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Which techniques to improve the early detection and prevention of pressure ulcers?

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Abstract— **Pressure ulcers are a serious health problem for people with mobility disorders, like elders in acute care, long-term care, and home care settings. It also concerns paraplegics, tetraplegics or persons with burned injuries. Pressure ulcers result in significant morbidity and mortality. Consequences are a high human suffering, with high cost in terms of treatment.**

Several risk factors have been identified for the development of pressure ulcers: they are classified into extrinsic and intrinsic factors. Extrinsic factors include interface pressure, shear forces, friction…Intrinsic factors are the nutritional state of the patient, its age, diseases…There is little information about the mechanism of the formation of pressure sores but it is agreed that it is a complex process. The difficulty of the prevention lies in the evaluation of these factors. It is an essential stage to optimize the preventative measures. Actually, no quantifiable parameters exist to predict the formation of a pressure ulcer.

This article is aimed to propose new techniques developed for the early detection of pressure ulcers. First, extrinsic parameters as the interface pressure and its consequences on the mobility are investigated. A new actimeter is presented to monitor the movements of the patient. The second part is dedicated to the presentation of a new imaging technique which can help the physician to control tissue elasticity of the patient. The technique is called elastography, it is a 3D strain estimation of soft biological tissues. Finally, the last way of investigation is the combination of extrinsic and intrinsic factors evaluation for a most relevant earlier diagnosis. Before the description of these techniques, it is essential to understand the phenomenology associated to the development of pressure sores. Only in this way, new techniques can be developed.

I. Introduction

According to the French Agency of accreditation and assessment in Health (ANAES), complications due to pressure ulcers cause the death of 7 to 8% of the subjects. Individual cost of pressure sores is estimated between $14 000 and $40 000 per incident and the annual cost at $1.3 billion [1]. It increases the duration of hospitalization by a factor of 2 or 3, as the cost by patient.

Several risk factors have been identified for the development of pressure ulcers: they are classified into extrinsic and intrinsic factors. Extrinsic factors include interface pressure, shear forces, friction, moisture…Intrinsic factors are the nutritional state of the patient, its age, infection, diseases… Three main mechanical factors are thought to play a part in the development of pressure ulcers: pressure, friction and shear. It is widely accepted that pressure ulcers can develop as a result of prolonged periods of immobility during which unrelieved pressure compresses tissues that overlie bony prominences. Anaesthetized patients are one example of immobile people at risk, they are unable to sense the discomfort of high level pressure and initiate movement.

The capillaries are where the blood's most important functions are carried out. Oxygen and other substances pass through the capillary walls into the body cells.

With prolonged pressure, capillaries collapse and the flow of blood and nutrients to the body tissues is disrupted, resulting in cell death and tissue necrosis. The level of pressure required to cause damage varies from person to person, according to factors such as location and disease process.

Actually, the prevention consists for the nurses in the repositioning of patients every two hours. They assess the skin to identify pressure damage. Subjective scales are also used to evaluate the global state of the patient and the risk for him to develop a pressure ulcer. Actually, no quantifiable parameters exist to predict the formation of a pressure ulcer. The difficulty in the prevention work is that damage begins at the bone. Indeed, muscles cannot live without oxygen contrary to the skin. Tissue necrosis is induced by toxic substances, metabolites which are produced by the compressed muscle. These metabolic wastes and toxins are not eliminated as a result of the blockage of both, the lymphatic flow and the microcirculation [2].

II. Extrinsic factors evaluation

The forces applied to the surface of the skin are of two components, one referred to as pressure which acts

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perpendicularly to the skin; and shear which acts parallel to the skin surface. Pressure is thought to be one of the key extrinsic factors in sore development and shear increases the effect of pressure in reducing flow through the blood vessels.

It is often reported that unrelieved pressure greater than capillary closure pressure (32 mmHg, on average) can cause pressure ulcers and consequently, for the patient at risk, it is necessary to reduce pressure on skin surfaces to below 32 mm Hg using pressure-reducing devices.

This threshold value is called into question. Indeed, this value depends on the persons characteristics (including Body Mass Index). Moreover, blood flow in capillaries decreases from 5mmHg applied on the skin, as described below on an experiment conducted in our laboratory (figure 1). The sensor dedicated to the microcirculation measurement is the Hematron sensor [3]. It is an active sensor, measuring the thermal conductivity of skin which is directly related to the microcirculation. A level below 2mW/cm.°C indicates that the skin blood flow is stopped. This particular value is the intrinsic thermal conductivity. Weights of increasing values are placed on the skin and the thermal conductivity is measured.

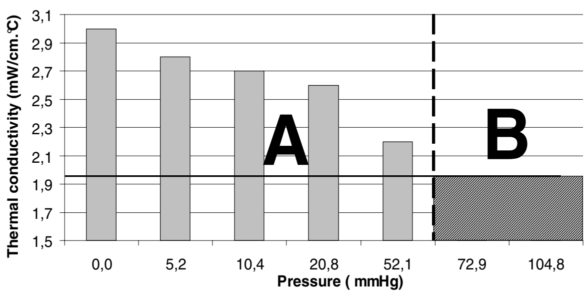

Figure 1: relation between the thermal conductivity (image of microcirculation) using Hematron sensor, as a function of the pressure. In area A, the microcirculation decreases with the pressure; in area B, microcirculation is blocked, only the intrinsic thermal conductivity is measured (2mW/cm.°C).

This experiment demonstrates the difficulty to prevent pressure ulcer by measuring only the interface pressure between the subject and its support. A 5mmHg pressure applied on the skin induces a decrease of the skin blood flow. Interface pressure devices have to measure accurately weak value of pressure, which is not the case actually.

These difficulties can explain the lack of consensus in the evaluation of the performances of interface pressure devices. Indeed, for the use of pressure relieving support surfaces, there is currently no consensus regarding how such surfaces should be evaluated and compared [4]. Moreover, methods of quantifying interface pressure exist even though a formal, research-based definition does not exist [5].

A. *Mobility monitoring using actimetry*

As regards the difficulty of interface pressure evaluation, actimetry is naturally justified. The pressure ulcer is induced by a mobility disorders. Monitoring this mobility can be relevant to prevent a subject from pressure ulcers.

1) *Ambulatory Device for Pressure Ulcer Prevention*

A new actimeter system has been designed in order to study movements of the human body whatever its support while seating [6]. This evaluation, at the interface between soft living tissues and any support has to consider the specificity of the human environment. Soft living tissues have non-linear mechanical properties making conventional rigid sensors non suitable for interface parameters measurement.

The actimeter is an active and flexible sensor, which measurement is independent from the weight of the subject. Our first prototype has been designed for a chair (figure 2). The *Ambulatory Device for Pressure Ulcer Prevention* system is based on a pneumatic cushion including 32 electrical cells made of flexible copper circuit.

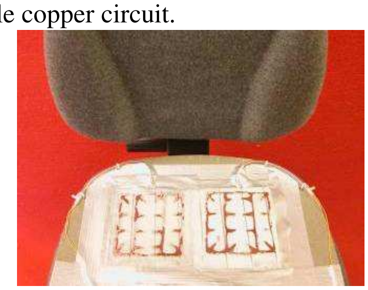

Figure 2: Flexible and active actimeter designed for a chair.

While a subject is sitting on the cushion, its position is represented by opened/closed cells. The recording of the cells state is performed at a sampling frequency of 10Hz. Movement is analyzed by calculations. A controlling system is used to deduce the horizontal or vertical displacement on the seat. Data are processed with a visualization program written in Matlab®.

2) *Results of the Ambulatory Device for Pressure Ulcer Prevention device*

Results are reported on figure 3. The movement quantity observed on a valid subject reveals three different phases: the first (A) is high activity phase, the subject is searching for a good position on the seat. Then we observe an inactivity phase (B), and finally a regular increase of the activity (C) with the time. During the second phase, tissues are compressed with the time. The perfusion of tissues between bony prominences (ischial tuberosities) decreases which creates an uncomfortable situation. To restore the microcirculation in muscles and tissues, the subject needs to move on its seat in order to modify the position of high pressure areas.

Interface pressure devices remain the only available system to detect high pressure areas for subjects in total immobility. It is the case of paraplegics who get no sensory warning of impending ischaemia, and more generally of patient with impaired mobility (lack of spontaneous movements).

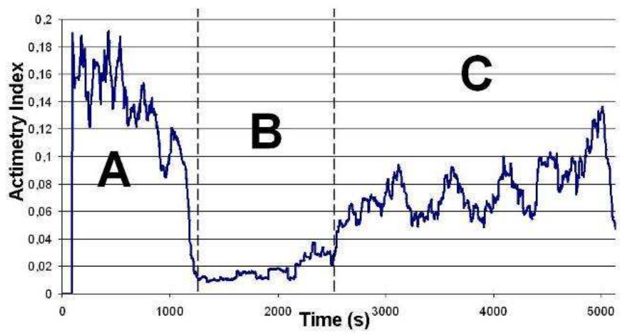

Figure 3: Measurement of the activity of a valid subject. 3 different phases are noted : the first (A) is a high activity phase, the second one (B) is an inactivity phase, and the third one (C) traduces a regular increase of the activity.

III. Intrinsic Factor Evaluation: Elasticity Imaging

Extrinsic factor evaluation can be completed with intrinsic one. Methods used to evaluate extrinsic parameters often depend on the subject characteristics. Levine, cited by Fay [5], points out that the interface pressure, which is considered as one of the three main extrinsic factors, may not be the best descriptor of internal stresses. Instead quantities such as tissue deformation may provide a better method for achieving the end goal of evaluating reduction of stresses for the prevention of pressure ulcer.

A. *Elastography Principle*

According to in-vivo tests performed on culture skin by L. Edsberg, pressure on skin tends to decrease the stiffness of epidermal tissues and modifies its mechanical properties, particularly near to bony prominences [7].

Providing physicians with information on the medium local mechanical properties could therefore be of fundamental interest for an early detection of pressure sores. Such information is currently not available with imaging modalities in clinical use. However, during the last years has emerged a new imaging technique based on ultrasound and termed elastography [8]. Its objectives are to access to local elastic properties of a tissue through the visualization of its deformation behaviour in response to an externally applied mechanical compression. Under a same stress, soft areas will deform more than harder ones.

In practical terms, radio-frequency (RF) ultrasound images are acquired from the tissue under investigation in both rest and compressed states. Tissue internal deformations are then locally estimated by segmenting the ultrasound data into many overlapping regions of interest (ROI) and by evaluating, within each ROI, the variations induced by the application of the stress.

It has to be underlined that elastography brings information complementary to ultrasound images. Indeed the result presented in figure 4 was obtained with experimental data from a test object. We can observe that the inclusion is clearly brought out on the strain image while it can not be detected on the corresponding conventional ultrasound images.

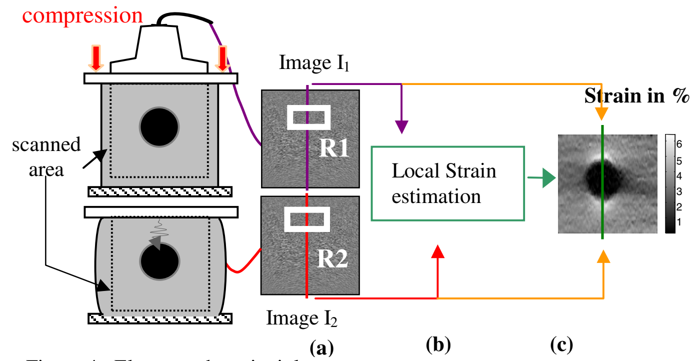

Figure 4 : Elastography principle.
Let us consider a soft cubic medium within which is embedded a harder spherical inclusion. Two ultrasound RF images are acquired one before (I_1) the other after (I_2) medium deformation **(a)**. For each 2D region of interest in the pre-compression image, denoted R1, its deformed version, R2, is searched in the post compression image and its deformation is estimated **(b)**, leading to the axial strain image **(c).**

Elastography is a developing imaging technique that already exhibits a strong potential interest in terms of pathology detection and tissue characterization. Based on ultrasound which is a low cost, real time and non invasive imaging modality, elastography can be used as well for the diagnosis or patient follow-up as for the screening.

B. *Strain Estimation*

The method we developed [9] to estimate strains works as follows. For each 2D RF ultrasound region R_1 selected in the pre-compression image, the technique consists in searching its deformed version R_2 in the post-compression image and in estimating its strain.

It has to be mentioned that RF ultrasound images are characterized by a highly anisotropic spatial resolution. The axial resolution (along the ultrasound beam propagation axis) is very fine, primarily determined by the carrier ultrasound frequency, whereas the lateral resolution is much coarser, limited by the acoustic aperture size. This has led us to consider a direction dependent modeling of the 2D region deformation. In the axial direction, R_2 is modelled as a shifted and scaled replica of R_1.

The axial shift results from the accumulation of axial deformations of regions located between the probe and the current position. In the lateral direction, R_2 is considered to be only a shifted version of R_1, owing to the poor resolution.

Locally after having compensated for the axial shift, the compressed region R_2 *is* iteratively axially stretched and laterally displaced until reaching a maximum correlation with R_1. This optimal parameters determination is performed through constrained optimization [9]. Finally the axial strain is directly deduced from the axial scaling factor.

This 2D method has been successfully adapted to process 3D data [10] as those provided by new generation arrays.

IV. Combination of Intrinsic and Extrinsic Factor Evaluations

A. Method

The idea is to relate the mobility disorder to autonomic nervous system (ANS) trouble. More precisely, the evaluation of the consequence of the discomfort on the ANS (stress induced by discomfort) can be relevant for the early detection of the pressure ulcer.

Mobility of a seated subject is evaluated through movement measurement using the actimeter described in part II. The stress induced by the discomfort is evaluated on through autonomic nervous system (ANS) analysis by recording the variations of six ANS parameters (two bioelectric, two thermovascular, and two cardiorespiratory). The E.motion device records: skin potential, skin resistance, skin temperature, skin blood rate, instantaneous cardiac frequency and instantaneous respiratory frequency.

B. Results of the combined study

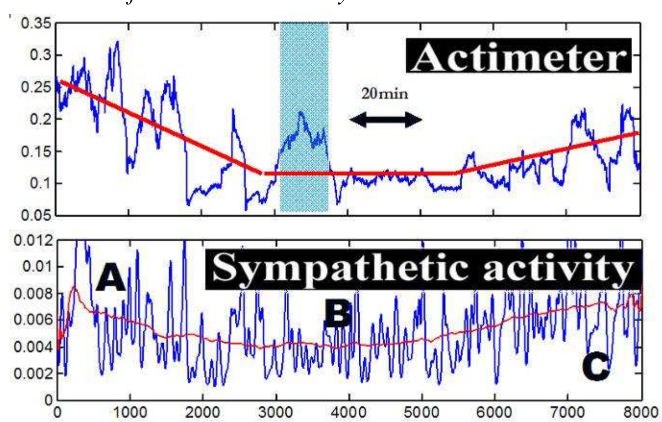

Figure 5. Comparison between seat activity and sympathetic activity (low frequency band of the Heart Rate Variability).

The complete study is reported in [6]. Actually, actimetry is only related to the Heart Rate Variability (HRV). The HRV is obtained by a time-frequency analysis on the instantaneous cardiac frequency signal. The cardiac rhythm high-frequency component (0.12 – 0.40 Hz) corresponds to the vagal influence of the sinus node. The very-low frequency band (0.003 – 0.04Hz) corresponds to metabolic and humoral processes, and the low frequency (0.04 – 0.12 Hz) to mechanisms in both the sympathetic and parasympathetic nervous system [11]. This last frequency band is the relevant band for this study. An energy analysis in operated on each frequency band.

Analysis in this band for a valid subject (figure 5) reveals 3 phases similar to the phases read on the mobility activity (figure 3). Time-frequency analysis seems a good way to investigate our research. We have to analyze the variations of all other parameter recorded by the E.motion system.

We also prepare a study on a large sample of valid and wheelchaired subjects, to improve our results and to validate our experimentations protocol.

V. Conclusion

Early detection and prevention of pressure ulcer have to be improved by a multiparametric approach, including both extrinsic and intrinsic factors evaluations. Indeed, pressure ulcer formation is a complex process which depends on several parameters.

Techniques presented in this paper are all non-invasive techniques dedicated to the monitoring of patients in risky situations. Actimetry is relevant to point out mobility disorder. Associated to the Autonomic Nervous System analysis, it can be a powerful tool, because the ANS receives alarm signs from the area under compression.

About intrinsic factor evaluation, elastography is a technique of interest to investigate any pathology characterized by modifications of the local mechanical properties and could be very helpful to early detect pressure ulcers.

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