Published in final edited form as:

Adv Skin Wound Care. 2009 November ; 22(11): 514–521. doi:10.1097/01.ASW.0000305495.77649.ee.

Promote Pressure Ulcer Healing in Individuals with Spinal Cord Injury Using an Individualized Cyclic Pressure-Relief Protocol

Mohsen Makhsous, PhD [Assistant Professor, Research Scientist],

Departments of Physical Therapy and Human Movement Sciences, Physical Medicine and Rehabilitation, Orthopaedic Surgery, Northwestern University, Chicago, Illinois; Sensory Motor Performance Program, Rehabilitation Institute of Chicago, Chicago, Illinois

Fang Lin, DSc [Research Assistant Professor],

Departments of Physical Therapy and Human Movement Sciences, Physical Medicine and Rehabilitation, Northwestern University; Sensory Motor Performance Program, Rehabilitation Institute of Chicago

Evan Knaus, MD [PMR Resident],

Physical Medicine and Rehabilitation, Northwestern University

Mary Zeigler, RN, MS, CRRN, CWOCA [Clinical Nurse Consultant],

Sensory Motor Performance Program, Rehabilitation Institute of Chicago

Diane M. Rowles, MS, ACNP-BC, CRRN [Assistant Professor, Nurse Practitioner],

Physical Medicine and Rehabilitation, Northwestern University; Sensory Motor Performance Program, Rehabilitation Institute of Chicago

Michelle Gittler, MD [Clinical Associate Professor],

Department of Physical Medicine and Rehabilitation, University of Chicago, Chicago, Illinois

James Bankard, BS [Research Assistant], and

Departments of Physical Therapy and Human Movement Sciences, Northwestern University

David Chen, MD [Associate Professor]

Physical Medicine and Rehabilitation, Northwestern University and Rehabilitation Institute of Chicago

Abstract

Objective—To evaluate whether an individualized cyclic pressure-relief protocol accelerates wound healing in wheelchair users with established pressure ulcers (PrUs).

Design—Randomized controlled study.

Setting—Spinal cord injury clinics.

Participants—Forty-four subjects, aged 18–79 years, with a Stage II or Stage III PrU, were randomly assigned to the control (n = 22) or treatment (n = 22) groups.

Interventions—Subjects in the treatment group used wheelchairs equipped with an individually adjusted automated seat that provided cyclic pressure relief, and those in the control group used a standard wheelchair. All subjects sat in wheelchairs for a minimum of 4 hours per day for 30 days during their PrU treatment.

Main Outcome Measures—Wound characteristics were assessed using the Pressure Ulcer Scale for Healing (PUSH) tool and wound dimensions recorded with digital photographs twice a week. Median healing time for a 30% healing relative to initial measurements, the percentage

reduction in wound area, and the percentage improvement in PUSH score achieved at the end of the trial were compared between groups.

Results—At the end of 30 days, both groups demonstrated a general trend of healing. However, the treatment group was found to take significantly less time to achieve 30% healing for the wound measurement compared with the control group. The percentage improvement of the wound area and PUSH scores were greater in using cyclic seating (45.0 ± 21.0 , $P < .003$; 29.9 ± 24.6 , $P < .003$) compared with standard seating (10.2 ± 34.9 , 5.8 ± 9.2).

Conclusions—The authors' findings show that cyclically relieving pressure in the area of a wound for seated individuals can greatly aid wound healing. The current study provides evidence that the individualized cyclic pressure-relief protocol helps promote pressure wound healing in a clinical setting. The authors concluded that the individualized cyclic pressure relief may have substantial benefits in accelerating the healing process in wheelchair users with existing PrUs, while maintaining the mobility of individuals with SCI during the PrU treatment.

Introduction

Pressure ulcer (PrU) management continues to be an important medical challenge facing today's healthcare community. Thirty-three percent of people with spinal cord injury (SCI) develop at least 1 PrU during their initial acute care hospitalization.¹ Pressure-concentrated areas, including the tissues of the is-chium and sacrum-coccyx regions, are most at risk because of prolonged sitting or bed rest with improper pressure relief.^{2–9} Once formed, PrUs are often slow to heal and can lead to expensive corrective surgeries followed by prolonged rehabilitation and the propensity for recurrences.^{1–10} PrUs place a heavy burden on an individual's health, resources, quality of life, family, and community reintegration.

According to the *National Spinal Cord Injury Statistical Report* published in 2005, PrUs represent the most common medical complication (14.9%–26.7%) and the second most common (33.6%) reason for hospital readmission 1 year after the initial injury.¹ The financial cost of healing a PrU depends on its severity, and has been estimated in the range of \$2000 to \$70,000 per wound,¹¹ contributing to an annual cost within the United States of approximately \$2.2 to \$3.6 billion.¹² Recognizing this, the Joint Commission has recently named the prevention of pressure wounds as one of its long-term-care national patient safety goals,¹³ and the National Health Prevention Program, Healthy People 2010, has proposed the prevention of PrUs among nursing home residents as a future objective.¹²

Individuals with SCI are at the greatest risk for developing PrUs.⁹ In this population, PrUs most commonly occur over the sacrum (33.2%) and the ischial tuberosities (12%), because of prolonged periods in the sitting position and decreased mobility.¹ SCI damages intrinsic physiological control mechanisms that result in a decreased vascular response to loading, reduced muscular tone, progressive muscle atrophy, and impaired sensory biofeedback systems.^{5,7,9,14} In 2002, Thorfinn et al⁹ demonstrated that seating pressures and pressure distribution were significantly higher in individuals with SCI compared with controls.

Pressure reduction is a critical factor in the prevention and treatment of PrUs. Brem and Lyder¹⁵ concluded that pressure relief and increasing blood flow are the 2 important factors to consider when selecting support surface for patients being treated for a PrU. Kosiak¹⁶ demonstrated that if pressures of 70 mm Hg for 2 hours were alternated every 5 minutes, only minimal changes were produced. Pressure-relief techniques have been devised to promote prevention among SCI population. Unfortunately, these maneuvers require physical strength, endurance,¹⁷ and self-discipline to be effective, and patients often are not medically stable enough to be an active participant. Extensive engineering has focused on the development of specialized pressure-reducing materials, such as foam and gel cushions.

Despite these advances, few randomized controlled studies have evaluated the efficacy of one material over another.¹⁸ A Cochrane review in 2004 compared the results of randomized controlled trials between different wheelchair cushions and concluded that there was inadequate evidence regarding wheelchair cushions in the prevention and treatment of PrUs.¹⁹

Previous research conducted in the authors' laboratories have studied a cyclic pressure-relief protocol to evaluate its effect on providing periodical pressure relief²⁰ and tissue-perfusion recovery²¹ for wheelchair users. The authors have found that, compared with a clinical pressure-relief protocol (arm push-up every 20 minutes), the cyclic pressure-relief protocol brought forth a significantly reduced interface pressure on the ischia,²⁰ promoted tissue perfusion in the occupant's buttock tissues,²¹ and decreased skin temperature elevation.²² These findings suggest that the cyclic pressure-relief protocol may also be beneficial in helping to heal existing PrUs. The objective of this study was to test, in a small sample of subjects, whether the cyclic pressure-relief protocol accelerated the healing process of PrUs in individuals with SCI. The null hypothesis was that the PrU healing in individuals with SCI with existing PrU wounds would not take less time when using a wheelchair cushion equipped with an individualized cyclic pressure-relief protocol, compared with that using a regular wheelchair cushion.

Methods

Participants

A total of 44 wheelchair users with SCI (paraplegia or tetra-plegia) who had existing Stage II or III PrUs in the sacral and/or ischial area were recruited following the institutional review board–approved consenting process. Participants were inpatients or outpatients at the Rehabilitation Institute of Chicago, Illinois, or the Schwab Rehabilitation Hospital at Chicago. Once enrolled, participants were randomized to 2 groups, one using a wheelchair cushion equipped with the individualized cyclic pressure-relief protocol (treatment group) and the other using regular wheelchair cushions (control group). The demographic statistics of the participants are shown in Table 1.

The patients who met the inclusion criteria were those who had Stage II or III PrUs in the sacral or ischial areas, who were able to independently use either a manual or a power wheelchair, and who had sitting tolerance for at least 4 hours per day. Individuals with degenerative disorders of the spine and with histories of injury or surgery of the pelvis, hip joint, and the thigh, or with hip contractures, were excluded. Also excluded were those with severe pain, spasm, and psychological concerns preventing proper cooperation.

Treatment for PrUs

All participants received PrU treatment by a physician or a trained nurse practitioner and were examined once per week. Treatment was specific for each individual wound, and a variety of wound care modalities was applied when appropriate. Modalities included topical wound dressings, such as wound gel, hydrocolloid, alginate, foam, and moisture barrier. More advanced modalities included silver antimicrobial dressing and negative wound pressure therapy.

Wheelchair and Cyclic Pressure-Relief Seating System

Two different types of wheelchairs were used: regular wheelchairs and wheelchairs equipped with a cyclic pressure-relief seating system. The control group utilized regular wheelchairs, either manual or powered ranging from 16- to 20-inch width and 16- to 20-inch depth fit according to the patient's body size. The treatment group used 8 wheelchairs (6

manual and 2 powered wheelchairs) equipped with a cyclic pressure-relief seating system. The cyclic pressure-relief seating system consists of a split seat and a backrest with an enhanced lumbar support.^{20,21} The wheelchairs were configured with the back-rest reclined 5 degrees from perpendicular and a split seat cushion oriented parallel to the floor. The split-seat cushion was designed with a movable portion located at the posterior one-third of the seat depth. This movable seat portion tilted downward away from the individual, reducing the contact between the user's buttocks and the seat. The seat height and depth were adjusted to accommodate the body build of the participants. The backrest incorporated an inflatable air pouch as an adjustable lumbar support that inflated simultaneously when the posterior portion of the split seat dropped. This seating system alternated the sitting configuration of the wheelchair between 2 sitting configurations, normal sitting, and the off-loading sitting in which the posterior seat portion was tilted down. During the trial, the cyclic pressure-relief protocol for the treatment group was maintained alternately as 10 minutes on normal sitting and 10 minutes on off-loading sitting. A customized system with a microprocessor (Basic Stamp; Parallax, Inc, Rocklin, California) was used to precisely regulate the tilting of the posterior seat section and the inflation/deflation of the lumbar air bladder via a motor and an air pump. To achieve the desired pressure relief in the off-loading sitting configuration, the microprocessor controlled the tilting down of the posterior portion of the seat based on the preset thresholds of the contact pressure (15 mm Hg) and the feedback readings from the contact sensors on the seat interface. In this way, during the off-loading sitting configuration, the contact pressure between the participant's buttocks and the posterior portion of the seat was maintained at the level less than 15 mm Hg. The material for the seat cushion and the cushion cover was viscoelastic foam and Rubatex (Rubatex International, LLC, Bedford, Virginia), respectively, for all wheelchairs used in this study.

Sitting Intervention

All participants were instructed to maintain a minimum of 4 hours' sitting in their assigned wheelchairs daily. Participants in the control group were instructed to perform arm push-ups every 20 to 30 minutes for pressure relief. Participants in the treatment group were informed about the intended pressure-relief effect of the experimental seating device, and they were told to maintain their regular pressure-relief routine while they were not in the treatment wheelchair. While they were in the experimental wheelchair, they were allowed to make their own decision to either maintain doing manual pressure relief or rely entirely on the experimental seating device.

Wound Assessment

PrU progress was assessed and documented twice a week using the Pressure Ulcer Scale for Healing (PUSH) tool²³ and the VeV Measurement Documentation System (Verg, Inc, Winnipeg, Manitoba, Canada).²⁴ The PUSH tool characterized the pressure wound according to length, width, amount of exudates, and tissue type. The VeV Measurement Documentation System, utilizing digital photography and a target plate placed in the plane of the wound as a reference, calculated the wound size, hue, and viewing angle, in comparison with the target plate, thereby reducing the potential errors related to variations in camera distance and angle when photographing the wound. The reason to choose VeV software for wound area measurement was because it was proved to be superior to manual techniques to achieve valid measurement of the wound area.²⁴ In this study, digital images with the target plate were taken using a digital camera (Power Shot A85; Canon USA, Inc, Lake Success, New York) with a resolution of 4 megapixels. Then the wound area was determined using VeV software from these images.

Protocol

Inpatients and visiting outpatients with established PrUs who met the inclusion criteria were enrolled by participating physicians. After informed consent was obtained, the patient was randomized to either the treatment or control group. Once the randomization was determined, an introductory session was conducted, which included an interview for information and a fitting and training session to fit the dedicated wheelchair for the participant and to instruct the participant on how to use the wheelchair and how to report daily activities. During the interview, the participant was assessed for his/her overall state of health, the detail of the history of their SCI (level of injury, date of injury, cause of injury), the status of his/her existing wound (stage of wound, date of discovery), current treatments for the wound, seating needs (width/length of seat, power vs manual chair, footrest, armrest, and back lengths, etc), and an initial schedule for tracking the wound was also arranged.

For each participant, a wheelchair, either power or manual as identified by the participant, was prepared and adjusted for optimum comfort and utility. Armrest height, wheel width, seat dip, and the footrest length and angle were adjusted for each participant during the one-to-one fitting session. For participants in the treatment group, the maximum dropping angle for the back part of the seat was adjusted to ensure that the subject got maximum possible pressure relief while maintaining sufficient support. At the same time, the lumbar support was positioned for optimal comfort. For both groups during the fitting and instruction session, the participants were encouraged to get accustomed to the wheelchair and to try a wide variety of their normal activities (transferring to and from the chair, passing through doorways, eating at tables, sitting for extended periods, etc) to ensure that the chair would be acceptable over the course of the study. Additional modifications could be made if necessary.

During this session, the participants were also informed that they should remain sitting in their designated wheelchair for at least 4 hours per day. They were also taught how to use an activity sheet to report their daily activities, especially the time when they were using the wheelchair. Once the introductory session ended, the formal day to start using the assigned wheelchair was scheduled as soon as possible. On the day the participant started to use the assigned wheelchair, he/she was considered formally enrolled in the study, and the data collection started as day 1.

To track wound healing, wound assessment was done twice a week, approximately 3 to 4 days apart. The participant was asked to lie on his/her side on a flat surface, and the wound area was exposed and cleansed. Several photographs were taken of the wound, together with a target plate (Figure 1), to ensure clear and referenced images that would be processed later using the VeV MD software. At the same time, the PUSH tool was applied. Additional factors, such as odor, tissue hue, irritation around the wound, or patient illness, were noted if significant and tracked. The wound was then redressed. The trial lasted for 30 days.

Data Processing

Using the VeV MD software, the wound area was measured in millimeters squared, for each wound at each inspection time. The wound area measurement and the PUSH tool score were documented twice a week along the time for each wound. For each participant, a linear regression was applied to the wound area data to obtain an estimated closure rate, in millimeters squared per day, for the entire 30 days of the trial. To be able to make comparison across the participants, the wound measurement, that is, the PUSH score and the wound area, was normalized as a percentage of the day 1 value for each individual participant.

Statistical Analysis

For continuous data regarding demographics of the participants, that is, age, body mass index, and years since SCI, average values were obtained for each group. A 2-sample *t* test was performed for these data to detect significant differences between the groups. For categorical data regarding demographics, that is, sex and the neurological category of SCI based on the American Spinal Injury Association category, a chi-square test was performed to detect the significant group effect.

A chi-square test was used to check the group difference for the stage of PrUs at the time the participants entered the study. For the rest of the data regarding the PrU at the beginning and end of the trial, a 2-sample *t* test was performed to test group difference.

To assess the wound healing results for the 30-day trial, 3 outcomes were computed and tested. For both groups, a Kaplan-Meier analysis was used to obtain the median time and the cumulative probability to achieve a 30% reduction of the wound area. The log-rank (Mantel-Cox) chi-square was calculated to assess the group difference. In addition, the percentage reduction in wound area and the percentage improvement in PUSH score achieved at the end of the trial were also obtained with the values at the start of the trial for each participant. A 2-sample *t* test was used to assess the group difference for these 2 outcomes.

The statistical analysis was performed using SPSS (SPSS 15.0; SPSS, Inc, Chicago, Illinois). *P* < .05 was considered significant.

Results

Participants

There was no significant difference for demographic data between the 2 groups of participants (Table 1). The time post-SCI and the time since the onset of the current PrU when entering the trial were not significantly different between the groups (Tables 1 and 2).

Typical Cases for Control and Treatment Groups

One typical result for wound healing from each group is shown in Figure 1. The patient in the control group (Figure 1 upper row) initially had a Stage III sacral wound with a size of 2321 mm², with 50% necrotic tissue and 50% red tissue. At day 16, the wound became unstageable, with approximately 60% blackish tissue and 40% unhealthy red tissue. At the end of the trial, the wound showed signs of healing, with 60% healthy red tissue with a reduced size of 2091 mm². The patient in the treatment group (Figure 1, bottom row) also had a Stage III sacral wound with the day-1 size of 3145 mm² with 50% yellow necrotic tissue. At the edge of the wound opening, there was apparent undermining with possibly a connected smaller wound bed. At day 15, there was less necrotic tissue and a greater amount of red granulation tissue. By the end of the trial at day 30, there was almost no necrotic tissue, which was considered as a healthy healing wound. The size of the wound was reduced to 1973 mm².

General Wound Description

The average wound description at the beginning and the end of the trial is summarized in Table 2. Patients in both groups entered the study with similar size, stage distribution, and PUSH scores of the PrU wounds. The patients in the control group had a longer time on existing wounds when they entered the study; however, no statistical significance was found (*P* > .05). At the end of the study, most wounds were in a general healing process with respect to area closure and the PUSH score improvement. The wound areas that remained were not significantly different between the groups, but the treatment group achieved a

significantly greater wound closure (785.0 [744.0] vs 124.9 [520.0] mm², $P < .001$), with a higher closure rate (21.7 [14.6] vs 2.3 [20.4] mm²/day, $P < .001$). At the same time, the PUSH score for the treatment group showed significantly greater improvement over the trial period (2.5 [2.3] vs 0.7 [1.1], $P = .001$).

Wound Closure Progress

The PrU wound closure progress assessed with 30% wound closure, percentage of wound area reduction, and the percentage of PUSH score improvement is summarized in Table 3.

Of the 22 participants in the treatment group, 16 achieved 30% wound closure, whereas there were 8 participants in the control group who achieved 30% wound closure. The median time to achieve this healing goal was 25 days for the treatment group, whereas it was more than 30 days for the control group. The Mantel-Cox chi-square test showed that the treatment group has significantly greater probability to achieve 30% closure during the trial time of 30 days ($P = .007$). Figure 2 shows the cumulative probability curves to achieve 30% wound closure along the trial time for both groups. For the control group, the probability to achieve 30% wound closure at day 30 was 0.364, whereas the same probability measure for the treatment group was 0.727 ($P = .007$).

The average percentage wound area closure for the treatment group was significantly greater than that for the control group (45.0% [21.0%] vs 10.2% [34.9%], $P < .001$).

PUSH Score Improvement

As summarized in Table 3, the percentage improvement in PUSH score was significantly greater for the treatment group than that for the control group (21.9% [24.6%] vs 5.8% [9.2%], $P = .003$).

Discussion

The reported randomized trial assessed the wound healing progress for 2 groups of patients with existing PrU wounds to investigate the potential effect of an individualized cyclic pressure-relief protocol on wound healing. The wound closure rate of the control group from this study averaged 2.3 mm²/day. Results were comparable to a study by Ferrell et al,²⁵ which reported wound closure of an average of 2.5 mm² daily for participants using regular foam mattresses in a randomized trial evaluating the effect of mattress selection on PrU wound healing.

Although both groups in the authors' study experienced general healing progress of their PrUs with standard wound care, participants using the wheelchair with an individualized cyclic pressure-relief protocol demonstrated significantly greater wound closure rate—more than 9 times higher than participants who were using regular wheelchairs. Based on the analysis of the current data, at day 30, patients on the individualized cyclical pressure-relief protocol had a significantly higher probability to achieve PrU wound healing to a certain degree, for example, 30% wound area closure.

Off-loading is a critical part of wound healing strategies.^{15,26} Brem and Lyder¹⁵ concluded that pressure relief and increasing blood flow are the 2 most important factors to consider when selecting support surfaces for patients being treated for PrUs. Previous studies^{20,21} showed that the cyclic pressure-relief protocol successfully addressed both of these factors. The protocol substantially reduced the pressure load at the ischia and, at the same time, significantly promoted tissue perfusion in the sitting area. In comparison to that of a clinical pressure-relief routine of arm push-up, these effects were significantly greater for the cyclic pressure-relief protocol. In fact, pressure load and tissue blood perfusion are related to each

other. It has long been accepted that the tissue blood flow is compromised when the externally applied sitting load exceeds a certain level and certain amount of time.²⁷ In the authors' previous study, tissue perfusion was found severely compromised as the sitting pressure increased and sustained.²¹ When the pressure was released, tissue perfusion started to recover. However, it would take the loaded soft tissue in the sitting area about 3 minutes' unloading time to recover from the sitting load-induced hypoxemia.^{21,28} In this case, pressure relief should last at least 3 minutes to achieve a full recovery of blood supply for the loaded tissue. The cyclic pressure-relief protocol in the authors' study was designed to maintain a significantly longer period for tissue unloading in the sitting area, which permitted a sufficient amount of time for tissue perfusion recovery. Moreover, the cyclic pressure-relief protocol used in this study was an individualized version of the laboratory protocol used in our previous studies, by incorporating an intelligent control mechanism. Previous protocol ran a fixed 10-minute by 10-minute loading/unloading cycle for all users with a back portion unloading at a fixed angle of 20 degrees. Current individualized protocol used contact sensors on the back portion of the seat to provide feedback to the controller to adjust the tilting angle of the back portion of the seat. This helped to ensure that the contact pressure between the ischia and the seat remained below the threshold of 15 mm Hg during the off-loading stage. In this way, the individualized cyclic pressure relief provided a substantially greater amount of pressure relief for each individual user, which is essential to achieve a better recovery of tissue blood flow.

Although there have been several pressure-relief seats for PrU patients, there is a lack of controlled clinical studies on objectively evaluating the effectiveness of these devices on PrU wound healing. Controlled clinical trials have been conducted for evaluating other support surfaces, such as mattresses, to help in wound healing.^{25,29,30} Findings showed that a dynamic alternating support surface halted the progression of established PrUs,¹⁵ and the air mattress significantly accelerated the PrU wound closure.²⁵ Clearly, these bed surfaces were found helpful for PrU wound healing, but a seating support surface that can achieve sufficient pressure relief yet maintain mobility during PrU wound care is essential to the quality of life for individuals with an SCI. By using a cyclic pressure-relief seating device, persons with an SCI who have existing PrUs will be able to sit and continue to heal, and even heal faster, while avoiding prolonged bed rest. Many pharmacologic interventions, such as wound dressings,³¹ growth factor synthesis,^{32,33} and human skin equivalents,³⁴ have been proposed for treatment of PrUs. None of them, however, have conclusively shown to be effective.²⁶ In addition, they can involve expensive and invasive surgical operation.

As a standard practice, bed rest is usually prescribed for the duration of treatment, which often lasts for months. Complications of prolonged bed rest, including cardiac deconditioning, loss of muscle mass, increased adiposity, loss of functional independence, and some other cognitive/psychosocial complications, frequently emerge.³⁵ Once a PrU is healed, the individual must spend additional time in rehabilitation to recover what was lost because of bed rest. Unfortunately, a high incidence of PrU recurrence exists, which may be related to the complications of prolonged bed rest. Developments in PrU management have concentrated on treatments and therapies, but little progress has been made in maintaining mobility for patients receiving PrU treatment. Therefore, an alternative strategy to allow a person with an existing PrU to heal without being confined to bed for months has the potential to significantly reduce the morbidity and cost associated with conservative PrU healing.

In the current study, the demographics were well matched between groups on age, sex, body mass index, the distribution of disabilities, and ASIA grades. The treatment group had a longer history of SCI, but the difference from the control group was not statistically significant. In addition, there were no significant differences between the 2 groups at the

start of the trial on any of the PrU-related measurements, which provided the evaluation a fundamentally unbiased comparison.

There are limitations for this study. First, the trial was relatively short in duration; therefore, only 1 participant achieved a 100% healing. PrU wound treatment usually lasts for months to years. Brandeis et al³⁶ found that 20% of PrU wounds were not healed or improved after 1 year of treatment. Thus, it would be difficult for the authors' 30-day trial to witness complete closure of the wounds. Second, the sample size of this study was relatively small, so data should be interpreted with caution when extrapolating to a larger number of population. Third, although the authors did not notice any perceivable changes in the pressure-relief behavior for the participants along the trial, they were unable to quantify the difference on pressure-relief behavior between the groups. Moreover, the additional cost for using the individualized cyclic pressure relief was not investigated. Additional cost could be associated with using a seating device equipped with the individualized cyclic pressure-relief function. Yet, if it helps to heal the PrU faster, maintains the patient's mobility, and reduces the time to heal the existing PrU wound, the additional cost can be well justified.

Conclusions

The current study rejects the null hypothesis that the PrUs would not take less time to heal when using an individualized cyclic pressure-relief protocol, compared with using a regular wheelchair cushion. Findings in this study suggest that the individualized cyclic pressure relief may have substantial benefits in accelerating the healing process in wheelchair users with existing PrU wounds. The authors' findings show that relieving pressure in the area of a wound can greatly aid wound healing.

Acknowledgments

This project was supported in part by National Institutes of Health Award no. R21 HD046844-01A1 and Falk Medical Research Trust. The authors thank Dr Christina Morton and Eileen French, RN, MSN, CRRN, for their generous help in screening participants.

References

1. National Spinal Cord Injury Statistical Center (NSCISC). Annual Report for the Model Spinal Cord Injury Care Systems. Birmingham, AL: NSCISC; 2005. Model Spinal Cord Injury Care Systems.
2. Panel on the Prediction and Prevention of Pressure Ulcers in Adults. Clinical Practice Guideline, No. 3. AHCPR Publication No. 92-0047. Rockville, MD: Agency for Health Care Policy and Research; 1992. Pressure Ulcers in Adults: Prediction and Prevention.
3. Brienza DM, Karg PE, Geyer MJ, Kelsey S, Trefler E. The relationship between pressure ulcer incidence and buttock-seat cushion interface pressure in at-risk elderly wheelchair users. *Arch Phys Med Rehabil* 2001;82:529–33. [PubMed: 11295017]
4. Hobson DA. Comparative effects of posture on pressure and shear at the body-seat interface. *J Rehabil Res Dev* 1992;29(4):21–31. [PubMed: 1432724]
5. Patterson RP, Cranmer HH, Fisher SV, Engel RR. The impaired response of spinal cord injured individuals to repeated surface pressure loads. *Arch Phys Med Rehabil* 1993;74:947–53. [PubMed: 8379841]
6. Reuler JB, Cooney TG. The pressure sore: pathophysiology and principles of management. *Ann Intern Med* 1981;94:661–6. [PubMed: 7235399]
7. Salzberg CA, Byrne DW, Cayten CG, et al. Predicting and preventing pressure ulcers in adults with paralysis. *Adv Wound Care* 1998;11:237–46. [PubMed: 10326341]
8. Staas WE, Cioschi HM. Pressure sores: a multifaceted approach to prevention and treatment. *West J Med* 1991;154:539–44. [PubMed: 1830985]

9. Thorfinn J, Sjöberg F, Lidman D. Sitting pressure and perfusion of buttock skin in paraplegic and tetraplegic patients, and in healthy subjects: a comparative study. *Scand J Plast Reconstr Surg Hand Surg* 2002;36:279–83. [PubMed: 12477086]
10. Kierney PC, Engrav LH, Isik FF, Esselman PC, Cardenas DD, Rand RP. Results of 268 pressure sores in 158 patients managed jointly by plastic surgery and rehabilitation medicine. *Plast Reconstr Surg* 1998;102:765–72. [PubMed: 9727442]
11. Gallagher SM. Outcomes in clinical practice: pressure ulcer prevalence and incidence studies. *Ostomy Wound Manage* 1997;43(1):28–32. 34–5, 38. [PubMed: 9087064]
12. Baranoski S. Raising awareness of pressure ulcer prevention and treatment. *Adv Skin Wound Care* 2006;19:398–405. [PubMed: 16943709]
13. The Joint Commission on Accreditation of Healthcare Organizations. Long Term Care National Patient Safety Goals. 2007 [September 25, 2009]. http://www.jointcommission.org/PatientSafety/NationalPatientSafetyGoals/07_ltc_npsgs.htm
14. Bogie KM, Nuseibeh I, Bader DL. Early progressive changes in tissue viability in the seated spinal cord injured subject. *Paraplegia* 1995;33:141–7. [PubMed: 7784116]
15. Brem H, Lyder C. Protocol for the successful treatment of pressure ulcers. *Am J Surg* 2004;188(1A Suppl):9–17. [PubMed: 15223496]
16. Kosiak M. Etiology of decubitus ulcers. *Arch Phys Med Rehabil* 1961;42:19–29. [PubMed: 13753341]
17. Henderson JL, Price SH, Brandstater ME, Mandac BR. Efficacy of three measures to relieve pressure in seated persons with spinal cord injury. *Arch Phys Med Rehabil* 1994;75:535–9. [PubMed: 8185445]
18. Reddy M, Gill SS, Rochon PA. Preventing pressure ulcers: a systematic review. *JAMA* 2006;296:974–84. [PubMed: 16926357]
19. Cullum N, Deeks J, Sheldon TA, Song F, Fletcher AW. Beds, mattresses and cushions for pressure sore prevention and treatment. *Cochrane Database Syst Rev* 2004;(3):CD001735. [PubMed: 15266452]
20. Makhsous M, Rowles DM, Rymer WZ, et al. Periodically relieving ischial sitting load to decrease the risk of pressure ulcers. *Arch Phys Med Rehabil* 2007;88:862–70. [PubMed: 17601466]
21. Makhsous M, Priebe M, Bankard J, et al. Measuring tissue perfusion during pressure relief maneuvers: insights into preventing pressure ulcers. *J Spinal Cord Med* 2007;30:497–507. [PubMed: 18092567]
22. Makhsous, M.; Patel, J.; Lin, F.; Hendrix, R.; Nam, E.; Bankard, J. Reduce skin temperature elevation using an alternating ischial support wheelchair. RESNA 27th International Conference; June 18-22, 2004; Orlando, FL. Edited
23. Stotts NA, Rodeheaver GT, Thomas DR, et al. An instrument to measure healing in pressure ulcers: development and validation of the Pressure Ulcer Scale for Healing (PUSH). *J Gerontol A Biol Sci Med Sci* 2001;56A(12):M795–9. [PubMed: 11723157]
24. Haghpahan S, Bogie K, Wang X, Banks PG, Ho CH. Reliability of electronic versus manual wound measurement techniques. *Arch Phys Med Rehabil* 2006;87(10):1396–402. [PubMed: 17023252]
25. Ferrell BA, Osterweil D, Christenson P. A randomized trial of low-air-loss beds for treatment of pressure ulcers. *JAMA* 1993;269:494–7. [PubMed: 8338511]
26. Cannon BC, Cannon JP. Management of pressure ulcers. *Am J Health Syst Pharm* 2004;61(18):1895–905. [PubMed: 15487879]
27. Bader DL. The recovery characteristics of soft tissues following repeated loading. *J Rehabil Res Dev* 1990;27:141–50. [PubMed: 2366198]
28. Coggrave MJ, Rose LS. A specialist seating assessment clinic: changing pressure relief practice. *Spinal Cord* 2003;41(12):692–5. [PubMed: 14639449]
29. Allman RM, Walker JM, Hart MK, Laprade CA, Noel LB, Smith CR. Air-fluidized beds or conventional therapy for pressure sores. A randomized trial. *Ann Intern Med* 1987;107(5):641–8. [PubMed: 3310792]
30. Munro BH, Brown L, Heitman BB. Pressure ulcers: one bed or another? *Geriatr Nurs* 1989;10:190–2. [PubMed: 2777121]

31. Calianno C. How to choose the right treatment and dressing for the wound. *Nurs Manag (Harrow)* 2003;12–4.
32. Landi F, Aloe L, Russo A, et al. Topical treatment of pressure ulcers with nerve growth factor: a randomized clinical trial. *Ann Intern Med* 2003;139:635–41. [PubMed: 14568851]
33. Robson MC, Phillips TJ, Falanga V, et al. Randomized trial of topically applied repifermin (recombinant human keratinocyte growth factor-2) to accelerate wound healing in venous ulcers. *Wound Repair Regen* 2001;9(5):347–52. [PubMed: 11896977]
34. Brem H, Young J, Tomic-Canic M, Isaacs C, Ehrlich HP. Clinical efficacy and mechanism of bilayered living human skin equivalent (HSE) in treatment of diabetic foot ulcers. *Surg Technol Int* 2003;11:23–31. [PubMed: 12931279]
35. Norton L, Sibbald RG. Is bed rest an effective treatment modality for pressure ulcers? *Ostomy Wound Manage* 2004;50(10):40–52. [PubMed: 15509881]
36. Brandeis GH, Morris JN, Nash DJ, Lipsitz LA. The epidemiology and natural history of pressure ulcers in elderly nursing home residents. *JAMA* 1990;264:2905–9. [PubMed: 2232085]

Figure 1. Typical Progress of Pressure Wound Healing

Top row: A patient with a pressure ulcer who used a regular wheelchair (control). A, Day 1. B, Day 16. C, Day 32. Bottom row: A patient with a pressure ulcer who was in the treatment group and used a cyclical pressure-relief protocol. D, Day 1. E, Day 15. F, Day 31. Wound size and appearance can be assessed relative to the target plate.

Figure 2. Cumulative Probability for 30% Wound Area Closure Along the Trial Time for Both the Control and the Treatment Groups

Table 1
Descriptive Statistics^a for Participants in the Control and the Treatment Groups

	Control (N = 22)	Treatment (N = 22)	Chi-Square Significance for Group Difference	t-test Significance for Group Difference
Age (year)	44.5 ± 15.1	42.4 ± 16.6	–	>0.05
BMI (kg/m ²)	25.2 ± 7.1	25.2 ± 6.7	–	>0.05
Years on SCI	3.9 ± 2.9	6.1 ± 6.6	–	>0.05
Sex			>0.05	–
Female	2	1		
Male	20	21		
Disability			>0.05	–
Paraplegia	9	10		
Tetraplegia	13	12		
ASIA			>0.05	–
A	12	11		
B	10	10		
C	0	1		

Abbreviations: ASIA = American Spinal Injury Association; BMI = body mass index; SCI = spinal cord injury.

^aValues are presented as mean (SD).

Table 2
Pressure Ulcer Data^a for the Control and the Treatment Groups

	Control (n = 22)	Treatment (n = 22)	Significance for Group Difference (χ^2 Test)	Significance for Group Difference (<i>t</i> Test)
Months of PrU entering the trial	9.5 $\pm$ 5.3	7.0 $\pm$ 5.0	—	>.05
PrU Stage entering the trial			>.05	—
Stage II	9	12		
Stage III	13	10		
Wound area entering the trial, mm ²	1672.4 $\pm$ 1938.0	1745.8 $\pm$ 1324.9	—	>.05
Wound area ending the trial, mm ²	1586.8 $\pm$ 1865.0	1094.5 $\pm$ 1056.8	—	>.05
Wound area closure, mm ²	124.9 $\pm$ 520.0	785.0 $\pm$ 744.0	—	<.001
Wound area closure rate, mm ² /day	2.3 $\pm$ 20.4	21.7 $\pm$ 14.6	—	<.001
Wound PUSH score entering the trial	12.8 $\pm$ 2.3	12.9 $\pm$ 2.0		>.05
Wound PUSH score ending the trial	12.1 $\pm$ 2.5	10.5 $\pm$ 3.7	—	.038
Wound PUSH score improvement	0.7 $\pm$ 1.1	2.5 $\pm$ 2.3	—	.001

Abbreviations: PrU = pressure ulcer; PUSH = Pressure Ulcer Scale for Healing.

^aValues are presented as mean (SD).

Wound Healing Outcomes

Table 3

		Log-Rank (Mantel-Cox)		
		Control (n = 22)	Treatment (n = 22)	χ^2 Significance <i>t</i> Test Significance
30% area closure:				
Number achieved	8	16		
Median time to achieve, day	>30	25.0 (2.9)	7.260	.007 —
Percentage area closure	10.2 (34.9)	45.0 (21.0)	—	— <.001
Percentage PUSH score improvement	5.8 (9.2)	21.9 (24.6)	—	— .003

Abbreviation: PUSH = Pressure Ulcer Scale for Healing.

Wound healing outcomes measured by the median healing time for 30% closure of wound area, the average [mean (SD)] percentage reduction in wound area, and the average percentage improvement of the PUSH scores for the 2 groups of participants during the 30-day trial.