COMPRESSION FATIGUE BEHAVIOUR OF A BIOMIMETIC 3D TEXTILE STRUCTURE FOR PRESSURE ULCERS PREVENTION

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ABSTRACT

The objective of the present research study is the development of a multifunctional textile structure to prevent the appearance of pressure ulcers. The concept of the overall structure was inspired by plant structures morphology, resulting in a 3D patchwork knitted fabric, specially designed according to the necessities of body segments, for a mattress overlay. To simulate the pressure that causes the occurrence of bedsores, compression tests were performed allowing the analysis of strain/stress behaviour, energy absorption and thickness variation under load. The results show the suitable behaviour of the textile structure developed to prevent pressure ulcers.

Key Words: pressure ulcers, biomimetics, 3D textile structures, compression

1. INTRODUCTION

In the last years, it was possible to verify the increased use of textile materials in high tech solutions. The field of smart textiles is, nowadays, an essential part in investigation, development and design of solutions for various applications. The use of smart textiles to promote hydrophobicity, flame retardancy, UV and anti-static protection, electricity conductivity, ballistics, among several others, have been successfully achieved. This kind of products adds considerable value to textiles, strongly contributing to the transition from conventional to high-end substrates [1]–[3].

Based on the area of application, the technical textile market can be divided into several segments. The healthcare and wellbeing sector can be brought under a few broad categories such as implantable products, non-implantable products, and extracorporeal devices, in which it's included the Medtech segment of technical textiles, that comprises the complete range of innovations in the manufacture, processing, and application of medical and hygiene products. The consumption of Medtech textiles is expected to grow through the years, and for that reason, many studies are being conducted, all over the world, in order to develop the next generation of solutions based on textile materials [4].

1.1 Pressure ulcers

The study of pressure ulcers pathology allows to fully understand the development of this type of wounds in bedridden persons. A wound can be defined as a rupture of an anatomical structure or normal functionalities of body tissues [5]. Furthermore, wounds can be classified as acute and chronic. Acute wounds exhibit normal cicatrization and can be cured over time, existing high probability of anatomic and functional rehabilitation [5], [6]. Chronic wounds are defined as any anatomic and physiological alteration in skin tissues, normally with the aggravation of chronic diseases with longer duration than 3 months [7], [8]. The most frequent chronic wounds are pressure ulcers, venous ulcers and ulcers of diabetic origin [9]. A major problem associated with this type of wound, specifically pressure ulcers, is the failing, at some stage, of the sequential healing process, due to hemostasis, inflammation, proliferation/reparation and maturing/remodelling, and for this reason they least on time [5], [6].

Definitions of pressure ulcers can be extensively found in literature: according to American National Pressure Ulcer Panel *(NPUAP)* e European Pressure Ulcer Advisory Panel *(EPUAP)*, pressure ulcers are localized lesions in the skin or underlying tissues, normally on a bone prominence, secondary to an increase in external pressure or pressure combined with shear [10], [11].

Pressure ulcers occur due to degenerative modifications of the skin/subcutaneous tissue exposed to pressure and shear forces. When this pressure occurs under bonne prominence there is prejudice in blood circulation, favouring cellular death and, consequently, the appearance of ulcers. In Figure 1 b) it is possible to perceive the damage promoted by pressure forces in blood vessels, and in Figure 1 c) by shear forces – where forces cause dislocation in different plans [11].

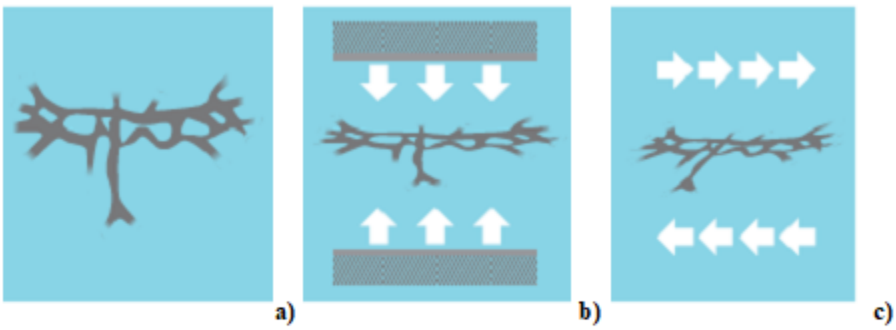

Figure 1. a) blood vessels; b) pressure forces; c) shear forces [10].

Pressure ulcers can be divided into 4 categories according to different stages of evolution and skin degeneration. This categorization system promoted by *EPUAP & NPUAP,* allows a most effective line to ulcers identification, in a way to promote an easier treatment: category I - non-bleachable erythema; category II - partial loss of skin thickness; category III - total loss of skin thickness; category IV - total loss of tissues thickness. In the United States of America, two different categories are distinguished, *unclassifiable* and *deep tissue injury*, being in Europe similar to category IV [10], [12].

Pressure ulcers are developed mostly as a result of the prolongated cessation of blood circulation or by rupture of the vascular network that sustains it [13]. When pressure ulcers emerge, it's because degenerative changes happened in the skin e/or subcutaneous tissue exposed [11]. However, several physiological characteristics can lead to the development of pressure ulcers, as excessive loss of heat, a thin layer of subcutaneous tissue and the fact that heat production is performed through thermogenesis without a tremor – involving increased metabolism and oxygen consumption [13], [14]. Besides, reduced mobility or immobility, sensorial deficiency, acute illness, level of consciousness, extremes of age, chronic or terminal illness, history of pressure damage, malnutrition and dehydration must be taken in consideration [15], [16].

Under normal conditions, arterial capillary pressure is about 32 mmHg, whereas in the venous it's approximately 12 mmHg. When blood pressure decreases or the external pressure is bigger than 32 mmHg, higher is the risk of pressure ulcers formation by blood flow interruption [17]–[19]. *Collier and Moore* propose a range of values between 18-22 mmHg for critical closing pressure, varying according to the body location, bone prominence, muscle e skin structure [18]. Critical pressure momentum – the moment when pressure collapses the vessel and body flow cease completely – and time of pressure exerted that causes the pressure ulcer is hard to define, however, reference values promote values between 23-32 mmHg [13], [20]. *Santos* compiled information from different authors *(Ruth Bryant and Denise Nix, JoAnn Maklebust and Mary Sieggreen)* and verified that low-intensity pressure for a long period of time, can cause the same prejudice to tissues that a high pressure applied for a short period of time. Still, smaller the body area pressed, bigger the pressure force [17], [21], [22].

Some body regions show a higher frequency of appearance of pressure ulcers, as the sacrococcygeal, trochanteric, scapular, occipital, malleolar and calcaneal regions, but also on soft tissues that undergo continuous pressure [10]. When an individual is lying down, normally he can assume 3 different positions: dorsal, lateral and ventral decubitus. When the 3 positions are studied, it's possible to conclude: in dorsal decubitus (Figure 2 a), pressure ulcers occur in heels, sacrum, elbows, shoulder blades and nape; in lateral decubitus (Figure 2 b), appears in malleoli, lateral and medial condyles, great trochanter, large costal, acromion and ear; in ventral decubitus (Figure 2 c), appear on the large toes, knees, genitals (men), breasts (women), acromion and on the face of the ear [19], [23].

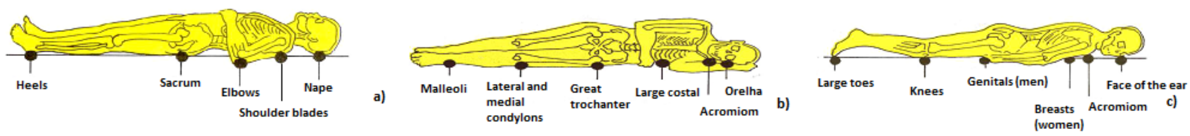

Figure 2. a) dorsal decubitus; b) lateral decubitus; c) ventral decubitus [22].

1.2 Pressure ulcers prevention

Pressure ulcers demonstrate intimate attachment with illness problems and lack of mobility. Bedridden persons are prone to the formation of pressure ulcers, therefore, they should receive special attention in this subject, because they have important repercussions on the quality of life of patients and their families. Pressure ulcers prevention may be divided into two main steps, one of them through the identification of persons with a high risk of developing this kind of wounds, a second one, trough the implementation of prevention strategies to the individuals identified in the first step [13].

Pressure ulcers prevention depends on the time spent in the same position, smooth surfaces, non-irritating and with good moisture management [24]. For prevention and treatment of pressure ulcers, support surfaces are important auxiliaries. It's important to fully understand, that support surfaces are important because they reduce the pressure and promote the pressure relieve if they have the capacity to reduce contact pressure for less than 33 mmHg [13].

Support surfaces must have a balance of immersion and involvement properties, considering that immersion is the capacity of a surface to submerge the user, promoting a better redistribution of height through a large area, increasing the contact surface between the user and the surface – better dispersion of pressure. On the other hand, involvement corresponds to the way a surface has the ability to shape/adapt to the contours of the body and accommodates uneven areas, such as folds in the clothing and bed [12], [16], [25], [26]. After all that, it's still necessary that the surface promote immersion without the bottoming out, which is an undesired effect that removes the capacity of surface recovery to the initial point [27].

2. MATERIALS AND METHODS

2.1 Surface design

The mattress overlay was designed based on the three main sleep positions: dorsal, lateral and ventral decubitus. In this way, different zones, based on the critical pressure points of each body zone, have been identified. An exercise based on the zone overlapping (Figure 3) allowed to define 5 different zones defined according to the pressure exerted by the body. As can be seen in Figure 3, 3 levels of body immersion were defined: yellow colour attributed to a low level, the orange to medium level and the red to a high level.

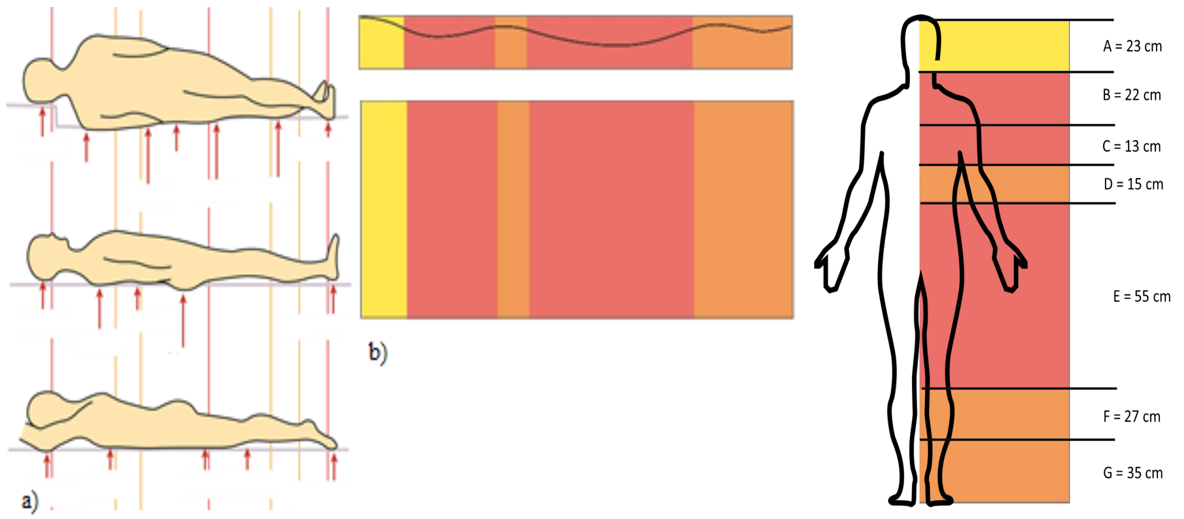

Figure 3. a) Illustrative diagram of the division of the pressure zones; b) segmentation and levels of body immersion.

Nine different fibrous surface designs (Figure 4) inspired on plant models, specifically the different patterns of vascular bundles of leaves, were developed. The pattern samples were ordinated from VT_1 until VT_9, coincident with its thickness. To note, the sample range decreases in thickness from VT_1 to VT_9.

Weft-knitted spacer fabrics, composed of 92% PES+8% elastane, filled with PES monofilaments fed at a rate of 1200/60, were used for the production of the samples.

Figure 4. Patterns used in the methodology of the study of the surface design**.**

2.2 Performance evaluation

Cyclic compression tests were performed in order to understand the behaviour of each knitted fabric developed in terms of deformation recovery and the energy absorbed over time.

A HOUNSFIELD H100KS universal testing machine was used with a 2.5 kN load cell. The parameters used in the cyclic routine created were: descendant speed - 10 mm/min; Standby time under pressure - 60s; standby pressure - 6N; return speed - 10 mm/min. For every 20 compression cycles, before the start of a cycle, and at the end of the 20 cycles, the thickness of the sample was measured over the compression area. To ensure that the compression was always performed in the same place, the position of the impactor was identified in each sample.

3. RESULTS AND DISCUSSION

Figure 5 presents the load-elongation curves for the cyclic tests performed on the samples. The absorbed energy was analysed in the 1st, 10th and 20th cycles. As can be seen, there is a similar behaviour in each sample between cycle 1 and cycle 20. This fact proves that there is no significant permanent deformation among cycles, as required in a substrate for the application envisaged, showing that the immersion behaviour is guaranteed even after several cycles of maximum load.

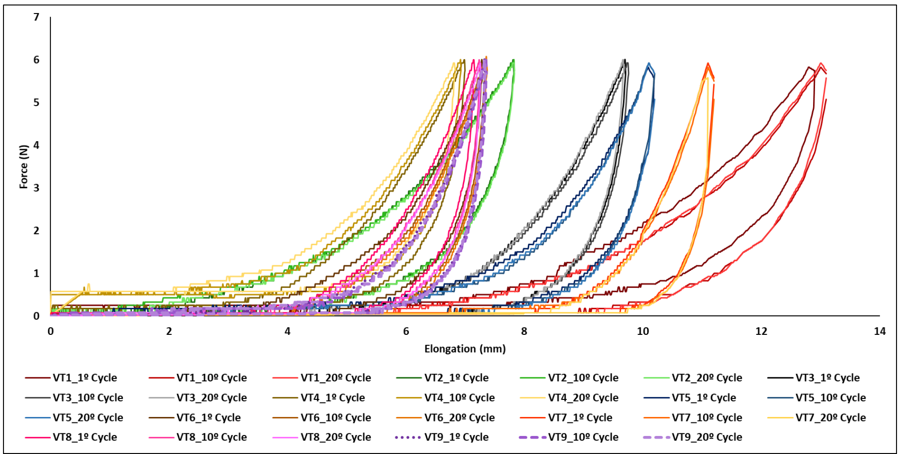

Figure 5. Absorbed energy measured in each sample (from VT_1 to VT_9) in the 1st, 10th and 20th cycles.

Table 1 shows the energy absorbed for the 1st and 20th cycles for each knitted fabric, based on the hysteresis behaviour. Under this type of test conditions, it's considered positive a percentage of variation lower than 10% for the difference between both cycles.

Table 1. Energy absorbed for the 1st and 20th cycles.

Absorbed Energy (N/mm^2)									
Sample	**VT_1**	**VT_2**	**VT_3**	**VT_4**	**VT_5**	**VT_6**	**VT_7**	**VT_8**	**VT_9**
1st cycle	6,56	7,16	5,70	5,02	6,67	4,87	4,36	4,46	4,02
20th cycle	8,69	7,20	5,68	5,24	6,17	4,11	3,80	4,34	4,04
Δ E	**32%**	**1%**	**-1%**	**4%**	**-7%**	**-15%**	**-13%**	**-3%**	**0%**

Analyzing the results inError! Reference source not found. Table 1, it's possible to demonstrate that only VT_1, VT_6 and VT_7 present a variation higher than 10%. Moreover, VT_1 demonstrates the highest variation value (32%) and, for this reason, it's necessary to verify is thickness variation along with the compression procedure (Table 2 and Figure 6).

Table 2. Thickness in the 1st and the 20th cycles of compression.

Thickness (mm)									
Sample	**VT_1**	**VT_2**	**VT_3**	**VT_4**	**VT_5**	**VT_6**	**VT_7**	**VT_8**	**VT_9**
1st cycle	7,53	7,91	6,94	6,21	6,87	5,22	5,40	5,28	5,63
20th cycle	7,46	7,46	6,81	6,15	6,90	5,23	5,41	5,56	5,66

Δ T	**-1%**	**-6%**	**-2%**	**-1%**	**0%**	**0%**	**0%**	**5%**	**0%**

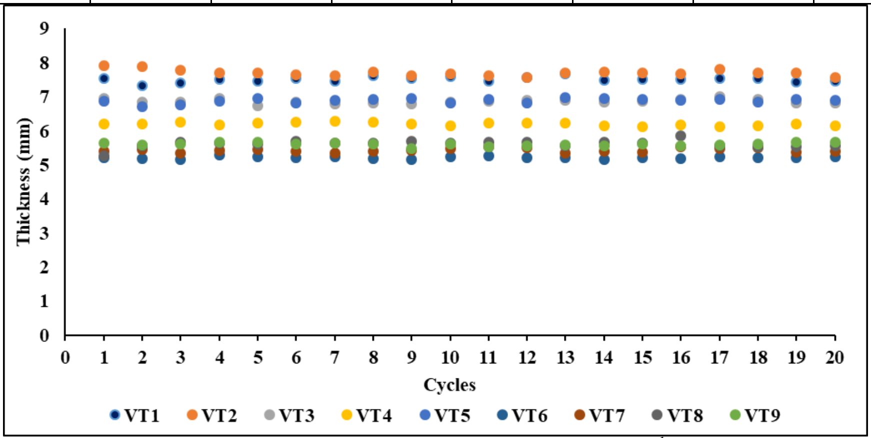

Figure 6. Thickness variation between 1st and 20th cycle.

Thickness variation is one of the most important verification means for performance validation, considering that immersion and involvement are directly related to the volume and the thickness of a sample. The results show that the structures maintain their characteristics over time and use, promoting high functional activity in every zone of the layer.

In this way, an innovative design for the underlay is proposed based on the needs of the human body and on the results obtained for each 3D weft-knitted fabrics developed. Figure 7 allows a full perception of the tested sample position in the bio-inspired mattress overlay and the pressure critical points in the human body. In Figure 7 a), the yellow point (head) is not considered in this study since the utilization of the cushion in this zone; red points represent the high-pressure areas; orange points the medium pressure points and blue points the lowest pressure points in body pressure points analysis. Herewith, shoulder blades, hips and heels should be placed in areas with high immersion and involvement.

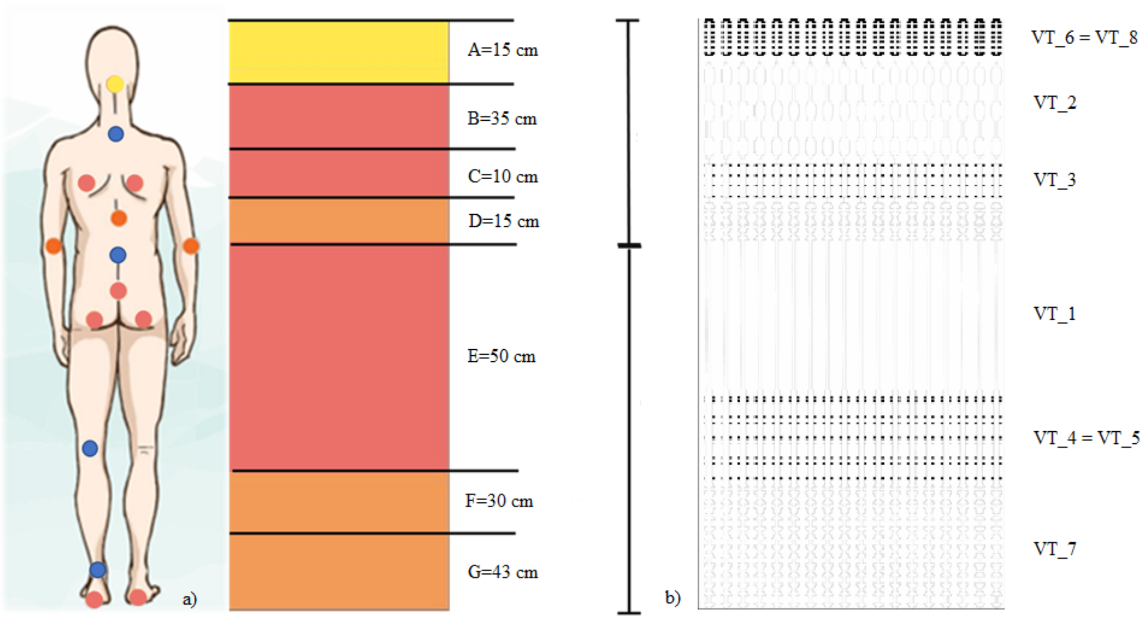

Figure 7. a) diagram on the body pressure points and mattress overlay; b) optimized overlay and sample identification.

In summary, all samples present good characteristics to promote comfort to bedridden persons. The low thickness variation indicates that the surface will not present deformation trough time.

4. CONCLUSIONS

The aim of this study was to analyze the behaviour of a 3D textile structure on pressure ulcer prevention. Using jacquard technology in weft knitting was possible to obtain a two-layer substrate with a polyester filling, that promotes by its construction high capacity of immersion. During bibliography, the analysis was possible to understand the high necessity of immersion and involvement of these structures to correspond to bedridden person needs, in a way to promote comfort and avoid pressure ulcers appearance.

For the compression tests analysis, a constant load of 6 N was applied in the surface, corresponding to 25 mmHg. This cyclic behaviour match with of critical point of compression, associate to the starting point of appearance of pressure ulcers. In this test conditions, a pressure value was obtained in N/mm^2 for each sample – convertible value in energy (Joules), that enable the perception of deformation of the structure along the time. In this point only VT_1, VT_6 and VT_7 did not correspond to requirements for an under 10% variation. Although, true the analysis of thickness variation, was possible to verify homogeneous comportment of the specimens, with variations under 6%. Correlating VT_1, VT_6 and VT_7 in both properties, the samples with a higher variation of energy, presented the lowest variation on thickness, a factor that can be associated with the dispersion of the inside filling.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] N. (Ning) Pan and G. Sun, *Functional textiles for improved performance, protection and health*. Woodhead Publishing, 2011.
[2] A. R. Horrocks and S. C. Anand, *Handbook of Technical Textiles*, 2nd ed. Woodhead Publishing, 2016.
[3] T. Matsuo, “Textile Progress Fibre materials for advanced technical textiles Fibre materials for advanced technical textiles,” vol. 40, no. 2, pp. 87–121, 2008.
[4] G. P. Nair and S. P. Pandian, “Technical textiles - 2 Medtech,” vol. 52, pp. 87–93, 2005.
[5] G. S. Lazarus, D. M. Cooper, D. R. Knighton, D. J. Margolis, R. E. Percoraro, G. Rodeheaver, and M. C. Robson, “Definitions and guidelines for assessment of wounds and evaluation of healing,” *Wound Repair Regen.*, vol. 2, no. 3, pp. 165–170, 1994.
[6] S. Baranoski and E. Ayello, *Wound Care Essentials - Practice Principles*, 3ª. Londres: Lippincott Williams & Wilkins, 2012.
[7] C. N. Parker, “Predicting the likelihood of non-healing: A venous leg ulcer risk assessment tool,” Queensland University of Technology, 2014.
[8] M. M. Popoola, “Paradigm shift: A clarion call for a holistic approach to chronic wound management,” *Adv. Skin Wound Care*, vol. 13, no. 1, pp. 47–48, 2000.
[9] J. A. M. Neil, “Living with a Chronic Wound: A Heideggerian Hermeneutical Analysis,” Virginia Commonwealth University, 1998.

[10] National Pressure Ulcer Advisory Panel, European Pressure Ulcer Advisory Panel, and Pan Pacific Pressure Injury Panel, *Prevenção e Tratamento de Úlceras por Pressão: Guia de Consulta Rápida*, 2ª. Cambrigde Media: Osborne Park, Australia, 2014.

[11] S. R. Thuler and S. R. P. E. Dantas, "Úlceras Por Pressão - Prevenção E Tratamento," p. 26, 2013.

[12] C. Afonso, G. Afonso, M. Azevedo, and M. Miranda, *Prevenção e Tratamento de Feridas Da Evidência à Prática*. Hartmann, 2014.

[13] M. F. de C. P. Silva, "Prevenção de úlceras de pressão em crianças no perioperatório," Instituto Politécnico de Setúbal, Setúbal, 2014.

[14] D. L. Wong, *Manual Clinico de Enfermagem Pediátrica*, 8ª. Mosby Elsevier, 2013.

[15] F. Stephens, C. Morrell, and A. Loftus-hills, *Pressure ulcer risk assessment and prevention*. Royal College of Nursing, 2003.

[16] International review, *Pressure ulcer prevention: pressure, shear, friction and microclimate in context*. London, 2010.

[17] C. Santos, "Sistema Automático de Prevenção de Úlceras por Pressão," Universidade da Madeira, 2009.

[18] M. Collier and Z. Moore, "Etiology and risk factors," in *Science and Practice of Pressure Ulcer Management*, M. Romanelli, Ed. London: Springer, 2006, pp. 27–35.

[19] P. S. Walton-Geer, "Prevention of Pressure Ulcers in the Surgical Patient," *AORN J.*, vol. 89, no. 3, pp. 538–552, 2009.

[20] AORN, "Perioperative Standards and Recommended Practices," Denver, USA, 2012.

[21] R. Bryant and D. Nix, *Acute and Crhonic Wounds Management*, 2ª. Missouri: Mosby, 2000.

[22] J. Maklebust and M. Sieggreen, *Pressure Ulcers: Guidelines for Prevention and Management*, 3ª. Springhouse, 1996.

[23] R. Grupo ICE – Cardoso, Leocádia; Carvalhal, Rosa; Chácon, M. À. Espírito Santo, Teresa; Estévez, Mª Luísa; Ferrera, R. Gomes, Miguel; Jardim, Helena; Jiménez, Juan Fernando; Luís, M. G. Mendes, Luís Filipe P.; Messias, Norberto; Reis, B. del Rocha, Ana Paula; Rodrigues, Alexandre; Rodriguez, and B. Carmen; Santos, Mª Luísa; Silva, Dulce; Teixeira, *Prevençao de úlceras por pressão. Manual de orientações para a Macaronésia*, 2ª. Açores, 2010.

[24] EPUAP-NPUAP, "Prevenção das úlceras de pressão: Guia de consulta rápida," *Guidel. Int. Úlceras Press. - Guia Ref. rápida – Prevenção*, pp. 1–28, 2009.

[25] P. Rodriguez Palma, M; López Casanova, P; García Molina, P; Ibars Moncasi, "Superficies especiales para el manejo de la presión en prevención y tratamiento de las ulceras por presión," Logroño, 2011.

[26] C. Lyner, E. Pina, and J. Gouveia, *Prevenção das úlceras de pressão: prática baseada na evidência*. 2010.

[27] E. Menoita, C. Gomes, S. C. Pinto, C. Testas, and V. Santos, "Superfícies de apoio na prevenção das úlceras de pressao," *J. Aging Inov.*, vol. 1, no. 4, pp. 34–52, 2012.