Safety and Feasibility of Intermittent Electrical Stimulation for the Prevention of Deep Tissue Injury

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Submitted for publication June 5, 2014. Accepted in revised form July 12, 2014.

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Objective: To investigate the safety, feasibility, and acceptability of a novel treatment, intermittent electrical stimulation (IES), for preventing deep tissue injury (DTI) in different healthcare settings.

Approach: Testing was conducted in an acute rehabilitation unit of a general hospital, a tertiary rehabilitation hospital, a long-term care facility, and homecare (HC). IES was delivered through surface electrodes placed either directly on the gluteal muscles or through mesh panels inside a specialized garment. Study participants at risk for DTI used the system for an average of 4 weeks. Outcome measures included skin reaction to long-term stimulation, demands on the caregiver, stability of induced muscle contraction, and acceptability as part of the users' daily routine.

Results: A total of 48 study participants used the IES system. The system proved to be safe and feasible in all four clinical settings. No pressure ulcers were observed in any of the participants. There was no difference between the clinical settings in patient positioning, ease of finding optimal stimulation site, and patient acceptance. Although donning and doffing time was longer in the long-term care and HC settings than the acute rehabilitation unit and tertiary rehabilitation facility, time required to apply the IES system was <18 min (including data collection). The patients and caregivers did not find the application disruptive and indicated that the stimulation was acceptable as part of their daily routine in over 97% of the time.

Innovation and Conclusion: We demonstrated the safety, feasibility, and acceptability of a novel method of IES to prevent DTI in a continuum of healthcare settings.

INTRODUCTION

PRESSURE ULCERS ARE common complications that affect people with limited mobility and sensation in a wide range of clinical settings. In Ca-

nada, prevalence of pressure ulcers is 25% in acute settings and even higher in nonacute settings.¹ In the U.S., the annual cost for treatment of hospital-acquired pressure ulcers is ~\$12 billion.²

Given the large financial burden of treating pressure ulcers after they had developed, it would be more economical to prevent them in the first place. Indeed, it has been estimated that prevention of pressure ulcers is ~2.5 times more economical than treatment.³

Deep tissue injury (DTI), a subtype of pressure ulcers that was formally recognized by the National Pressure Ulcer Advisory Panel in 2006, is particularly deadly. It starts in the deep muscle layers overlying bony prominences.⁴ Clinically, it is very difficult to detect and often goes unnoticed until it breaches the skin. Major contributing factors leading to the formation of DTI include unrelieved mechanical deformation, tissue ischemia, and ischemia-reperfusion injury.^{5–9} Current prevention strategies such as pressure distributing mattresses, foams, and periodical weight shifts have been insufficient for preventing pressure ulcers. Furthermore, with the increased awareness of DTI, reporting of pressure ulcers of suspected deep origin has been on the rise.¹⁰

CLINICAL PROBLEM ADDRESSED

To address limitations in the current treatment strategies, intermittent electrical stimulation (IES) may be an effective alternative.¹¹ Ten seconds of stimulation causing fused muscle contractions in the gluteus muscles every 10 min while sitting has been shown to be capable of redistributing surface pressure away from the ischial tuberosities, and significantly increasing tissue oxygenation in the gluteus maximus muscles of study participants independent of muscle mass.^{12,13} These periodical contractions mimicked the subconscious postural adjustments performed by able-bodied individuals in response to discomfort while sitting or lying down. The IES-induced contractions significantly redistributed internal pressure away from the bony prominences¹⁴ and alleviated deformation in the muscles between the ischial tuberosity and skin with loading levels as high as 75% of body weight in adult pigs with spinal cord injury.¹⁴ IES also reduced the size of DTI in rat and pig models.^{14–16} These findings suggest that IES may be an effective means for the prevention of DTI. In this study, the safety and feasibility of IES in a wide range of healthcare settings were tested. The IES system was applied on patients in four different healthcare facilities and its acceptability to both patient and caregiver was evaluated.

MATERIALS AND METHODS

Participants

A total of 48 participants were recruited from an acute neuro-rehabilitation unit (ANR) in a general

hospital, tertiary rehabilitation hospital (RH), long-term care (LTC) facility, and HC settings. Ethics approval was given by the institutional review boards at the University of Alberta and University of Calgary.

Subject inclusion/exclusion criteria

Eligible participants were inpatients and HC clients at risk of developing DTI due to impaired sensation and decreased mobility. Other inclusion criteria included a body mass index (BMI) <32, intact skin in the gluteal region for the past 3 months, and the ability to provide informed consent.

Treatment

IES system. The IES system was comprised of a stimulator (Impulse EMS D7; Biomedical Life Sciences, Inc., Vista, CA) and self-adhesive 7.5 × 10 cm surface gel electrodes (Axelgaard Pals Platinum Neurostimulation electrodes, Model 895340-4-40, Fallbrook, CA) applied either directly on the skin (Fig. 1A) or through mesh pannels in a form-fitted garment (Fig. 1B, C).¹⁷ The stimulator, with a compliance voltage of 50 V and 100 mA through a 500-Ω resistor, was modified to include recording capabilities and safety features in case electrode shorting or peeling occurred.

Features of garment for application of IES. A garment designed to replace the participants' underwear, was made of cotton and Lycra fabrics to provide breathability and comfortable form-fit (Fig. 1B). A horizontal front zipper facilitated catheterization, midline thigh markers guided pant alignment, and belt loops routed the electrode leads. The surface electrodes were placed onto mesh panels in the rear (Fig. 1C). The electrode panels were additionally protected by a smooth top cover that glided during transfers and weight shifts without risking dislodging, peeling, or rolling the edges of the electrodes. The stimulator was held in place in a detachable pocket at the waist.

IES stimulation parameters and duration of testing. Trains of charge-balanced bi-phasic 300 μs pulses at 17.5 Hz with stimulation intensity sufficient to generate visibly fused muscle contractions were delivered to the gluteus maximus muscles on both sides of the buttocks for 10 s every 10 min. These parameters closely approximated those shown to be effective in inducing pressure redistribution and sustained elevation in tissue oxygenation levels in previous studies.^{12,13,16} Each subject received IES 12 h a day, 4 days per week for 4 weeks or upon discharge. In cases where the participants chose to continue using the IES system

Figure 1. The IES system. In incontinent patients, the electrodes were applied directly on the skin (**A**). In other patients in whom soiling was not a concern, the specialized garment (**B, C**) could be used. Localization of the motor points was made easier by placing the electrodes on a mesh (**C**) of the form-fitting garment. Two guide markers on the *front* (**B**) were designed to help align the garment whereas the *belt loops* were used to route the electrode cables away from the skin and to prevent them from getting caught on mattresses and cushions. A *pouch* was used to secure the portable stimulator and a *front zipper* was included to facilitate catheterization. IES, intermittent electrical stimulation. To see this illustration in color, the reader is referred to the web version of this article at www.liebertpub.com/wound

beyond the designated period, regular skin monitoring was maintained.

Study protocol

Clinical administration of IES. IES was administered to the gluteus maximus muscle through pairs of surface electrodes with the cathode placed over the motor point located ~2.5 cm above the ischial tuberosity on each side of the buttocks. In incontinent participants, electrodes were placed directly on the skin, with an incontinent product covering the electrodes. Continent participants tested the IES systems both with and without the garment. The system was doffed 12 h later before bedtime.

Performance measures and evaluation. Data collection was performed when the IES system was donned and doffed. Outcome measures included demands on the caregiver, skin monitoring, sustainability of muscle contractions throughout the hours of stimulation, and participant acceptability of the IES system. Details are shown in Supplementary Data (Supplementary Data are available online at www.liebertpub.com/wound).

Demands on the caregiver: These included: (1) the effort required to position or turn the participant to place the electrodes on a scale from 1 to 5, where 1 was very easy and 5 very difficult; and (2) the ease of eliciting visibly fused muscle contractions once the electrodes are placed on a scale of 1–5.

The time required to apply the IES system included turning the participant, applying the elec-

trodes, setting up the stimulator, and filming the resulting muscle contractions. Time needed to doff the system included positioning the participants, checking the presence of muscle contraction, removing the electrodes and garment, inspecting and documenting the condition of the skin, and evaluating the participant's acceptance of the system (questionnaire in Supplementary Data).

IES system performance: The performance of the IES system after prolonged stimulation at the end of each day was assessed by documenting the stability of the electrodes (*e.g.*, peeling) and presence of muscle contractions during stimulation.

Skin monitoring: Skin was inspected each day after the IES system was removed. The skin condition was rated on a scale of 1–5, where 1 was no redness and 5 was full-thickness skin loss.

Participant feedback: At the end of each day participants were asked to rank their acceptability of the system. Participants were also asked if they could fall asleep during stimulation and if the stimulation (applied every 10 min) was acceptable as part of their daily routine.

Data analysis

Participant characteristics, skin assessment, IES system performance, and participant feedback were analyzed using descriptive statistics. All results are reported as mean ± standard deviation. For caregivers' demand, descriptive statistics were also used to describe ease of positioning the subject for applying the IES system, obtaining a visible

Table 1. Summary of study participants testing the intermittent electrical stimulation system through direct application of electrodes on the skin or through a specialized garment

	Recruited Subjects (n)	Age $\pm$ SD	Sex (%) males	Intact Sensation (%)	Incontinent (%)	Primary Cause of Immobility (No. of Subjects)
LTC	9	68 $\pm$ 13	33	100	100	Stroke (3), MSA (1), TBI (1), multiple sclerosis (2), diabetes (1), hip fracture (1)
RH	18	44 $\pm$ 21	83	65	6	SCI-paraplegia (9), SCI-quadruplegia (5), stroke (4)
ANR	10	51 $\pm$ 12	67	55	10	SCI-paraplegia (3), SCI-quadruplegia (5), stroke (2), GBS (1)
HC	11	47 $\pm$ 16	27	55	27	SCI-paraplegia (4), SCI-quadruplegia (3), multiple sclerosis (4)

ANR, acute neuro-rehabilitation unit; GBS, Guillain-Barre Syndrome; HC, homecare; LTC, long term care; MSA, multiple system atrophy; RH, rehabilitation hospital; SCI, spinal cord injury; TBI, traumatic brain injury.

contraction, and the time requirements for donning and doffing the system. To compare differences in caregivers' demands, IES system performance and participant feedback at different clinical settings, Kruskal–Wallis test was done using the Stata 12 software. When a significant difference was found, pairwise comparisons were done using the Wilcoxon Rank Sum test. Comparisons with p -values < 0.05 were deemed statistically significant.

RESULTS

Participant description

A summary of the 48 participants enrolled in the study is shown in Table 1. At the RH, 11 subjects used the IES system until their discharge date, 6 of whom went beyond the 4-week testing protocol for an additional 2–5 weeks. On the ANR unit, one participant used the IES system until hospital discharge 8 months after enrolment in the study. At the HC setting, one participant had used the system for 14 months at the time of writing.

Demands on the caregiver

Information on the ease of: (1) participant positioning for applying the IES electrodes directly on the skin, and (2) localizing visible muscle contractions are shown in Figure 2. Ease of participant positioning and ease of localizing visible contractions were rated in four categories: easy, moderate, difficult, and impossible. Participant positioning in LTC was rated as easy in 35/47 trials (74%), in HC 167/212 (79%), and in the RH 338/388 (87%) (Fig. 2A). Given the substantially older age range and fragility of the participants in LTC, the slightly greater demands in this facility are not surprising. Nonetheless, the differences were not statistically significant between those clinical sites. Since the participants on ANR unit were already set up in position during the morning caregiver routine when applying the electrodes on the skin, this parameter was not captured.

In addition to participant positioning, the ability of eliciting visible muscle contractions depended on the ease with which the motor points of the gluteal

Figure 2. Ease of positioning the patient (A) and obtaining visible muscle contractions (B) were two of the major factors considered when assessing caregiver demands. Because of older age and/or heavier physical needs, clients in the LTC facility were more challenging than in the other three settings; however, these factors were not significantly different between settings. ANR, acute neuro-rehabilitation unit; HC, homecare; LTC, long term care; RH, rehabilitation hospital.

muscles could be located. Although there was no overall statistically significant difference between the clinical sites, there are noticeable variations in trend among the different settings. For example, while muscle contractions were easily elicited at the ANR, HC, and RH settings in over 70% of time (Fig. 2B), the percentage of contractions localized with ease at the LTC facility was lower at 59%. In addition, in 10% (LTC) and 13% (HC) of cases, contractions could not be elicited regardless of where the electrodes were placed. That is not surprising considering that participants in LTC were generally elderly with atrophic muscles due to years of immobility. The same also applied to some of the HC participants who had had chronic neural injuries or diseases of 4 or more years as compared to recently injured subjects in the ANR and RH settings.

At the RH setting, in subjects who wore garments, it was difficult to visualize muscle contractions 19% of the time. This was due to the fabric partially obscuring the visualization of the skin and the underlying muscle contraction. In those cases, the visual inspection was supplemented by muscle palpation.

The time needed for donning and doffing the IES system is shown in Figure 3. In LTC, the time needed to don the system was 17 ± 8 min whereas removing the system took 10 ± 4 min. In HC and RH, time needed to apply electrodes directly to the skin took 14 ± 5 min (HC) and 14 ± 5 min (RH), whereas removing the electrodes took 9 ± 4 min (HC) and 5 ± 3 min (RH). At the ANR, time to apply

Figure 3. Time to don (A) and doff (B) the IES system. Applying the system took <18 min whereas removing it took <10 min (including data collection). Use of the specialized garment helped in reducing the donning and doffing times. $*p < 0.05$. Application and removal of the IES system took longer in LTC and HC than in the RH and ANR settings. Abbreviations used for facility names are same as in Figure 2.

electrodes was faster as patient positioning was not included because the patient was already in position during the morning care routine. Donning the system took 8 ± 2 min, whereas removing it took 5 ± 2 min. Another reason for the significantly faster application of the IES system in the RH and ANR settings was that subjects in those facilities were generally younger with less comorbidities.

IES system performance

At the end of each day, the IES system performance was assessed by determining: (1) if any of the electrodes had edges that peeled or rolled, and (2) if the gluteal muscle contractions were still visible. The data are presented in Figure 4. The electrode edges were highly stable in the RH, HC, and ANR where they remained unpeeled or unrolled over 75% of the time. In comparison, stability of the electrodes in LTC was lower at $66\% \pm 16\%$ of the time (Fig. 4A). A potential reason for the discrepancy is that all subjects in the LTC facility had electrodes applied directly to the skin where peeling is more liable to occur. That problem was later solved by securing edges of the electrodes with soft silicone tape.

With electrodes applied directly to the skin in participants whose muscle contractions were visible in the morning, muscle contractions continued to be visible in the evening when the system was removed between 83% and 98% of cases at the different settings (Fig. 4B). The slightly lower visible contraction rate in the LTC setting could potentially be attributed to the older age of the subject and that many had been immobile for years. Interestingly, in 10% of the LTC cases where muscle contractions were not detected in the morning (Fig. 2B, impossible category), half of them became visible in the evening. Similarly, in the HC setting, 13% of the cases with no visible muscle contractions in the morning, muscle contractions were found in 77% of them in the evening. With electrodes applied through the garment, muscle contractions in 203/218 (93%) of the cases in the RH and 54/76 (71%) on the ANR unit continued to be observable in the evening (Fig. 4B). Of the 19% of cases in the ANR setting where muscle contractions were impossible to observe in the morning (Fig. 2B), visible contractions were present 65% of the time in the evening.

Skin monitoring

Very few adverse skin reactions were observed whether the electrodes were placed directly on the skin or through the garment. Application of electrodes directly on the skin caused blanchable redness in 12/396 of skin observations (3%) in the LTC and in 29/968 (3%) in the RH settings, 18/1,560 (1%) in the ANR setting, and 382/1,622 (24%) in the

Figure 4. Stability of the stimulating electrodes. Use of the specialized garment or taping the edges of the electrodes helped reduce electrode peeling (A). Contraction of the gluteal muscle continued to be visible after 12 h of use in >70% of observations (B). * $p < 0.05$. Electrode peeling was higher and visible contraction after 12 h was lower in the LTC setting. Abbreviations used for facility names are the same as in Figure 2.

HC setting. A likely reason for the disproportionately high percentage of blanchable redness being observed in the HC subjects is that they tended to be more active and spent much more time in their wheelchair. That, coupled with perspiration and heat, resulted in skin redness. All cases of blanchable redness disappeared within 30 mins and none resulted in pressure ulcers.

Two incidents of minor skin tears occurred in incontinent subjects with compromised skin quality (Fig. 5) in the LTC facility. The first incident occurred in a 90-year-old female with a history of corticosteroid use for over 20 years that may have contributed to compromised skin integrity. Skin irritation causing a 0.3 cm-long tear arose due to loose skin rubbing against the electrode edge that healed over 21 days (Fig. 5A). The second incident occurred in a 47-year-old female on whom standard

clinical paper tape was applied to secure the electrode edges. Removal of the tape resulted in a 1 cm-long skin loss around one edge, which healed over 14 days (Fig. 5B). To mitigate this problem, electrode stickiness used for the LTC study participants was attenuated by applying soft cotton fuzz, and soft silicon tape (Mepitac®) was used instead of paper tape. No further skin concerns were observed in any of the subjects. No adverse effects were reported in participants using the specialized garment for applying the IES intervention.

Participant feedback

The IES system was well accepted in all clinical settings. Participants reported that the stimulation was not at all or very little irritating, distracting, or uncomfortable in more than 96% of the 648 sessions when the system was used, regardless of the clinical

Figure 5. Two incidences of skin tears. The first case (A) was in a 90-year-old participant who had been on corticosteroid for over 20 years with fragile skin. The second case (B) was a minor skin tear caused by the tape used to secure the electrode edges. Both occurred at the LTC facility, the first site of clinical implementation. After switching to using a soft silicone-based tape, no further skin tear complications were observed in subsequent participants. The arrows point to the site of the skin lesion. The * on (B) refers to a soft gel cover used to protect the skin. To see this illustration in color, the reader is referred to the web version of this article at www.liebertpub.com/wound

Figure 6. Participant feedback. Responses to questions regarding irritability, distraction, and discomfort are shown in the *top panels*, whereas whether the participant could sleep or find the IES acceptable or cumbersome to use are shown in the *lower panels*. Subjects' perception was generally favorable with no significant difference between different clinical settings. Abbreviations used for facility names are the same as in Figure 2.

setting (Fig. 6). The participants reported that they thought they could (or in fact did) fall asleep 84% (62/74), 79% (166/203), 86% (213/248), and 90% (84/93) of the time in LTC, HC, RH, and ANR settings, respectively. When asked if IES is acceptable as part of their daily routine, participants answered "yes" 97% (57/59), 100% (200/200), 97% (250/259), and 100% (91/91) of the time in LTC, HC, RH, and ANR settings, respectively. No statistical significance was found.

Subjects were also asked to rate if the use of the IES system was cumbersome during their daily routine. Without the garment, subjects in HC, RH, and ANR settings reported that using the system was moderately cumbersome 12% (25/210), 10% (24/121), and 11% (7/65) of the time, respectively, whereas only 2% (1/55) in LTC facility found the system cumbersome. However, no statistical significance was found. In contrast, 6% (9/142) and 4% (1/28) of the time participants in the RH and ANR settings using the garment found the IES system moderately cumbersome to use.

DISCUSSION

In this clinical feasibility study, we found that the use of IES, whether with direct electrode ap-

plication on the skin or through the specialized garment, could be safely implemented in a wide range of clinical settings. Overall, the time demands were deemed reasonable and in the majority, muscle contractions were still clearly visible after 12 h of stimulation. Although the donning and doffing time of the IES system was longer in LTC and HC than in RH and ANR settings, it took <18 mins (which included documentation time). IES was deemed acceptable to the participants and did not interfere with their daily routines.

The study protocol was chosen based on the availability of resources and the ability of the study participants and associated staff to meet the research demands. Those limits do not necessarily reflect the capability of the IES system or patient tolerance. Indeed, when study participants were free to choose whether to continue using the IES system beyond the study period and when they were not constrained by hospital discharge date, six elected to carry on using the system for an additional 2–5 weeks, one for 8 months until hospital discharge and one in the community for 14 months at the time of writing with no adverse effects. A number of additional subjects would have continued using the IES system if not because of hospital discharge.

What lessons were learned in different healthcare settings?

The LTC facility was chosen to start testing the IES system because it is one of the most challenging clinical settings. From that experience, we learned that incontinence, skin fragility, high BMI, and compromised cognition in residents who needed continuous, round the clock care were major factors that must be taken into consideration. All participants at the LTC facility were incontinent making them ill-suited for the fabric-based prototype of the garment shown in Figure 1 and an incontinent version of the garment has since been developed to address this need. Higher patient to staff ratio in LTC also made implementation more challenging. Electrode peeling was an initial concern; however, that was alleviated by securing the electrode edges using soft silicone tape.

In contrast, in the rehabilitation hospital settings (RH and ANR), patient turnover rate was higher with lengths of stay ranging from 2 weeks to 8 months. Many patients at those sites considered at high risk of developing pressure ulcers were young males with recent spinal cord injuries, healthy skin and were cognitively intact, making recruitment easier. Also, incontinence at the RH and ANR sites was substantially lower, facilitating the use of the garment (Fig. 1). To address the incontinence issue, we have now developed a new garment that incorporates an incontinence product.

Electrode application: garment or no garment?

Study participants in the rehabilitation settings found the IES system with electrodes applied directly to the skin more cumbersome than with the garment. Without the garment, especially during rehabilitation sessions or independent transfers, the cables and the stimulator sometimes got in the way. In contrast, participants at the LTC facility found the IES system with electrodes applied directly to the skin less cumbersome, likely because of their generally lower level of activity with time mostly spent in a wheelchair or bed, fewer hours of rehabilitation and fewer activities requiring transfers.

For the caregivers, the garment made donning the IES system easier as the panel clearly marked out the locations where the electrodes should be placed. This made a difference particularly for the less trained nursing staff and infrequent users. Regardless of the system deployed, time to don and doff the IES system was ~15 min in total (including data collection). That can be easily incorporated into the user's care routines.

Was IES acceptable to end-user?

All study participants in the LTC facility were sensate while in RHs and HC settings more than 50% of the participants had gluteal sensation, albeit impaired in many cases. Even in those with intact sensation, participants found the stimulation acceptable as part of their daily routine. In more than 79% of the cases, participants thought they could or indeed did fall asleep while receiving IES. That was an important finding suggesting that undue discomfort would not be a barrier for using the IES system. Moreover, six participants reported that the IES system helped relieve the discomfort associated with prolonged sitting. This allowed them to sit more comfortably in their chair for up to 12 h. This finding suggests that the IES system may not only be important for preventing DTI, but may also be important in mitigating pain associated with prolonged sitting and improve the quality of life of individuals confined to a wheelchair, especially those who have less upper body strength and are unable to complete pressure relieving manoeuvres independently.

Were muscle contractions sustained after 12 h of IES use?

The therapeutic benefits of IES for prevention of DTI depend on fused muscle contractions¹⁶ administered throughout the hours of sitting on a regular basis. When IES was administered through electrodes applied directly to the skin, shifting in electrode position or peeling from the motor points did occasionally occur. When electrode edges were taped down or IES was administered through a specialized garment, electrode peeling and rolling were eliminated. On the other hand, direct electrode application allowed easier visualization of the contractions compared to the garment. This highlights the importance of finding easier objective methods to detect the presence of muscle contractions. We are currently investigating if electromyography (EMG) is a feasible technique for monitoring the strength of IES-evoked muscle contractions in the buttocks.

INNOVATION

Conventional measures in clinical settings such as through the use of pressure distributing mattresses, foams, and periodical weight shifts are inadequate in preventing DTI, as the prevalence of pressure ulcers is on the rise. IES presents a paradigm shifting approach to the prevention of pressure ulcers and DTI. This approach tackles the true physiological factors leading to DTI and mimics the natural strategies utilized by healthy individuals for the prevention of pressure ulcers.

None of the participants in the various clinical facilities developed a pressure ulcer throughout the use of the IES system. Moreover, the cases of encountered redness after system doffing were very low across all participants throughout the duration of the IES use. These findings demonstrated that the IES system is safe for use across the clinical environments tested in our study. Most importantly, nearly 100% of the participants agreed that the IES system was a feasible preventive method for DTI. Therefore, IES is a promising novel treatment that can be used safely in a wide range of clinical settings and is well accepted by caregivers and patients.

ACKNOWLEDGMENTS AND FUNDING SOURCES

Alisa Ahmetović was partly supported by a TD Bank Financial Group Scholarship for Interdisciplinary Research. This study was conducted with funding from the Alberta Innovates–Health Solutions (AIHS) Interdisciplinary Team Grant program. Vivian K. Mushahwar is an Alberta Heritage Foundation for Medical Research Senior Scholar. Special thanks to Anita Clarke for her help with participant recruitment and with conducting training workshops for caregivers, and to Naomi Hui for the art work in Figure 1.

AUTHOR DISCLOSURE AND GHOST WRITING

V.K.M. is the Chief Scientific Officer of Prev Biotech, Inc., the spin-off company overseeing the commercialization of the IES system.¹⁷ No competing financial interests exist for the other authors. The content of this article was expressly written by the authors listed. No ghostwriters were used to write this article.

KEY FINDINGS

- IES for the purpose of preventing DTI in the pelvic region is well tolerated.
- It is applicable in different health settings.
- The treatment is safe and well accepted by patients even when used over an extended period of time.

ABOUT THE AUTHORS

Alisa Ahmetović, MSc, was a graduate student who completed a master's degree based on this project and contributed to the conception, design, acquisition and analysis of the data, and writing of the manuscript. She now works for a mining company in a multidisciplinary team. **Vivian K. Mushahwar, PhD**, is the inventor of the IES system and oversaw the foundational investigations of the concept in animal models and human volunteers. **Vivian K. Mushahwar, PhD, Martin Ferguson-Pell, PhD, Sean Dukelow, MD, PhD, FRCPC, Chester Ho, MD, FRCPC, and K. Ming Chan, MD, FRCPC**, all have academic appointments at the University of Alberta or University of Calgary, and are members of the interdisciplinary Project SMART Team that supported the present study. **Ryan Sommer, MSc, Dana Schnepf, BSc, Robyn Warwaruk-Rogers, BSc, Tim Barlott, MSc, and Su Ling Chong, BSc**, served as study coordinators at the different healthcare facilities. **Glen Isaacson** was responsible for designing and fabricating the IES garment. **Lisa Kawasaki, BSc, and Seoyoung Kim, BSc**, are postsecondary trainees. **K. Ming Chan, MD, FRCPC**, a professor at the University of Alberta and **Sean Dukelow, MD, PhD, FRCPC**, an associate professor at the University of Calgary, are both responsible for overseeing clinical projects on implementing methods of early detection and prevention of deep tissue injury in high-risk patients.

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Abbreviations and Acronyms

ANR = acute neuro-rehabilitation unit
 BMI = body mass index
 DTI = deep tissue injury
 GBS = Guillain-Barre Syndrome
 HC = homecare
 IES = intermittent electrical stimulation
 LTC = long-term care
 MSA = multiple system atrophy
 RH = rehabilitation hospital
 SCI = spinal cord injury
 TBI = traumatic brain injury