Spinal Cord (2012), 1–5
© 2012 International Spinal Cord Society All rights reserved 1362-4393/12 $32.00
www.nature.com/sc

ORIGINAL ARTICLE

Effects of electrical stimulation-induced gluteal versus gluteal and hamstring muscles activation on sitting pressure distribution in persons with a spinal cord injury

CAJ Smit[1], GLG Haverkamp[1,2], S de Groot[1,3], JM Stolwijk-Swuste[1] and TWJ Janssen[1,2]

Study design: Ten participants underwent two electrical stimulation (ES) protocols applied using a custom-made electrode garment with built-in electrodes. Interface pressure was measured using a force-sensitive area. In one protocol, both the gluteal and hamstring (g+h) muscles were activated, in the other gluteal (g) muscles only.
Objectives: To study and compare the effects of electrically induced activation of g+h muscles versus g muscles only on sitting pressure distribution in individuals with a spinal cord injury (SCI).
Setting: Ischial tuberosities interface pressure (ITs pressure) and pressure gradient.
Results: In all participants, both protocols of g and g+h ES-induced activation caused a significant decrease in IT pressure. IT pressure after g+h muscles activation was reduced significantly by 34.5% compared with rest pressure, whereas a significant reduction of 10.2% after activation of g muscles only was found. Pressure gradient reduced significantly only after stimulation of g+h muscles (49.3%). g+h muscles activation showed a decrease in pressure relief (Δ IT) over time compared with g muscles only.
Conclusion: Both protocols of surface ES-induced of g and g+h activation gave pressure relief from the ITs. Activation of both g+h muscles in SCI resulted in better IT pressure reduction in sitting individuals with a SCI than activation of g muscles only. ES might be a promising method in preventing pressure ulcers (PUs) on the ITs in people with SCI. Further research needs to show which pressure reduction is sufficient in preventing PUs.
Spinal Cord advance online publication, 21 February 2012; doi:10.1038/sc.2012.6

Keywords: spinal cord injury; pressure ulcers; electrical stimulation; sitting pressure

INTRODUCTION

Pressure ulcers (PUs) are serious and costly complications for people with a spinal cord injury (SCI), occurring in up to 80% of cases.[1,2] A PU is an area of localized damage to the skin and underlying deeper tissue caused by unrelieved pressure, shear, friction or a combination of these.[3] The most common areas for PUs for individuals with SCI are the sacrum and ischial tuberosities (ITs), which account for approximately 50% of incidents.[4] Prevention of PUs in SCI is therefore of utmost importance.

Muscle contractions induced by electrical stimulation (ES) might help prevent PUs as they improve both the intrinsic risk factors for developing PUs, because ES may reduce atrophy,[5] improve blood flow and oxygenation,[6,7] and sitting pressure distribution as it redistributes pressure away from the IT area.[8] Levine *et al.*[6–8] found that surface ES of the gluteal (g) muscles produces a sizeable pressure reduction below the ITs. In addition, Ferguson *et al.*[9] noted reduced sitting pressure after stimulating the quadriceps while the lower legs were attached to the cranks of the footrests. Liu *et al.*[10] studied the acute effects of ES of the g muscles, using implanted electrodes, resulting in clinically significant reductions in IT pressures. In conclusion, one could maintain that ES might help preventing PUs in the IT region.

In line with these findings, in a previous study in our research lab Van Londen *et al.*[11] showed that activation of g muscles relocates pressure from the ITs. However there were limitations and topics for further research in this study, as only g muscles were stimulated, and participants were sitting on the electrodes, which is, of course, an undesirable situation. In this study, we compared the effects on sitting pressure and pressure distribution between g muscle activation versus both gluteal and hamstring (g+h) muscles activation. The hamstring muscles have an extension moment in the hip joint and we expect to find that contraction of both g+h muscles changes the shape of the buttocks in another, possibly better way than stimulation of the g muscles only. On the other hand, we wondered if the electrical intensity would be sufficient when the large hamstrings were activated. Furthermore, in this study electrodes were placed halfway up the hamstrings and above the sitting surface at the g muscles. The electrodes were fitted inside a newly developed garment or shorts (ES shorts), which prevent participants who are wearing the shorts from sitting on electrodes or wires. This gave rise to the question if it would be possible to adequately activate two large muscles with only two electrodes, without complications.

This study aimed to answer two questions:

1. What are the acute effects of 1 h of ES-induced (g+h or g) muscles activation on interface pressure distribution in sitting individuals with SCI?

[1]Amsterdam Rehabilitation Research Institute, Reade, Centre for Rehabilitation and Rheumatology, Amsterdam, The Netherlands; [2]Research Institute MOVE, Faculty of Human Movement Sciences, VU University, Amsterdam, The Netherlands and [3]Centre for Human Movement Sciences, University Medical Centre, Groningen, University of Groningen, The Netherlands
Correspondence: Dr CAJ Smit, Spinal Cord Injury Ward, Reade, PO Box 58271, 1040 HG Amsterdam, The Netherlands.
E-mail: c.smit@reade.nl
Received 6 October 2011; revised 23 December 2011; accepted 24 December 2011

2. Do the effects of two stimulation protocols on interface pressure differ over time?

MATERIALS AND METHODS

Participants

Ten individuals with a SCI, having a complete or incomplete upper-motor neuron lesion (ASIA A, B or C), aged 34 (±9) years, with intact g+h muscles participated. Exclusion criteria were the presence of PUs on the buttocks, a flaccid paralysis (areflexia), intolerance to or contra-indication for ES, a history of severe autonomic dysreflexia or severe cognitive or communicative disorders. The study was approved by the local institutional review board and participants signed an informed consent form. Participants characteristics in Table 1.

Study design

Two different 1-h stimulation protocols were performed in one session. Each participant had to put on the ES shorts and was allowed to wear normal pants over them. Participants all used their own wheelchair with a regular cushion. In Figure 1, these ES shorts with electrical stimulator are shown.

Both protocols consisted of four blocks of 3-min stimulation (t0, t1, t2 and t3) and 16+1 min of rest in between blocks (Figure 2). Pressure values were recorded during the 3 min of stimulation and during the last minute of the preceding rest period. A duty cycle of 1-s stimulation and 4-s off was performed within the 3 min of ES. Stimulation–rest ratio was identical for both protocols. First g muscles were stimulated and then g+h. There was a 30-min rest period in between protocols.

ES with the ES shorts

The ES shorts (Axiobionics, Ann Arbor, MI, USA) were custom-developed lycra shorts in which wires and surface electrodes had been processed. Two built-in surface electrodes are placed over g muscles and over h muscles, on both sides (Figures 1 and 2). The surface electrodes (with conductive gel) are connected to elastic conductors, guided through the side of the shorts to the front, ensuring the participant does not sit on these wires. An eight-channel electrical stimulator (Neuropro, Berkelbikes Nijmegen, The Netherlands) connected to the shorts was used. The standard stimulator potential is 150 V. Stimulation was delivered biphasically at 50 Hz to induce a tetanic contraction. First the g muscles were activated, and then the same absolute amplitude was also used for activation of g+h muscles of that individual. The current amplitude was adjusted for each subject by increasing the current amplitude in steps of 5 mA, while recording interface sitting pressure, until the best reduction in sitting pressure, without discomfort or excessive muscle contractions was found. The average current amplitude was 94 ± 12.5 mA, ranging from 70 to 115 mA.

Interface pressure measurements

Interface sitting pressure was measured using a force-sensitive array (FSA, Vista Medical, Vancouver, Canada). In this, thin 42×42 cm soft flex mat 256 pressure sensors (1.82 cm^2 per sensor) have been incorporated. It was calibrated between 0 and 200 mm Hg according to the systems protocol. From each of the eight FSA recordings per participant, the mean IT pressure and pressure gradient were calculated. The ITs were defined by inspection of the FSA profiles and selecting the 3×3 sensors with the highest pressure values, from which the mean (left and right) IT pressure was calculated (IT pressure) (Figure 3).

The pressure gradient was calculated by subtracting the average of the 16 surrounding sensor values from the IT pressure. This pressure gradient may indicate shear forces and a high pressure gradient is associated with high shear forces within the tissue, increasing the risk of developing PUs.

Data analysis

The acute effects of the stimulation were investigated by calculating the mean IT and gradient pressures, by averaging all the recorded pressures during the 3-min stimulation blocks (1-s stimulation, 4-s rest). In total, this resulted in 8 times 36 recordings of ES-induced activation, which were added to the pressures of 8 times 144 recordings in rest. In Figures 4 and 5, these are compared with pressures in rest (no ES). In Figure 6, an overview of 64 min of measurements is shown.

Table 1 Subjects' characteristics

	Mean ± s.d. (range)
Age (years)	33.7 ± 8.9 (22–54)
Lesion level	C3–C8 (*n*=8)
	Th1-Th12 (*n*=2)
Asia impairment score	Asia A; *n*=8
	Asia B; *n*=1
	Asia C; *n*=1
Time since injury (months)	55 ± 63 (6–173)
Body mass (kg)	76.0 ± 13.5 (60–99)
Height (m)	1.75 ± 0.31 (1.71–2.01)

Figure 1 ES-shorts connected with the eight-channel Neuropro stimulator; front and back. Arrows indicate the electrodes for right g+h muscles.

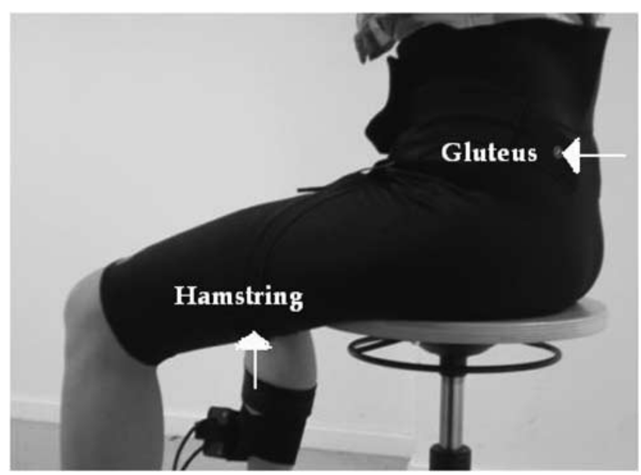

Figure 2 Arrows indicate the position of electrodes in the ES shorts.

ΔIT and Δpressure gradient were calculated by subtracting the mean values with ES from these pressure values during the preceding rest (=no ES). This resulted in variables ΔIT and Δpressure gradient at t0, t1, t2 and t3 for both protocols (g, and g+h).

Statistical analysis

SPSS for Windows software (version 16.0, Chicago, IL, USA) was used to analyze the data collected with the FSA. All results were described as mean ± s.d. A paired samples *t*-test was performed, comparing the IT pressure and pressure gradient of the values in rest with the average of the pressures during stimulation.

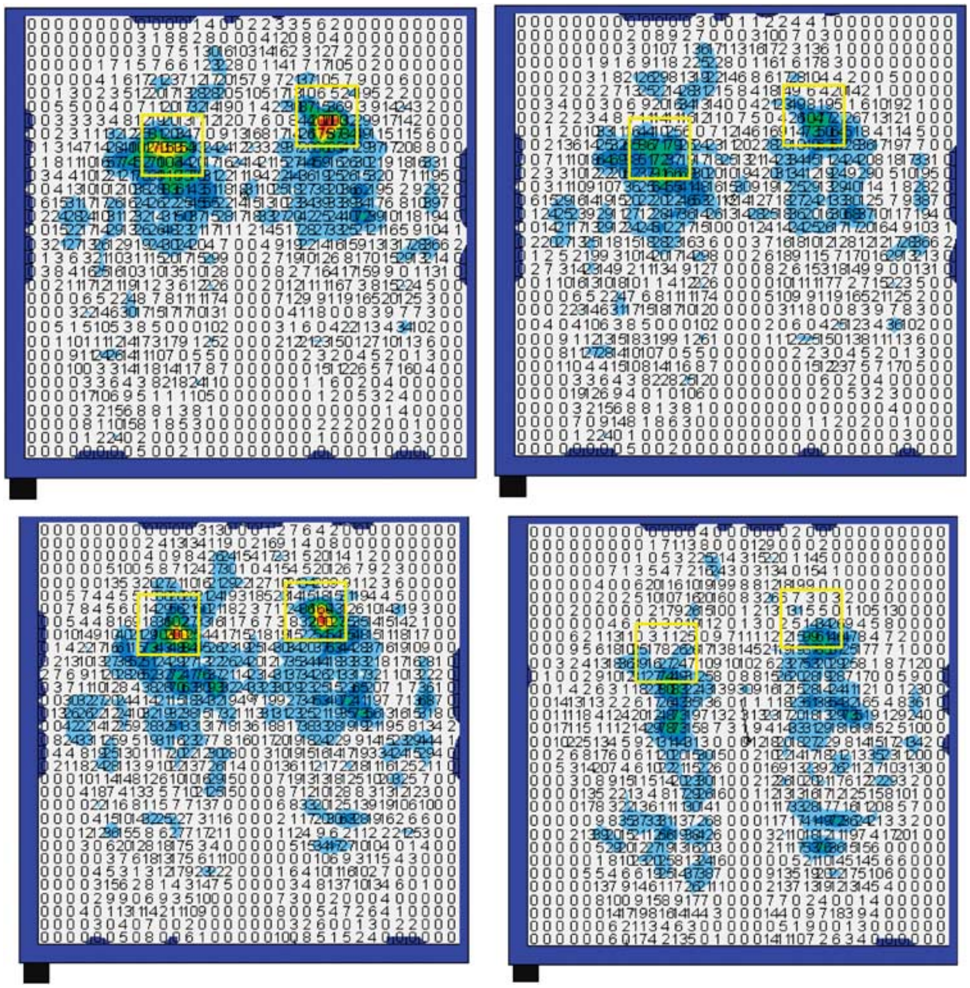

Figure 3 FSA frames of interface pressure distribution as a two-dimensional map. The highest pressure values represent the ITs. Recordings of one participant during rest (above left and below left), and during activation of g muscles (above right) and both g+h muscles (below right). The squares in left frames indicate the 3×3 sensor areas with the highest pressure values (ITs). In the right frames, pressure is relocated after muscle activation.

A general linear model analysis of variance with repeated measures was used to analyze the effect of time within both protocols (factor: time (n=4) per protocol). To analyze the differences between activation of the g+h muscles and activation of the g muscles only over time (interaction effect 'time × protocol') a second general linear model analysis of variance with repeated measures was performed with two within factors: time (n=4), and protocol (n=2). Differences with a P-value $\leqslant$0.05 were considered significant.

RESULTS

Both g and g+h muscle activation gave significant IT pressure relief compared with rest. When averaging all pressure values, activation of g+h muscles gave significantly more pressure relief from the ITs than activation of g muscles only (37.8 ± 23.2 versus 11.8 ± 11.7 mm Hg). The average pressure gradient only reduced significantly over time for the stimulation of both the g+h muscles (14.7 ± 17.1 versus 5.3 ± 9.2; Figures 4 and 5). Mean between group difference: 25.9 (confidence interval: 14.6–37.3 mm Hg).

ΔIT showed no significant change over time for g muscle activation only, but significantly decreased over time for activation of g+h muscles: from 44.0 mm Hg at t0 to 28.5 mm Hg at t3 (P=0.01).

ΔPressure gradient showed no significant change from 18.4 mm Hg at t0, to 8.2 mm Hg (−55.4%) at t3 (P=0.10) during activation of both g+h, nor for activation of g only (6.5 mm Hg at t0 to 4.3 mm Hg (−66.2%) at t3) (P=0.65) (Table 2).

There was no significant interaction effect between the stimulation protocols and the moments of time. When activating both g+h muscles, neither the IT pressure (P=0.28) nor pressure gradient (P=0.41) changed differently over time compared with activation of the g muscles only (Table 2).

DISCUSSION

Both protocols induced significant reductions of pressure at the ITs, but activation of both the g+h muscles resulted in larger pressure reductions. This is likely caused by changes in tone and shape of the activated muscles, with larger effect when adequately activating more muscles (g+h), in combination with the extension in the hip with lifting effect, by activation of the hamstrings.

We compared our results with other studies, such as the study by Van Londen *et al.*[11] In that study, IT pressure reductions found during ES (mean 19.0 mm Hg), were better than the results for stimulation of the g muscles only in this study (11.8 mm Hg). The pressure gradient reduced 14.0 mm Hg in the study of Van Londen *et al.* while in this study the pressure gradient reduced 5.3 mm Hg. This difference may be caused by the use of a different stimulation protocol, as

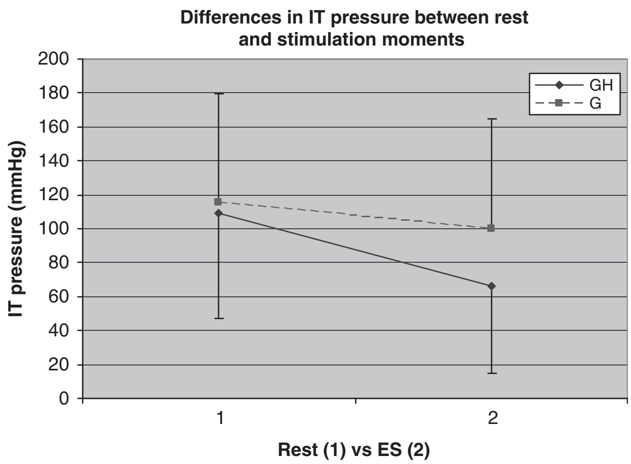

Figure 4 Average IT pressure in rest and after activation of both the g+h muscles or the g muscles only.

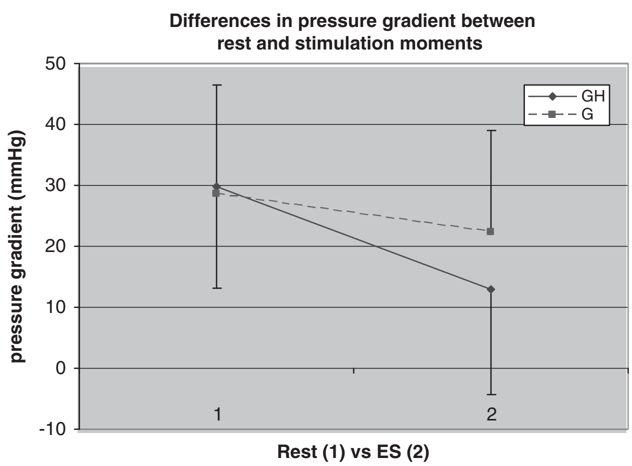

Figure 5 Average pressure gradient in rest and after activation of both the g+h muscles or the g muscles only.

Van Londen *et al.* stimulated with a stimulation–rest cycle of 0.5-s on and 15-s off, and also by the electrodes that were positioned for each participant individually, whereas in this study the electrodes were fixed to one place in the only pair of shorts used. If, in the future these shorts were to be tailor made, the effect could increase even more, as not only the electrodes in the shorts would then be individually positioned, but also the better stimulation–rest ratio would be used. In this study, g+h muscles activation showed larger reductions compared with Van London (IT pressure reduction 37.8 mm Hg and in pressure gradient 14.7 mm Hg versus Van Londen: 19.0 and 4.0 mm Hg). Ferguson *et al.*[9] studied the effect of functional ES on the quadriceps muscles, with both feet fixed on the footrests. The average pressure drop when activating both legs was 35.5 mm Hg. This reduction is higher than achieved by activating the g muscles only, but approximately the same compared with g+h activation. One can conclude that ES-induced surface activation of both g+h muscles is an effective manner for reducing pressure from the ITs, more effective than only g muscle activation.

In this study, while activating g+h muscles, an increase in pressure was seen in the area of the upper legs, as the pressure was relocated from the ITs to the front of the sitting surface. This (desirable) relocation did not cause any skin problems in this area, as there are no bony prominences at the hamstring site near the knees.[12,13] ΔIT showed no significant change over time for g muscle activation only, but significantly decreased over time for activation of g+h muscles. But ΔIT for g+h activation was higher than g muscle activation at T0 (44.0 versus 14.7 mm Hg), and at T3 (28.5 versus 7.6 mm Hg). Therefore, a larger decline but 'higher start and end' pressure difference between activation and rest for g+h versus g muscle activation was found. The decline over time might be caused by less forceful contractions because of muscle fatigue after repetitive activation. This needs further investigation. We also wondered what effects training of these muscles will have, as we hypothesize that ES training might reduce the negative effects of fatigue.[14,15] In literature, no studies were found describing effects of ES training on fatigue or sitting pressure in people with SCI or other diagnose groups.

The best current was determined for each participant by first activating g muscles up to a maximum, with effective contractions

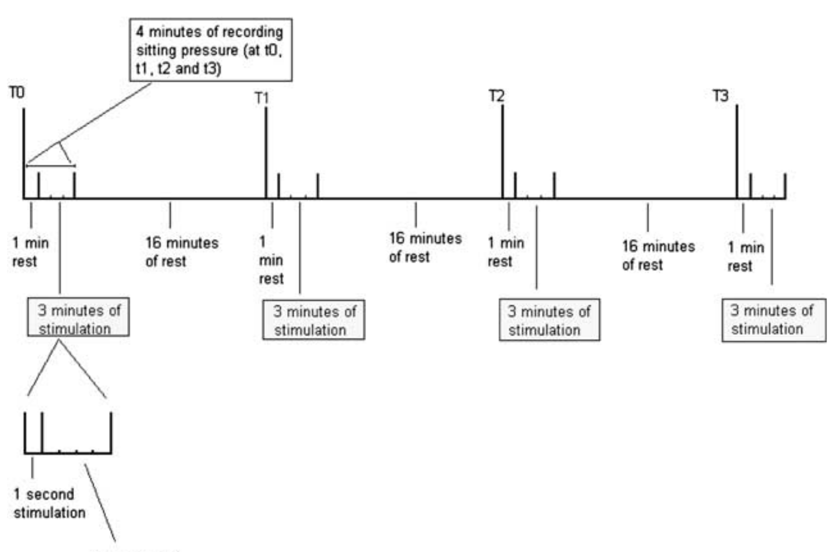

Figure 6 Overview of 64 min of measurements, this is the same for both the stimulation of the g+h muscles and the exclusive stimulation of the g muscles.

Table 2 Differences (Δ) in pressure of the ITs and pressure gradient between stimulation and in rest, and for the last 3 min of stimulation for both protocols g and g+h muscle activation at several moments in time

	t0 (Mean ± s.d.)	*t1 (Mean ± s.d.)*	*t2 (Mean ± s.d.)*	*t3 (Mean ± s.d.)*	*Time (within protocol)* P-*value*	*Time * protocol* P-*value*
Δ *IT*						
g	14.7 ± 12.4	13.1 ± 15.3	12.0 ± 13.2	7.6 ± 9.3	0.07	0.28
g+h	44.0 ± 28.1	42.0 ± 28.5	35.1 ± 24.2	28.5 ± 17.7	0.01*	
Δ *Gradient*						
g	6.5 ± 7.7	5.9 ± 12.4	4.4 ± 10.8	4.3 ± 8.9	0.65	0.41
g+h	18.4 ± 19.8	18.3 ± 19.0	13.9 ± 18.0	8.2 ± 19.8	0.10	

Abbreviations: g, gluteal; g+h, gluteal and hamstring; IT, ischial tuberosity.

without discomfort. The current amplitude for that individual was then kept equal for the activation of the g+h muscles. The effect of the stimulation was higher when stimulating both the g+h muscles, no matter what current was used. We expected a higher current would be needed for activation of g+h compared with g muscles only, as a larger muscle volume had to be activated, but this expectation proved incorrect. It appeared that activation with equal current amplitude of g+h muscles compared with activation of g muscles only was possible and most effective, despite the larger distance between the two electrodes.

A limitation that might have influenced this study were the ES-shorts. As this study only had one (washable) pair of ES shorts to work with. A few individuals, who met the inclusion criteria, were not to be able to participate, as the ES-shorts were too small. Unfortunately, the method of activating muscles as in this study is not suitable for persons with a flaccid paresis like in cauda equina syndrome. Intact sensibility might also sometimes be a problem, although in our study two participants had incomplete lesions with partially intact sensibility, but did not find the ES painful or even unpleasant.

ES-induced muscle activation might be a promising method in people with a SCI,[16] as it not only reduces pressure from ITs, but also may help to restore blood flow in compressed tissue, help to improve muscle condition and volume, and prevent PUs. Further study is needed to determine which pressure reduction is efficient and clinically relevant. The future aim is not to reduce pressure, but lower the incidence of PUs.

CONCLUSION

Both ES-induced activation of the g muscles only and g+h muscles provided significant reductions of IT pressure and pressure gradient. Activation of both the g+h muscles resulted in significantly better pressure reductions than activation of g muscles only, and the effect of the stimulation (pressure relief) was higher when stimulating both the g+h muscles, no matter what current was used. The pressure gradient only reduced significantly for the stimulation of both the g+h muscles. ES-induced muscle activation might be a promising method in people with a SCI, as it not only reduces pressure from ITs, but also may help to restore blood flow in compressed tissue, help to improve muscle condition and volume. Further research is needed to determine how much pressure reduction is sufficient to prevent PUs.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

1 Krause JS, Broderick L. Patterns of recurrent pressure ulcers after spinal cord injury: identification of risk and protective factors 5 or more years after onset. *Arch Phys Med Rehabil* 2004; **85**: 1257–1264.
2 Byrne DW, Salzberg CA. Major risk factors for pressure ulcers in the spinal cord disabled: a literature review. *Paraplegia* 1996; **34**: 255–263.
3 European Pressure Ulcer Advisory Panel. Pressure ulcer treatment guidelines. [serial online] 1998 Jan-Mar [cited 10 Dec 2007]. Available from: http://www.epuap.org/gltreatment.html.
4 Tam EW, Mak AF, Lam WN, Evans JH, Chow YY. Pelvic movement and interface pressure distribution during manual wheelchair propulsion. *Arch Phys Med Rehabil* 2003; **84**: 1466–1472.
5 Solis LR, Hallihan DP, Uwiera RRP, Thompson RB, Pehowich ED, Mushahwar VK. Prevention of pressure-induced deep tissue injury using intermittent electrical stimulation. *J Appl Physiol* 2007; **102**: 1992–2001.
6 Levine SP, Kett RL, Gross MD, Wilson BA, Cederna PS. Blood flow in the gluteus maximus of seated individuals during electrical muscle stimulation. *Arch Phys Med Rehabil* 1990; **71**: 682–686.
7 Levine SP, Kett RL, Cederna PS, Brooks SV. Electric muscle stimulation for pressure sore prevention: tissue shape variation. *Arch Phys Med Rehabil* 1990; **71**: 210–214.
8 Levine SP, Kett RL, Cederna PS, Bowers LD, Brooks SV. Electrical muscle stimulation for pressure variation at the seating interface. *J Rehab Res Dev* 1989; **26**: 1–8.
9 Ferguson AC, Keating JF, Delargy MA, Andrews BJ. Reduction of sitting pressure using FES in patients with spinal cord injury. A preliminary report. *Paraplegia* 1992; **30**: 474–478.
10 Liu LQ, Nicholson GP, Knight SL, Chelvarajah R, Gall A, Middleton FRI *et al*. Pressure changes under the ischial tuberosities of seated individuals during sacral nerve root stimulation. *J Rehab Res Dev* 2006; **43**: 209–218.
11 Van Londen A, Herwegh M, van der Zee CH, Daffertshofer A, Smit CA, Janssen TW. The effect of surface electrical stimulation of the gluteal muscles on the interface pressure in seated people with spinal cord injury. *Arch Phys Med Rehabil* 2008; **89**: 1724–1732.
12 Bader DL. The recovery characteristics of soft tissues following repeated loading. *J Res Rehabil Res Dev* 1990; **27**: 141–150.
13 Reenalda J, van Geffen P, Nederhand M, Jannink M, IJzerhand M, Rietman H. Analysis of healthy sitting behavior: interface pressure distribution and subcutaneous tissue oxygenation. *J Rehab Res Dev* 2009; **46**: 577–586.
14 Knight SL, Taylor RP, Polliack AA, Bader DL. Establishing predictive indicators for the status of loaded soft tissues. *J Appl Physiol* 2001; **90**: 2231–2237.
15 Bogie KM, Triolo RJ. Effects of regular use of neuromuscular electrical stimulation on tissue health. *J Rehab Res Dev* 2003; **40**: 469–475.
16 Bogie KM, Wang X, Triolo RJ. Long-term prevention of pressure ulcers in high-risk patients: a single case study of the use of gluteal neuromuscular electric stimulation. *Arch Phys Med Rehabil* 2006; **87**: 585–591.