thus, it can be used, also, for the evaluation of materials like foams, since FE method can incorporate non-linear material properties, such as creep, present in materials like foam. Additionally, the weight of the simulated human body, as well as its material properties and body posture, can be altered leading to the evaluation of different anthropometry data.

Although, within this paper, sorted listings, concerning, mainly, the deformation and the interface pressure of different fabric spacers have been provided implementing the proposed methodology, these listings can become more detailed enhancing the experimental investigation of the materials and subsequently the computational models. The FE models, used for the final evaluation of the spacer fabrics, could contain information for time – depended material properties, such as stress relaxation and fatigue. Additionally, also the computational model of the human body can become more accurate embedding also material nonlinearities. The FE model of human body used in this methodology can be created using CTs, including the changes in the pressure contours because of bony areas, muscle and ligament topology inside the body. The creation of patient specific models of the human body could allow the development of patient specific support surfaces.

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