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Seating-Related Pressure Injury Prevention in Spinal Cord Injury: A Review of Compensatory Technologies to Improve In-Seat Movement Behavior

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Structured Abstract

a) Purpose of review—The purpose of this review was to (1) assess the factors related to the occurrence of pressure injuries in people with a spinal cord injury (SCI), (2) review methods of pressure injury prevention, and (3) examine compensatory technologies developed to promote in-seat movement to reduce the risk of pressure injuries.

b) Recent findings—Risk factors for seating-related pressure injuries are well documented, yet, ulceration remains a daily concern for individuals with SCI. While prompts and alarms have been shown to be effective at increasing in-seat movement, the devices thus far were not designed for long-term use. Wheelchair users will benefit from continued development of novel technologies designed to help them self-manage pressure injury prevention.

c) Summary—Optimized feedback about pressure and movement will help wheelchair users with SCI perform more effective movements to relieve pressure, perform movements more frequently and consistently, and maintain effective and frequent movement behaviors over time while feedback is available.

Keywords

pressure ulcers; assistive technology; spinal cord injury; ulcer prevention; weight shifts; wheelchair users

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Conflict of Interest

Tamara L. Vos-Draper and Melissa M. B. Morrow declare that they have no conflict of interest

Human and Animal Rights and Informed Consent

This article does not contain any studies with human or animal subjects performed by any of the authors.

INTRODUCTION

In the United States, approximately 282,000 individuals have a spinal cord injury (SCI), and 17,000 new SCIs occur annually [1]. The top three secondary conditions associated with SCI include genitourinary complications, respiratory conditions, and seating-related pressure injuries, which may be accompanied by infections including septicemia. Infections due to pressure injuries are second to pneumonia for cause of death in individuals with SCI [1, 2]. The National Pressure Ulcer Advisory Panel recently updated their terminology and “pressure injury” now replaces the term “pressure ulcer”.[3]

Pressure injuries involve localized damage “to the skin and/or underlying tissue usually over a bony prominence, as a result of pressure, or pressure in combination with shear.” [4] Individuals with SCI who use wheelchairs for mobility spend the majority of their time sitting, putting them at risk for pressure injuries at the ischial tuberosities (ITs), coccyx, sacrum, and greater trochanters. Pressure injury risk is highly individual and based on many unique factors. Thus, any approach toward prevention needs to be relevant and customizable to each person’s needs. There are several mechanistic or biomechanical factors that lead to the breakdown of the tissue that are common to many forms of pressure injuries. Additionally, there are several features particular to the SCI population that play a role both in the effects of the biomechanical factors and the cueing stimuli that are integral to the body’s attempts to change the tissue’s environment and prevent ulceration.

A key component to prevent pressure ulcer development is education to minimize pressure under the sacral, ischial, sacral and coccygeal areas [5–7]. Weight shifts are movements that change pressure distribution and can mitigate harmful magnitudes and durations of pressure that accumulate under areas of the skin that are most at risk for pressure ulceration. These weight redistributing movements occur when an individual leans forward or laterally as well as through use of power seat functions such as tilt or recline. Skin health in SCI requires persistent attention to a specific set of behaviors on a daily basis, including frequent weight shifts to offload pressure between the buttocks and seat cushion of the wheelchair. Effective self-management strategies are needed to facilitate consistent daily engagement in use of weight shift maneuver with the ultimate goal to reduce pressure ulcer risk. Sustaining attention on weight shifts when there is a lack of sensation to provide a natural cue to move is a challenge in wheelchair users with SCI. There have been many attempts to facilitate increased engagement in performing weight shifts through use of technology over the past few decades. [8]

The purpose of this article was to assess the biomechanical factors related to the occurrence of pressure injuries in people with SCI, briefly review methods of pressure injury prevention through in-seat movement including clinical guidelines, and examine the history of compensatory technologies developed to promote in-seat movement to reduce the risk of seating-related pressure injuries. The key elements to reducing risk are (1) understanding factors that contribute to ulceration, (2) the technical ability to measure these factors, as well as (3) the ability to use these measurements to impact users and mitigate risk of ulceration.

FACTORS RELATED TO THE OCCURRENCE OF PRESSURE INJURIES

Several biomechanical factors contribute to the physiological manifestation of a pressure injury: pressure, shear, moisture, temperature, internal versus external forces, capillary flow and oxygenation at skin and tissue, and tissue tolerance. The interplay of these factors defines the relationship between mechanical pressure and an individual's physiological tolerance for pressure [9].

Pressure

Pressure is caused by compressive force applied at an individual's skin. The effect on the skin and underlying tissues is based on both the magnitude of the force and the loading time [10]. Both high pressure for short durations and low pressure for long durations can result in tissue damage. Pressure can be directly altered through equipment choices, positioning options, and by movement-related strategies aimed to reduce duration and magnitude of pressure when sitting.

Tissue tolerance for pressure

Tissue tolerance to pressure depends on individual intrinsic factors such as nutritional status, hydration, degree of atrophy, shape of underlying bones, and posture [9]. It is well-established that individuals with SCI have a lower threshold to pressure compared to neurologically normal individuals due to changes in muscle tone, muscle bulk, and bone shape [11, 12].

Tissue tolerance for oxygen

Tissue tolerance for oxygen is impacted by physiological characteristics such as skin temperature, use of medications, tobacco abuse, and other diseases such as diabetes [9]. Some of the factors affecting tissue tolerance threshold and oxygen can be remediated through medical and lifestyle changes. While not all of these factors are modifiable, for those that are, each mediated factor tips the scale favorably for an individual's tissue tolerance to prolonged or higher seat interface pressure.

Sensing the need to move

Sustaining attention on movement when there is a lack of sensation to provide a natural cue to move is a challenge in wheelchair users with SCI. Permanently impaired or absence of sensation on the buttocks means that the protective feedback loop alerting one to move is absent. Additionally, there is little or no sense of relief from discomfort experienced with pressure offloading. Wheelchair users must maintain constant attention on the need to reduce pressure across areas at risk. A number of personal, social, and environmental factors may deter one's focus from completing pressure relief maneuvers. Thus there is a clear need for effective strategies that provide essential feedback to prompt the need to move, devices to train someone to move frequently, alert a wheelchair user to a problem with seating equipment, or to affirm that weight shifts were effective in redistributing pressure. Feedback should be provided in a way that is motivating and engaging over time.

Quality of movement

Evidence exists about the quality and quantity of movement as a protective factor, but with some discrepancies. Differences exist between how individuals with and without SCI typically move when sitting which may further confound the understanding of what may constitute a protective level of movement.

IN-SEAT MOVEMENT AS PREVENTION

Clinical Guidelines

Prior to mid-1990, it was recommended that individuals with SCI complete a full pushup every 10–15 minutes and hold for at least 5 seconds. Over time, clinical guidelines have shifted away from recommending pushups due to risk of repetitive strain injuries at the shoulders. New guidelines recommend leaning forward or laterally, or using power seat functions such as tilt and recline. Currently the consensus is that weight shifts should occur every 15–30 minutes and last for 1–2 minutes each time [4, 7, 13]. Weight shifts and visual inspection of the skin each day are two recommendations specifically targeted toward management of seated pressure for wheelchair users.

Self-reported and Objectively Measured Movement

According to studies by Reenalda, et al. (2009), Yang, et al. (2009), and Chenu et al. (2013), in comparison to individuals without neurological injuries who shift weight 6–10 times per hour [14], individuals with SCI perform pressure reliefs, of at least 5 seconds, 4–7 times per 10 hour day [15, 16]. These studies show that pressure reliefs are being performed at a frequency of less than 1 relief per hour. In a survey of 200 community-dwelling wheelchair users, of which 34% had SCI, 80% self-reported being physically capable of completing weight shifts to relieve pressure, but only 54.7% reported that they actually completed weight shifts every hour or more [17].

Correlating Movement and Pressure Injuries

In a recent systematic review, the investigators attempted to tease out specific protective factors for pressure injury prevention not specific to seating-related pressure injuries [18]. Thirty-six of the 54 studies concluded that in-seat movement was as an outcome measure related to pressure injury prevention. Twenty-nine of these studies concluded a significant association exists between increasing movement overall and a reduced risk for developing a pressure injury. While identifying specific movements, how much, and for how long was not possible due to the varied protocols in the studies, the results are clear that increased movement has a protective impact on reducing risk for pressure injuries.

Conversely, in a survey of 633 community-based individuals with SCI and a history of at least one pressure injury, there was no statistically significant correlation between completion of weight shift maneuvers on a scale of “never, sometimes, regularly, and daily” and reduced risk of recurrence [19]. Similarly, in a survey of 472 community-based individuals with SCI, no correlation was found between self-reported frequency of weight shifts (defined as regularly lifting at least once per hour) and reduced pressure injury prevalence [20]. A very important distinction is that both surveys relied on subjects’ self-

report of completion of weight shifts and didn't ask about specifics about weight shift type, duration, or frequency within a typical day. Self-report has significant limitations as an outcome measure in general, which is a trade-off to the convenience offered in obtaining information from large samples.

Two important conclusions from existing studies on what type of movements are effective in redistributing pressure are: 1) the percent change in pressure is directly proportional to magnitude of movement, and 2) even small movements can result in a significant reduction in pressure at highest risk bony areas [21–26]. While these conclusions do not provide prescriptive magnitudes, frequencies, or durations of movement, or there appears to be evidence of an inverse correlation between percentage of pressure redistribution and pressure ulcer incidence. Thus, we can conclude that movement is a viable outcome of interest to target with an intervention.

COMPENSATORY TECHNOLOGIES TO PROMOTE IN-SEAT MOVEMENT

In-seat Movement Training Strategies using Technology

In Table 1, a historical timeline of technologies that have been developed since 1968 is presented that show past efforts to monitor and elicit change in sitting behavior, or train a wheelchair user to perform weight shifts. All 15 of the devices presented in Table 1 were intended to have an impact on pressure injury reduction in manual and power wheelchair users. For almost 50 years, clinicians and researchers have been interested in devices to monitor pressure, weight shifts, send alerts, provide cues, or track movement patterns in wheelchair users. We are now in an era of technological advancement that allows large amounts of data to be collected and analyzed almost instantly and then displayed on a smartphone, which about 75% of wheelchair users will SCI carry [1]. This advancement in technology provides new opportunities to revisit use of feedback to encourage movement.

Applied behavior interventions for pressure injury prevention in SCI have included the use of auditory, visual, and tactile prompts as antecedents (stimulus to cause a desired behavior, alarms as negative consequence, and verbal/written feedback and monetary awards as positive consequences to cause change in behavior). The feedback in the technologies reviewed here within were provided in varying ways: verbally, printouts of logged data, use of alarms, prompts provided through visual, auditory, or tactile delivery methods (Table 2).

Antecedent: Prompts

Prompts to cue weight shifts or pressure reliefs have been implemented in devices with watches, timers, and LED indicators [8, 27–29]. In a study from 1979, a pressure relief-training device was developed with 10 participants with acute SCI prior to discharge from inpatient rehabilitation [8]. The purpose of their device was to train individuals to complete push-ups as recommended without reminders. Training included use of an LED prompt and an alarm. The device consisted of a pressure-sensing mat placed between the individual and his wheelchair cushion and a data logger that tallied the number of push-ups and push-up error (defined as not holding for required 20 seconds) events. The recommended frequency/duration of push-ups was every 10 minutes for 20 seconds. Every 10 minutes, an LED light

(the prompt) on the armrest of the wheelchair would light up to remind the participant to complete a pushup. If a push-up occurred during any 10-minute period, the timer would reset at 0. If the pressure sensor detected no movement for a full 10 minutes, the LED would turn on again as a reminder.

In 1985, Merbitz, et al. studied 7 participants with acute SCI with a pressure map with attached data logger each day while in the hospital [27]. While the intent of the system was to provide information to rehabilitation staff on patient adherence to their recommendations, the staff used the printouts to provide individualized suggestions to help each participant work toward improved adherence. For two of the participants, the staff decided to implement use of a timer as a prompting device as an intervention to correct specific problems with timing of pushups. The timer emitted a soft beep every 30 minutes to remind participants to complete a push-up.

White, Mathews, and Fawcett (1989) evaluated push-up adherence using a combination of prompts and alarms in two children with spina bifida [28]. The device used was similar to the one described in Chawla et al. (1979) study, consisting of a pressure sensing mat, small computer data logging system, but included use of auditory prompts through a wrist-watch. Push-up frequency was measured as the percentage of 30-minute intervals that at least a 3 second push-up was performed. For participant 1, push-up frequency at baseline averaged 23% and with use of prompt the average increased to 65%. For participant 2, push-up frequency at baseline averaged 22%, and with use of the prompt the average increased to 38%. Both participants returned to baseline averages when the prompt was removed and this occurred multiple times, providing strong evidence that the prompt can be attributed as the factor that facilitated an increase in push-up frequency.

In a study with long-term follow-up published in 1992, 16 adult patients with SCI leaving the hospital after a pressure injury surgical repair were provided with a watch that had variable settings that the participant could use to set audible reminders to complete pressure reliefs [29]. The user when desired could turn off the prompt. Despite careful attention to device acceptance, seven participants chose to not use the watch upon returning home. After one year, seven participants continued to use the watch, and six participants who used the watch remained seating-related pressure injury-free throughout the follow-up period.

In all of the studies presented that used prompting to impact completion of push-ups or weight shifts, there was an increase in movement while the prompts were used. When the prompts were removed, the frequency declined. These examples provide support that prompts used as a compensatory strategy for absent sensory stimuli are effective in increasing movement.

Consequences: Alarms

In contrast to prompts used to remind individuals to perform a task, alarms are meant to be aversive. The intent of alarms has historically been for participants to prevent the alarm from sounding by completing the required weight shift (push-up or lean). Alarms were used in four of the studies in Table 2 [8, 28, 30, 31]. Two of the four studies also used prompts, and were discussed in the previous section [8, 28].

Malament, Dunn, and Davis (1975) utilized a simple pressure sensing pad with alarm under 5 participants with acute SCI in a rehabilitation center with intent to train a habit of completing push-ups every 10 minutes [30]. If a participant sat for >10 minutes without a push-up, the alarm would begin and it would remain on for 30 seconds unless the participant initiated and held a push-up for at least 4 seconds. If the participant sat down too soon, the alarm would resume and continue until a push-up of at least 4 seconds occurred. The participants could avoid the alarm by completing push-ups within 10 minutes, which would reset the timer to 0. The intent of this device was for training newly injured individuals. No prompt was given, so the participants needed to stay focused on completing push-ups to avoid the alarm. Two participants completed the study, and both individuals had strong improvement in push-up completion with use of alarm avoidance.

Yang, Chou, Hsu, and Chang (2010) studied 20 community-dwelling individuals with SCI using a pressure sensing mat between the individual and their seat cushion to detect weight shifts and an alarm if a weight shift did not occur within the set time. The sensor data was read every 10 seconds. During the intervention phase, weight shift average was 12.3 (SD 9.76) per day ($p=.01$). These results provide evidence that alarm avoidance was effective in increasing weight shift adherence. White, et al. (1989) implemented a combination of prompts and consequences that were effective in increasing movement [28]. The alarm sounded if a 3 second push-up within the last 30-minute period was not detected by the pressure sensors. The alarm sounded for 6 full seconds and was very loud, 86dB. The alarm could not be disarmed by immediately completing a push-up but could be avoided by completing a pushup before 30 minutes elapsed.

Other Feedback used to Change Behavior

In two of the studies (Table 2), feedback was provided to the participants either verbally or through printed charts of prior performance with intent to use the information to shape future behavior [27, 32]. Carr and Wilson (1983) presented a single case report of an individual with acute SCI learning to complete push-ups during inpatient rehabilitation. The investigators compared baseline periods during which the subject was observed for frequency of push-ups with intervention periods when daily printed reports about movement frequency were verbally reviewed with the participant about his previous day's performance. They observed an increase in push-up frequency when verbal feedback was provided, even with the one-day delay in providing the feedback. The participant took over reviewing his own printouts after 2 months of receiving verbal feedback and continued to use the information to self-monitor his performance. Merbitz et al. (1985) used daily printouts from a data logging device with 7 participants to individualize the education and intervention provided by the therapists and nurses to encourage successful adherence to weight shifting recommendations. The staff presented weekly summaries of the prior week's weight shifting performance to the participants and then worked on the weak areas together with the participant to improve performance.

Decay of prevention behaviors

Decay of prevention behaviors results in a decline in using prevention strategies over time. Despite how well an individual understands the need to change position frequently, as other

demands are placed on an individual, the attention on weight shifting behavior deteriorates over time. Individuals with SCI lack the normal sensory feedback that stimulates the need to move when pressure accumulates. Prevention behaviors that aren't paid attention to through conscious awareness and effort are difficult to maintain, especially if the stimulus is lacking.

The next stages of technology

The devices reviewed here were not designed for long-term use as compensatory strategies for lack of sensation. Despite the technology and design limitations, the results showing positive effects on movement with use of prompts and alarms can help shape future strategies. Smartphones are extremely capable devices that could facilitate behavior-shaping strategies. For example, a recently developed intervention, the Virtual Seating Coach uses smartphone technology combined with motion sensors on power wheelchair seat actuators to provide individualized reminders and feedback to the user regarding tilt and recline use over time [33]. Additional technologies, such as activity monitors combined with seat interface pressure mapping (IPM), could produce powerful behavior change drivers through real-time, immediate information about the need to shift weight or about the effectiveness of a weight shift when it is done. Our team is interested in how visual feedback provided on a smartphone about seat interface pressure distribution impacts weight shift performance in manual and power wheelchair users. Smartphone technology presents exciting opportunities to create novel interventions to help individuals with SCI more effectively manage their own risk factors. When considering use of these technologies, including the addition of prompts or alarms, it will be important to understand possible barriers to acceptance of such a system. For this reason, developers should include wheelchair users in the design and testing process of new interventions.

CONCLUSIONS

Individuals with SCI not only move differently than non-SCI individuals, they also lack an important sensory feedback loop that provides natural prompts and consequences that protect skin from too much pressure. The literature reviewed spanned a range of small sample size case series to more robust, repeated-measures interventions. Despite the varied study designs, the potential positive effect of compensatory feedback was significant. Wheelchair users will benefit from continued development of novel strategies designed to help them self-manage pressure injury prevention. Success of these strategies should be assessed with methods guided by a health behavior change approach. Optimized feedback about pressure and movement will help wheelchair users with SCI perform more effective movements to relieve pressure, perform movements more frequently and consistently, and maintain effective and frequent movement behaviors over time while feedback is available.

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Table 1**Timeline and Progression of Technology Aimed at Development of Pressure Monitors**

Author(year)	Device	Purpose	Criteria	Comments
Fordyce & Simons, 1968 [34]	Push-up training device with alarm	Train users to avoid alarm by completing pushups before time runs out and to hold pushup for duration.	Adjustable 10 or 20 min frequency and 5–10 second duration; alarm sounds at end of time period. Push-up stops alarm. Alarm sounds if duration is not held.	Goal: wean from device Outcomes: counts # of pushups with/without alarm, # held for duration or not.
Roemer, Lee, & Meisel, 1976 [35]	Warning device with reminders training aid	Designed for use by those with tetraplegia and monitors leans instead of pushups	LED on armrest flashes R or L as prompt for leans; adjustable volume alarm if no lean after initial prompt. Adjustable frequency 2–30 minutes and duration 10–60 seconds. LED stays on until duration is finished.	Goal: wean from device. Doesn't provide feedback on behavior over time, but provides a visual prompt and auditory alarm consequence.
Temes & Harder, 1977 [36]	Device for training those with new SCI	Patient training in adherence schedules	Pressure sensing pad and timer. Adjustable to 15, 30, or 60 minutes frequency and between 5–60 seconds duration. If no pushup by designated time, then adjustable volume alarm.	Goal: wean from device and retain behaviors. Outcomes: # weight shifts AND # of buzzers for day.
Patterson & Fisher, 1980 [37]	Monitor pressure relief patterns	Patient monitor for adherence	Pressure sensors under ischial tuberosities with 7-hour recording time capability.	2 pressure sensors counts all offloads of >1 sec as a pushup
Werner & Perkash, 1982 [38]	Detection of loss of air in air-filled seat cushion	Alert device for cushion failure	Pressure sensing pad between cushion and wheelchair sling. If pressure increased to 50mmHg, an alarm was triggered.	An early attempt to solve the problem of deflating air cushions. No follow up studies located to determine if this was effective.
Fisher & Patterson, 1983 [39]	Monitor pressure relief patterns in w/c users	Caregiver monitoring of patient adherence	Pressure sensors under ischial tuberosities only. Measured time between pushups >1 second and >5 seconds.	Push up occurrence determined by a 10mmHg drop in average pressure
Cumming, Tompkins, Jones, & Margolis, 1986 [40]	The Wheelchair Patient Monitor	Device incorporates alarms and stores performance records	Pressure sensing pad and microprocessor checks weight shifts every second and monitors duration of detected shifts. A prompt alerts the user when time to shift weight. Author focused on making the setting adjustable for individualization of programming.	If meeting criteria for duration/freq, then weight shift is counted.
Grip & Merbitz, 1986 [41]	Timer Logger Communicator	Training device for completion of push-ups	Pressure sensors detect reduced overall pressure and define as pushup if of >5 sec durations; printed logs provided to w/c user for review of trends and past behavior. Prompts provided based on time, and are LED or audio. Alarms also optional as LED or audio.	More thought going into design of prompting strategies for improved user buy in. Still limited by technology capabilities of the era. Feedback not provided immediately.
Bain & Ferguson-Pell, 2002 [42]	Device to monitor remote sitting behaviors	Identify patterns of sitting behavior in w/c users. Intended for research.	Mini pressure logger. No feedback provided to user. Device “woke up” every 5 seconds to record pressure and processed sensor readings to look for changes over time of at least 10%. If values close to zero for total across mat, then indicates full pushup and counts as 1 pushup. Center of pressure to determine symmetry of sitting	Technology still bulky, cumbersome and requiring frequent clinician/ researcher interaction so difficult for uninterrupted long term monitoring. No feedback provided to wheelchair users.

Author(year)	Device	Purpose	Criteria	Comments
Wilson, et al., 2004 [43]	Mobile Activity Monitor	Track weight shifts with visual feedback to wheelchair user	Wireless; 4 force sensors and blackberry pager. Ratio of pressure between sensors used to determine weight shifts side to side and front/back. Flower design with petals with lengths corresponding to frequency of weight shifts throughout the day shown via visual screen display.	First device of this type to utilize stronger visual feedback about pressure and completion of weight shifts with trend data for a full day at a time. Also, authors were first to indicate the need to use different sensor configurations depending on type of wheelchair cushion used, with realization that patterns of pressure distribution differ across major categories of cushion types.
Brizzi et al, 2008 [44]	“Auto-RRT” provides cues to perform pressure relief maneuvers	Training device with goal of reducing need for healthcare worker providing reminders	Prompts every 15 minutes to perform 15 second pressure relief. Auditory and visual feedback prompts can be self-selected by user	Goal: improve patient compliance, reduce healthcare provider burden
Y.S. Yang et al., 2009 [16]	Data logger for detecting sitting behaviors remotely	Describe sitting behavior through long term monitoring in wheelchair users	Data logger with 6 pressure sensors (4 in back, 1 under each thigh). Ratios used to determine weight shifts side to side and front/back. When sum of pressure reached 0, indicates out of chair.	Data processing limitations; by collecting only 1 frame every 10 seconds, may miss small but important weight shifts.
Eneling et al., 2009 [45]	Bluetooth enabled pressure monitor	Monitor seated pressure, provide alerts	64 pressure sensors; alarm signals user when “dose” of pressure has reached designated critical level (not defined in the descriptive paper); feedback provided to user about weight shift adherence. Use of an initial clinical fitting to create an individualized baseline to compare future sessions with.	Technology capability is improving, but still the live pressure sensor information is not provided visually to give immediate feedback.
Verbunt & Bartneck, 2010 [46]	Sensing mat with multiple biofeedback modes	Determine if tactile or audio feedback is more effective in a system designed to affect posture/position	Use of a commercial mat, microcomputer and chest belt with vibration. Chest belt vibrates on side of body person needs to move toward for optimized posture, based on sensor readings from pressure mat.	Authors tested this with healthy adults. Small difference in reaction time with use of tactile feedback (less than 1 second difference) compared with audio feedback. Tactile may be more desirable because it is discrete, but it's not necessarily more effective. No visual feedback was used in this project.
Chenu et al., 2013 [15]	Pressure mat with smartphone visual display and audio/tactile feedback to user using a watch	Device intended for home use by individuals at risk for pressure injury to self-monitor live pressure and to receive feedback in form of prompts and alarms when needed.	Wireless technology utilized. Smartphone used. Live pressure feedback to user.	Author developing alerts, alarms. Indicated plan for testing device with more subjects in 2013, no studies found to date as follow up.

Notes: The progression of technology is evident in this chart as it relates to our ability to discreetly and objectively observe sitting behavior and movement in wheelchair users for longer periods of time and in a variety of environments.

Table 2**Effectiveness of Behavior Shaping Via Feedback for Pressure Relief Adherence**

Author(year)	Sample	Design/Methods	Outcome/comments
Malament, 1975 [30]	N=5 SCI with history of pressure ulcer	Within subject repeated design, 3 phases. Phase 1: count of pushups, no feedback. Phase 2: Loud alarm if no pushup in designated time. Phase 3: count of pushups, no feedback. Subjects told to prevent the alarm from sounding by completing pushups. Stability criterion used to determine when each phase should be stopped.	Alarm used as aversive stimuli with goal that subject would attempt to avoid it. Alarm shown to increase both consistency and frequency of pushups. *Alarm improved performance while it was present
Chawla, 1979 [8]	N=10 with paraplegia	Within subject repeated design, 4 phases. Phase 1: count of pushups, no feedback to user. Phase 2: LED prompt and alarm turned on. Count of pushups. Phase 3: Alarms/LED deactivated, count of pushups. Phase 4: Follow up at 3 months, no feedback, count of pushups. Subject asked to prevent alarms from sounding by watching LED for reminder and then completing pushups.	Use of LED reminder: 9 of 10 subjects increased consistency, frequency, and duration of pushups. There was dependence on the LED prompt in avoiding alarm indicated by return to high error rates in Phase 3. At follow up, errors in frequency and duration increased without use of feedback. *Prompt improved performance while it was present
Carr, 1983 [32]	N=1 with SCI and pressureulcer	Single case report. Baseline phase: pushups counted, no feedback. Intervention phase: Verbal feedback on pressure relief behavior (completion of pushups) provided with 1-day delay. Used printouts of pressure map and data logger. Therapist provided reward in form of positive comments depending on daily performance. Thinning of intervention: reduced frequency of feedback. Self-monitoring occurred at 2 months (subject reviewed his own printouts.)	More pushups per hour observed when feedback was provided, even with one-day delay of feedback. *Verbal reinforcement effective while used
Merbitz, 1985 [27]	N=7, new SCI injuries in acute rehab	Printouts from pressure map and data logger for each patient daily; weekly feedback about performance given to subjects by nurse. Nurse used printout data to determine how to individualize training approach. Approaches thus differed among subjects. Timer introduced (prompt) for two subjects to improve frequency or consistency of pushups.	For the two subjects who used a timer as a prompt to complete pushups, frequency and consistency improved while timer was used. *While prompts were used, movement increased
White, 1989 [28]	N=2 children with spinabifida	Within subject, multiple baseline design. Periods of baseline (count of pushups, no feedback) alternated with use of either a reminder beep (prompting) or an alarm (alarm avoidance) if no pushup occurred in allotted time. Follow up phase one month after completion of study measured pushups, no feedback.	Pushup frequency increased with both use of the prompt and with the alarm, but increased the most when both were used for both subjects. Performance declined at follow up when device was deactivated. *Prompt AND alarm together more effective than separately, when used.
Bridle, 1992 [29]	N=16 with SCI; all with surgical repair for pressure ulcer leaving hospital	All subjects provided with a watch as prompting device for completing pushups. Cohort followed for mean of 27 months after dismissal for presence of any new pressure ulcer.	7 subjects still used watch prompts at end of study. 7 abandoned it immediately. No info on remaining 2 on watch use. 50% had skin breakdown, however the distribution is skewed toward ulcers occurring in those who did not use prompting. 6 of 8 with intact skin had used the watch prompts consistently. *Indication that use of prompts in daily routine can be protective against pressure ulcers
Yang, 2010 [31]	N=20 with SCI living in community	Within subject, repeated design with baseline and intervention phases. Baseline: sitting behavior (pushups and leans) monitored with pressure sensors, no feedback. Intervention: Alarm (audio	Significant increase in pushups and leans with use of alarm compare to baseline. *Use of alarm improved frequency/consistency of pushups and leans

Author(year)	Sample	Design/Methods	Outcome/comments
		feedback) provided if weight shift not detected.	

Notes: The studies shown in this table used within-subject multiple baseline designs to determine the individual's responses to use of feedback for completion of pushups or leans to reduce sitting pressure. All of the studies used subjects with spinal cord injury who use wheelchairs. All of the studies reported an increase in frequency, consistency, or duration of pushups or leans when a prompt or alarm-avoidance system was being used and return toward poorer performance when the feedback was removed.