The effects of intermittent electrical stimulation with varying load and stimulation paradigms for the prevention of deep tissue injury

Curtis C[1], Chong SL[2], Mushahwar VK[1,2]

[1] Department of Cell Biology, University of Alberta, Edmonton, Alberta, Canada

[2] Centre for Neuroscience, University of Alberta, Edmonton, Alberta, Canada

Abstract

A pressure ulcer is a medical complication that arises in persons with decreased mobility and/or sensation. Deep pressure ulcers starting at the bone-muscle interface are the most dangerous, as they can cause extensive damage before showing any signs at the skin surface. We proposed a novel intervention called intermittent electrical stimulation (IES) for the prevention of deep tissue injury. In this study, we tested the effects of four paradigms of IES and one conventional pressure relief paradigm in preventing the formation of deep pressure ulcers in rats. Pressures equivalent to 18%, 28%, or 38% of the body weight of each rat were applied to the triceps surae muscle in one limb. Treatment groups received IES every ten minutes for either 5s or 10s and maximal or moderate contraction, or complete pressure removal every ten minutes for 10s. The results showed that conventional pressure relief, emulating a wheelchair pushup every ten minutes, was inadequate for the prevention of deep tissue injury. In contrast, all IES paradigms were equally effective in significantly reducing the extent of deep muscle damage caused by 28% or 38% BW pressure application. This outcome provides important information for the development of an alternative method for pressure ulcer prevention.

***Keywords**: deep tissue injury, intermittent electrical stimulation.*

Introduction

Pressure ulcers are a serious complication associated with loss of mobility and/or sensation. They result from the entrapment of soft tissues between a bony prominence and an external surface. The resulting lesion may involve damage to the skin, fat, and muscle layers, and in extreme cases exposing bone.

The costs to heal a pressure ulcer range from US$15,800 to US$72,680 [1]. The total financial costs to the health care system are between $2.2 and $3.6 billion USD [2] annually, in North America alone.

Pressure ulcers can begin at the surface of the skin and progress inwards. These ulcers are mainly the result of bad nutrition, excessive wetness, and frictional forces applied to the skin [3]. More dangerously, ulcers can begin deep at the bone-muscle interface and progress through tissue layers towards the skin. This type of ulcers has been recently identified as deep tissue injury (DTI). It develops as a result of sustained compressive pressure which leads to: 1) damaging mechanical deformation in muscle tissue, and 2) ischemia and an ensuing cascade of harmful metabolic changes. Because muscle is more susceptible to breakdown due to pressure than skin, this latter class of pressure ulcers can develop unbeknownst to the afflicted individual or their care giver. Once skin signs become apparent, substantial damage to underlying tissue would have taken place.

There are currently several interventions for the prevention of pressure ulcers. These include frequent repositioning of individuals [4-6], as well as the use of specialized cushions and mattresses. Despite these efforts, none of the current interventions has succeeded in decreasing the incidence of pressure ulcers consistently and reproducibly [7,8]. An alternative prevention technique is needed, particularly for ulcers of deep origin.

We have previously shown that intermittent electrical stimulation (IES) can be effective in the prevention of DTI [9]. It was suggested that the IES-evoked contractions allow the muscle to reshape periodically, thus relieving pressure at the bone-muscle interface, restoring blood flow, and increasing oxygen in the tissue. The hallmark feature of IES is the substantially longer “OFF” period relative to the “ON” period of stimulation, which prevents muscle fatigue. To date, the standard IES pattern has been 10s of maximal stimulation once every ten minutes.

The goal of this study was to determine the most suitable parameters of IES that could be used in clinical settings. More specifically, we investigated the effect of the duration of the “ON” period of IES and intensity of stimulation on its ability to prevent deep muscle damage under varying levels of loading pressure.

Materials and Methods

Experimental Setup and Procedures

Experiments to quantify damage in the deep tissue caused by externally applied pressure were performed in sixty-four adult female Sprague-Dawley rats. All procedures were approved by the University of Alberta animal ethics committee.

Under isoflourane (2%) anaesthesia, constant pressure equivalent to 18%, 28%, or 38% of the rat’s body weight (BW) was applied to the triceps surae muscle group in one hind limb. The 38% BW load resembled the load experienced by tissue around the ischial tuberosities (ITs) while sitting on a hard surface [10]. The 28% and 18% BW loads represented the loads experienced when sitting on softer surfaces including wheelchair cushions. Pressure was applied via a 3mm-diameter indenter for two hours (see Fig. 1).

The rats were divided in two groups: one that received stimulation of the experimental limb during the loading period and one that did not. The no IES group included a control subgroup (CG), and a conventional pressure relief subgroup (PG). Rats in CG only received the pressure application, and rats in PG received manual removal of the pressure for 10s every 10 minutes.

The IES group included four subgroups: maximal stimulation for either 5 or 10s (Max5 & Max10), and moderate stimulation for either 5 or 10s (Mod5 & Mod10). Prior to the pressure application, all animals in the IES group were implanted with a nerve cuff around the tibial nerve. Rats in this group received the 5 or 10s bouts of stimulation (50Hz, 100µs, charge balanced, constant current) every 10 minutes throughout the period of pressure application. After the two hour period, all rats recovered from anaesthesia and the opioid analgesic, buprenorphine, was administered to ensure comfortable recovery.

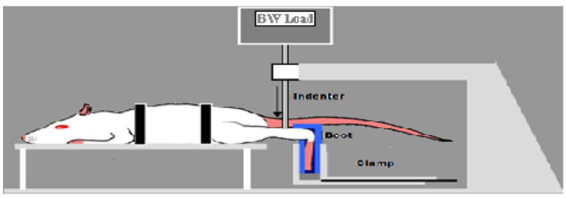

Fig. 1: Diagram showing the apparatus used for applying controlled levels of pressure.

Assessing the Extent of Deep Tissue Injury

Between 17 and 24 hours after the removal of pressure, the rats were anesthetized with sodium pentobarbital (i.p., 45mg/kg). Magnetic resonance imaging of both hind limbs was performed in a 3.0T magnet using a custom-built, 8 cm birdcage coil and a T_2-weighted spin-echo sequence. Subsequently, the rats were perfused and the triceps surae muscles from both hind limbs were extracted and prepared for later histological analysis.

The acquired images were analysed using custom written Matlab codes, allowing the quantification of muscle regions exhibiting edema (see Fig. 2). The contralateral leg was utilized as an internal control for each rat, and the extent of edema in the experimented limb was expressed as a percent of the muscle volume.

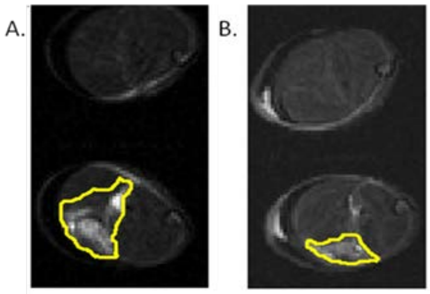

Fig. 2: Quantification of edema with *in vivo* MR; reduction in edema from 60.31% in a CG rat (A) to 31.23% in a Mod10 rat (both loaded with 38% BW)

Results

Effect of IES on Extent of Deep Tissue Injury

As expected, the extent of edema in the control groups (CG) increased significantly with increasing load (p=0.003, one-way ANOVA), demonstrating that an increase in pressure corresponds to an increase in muscle damage. The extent of muscle edema in the conventional pressure relief group (PG) was not significantly different from that in the control group for all loading levels, in clear contrast to the outcome seen with IES.

A significant reduction in the extent of edema was produced with IES in the rats that received 28% and 38% BW loading relative to the non-IES groups (p=0.05, one-way ANOVA). IES reduced edema by approximately 50% in both groups: from an average of 28.75% to 13.92% in the 28% BW group and from an average of 43.23% to 23.45% in the 38% BW group. Surprisingly, there were no significant differences between the Max10, Max5, Mod10, and Mod5 groups for both of the higher load groups; all were equally effective in reducing damage in deep muscle tissue (see Fig. 3).

The level of edema in the 18% BW group was variable in this data set. None of the treatments in this group significantly reduced edema produced by the application of pressure.

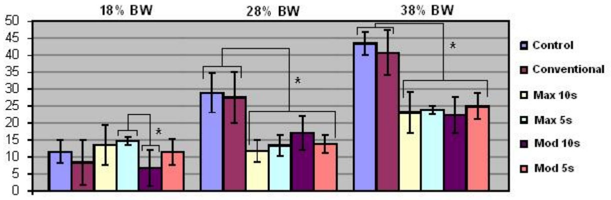

Fig. 3: The average percent of edema in the experimental hind limb in each group for all loads, mean ± SE; (A) 18% BW, (B) 28% BW, (C) 38% BW. *, † significantly different from each other

Discussion

The results showed that the application of external pressure equal to 28% or 38% BW for durations as short as two hours is enough to generate a significant amount of damage in the deep tissue. The extent of the damage was closely correlated to the level of pressure applied. We found that the muscle indeed is more susceptible to damage than the skin. The outside surface of the skin in all experimental limbs appeared normal and provided no clues regarding the underlying edema in the muscle.

The use of IES showed a significant beneficial effect when applied to muscles exposed to prolonged periods of loading with 28% or 38% BW. Interestingly, conventional pressure relief, which is similar to a person performing wheelchair push-ups, did not show the same beneficial effects obtained by IES. We believe this is due to the dynamic and active nature of the IES-induced contraction which allows not only for a transient increase in blood flow, but also to a sustained increase in oxygen in the compressed tissue [11]. We found that IES worked equally well for all parameters of “ON” period tested, which varied in intensity and duration. This suggests that a 5s-long moderate muscle contraction produced every 10 minutes is adequate for reducing the extent of deep tissue injury. Future studies will explore additional parameters including the longest duration of “OFF” period needed to retain the benefits of IES. Understanding the effect of IES parameters on deep tissue injury will allow for implementation of this approach at its maximal potential.

Conclusions

The results demonstrate that IES reduces the extent of damage in deep tissue even when utilized to elicit 5s-long moderate contractions in the compressed muscles every 10 minutes. When combined with existing pressure relief strategies, IES could provide an effective prophylactic means for preventing the formation of pressure ulcers. Plans are underway for utilizing IES in clinical settings to prevent the formation of pressure ulcers in persons with decreased mobility.

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Author’s Address

Cara A. Curtis
Research Assistant
caraanne@ualberta.ca