An Alternating Pressure Sequence Proposal for an Air-Cell Cushion for Preventing Pressure Ulcers

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Abstract— **The distribution and release of pressure on ischial regions are two important parameters for evaluating the effectiveness of a cushion; especially the release of pressure over time on ischial tuberosities, which is significant for preventing pressure ulcers. The aim of this work is to evaluate the effect on interface pressure through the application of a proposed alternating pressure sequence for an air-cell cushion. Six healthy volunteers were asked to sit on the air cell cushion, in static and alternating modes, as well as on a typical foam cushion for 12 minutes. Interface pressure was monitored with a matrix sensor system. Interface pressure values on ischial tuberosities, user contact area and pressure distribution were analyzed. Results showed that IP on IT tends to increase in both foam and static cushions, while in alternating cushion IP on IT tends to decrease. User contact area was significantly larger in alternating cushion than in static or foam cushions. Moreover, there is a better pressure re-distribution with alternating cushion than with the other cushions. The goal of the alternating sequence is to redistribute pressure and stimulate the ischial regions in order to promote blood flow and prevent pressure occurring in wheelchair users.**

I. Introduction

When sitting, the highest load is mainly concentrated on the ischial tuberosities (IT) areas[1][2][3]. Sustained and prolonged pressure on this area may diminish skin blood flow which in turn can induce tissue breakdown and pressure ulcer development[4][5]. These injuries are hazardous and limited to people that spend many hours on wheelchairs, with implications not just for the suffering patient, but also the treatment cost[6]. Therefore, preventing pressure ulcers is better than treating them.

One of the strategies for pressure ulcer prevention is the release of pressure. For this reason several wheelchair cushions have been developed. These cushions typically are made of foam, sometimes filled with gel, water, air, or a combination of these[7][8]. The goal of wheelchair cushions is to release pressure below the ischial tuberosities[1]. However, time of loading and pressure distribution are parameters that have been incorporated into the strategy for preventing pressure ulcers[9]. It has been suggested that a cushion, which envelopes the shape and contour of the body improves pressure distribution and also reduce pressure in the tissue[10]. Despite the wide varieties of wheelchair cushions, pressure ulcers remain a health problem for wheelchair users.

The aim of this work is to evaluate the effects on interface pressure (IP) through the application of an alternating pressure sequence designed for an air-cell cushion developed previously[11]. The purpose of this alternating sequence is to produce pressure distribution and to release interface pressure on the ischial regions thereby attempting to reduce the risk of formation of pressure ulcers in wheelchair users. For this purpose, a comparison study among responses of the developed air-cell cushion under with/without the alternating pressure sequence and a typical foam cushion was done. To estimate interface pressure values, some techniques based on positioning a sensor between the bony prominence of the body and the support surface; taking a single reading for static cushions and recording one or more cycles for alternating cushions, has been done [1][9]. In this work, there is an additional proposed method for evaluating pressure distribution on the ischial regions by dividing the entire area into 8 regions then comparing the temporal distribution in each cushion.

II. Methodology

A. Cushions

1) Developed alternating cushion.

This cushion consists of 12 air cells interconnected in pairs. Each cell has an air pressure sensor and an electrovalve and they are controlled by a software developed in LabVIEW. The description and calibration of this system is reported in a previous work[11]. We developed an alternating sequence for this cushion. This consists of inflating and deflating the air cells strategically in order to redistribute and release pressure on the ischial regions. This cushion was evaluated on both alternating and static modes. The static mode is performed with a basal inner pressure on air cells. At this point, we are going to refer to the static mode as 'static cushion'. Figure 1, shows the inner pressure in each section resulting from the alternating sequence.

2) Foam cushion

This cushion is a typical wheelchair cushion; it consists of 7cm thick inner foam with a vinyl cover.

B. Volunteers

Six healthy volunteers, 4 females and 2 males, were recruited to participate in this study. The participants were between 25-40 years old. The study protocol was fully explained to the volunteers and written informed consent was obtained before starting the study. Characteristics of the participants are provided in Table 1.

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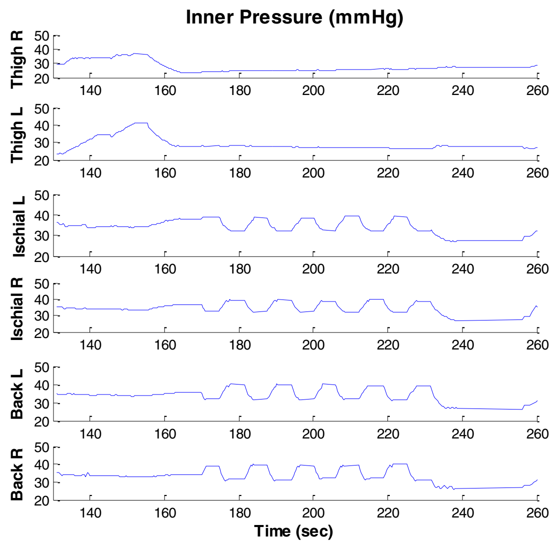

Figure 1. Sequence of the alternating mode. *One cycle of the sequence lasts about 2 minutes, during this time, thighs and ischial regions are stimulated by the inflation and deflation of the air cells, then, small pushes and releases of pressure resulted below the thighs. After a defined threshold is achieved the inner pressure in thighs remains low, subsequently an stimulation on ischial regions is done below ischial and back zones, after 5 cycles are completed there is relief of pressure on all the area by deflating all the air cells, and then the process starts again.*

TABLE I. CHARACTERISTICS OF THE VOLUNTEERS

Number of subjects	6
Age(years)	29.8 (5.7)
Weight(kg)	53.0(5.8)
Height(m)	1.60(0.08)
BMI	20.6(1.5)

*Data are Mean(SD)

C. *Protocol of evaluation*

The volunteers were asked to use three support surfaces in randomized order; foam cushion, static cushion and alternating cushion. The cushion was placed on a non powered wheelchair. The air cushion was inflated with a programmed algorithm to a standardize set up. The volunteers were asked to sit on the cushion, placing their feet on the footrest and their back against the backrest. They were asked to try as much as possible not to move their hips or backs during the study. The study for each condition lasted 12 minutes. In the case of the alternating sequence, 2 initial minutes were for the static mode and 10 minutes for the alternating sequence of the cushion.

D. *Equipment for evaluation of interface pressure*

For assessing pressure distribution of different support surfaces, a pressure mapping system (CONFORMat, Nitta Co., Osaka Japan) with a 32x32 sensor matrix and 2.17cm^2 resolution was used [12]. The sensor mat was placed between the cushion and the participant for pressure distribution measurement. The system was calibrated according to the manufacturer's instructions before starting the study. The software included with the system was used for data recordings at a sample rate of 8 frames per second. Continuous measurements were made during each trial.

E. *Data Analysis*

The recordings given by CONFORMat system were analyzed on Matlab. In order to analyze the pressure distribution on the sitting area, the entire matrix given by that system was divided into 8 regions, 4 regions on the right side and 4 regions on the left side (Front right, Front Left, Middle right, Middle left, Ischial right, Ischial left, Back right and Back left); mean was calculated for each one. To observe the temporal pressure distribution of the cushions, the percentage of increase or decrease were computed for each region according to equation 1. Baseline or initial interface pressure was compared with the final interface pressure of the study; that is, 2 initial minutes of recording and 2 minutes before ending the trial. Positive values indicate that pressure increased while negative values indicate that pressure decreased at the end of the study. Another parameter for comparing performance of the cushions was the total user contact area; it was computed for each trial.

$$\%\ \text{Increasing} = \frac{\text{IP}_{\text{final}} - \text{IP}_{\text{initial}}}{\text{IP}_{\text{initial}}} * 100 \qquad (1)$$

III. RESULTS AND DISCUSSION

A. *Interface Pressure*

Interface pressure over the ischial tuberosities tends to increase in the foam and static cushions, while interface pressure in the alternating cushion tends to decrease on both the left and right sides. Figure 2 and Figure 3 show the tendency of IP on the three cushions. We can observe that IP over left ischial tuberosity tends to exceed 60mmHg for the foam and static cushions, while for the alternating sequence tends to be at 60 mmHg. It is thought that at 60 mmHg and higher, interface pressure may lead to the development of pressure ulcers[13][8]. On the right side, interface pressure seems to be lower than 60 mmHg for all 3 cases. On average pressure values, significant differences among the three cushions were not observed, comparing the baseline with the IP at the end of the trial. However, we observe a tendency of decreasing IP on the alternating sequence.

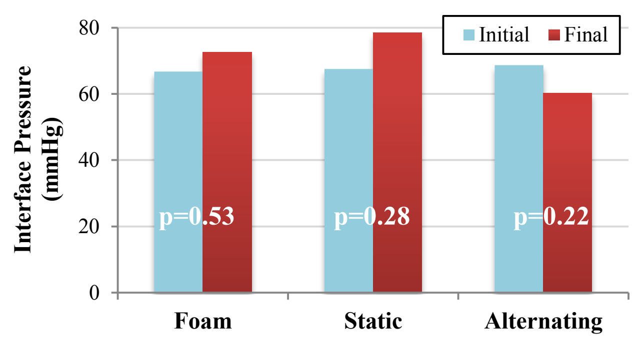

Figure 2. Mean values of interface pressure on left ischial tuberosity. *Despite there were no significant differences among the average values of IP on IT, IP tends to increase after 10 minutes for the foam and static cushions, and IP tends to decrease for the alternating sequence as expected.*

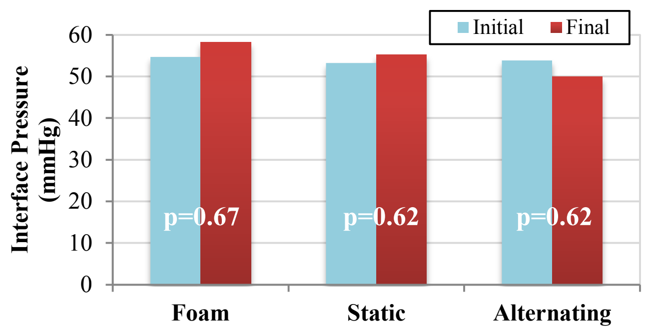

Figure 3. Mean values of interface pressure on right ischial tuberosity. *Although no significant difference among the absolute values of IP on right IT was observed, IP remains lower than 60 mmHg for the three cushions.*

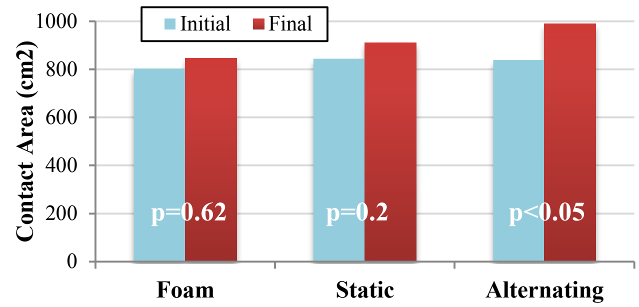

Figure 4. Total contact area. *A significant increase in the final contact area is observed for the alternating cushion, p <0.05, on the other hand, there are no significant differences with foam and static cushions.*

B. Pressure distribution

In order to observe the temporal interface pressure distribution, percentage increase/decrease of IP was calculated according to eq. 1, as shown in Figure 5; that represents the tendency of IP in each region of the sitting area. There was an increase of about 6% more than the initial IP for foam cushion in all the regions, while, in static cushion interface pressure was higher at ischial and back left sides than in other regions.

For alternating cushion, interface pressure increased in front and middle areas, diminished in back areas, and significantly decreased around 7% and 13% in ischial areas. This suggests that IP was better redistributed after the alternating sequence. It could be inferred that IP in the front and back sides increased because of the augmented contact area.

C. Contact area

Total contact area (TCA) tends to increase in the three cases, Figure 4. In foam cushion the increase is lower than in static and alternating cushions, but after 10 minutes of the study, TCA in alternating cushion resulted larger than static and foam cushions, as expected. In alternating cushion, TCA increased significantly and p value < 0.05 was obtained when comparing initial versus final TCA. This is because the body was more immersed and enveloped into the cushion[14]. On the other hand, there was no significant difference in the foam and static cushions. That is, the contact area maintained almost the same values in these cushions.

IV. Conclusion

We confirmed that the alternating pressure sequence showed the best performance in relation to pressure redistribution, release of interface pressure on ischial areas and increase in user contact area when compared with static mode and foam cushion.

The method used in studying the data obtained from the pressure matrix divided into 8 regions separately, permitted us to observe the temporal distribution of IP in a better way than only analyzing the IP on ischial tuberosities.

The proposed cushion on static mode does not provide favorable conditions for preventing pressure ulcers by itself, however, with the alternating sequence algorithm there was an improvement in the main parameters considered important for pressure ulcer prevention, release of pressure and pressure distribution. Furthermore, it is expected that the alternating stimulation on the ischial regions could promote the blood flow. To demonstrate this, clinical studies need to be done in the future, where conditions of underlying tissues in the ischial regions are evaluated in addition to interface pressure.

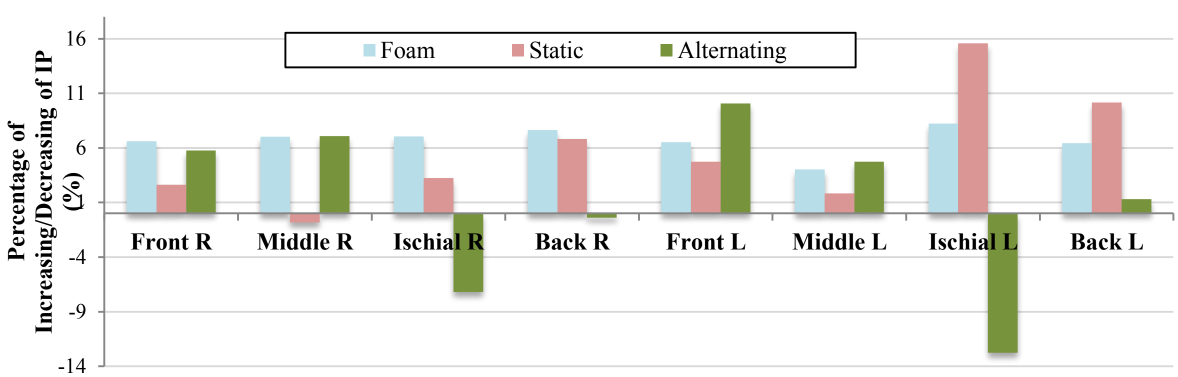

Figure 5. Pressure distribution. *Positive values means IP increased and negative values means IP decreased after 10 minutes of sitting. This suggests a good IP distribution for alternating cushion.*

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