Changes in superficial pressure and tissue oxygenation levels due to contractions elicited by intermittent electrical stimulation for the prevention of deep tissue injury.

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Abstract

Deep tissue injury (DTI) is a severe type of pressure ulcer that commonly affects people with spinal cord injury (SCI). We have proposed the use of intermittent electrical stimulation (IES) as a novel preventative technique for DTI. The main goal of this study was to compare the changes in superficial pressure and tissue oxygenation generated by two different IES protocols: Continuous or Bursting IES. Experiments were performed in intact volunteers whose gluteus maximus muscles were stimulated bilaterally through surface electrodes. The volunteers sat in either a regular chair or a wheelchair with a specialized cushion. Surface pressure profiles were acquired with a pressure sensing mattress and magnetic resonance imaging was utilized to quantify the changes in oxygenation levels throughout the muscles. The results show that both Continuous and Bursting IES generate a significant reduction in pressure over the ischial tuberosities during stimulation when seated on a regular chair. Oxygenation levels were also significantly higher after the use of both protocols.

1 Introduction

1.1 Significance of pressure ulcers

Pressure ulcers are a serious complication commonly associated with individuals with reduced mobility and/or loss of sensation. Populations typically at risk of developing a pressure ulcer include patients in hospital intensive and acute care units, people living in long-term care facilities and nursing homes, and in particular people with spinal cord injury (SCI). It has been estimated that, depending on the level and completeness of the injury, between 29 and 80% of individuals with SCI will develop a pressure ulcer [1]. The cost of treating pressure ulcers exceeds $2.2 billion in North America each year [2]. In addition to the economic cost, developed ulcers severely impair the quality of life of those affected, and could be fatal in some cases.

1.2 Etiology of deep tissue injury

Pressure ulcers develop when soft tissue is compressed between a bony prominence and a surface for a prolonged period of time. Pressure ulcers can initiate at the level of the skin, and progress inwards, or at the deep bone – muscle interfaces, and progress outwards. The latter is referred to as deep tissue injury (DTI) and is more dangerous because extensive damage to the deep layers of tissue can take place before exhibiting any skin signs. The two main causes of DTI are excessive mechanical deformation of the tissue; and ischemia and reperfusion injury induced by the compression of tissue.

1.3 Prevention of deep tissue injury

Traditionally, techniques for the prevention of pressure ulcers have focused on the use of specialized wheelchair cushions or bed mattresses to reduce superficial pressure levels (skin – surface interface). In addition, individuals at risk are encouraged to perform frequent postural changes to relieve pressure from areas at risk. Although helpful, postural changes are dependant on the individual's ability to perform such changes, or the availability of a person to assist with the movements. We have proposed the use of intermittent electrical stimulation (IES) as a novel technique for the prevention of DTI. In a previous study performed in rats, we have shown that the application of 10 second bouts of electrical stimulation applied every 10 minutes [3, 4] to a loaded muscle significantly reduces the amount of DTI in the affected muscle. We hypothesized that IES-induced contractions reshape the muscle, changing its pressure profile and increase the tissue oxygenation levels, mimicking the effects of the subconscious postural reposition frequently performed by intact persons when seated for extended periods.

2 Methods

2.1 Intermittent electrical stimulation protocols

The main goal of the ongoing study is to test two different IES protocols, and examine the changes induced in superficial pressure and tissue oxygenation in able-bodied volunteers by each protocol. The two protocols tested were: a) 10 sec of bilateral continuous stimulation (Continuous), or b) three successive short bursts (3 sec each), separated by a 2 sec rest period (Bursting)(see **Fig 1**).

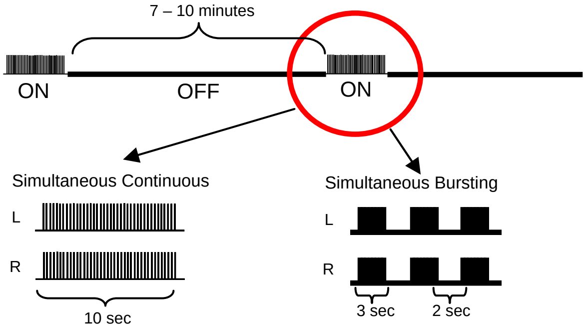

Fig. 1 Stimulation protocols tested [3]

Stimulation was applied through surface electrodes placed bilaterally over the motor point of the gluteus maximus muscles. Pulse width and frequency were kept constant across all volunteers (200 µs, 40 Hz), with the pulse amplitude varying from 20 – 80 mA depending on the requirements to generate a strong fused muscle contraction in each volunteer. All experiments were performed in 5 able-bodied volunteers (3 Female/ 2 Male)

2.2 Superficial pressure measurements

The effect that each IES protocol had on superficial pressure was tested by seating the volunteers either on a regular chair, or a Jay 2® composite gel/foam wheelchair cushion (Sunrise Medical, Longmont, CO). Pressure measurements were obtained using a pressure sensing pad (XSENSOR, Calgary, AB) placed over the sitting surface. Two volunteers were tested on the regular chair, two on the wheelchair cushion, and one volunteer was tested on both surfaces in two separate experimental sessions.

Pressure profile maps were obtained from periods of sitting without stimulation, as well as sitting while using each of the IES protocols (see **Fig 2**). Each protocol was replicated 3 times, with each replicate consisting of the acquisition of a 5 sec baseline followed by one of the two IES protocols, and finally 5 more seconds of baseline. All pressure measurements were imported into Matlab (Mathworks, Cambridge, MA) for analysis. For all volunteers the data were grouped by the condition measured (Continuous, Bursting, Baseline). Once grouped, the pressure measurements obtained from each sensor location during both IES protocols were compared against the baseline measurements of the corresponding sensor. Afterwards, a ratio of pressure change between baseline and each IES protocol was calculated for each sensor location. Finally, the ratios of the Continuous and Bursting protocols in the sensors located under the ischial tuberosities were compared against each other.

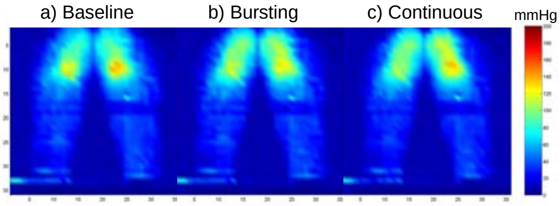

Fig. 2 Average pressure map of volunteer during: a) Baseline, b) Bursting, and c) Continuous.

2.3 Tissue oxygenation measurements

Magnetic resonance imaging (MRI) was utilized to assess the changes in tissue oxygenation generated by the two IES protocols. After electrode placement, volunteers were positioned in an apparatus made to simulate the pressure experienced while sitting (see **Fig 3**). The volunteers were then transferred to a 1.5 T magnet and a T_2* weighted sequence was utilized to acquire transverse images of both gluteus maximus muscles. The IES parameters were the same as those used in the pressure mapping session. For each trial, scans were initiated 30 sec before stimulation and continued for up to 7.5 minutes after the end of stimulation.

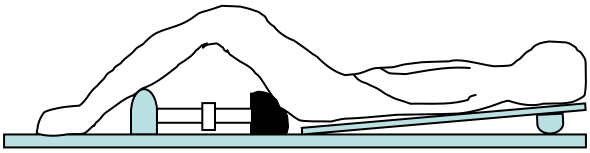

Fig. 3 Device utilized to compress the gluteus and simulate seating pressure inside the MRI magnet.

After the MRI session, all images were imported into Matlab for analysis. An estimate of the oxygenation level in the muscle was obtained by quantifying the signal intensity in two slices of the left and right gluteus maximus muscles, and a time course of these changes was obtained. For each trial, the oxygenation levels obtained after the use of IES were normalized to the levels acquired during the initial 30 sec before the use IES. Afterwards, the data were grouped by protocol tested, and the oxygenation levels after IES from each protocol were compared against baseline oxygenation levels. Finally, the oxygenation levels obtained after IES from each protocol were compared against each other.

3 Results

3.1 Changes in superficial pressure measurements

Both IES protocols tested produced significant pressure changes ($p <= 0.05$) with similar pressure redistribution patterns. A clear difference in the pressure profiles was observed when comparing results from the two different sitting surfaces. When IES was applied in volunteers sitting on the wheelchair cushion, there was a significant decrease in pressure around the edges of the buttocks, with sporadic and seemingly random areas with increased and decreased pressure in the medial parts of the buttocks (see **Fig 4 A**). When IES was utilized in volunteers sitting on the regular chair, there was a significant decrease of pressure around the edges of the buttocks as well as over the ischial tuberosities (see **Fig 4 B**). When compared against each other, there was no significant difference between the Continuous and Bursting protocols.

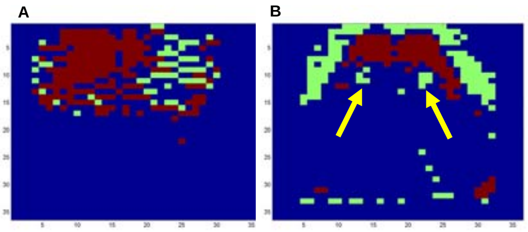

Fig. 4 Significant changes in pressure due to Bursting IES in one volunteer. Green indicates a significant reduction in pressure. Red indicates a significant increase in pressure. A) Volunteer sitting on wheelchair cushion. B) Volunteer sitting on regular chair. Yellow arrows indicate location of ischial tuberosities.

3.2 Changes in tissue oxygenation levels

Both IES protocols produced a significant increase in oxygenation immediately after the application of stimulation in all but one volunteer. Depending on the volunteer, the oxygenation level remained elevated significantly from two to seven minutes after stimulation (see **Fig 5**). When compared against each other, the Continuous protocol produced a larger increase in the oxygenation level.

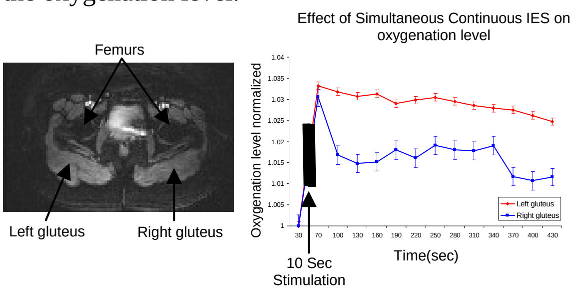

Fig. 5 Transverse slice of gluteus maximus muscles and oxygenation levels from one subject. All time points after stimulation were significantly higher than baseline (P <= 0.05).

4 Discussion

The effect of both IES protocols was similar in all volunteers; however, there was a marked difference in pressure redistribution between the two surfaces. We believe the stark contrast found between the wheelchair cushion and regular chair stems from the manner in which the gel cushion and sensor pad conform at all times to the shape of the buttocks, which does not happen with the regular chair. This interesting interaction between active muscle contractions and different cushion materials will be investigated in the future.

Both IES protocols resulted in significant reductions in pressure around the ischial tuberosities in the regular chair, and increased tissue oxygenation levels. The bigger increase in oxygenation levels observed in the Continuous protocol (10 sec contraction) thathad the desired result in both the pressure mapping in the regular chair, and the changes in tissue oxygenation levels, each performed better than the other in only one aspect. The simultaneous bursting protocol showed a better reduction of pressure. This could be because the more dynamic nature of the three stimulation bursts keeps reshaping the muscle compared to a single longer contraction. However, the single 10 sec contraction from the simultaneous continuous protocol showed a bigger increase in the oxygenation levels. This suggests that the reactive hyperemia that takes place after a single 10 sec contraction may be more effective in bringing blood back into the tissue than the pumping effect generated by the three successive bursts.

5 Conclusion

The results obtained so far indicate that the use of both IES protocols may be effective in preventing the formation of DTI. If effective in the long-term, it could help reduce the dependence on caregivers for postural shifts and reduce the incidence of pressure ulcers.

3 Literature

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