New Methodology For Preventing Pressure Ulcers Using Actimetry and Autonomous Nervous System Recording

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***Abstract*— Pressure ulcers constitute an important health problem. They affect lots of people with mobility disorder and they are difficult to detect and prevent because the damage begins on the muscle.**

This paper proposes a new approach to study pressure ulcers. We aim at developping a methodology to analyse the probability for a patient to develop a pressure ulcer, and that can detect risky situation. 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 is evaluated through movement measurement. 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.

A new actimeter system has been designed in order to study movements of the human body whatever its support while seating. The device is based on elementary active cells. The number of pressure cells can be easily adapted to the application. The spatial resolution is about 4cm².

In this paper, we compare activity measurement of a seated subject with his autonomic nervous system activity, recorded by E.motion device. It has been developped in order to record six parameters: skin potential, skin resistance, skin temperature, skin blood rate, instantaneous cardiac frequency and instantaneous respiratory frequency.

The design, instrumentation, and first results are presented.

I. Introduction

PRESSURE ulcers represent in our days an important health problem. They affect a large part of hospitalized people: 9.2% in United States, 8% in United Kingdom and 10% in Netherlands [1]. This health problem is also an economical problem, its cost has been estimated to more than 6.4 billion dollars per year in United States [2]. Appearance of a pressure ulcer during hospitalization increases the journey duration [3], as well as the cost and the overcrowd of hospitals.

The consequences of a risky situation are a tissues necrosis. The muscle is first damaged because it is unable to live without oxygen as contrary to the skin. When the pressure ulcer is visible on the skin it's too late. Detecting dangerous situations is essential to prevent this situation.

To improve the prevention of this phenomenon, the origin has to be detected. Many factors are involved in the formation of pressure ulcer: age, limited mobility, incontinence, temperature, nutritional state [1]. The major factor remains the pressure. Indeed the pressure prevents blood to circulate in muscle and to deliver oxygen and oligo-elements into the muscle. In his study on elderly patients [4], Brienza finds a relationship between the average pressure, the maximum peak pressure and the incidence of seatting-acquired pressure ulcers. He also underlines that the use of specific cushions to reduce interface pressure also reduces the probability of developping a pressure ulcer due to pressure. He also suggests that peak preassure and the average of the highest 4 pressures are significant predictors of pressure ulcer incidence.

A strategy to predict pressure ulcers is based on the fact that interface pressure reveals strain distributions that may occur between muscles and bones [1], [2]. 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 [5]. However this measurement is difficult to perform, pressure also induces shear forces on the tissues, which cannot be measured correctly today. J. E. Sanders analyses the effect of pressure and stress on skin blood flow and points out that for high pressure (more than 142.9 kPa) stress and pressure had a more significative impact than pressure alone [6].

Measurement in soft living tissues has to consider the soft tissues specificities. Soft tissues refer to muscle, fat, fibrous tissue, blood vessels, or other supporting body tissues. Skin layers are directly involved when interface pressure devices are used.

Skin is organized into two biaxial membranes [7]: the epidermis, a relatively thin layer of stratified epithelium and the dermis, a thicker layer of disordered wavy coiled collagen

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and elastin fibers. The epidermis and the dermis are also connected by collagen fibers to the hypodermis (subcutaneous fatty tissue).

Mechanical properties of these soft tissues are complex: they exhibit non-linear elastic and viscoelastic properties [8] (stress relaxation and creep, hysteresis [9]). Characterization of the non-linear mechanical skin behavior with a mathematical method is a complex and difficult project [10]. Due to non-linear mechanical behavior, the human skin doesn't correspond to traditionnal study principles, such as the Young Modulus constant characterisation.

As regard the non-linear properties of the skin, any method to evaluate interface parameters has to be optimised. Conventional sensors as rigid sensors are not appropriated for this measurement.

II. State of Art

The studies of T. W. Kernozek on elderly people [11] outline a correlation between Body Mass Index (BMI) and pressure peaks. The BMI is obtained by dividing the suject body in kilograms by their height in square meters. This paper underlines that a high BMI reveals a lower risk of pressure peak. Stinson reveals the relation between average pression and BMI [12], and finds that high BMI is a testimony of weak pressure peaks under the seat.

Subjects who remain in immobility (wheelchaired people, eldery people) are more susceptible to develop pressure ulcers [13]. It's our inconscious or conscious mobility that protects us from this kind of damage. The difficulty is how to measure this movements and how to extract information associated to pressure ulcers developpement.

In her study [14], Sonja Hermann intends to evaluate the discomfort felt by car drivers, by analyzing the movements of the Center Of Pressure (COP). She distinguishes two kinds of movements: the first one is a vertical movement of the subject on the chair, and the second one is a left/right movement that tends to move the COP in order to unweight one side of the body. The two movements aim at changing the pressure repartition under the subject.

Fenety [15] shows that in-chair movement increases with time. This interpretation has to be treated carefully as in-chair movement is composed of required task movements and extraneous movements, as well as an increasing displacement of the COP during time.

According to Jensen [16], the legs movement is increasing during time. He also finds that seat inclinaison had no influence on subject movement.

As R. S. Goonetilleke describes [17], the pressure peaks are directly correlated to the comfort felt by people while seating. Subjects feel more uncomfortable while applying small but high pressure peaks than well distributed pressure, he reports it as the Maximum Pressure Tolerance. As we know that these high pressure peaks are also involved into pressure ulcer developpement, the estimation of the comfort allows to also predict the risky situation for pressure ulcers.

The E.motion system is a measurement device for autonomic nervous system. It records many parameters: skin potential, skin resistance, skin blood flow, skin temperature, respiratory frequency and cardiac frequency. It has been developped by our team [18]. Many studies were driven using this measurement device. Studies made on emotional response [19] reveal the correlation between emotions induced by odors and the autonomic nervous system activity. Sporting performance [20] was also treated with E.motion during experimentations on mental visualization of great sportmen. Estimation of seating comfort can be found using E.motion system.

III. Working Principle

Fig. 1. View of the electropneumatic sensor. The 32 contacts are distributed in 2 groups

The CAPE (Centrale Ambulatoire pour la Prevention de l'Escarre – Ambulatory Device for Pressure Ulcer Prevention) system is based on a pneumatic cushion. The cushion is made of 300µm thickness PVC. Its internal surface is recovered by 32 electrical cells made of flexible copper circuit. The cushion is connected pneumatically and electrically to the CAPE device. The system is driven by a PIC microcontroler (16F877), that manages the pressure control into the cushion thanks to a pump and a pressure sensor (Honeywell). The microcontroler records the state of each cell. The system is connected to a laptop computer on which the C++ human / machine interface program is running. The program enables the user to give settings to the system and to visualize the results.

During an acquisition, the internal pressure of the cushion is maintained to a value of 80 mmHg. While a subject is sitting on the cushion, we can observe his position with the representation of the opened/closed cells. The recording of the cells values is performed at a sampling frequency of 10Hz, the movement is analyzed by juxtaposing the pictures obtained and by calculating the differences. By controlling the number of closed cells, we can deduce if the suject is moving horizontally or vertically on the seat.

IV. PROTOCOL

In order to test the device and the methodology, a comparative test is performed between a valid subject and a subject borned with a spina bifida malformation. The first subject is a 23 years old man, whose height is 1,83 meters tall and who weighted 80 kilograms. He is a valid person, who never developped any pressure ulcer nor any health trouble that could induce pressure ulcer. The second subject is a wheelchair user since his birth, his particularity is to have never developped any pressure ulcer due to good education on good practices during his everyday life, such as regular rising. He pretends to have no feeling of the lower body. He sometimes has a very small signal of sensing, sometimes several days after the traumatism that has induced the feeling.

The sujects are placed on a chair instrumented with the CAPE system, and they are equipped with the E.motion sensors. The chair had two balustrades and a back. They are in a closed room, in front of a table, during 1 hour and 40 minutes. They have available comics, and have no communication with the outside.

Concerning the E.motion device, electrode positionning is in compliance with traditional recommendations [21]. Skin resistance is recorded using 50 mm² Ag/AgCl round electrodes (Clark Electromedical Instruments), placed on the second index phalanx and the non-dominant hand third digit, held by adhesive tape, and it is measured with a 15 µA current. Skin potential is recorded using 50 mm² Ag/AgCl round electrodes. The electrodes are placed on the hypothenar eminence of the subject's non dominant hand. Skin temperature is measured with a slow inertia thermistor (10,000 Ohms MCD2 Betatherm) placed in the middle of the non-dominant hand. Instantaneous repiratory frequency is recorded with a similar thermistor placed at the entrance of the left nostril with a flexible but stable system hang on the head of the subject. Instantaneous heart rate was recorded with three 50 mm² silver electrodes (ASEPT – INMED SA) in a precordial position. Skin blood flow is measured with the original patented Hematron sensor [22] placed on the skin with adhesive tape.

V. RESULTS

Data are then treated with a visualization program written with Matlab 6.5^R. We note that the subjects tend to lean on the side where the sensors are placed.

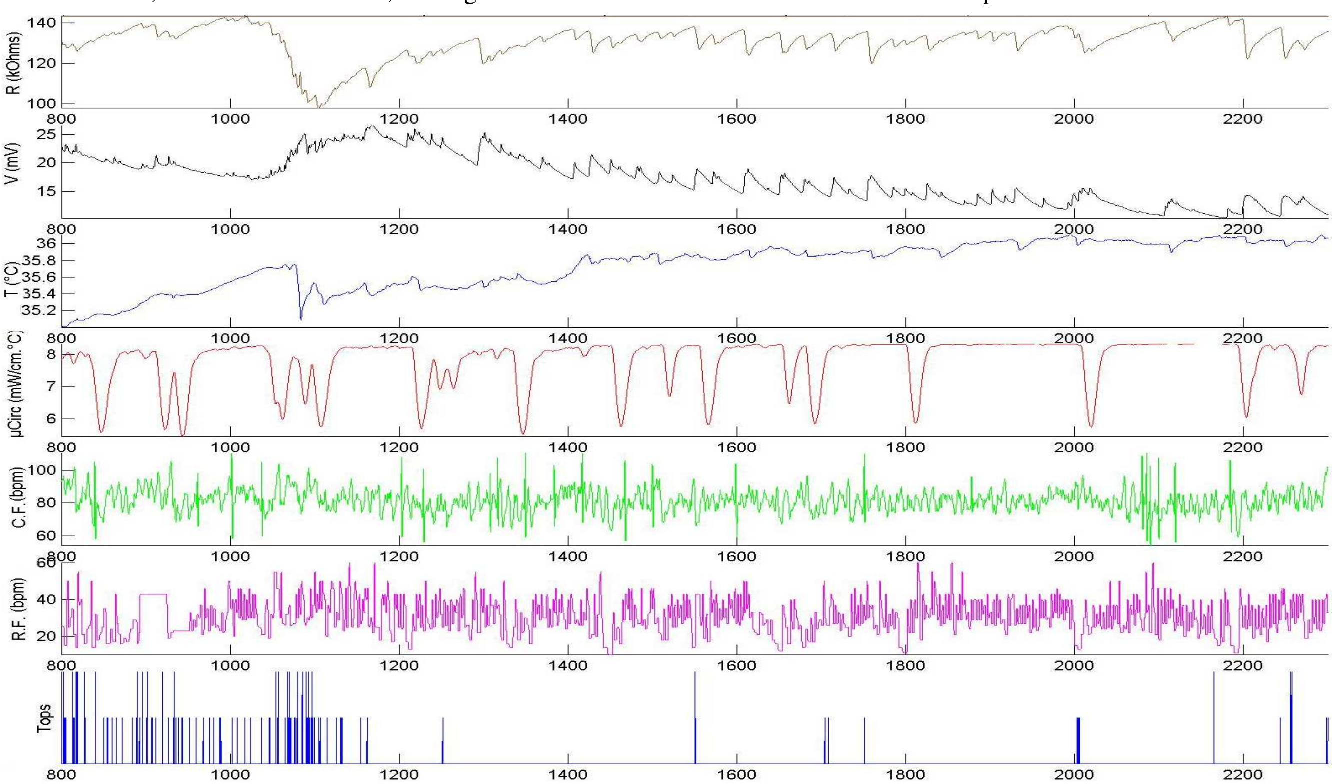

Fig. 2. Example of acquisition. From up to down, the signals read are: skin resistance, skin potential, skin temperature, skin blood flow, instantaneous cardiac frequency, instantaneous respiratory frequency, total activity of the seat.

The movement quantity observed on the valid subject reveals three different phases: the first (A) is high activity, the subject is searching for a good position on the seat. Then we observe inactivity (B), and after an increase of the activity (C).

The wheelchaired subject doesn't present that kind of activity. We observe a nearly constant movement intensity during seating time. The exception is a period of inactivity from second 1350 to second 1775, followed by a period of higher activity from second 2200 to second 2650.

We then intented to study the Heart Rate Variability by proceeding a time-frequency analysis on it. The cardiac rhythm high-frequency component (0.12 – 0.40 Hz) corresponds to the vagal influence of the sinus node, the very-low frequency (0.003 – 0.04Hz) to metabolic and humoral processes, and the low frequency (0.04 – 0.12 Hz) to mechanisms in both the sympathetic and parasympathetic nervous system [23]. That's this last frequency band that will interest us for the study. We operated an energy analysis in each band of frequency. Analysis in this band for the valid subject reveals 3 phases similar to the phases read on the mobility activity.

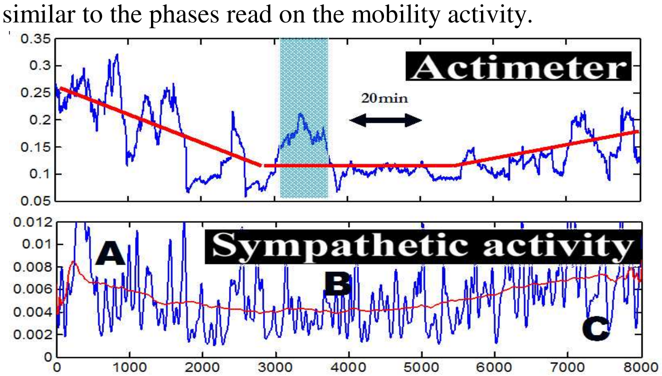

Fig. 3. Comparison between seat activity and sympathetic activity (low frequency band of the Heart Rate Variability)

VI. Conclusion

Next steps are the developpement of more mathematical tools for the study of the results. Time-frequency analysis seems a good way to investigate our research, but some of the signals recorded by the e.motion system are not still used for our analysis. We also prepare a study on a large sample of valid and wheelchaired subjects, to improve our results and to validate our experimentations protocol.

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