Designing and Constructing Blood Flow Monitoring System to Predict Pressure Ulcers on Heel

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ABSTRACT

Background: A pressure ulcer is a complication related to the need for the care and treatment of primarily disabled and elderly people. With the decrease of the blood flow caused by the pressure loaded, ulcers are formed and the tissue will be wasted with the passage of time.

Objective: The aim of this study was to construct blood flow monitoring system on the heel tissue which was under external pressure in order to evaluate the tissue treatment in the ulcer.

Methods: To measure the blood flow changes, three infrared optical transmitters were used at the distances of 5, 10, and 15 mm to the receiver. Blood flow changes in heels were assessed in pressures 0, 30, and 60 mmHg. The time features were extracted for analysis from the recorded signal by MATLAB software. Changes of the time features under different pressures were evaluated at the three distances by ANOVA in SPSS software. The level of significance was considered at 0.05.

Results: In this study, 15 subjects, including both male and female, with the mean age of 54±7 participated. The results showed that the signal amplitude, power and absolute signal decreased significantly when pressure on the tissue increased in different layers ($p<0.05$). Heart rate only decreased significantly in pressures more than 30 mmHg ($p=0.02$). In pressures more than 30 mmHg, in addition to a decrease in the time features, the pattern of blood flow signal changed and it wasn't the same as no-load signal.

Conclusion: By detecting the time features, we can reach an early diagnosis to prognosticate the degeneration of the tissue under pressure and it can be recommended as a method to predict bedsores in the heel.

Keywords
blood flow, heel, optical system, pressure ulcer

Introduction

Pressure ulcers, also known as bed sores, pressure sores, or decubitus ulcers, are wounds caused by unrelieved pressure on the skin. They usually develop over bony prominences, such as the elbow, heel, hip, shoulder, back, and back of the head [1-3]. Pressure ulcers are serious medical conditions and one of the important measures of the quality of clinical care in nursing homes [1,4]. Living with a pressure ulcer affects a person's life physically, socially and mentally, and is often associated with pain [1-4]. Pressure ulcers on any sites in the

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body, are caused by pressure that exceeds capillary closing pressure and results in ischemia [5]. Heel ulcers like pressure ulcers occur on persons of all ages and in all settings including the hospital, nursing home, and patient's residence[1]. When patients are in bed and immobile, the source of external pressure can be a bed surface, tight bed-covers, or pressure and friction generated when the leg becomes restless. Heel skin blood flow is reduced with high external pressure [6,7]. Patients who have many risk factors such as friction, shear, and moisture are more likely to develop heel ulcers in the hospital when compared to those that have few risk factors [7,8]. The heel may be more prone to tissue breakdown than some other parts of the body because it has a small subcutaneous tissue volume with pressure exerted directly on bone [9].

There are different tools to prognosticate the degeneration of the tissue under external pressure, including measuring the changes blood circulation, biochemical measurement, temperature measurement, chemical responses. There is great variance of these variables between the studies as well as duration of applied pressure, which makes it difficult to compare their results and summarize the knowledge in this field. In measuring the blood flow changes by the indicator materials, there is no precise measurement available first, and then this method is highly sensitive to the motion [10]. The biochemical measurement method needs specific pieces of invasive operations which are not plausible clinically. Another method to make an early prognosis on the pressure ulcer is the temperature measurement. In this method, the skin temperature changes are considered as a reaction to the blood flow of the area that can show ischemia or hyperemia amplitude [11]. First of all, the temperature increase in a part can be caused by other factors such as inflammatory lesions and not hyperemia after loading the pressure. Second, temperature measurement needs to be recorded and controlled in long terms by precise thermocouples. Even utilizing this method will not be efficient for the limitations stated. On the one hand, ischemia is the key factor in the pressure on the tissue due to the vessel obstruction, and on the other hand, based on various study, the blood flow changes measurement could be indicated ischemia [12-14]. Blood flow can be an appropriate parameter to study the tissue function when it is under the external pressure. Photoplethysmography is a noninvasive method in which the invisible infrared light is radiated to the tissue and the ray reflected from the tissue demonstrates the blood flow changes [13,15]. PPG is used for studying the external pressure changes in the blood vessels, the blood flow reaction to the external pressure of the tissue, probable potentiality of the bedsores cure, and determining the reactional ischemia and hyperemia [13,16].

The aim of this study was to measure the blood flow changes in different layers of the heel tissue under pressure by the PPG method. The aim was achieved by designing a optical probe with 3 channels for the simultaneous measurement of blood flow at different depths in the heel tissue when the tissue is exposed to external load.

Materials and Methods

Three infrared optical sensors (Three optical transmitters) with 915, 950 and 980 nm wavelengths and an optical receiver were employed to design the system. The optical transmitters were located at the distances of 5, 10 and 15 mm from the optical receiver so that the blood flow of the tissue under pressure could be studied in different layers of the tissue. For primary processing on the signal, the output of the optical receiver was inserted into an instrumentation amplifier (AD620). Since the PPG signal has DC frequency components up to 30 Hz frequency, to eliminate the low frequency distortions caused by the skin absorption, bone, other non-pulsatory tissues and the high frequency noises greater than 30 Hz a passive band-pass filter were employed with 0.5-20Hz bandwidth. Moreover, to have a signal with an appropriate range, an amplifier was utilized with variable gain. While recording, the recorded signal might have positive voltage level as well as negative voltage level and since a microcontroller is not possible with the negative voltage level, a level shifter was used in the last level of the circuit to shift the voltage level into an appropriate range, 0-5 V [17]. The output of the designed analog circuit was inserted into an analog-to-digital converter of ATMEGA 32 microcontroller so that the analog signal can be transferred digitally to the computer [18]. Software interface (MATLAB) was used to display, save, process and analyze the signal in the computer. By changing the distance between the transmitters and the optical receiver, the blood flow changes could be evaluated on the tissue under pressure in different layers. Figure 1 shows the location of the optical transmitters and receiver.

A four-minute recording was taken for each subject. Subjects were chosen from various ages randomly. Each subject was asked to lie on a bed and a pressure cuff with a sensor was fastened to his left heel. Body temperature, skin temperature pre and post and blood pressure were noted. At first, the cuff and the sensor were fixed somewhere on the left heel and the signal changes at the three distances recorded in 20-sec intervals, changing the way the optical transmitters turned on. Then the cuff was inflated 30 mmHg and then to eliminate the primary and the transient factors we waited for a while and after that recording started for 20 seconds by turning the first transmitter on. After the data recording in this interval, we waited for a while so that the blood flow in that part restored to its normal status. Subsequently, the second and third transmitter was turned on and just like the previous step the recording process repeated. In the last step, the cuff inflated 60 mmHg and by changing the method of turning the transmitters on and off in this status, the signal became stable. Turning the transmitters on and off was controlled by programming in micro. When recording the data, the location of the recording was the same and the conditions were selected in a way that could be replicable. Because the specifications of the tissue under study is physiologically different for each person, a signal at the three layers was recorded for each person separately before loading the pressure on the tissue so that we could compare it with the recorded signals that were measured individually, when pres-

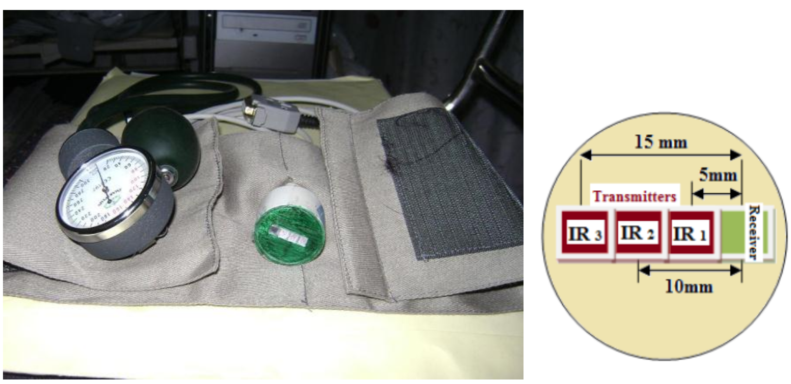

Figure 1: Optical transmitters and receiver position in the optical system

sure was loaded. The recorded data was saved in the computer via a 50 Hz sampling rate.

At first, the signals were standardized to have a mean of zero and a standard deviation of one, and then the time features were extracted for analysis from the recorded signal by MATLAB software version 2011. The time features were heart rate, signal amplitude, power and absolute signal. The time features were calculated by computing the mean amplitudes, absolute, power and heart rate for the blood flow signal. The computed time periods were between 15 and 20 s and were chosen based on the quality of the signal. The background data was distributed normally was therefore presented in terms of mean ± standard deviation. Differences in skin temperature pre and post measurement were compared using a paired sample t-test, Differences in all background measurements between genders were compared using an independent sample t-test. For evaluating the time features, ANOVA test and Post hock were used. A significance level of $p < 0.05$ was considered to be significant. Al statistical analyses were performing using SPSS version 16.

Results

15 subjects, including both male and female, with the mean age of 54±7 participated in this study. 9 of them were men and 6 of them women. All background measurements such as blood pressure, skin temperature, body temperature, BMI were within the reference intervals. There were no significant differences in regard to gender. All participants had systolic blood pressure of 131±8.9 and diastolic blood pressure of 88.4±7.7. Skin temperature varied from 32.1 ± 1.1°C prior to measurement to 32.4 ± 0.7°C after measurement and the difference was not significant. When lying on the test bench, the subject´s mean contact area on the heel was 36.2 ± 12.85 cm2. Data collection was done in a room with a temperature of 26 ±1°C.

Table1 shows the changes of the time features

Table 1: The changes of the time features in different pressures and distances

Pressure on tissue	Distance of transmitters to receiver	Heart Rate	Amplitude	Absolute	Power
0 mmHg	D=5 mm	77.92±6.74	2.98±1.08	1.75±1.12	0.96±0.03
	D=10 mm	78.23±10.11	1.52±0.88	1.11±0.88	0.92±0.02
	D=15 mm	80.37±6.27	0.81±0.23	1.05±0.65	0.86±0.03
30 mmHg	D=5 mm	82.14±6.91	2.14±0.61	1.17±0.78	0.91±0.04
	D=10 mm	81.36±9.11	1.31±0.64	1.04±0.74	0.84±0.03
	D=15 mm	80.92±7.51	0.69±0.31	0.91±0.41	0.81±0.03
60 mmHg	D=5 mm	81.11±7.51	1.62±0.46	1.06±0.83	0.88±0.03
	D=10 mm	80.33±10.02	0.86±0.22	0.86±0.51	0.81±0.02
	D=15 mm	76.66±9.13	0.49±0.15	0.81±0.33	0.77±0.04
	P-Value	0.166	0.004	0.039	0.044

when pressure and distance were changed. By increasing the distance of transmitters to receiver, the signal amplitude, power and absolute signal decreased significantly ($p<0.05$). There was not significant relation between heart rate and the distances ($p=0.1$). Also, the signal amplitude, power and absolute signal changed when the pressure was increased. According to the results, when the pressure on the tissue increased, these features in the three distances also decreased significantly ($p<0.05$). The heart rate at 60 mmHg pressure was lower in comparison with heart rate at other pressure. The changes of heart rate were not significant between 0 and 30 pressure but at 60 mmHg reduced meaningfully ($p=0.03$). Figure 2 shows the signal changes in different layers under 3 various pressures. Based on the figure 2, under the pressures more than 30 mmHg, the pattern of the signal changes and it wasn't the same as no-load signal. While loading blood flow signal was more affected in the superficial parts of the heel tissue. Figure 3 shows the time feature changes in different pressures and distances. Figure 3 shows that the signal power, absolute signal and signal amplitude followed a linear relation but the heart rate in different pressures and distances changed based on a non linear relation.

Discussion

This study presents a system to monitor blood flow in different layers on the heel tissue under pressure. The results showed that the signal amplitude, power and absolute signal decreased significantly when pressure on the tissue increased in different layers. These features decreased linearly when the distance between transmitter and receiver was increased. Heart rate decreased significantly only in pressures more than 30 mmHg in different layers. In pressures more than 30 mmHg, in addition to a decreased in the time features, the pattern of blood flow signal changed and it wasn't the same as no-load signal. By detecting the time features, we can reach an early diagnosis to

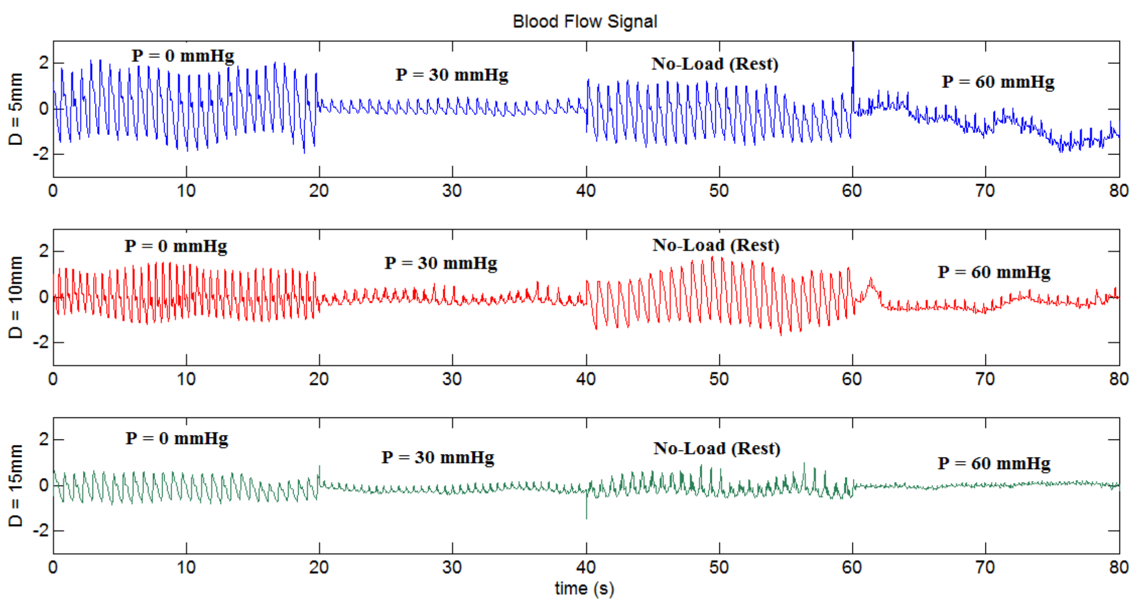

Figure 2: The signal changes in different layers under 3 various pressures (D= distance of transmitters to receiver).

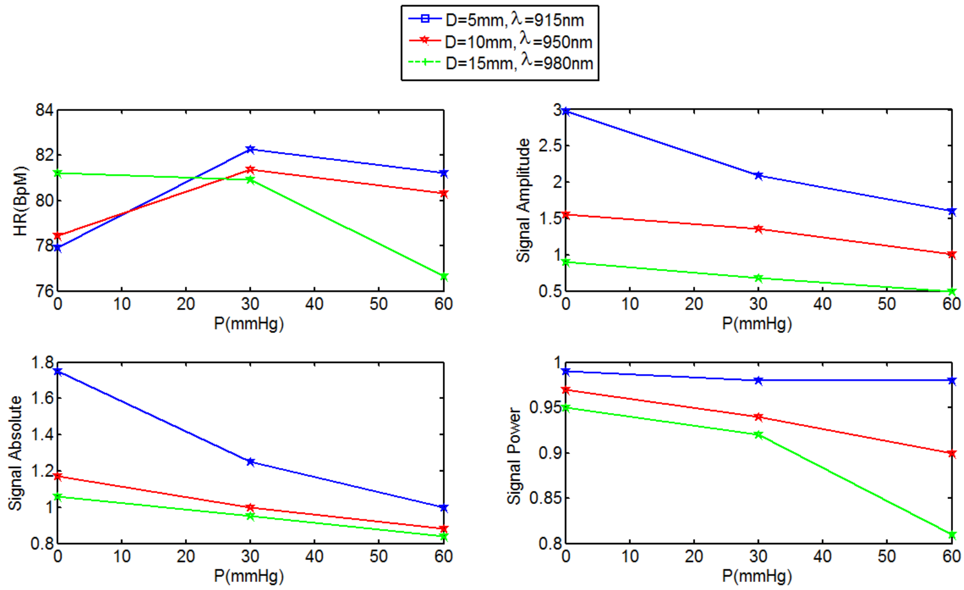

Figure 3: The time feature changes in different pressures and distances.

prognosticate the degeneration of the tissue under pressure.

In Hagblad *et al* study, Doppler flow meter was used to analyze the blood flow changes with pressure on the tissue putting 4-10 kg weights on trapezius, and the blood flow changes was analyzed regarding the pressure weights load on the tissue [13]. Also, in the Ek *et al* study, with 35-50 mmHg pressure, equivalent to the pressure when one lies on the bed, and by employing Doppler flow meter to measure the blood flow for only elderly people, the function of the tissue under pressure was assessed [7]. Among the studies done in this scope, the color change of the optical sensors to green, red and infrared wavelengths, the blood flow was analyzed in different depths of the tissue [7,13]. This study measured the blood flow changes in different depths with the wavelength and with changing the distance between the receiver and the transmitter. Though the research data collection was the same as other studies quantitatively, it has more variety in terms of samples comparing similar works.

In spite of all these remarks, other parameters with less influence are still effective on degeneration of the tissue under pressure and can be highly influential in estimating tissue degeneration time. Of these parameters, temperature of the tissue under study, moisture effect, location of the tissue under study, stress and many other cases can be referred [7-10]. In this study, we have tried to eliminate the moisture effects by stabilizing the temperature and the moisture of the environment and the location of the tissue. Considering other factors is of importance too. We have examined the heels here while the pressure level in other highly dangerous points for bedsore formation shall also be studied. Additionally, the distance between the receivers and the transmitters and also their wavelength were designed to clarify the blood flow changes in the heels, and, if the blood flow changes in other highly dangerous points is evaluated, evaluation in different depths of the tissue under pressure would be possible by changing the transmitter wavelength or the distance between the receiver and the transmitter. The replication of this study suggests for other places with the possibility of pressure ulcer. Moreover frequency and time-frequency analysis of blood flow signal can also be a major step towards creating a suitable model to recognize the tissue behavior under pressure and predict the bed sores.

Conclusion

The aim of this study was to design and construct a blood flow monitoring system in different layers on the tissue under pressure. The results showed that the signal amplitude, power and absolute signal decreased significantly when pressure on the tissue increased in different layers. In pressures of more than 30 mmHg, in addition to, decreased in the time features, the pattern of blood flow signal changed and it wasn't the same as no-load signal. In conclusion, the signal amplitude, power and absolute signal changes are appropriate parameters to evaluate the blood flow changes and by measuring them in different layers, an early prognosis on the tissue under pressure will be possible.

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Conflict of Interest

None

References

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