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# Assessing evidence supporting redistribution of pressure for pressure ulcer prevention: A review

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**Abstract—**The formation and underlying causes of pressure ulcers (PUs) are quite complex, with multiple influencing factors. However, by definition pressure ulcers cannot form without loading, or pressure, on tissue. Clinical interventions typically target the magnitude and/or duration of loading. Pressure magnitude is managed by the selection of support surfaces and postural supports as well as body posture on supporting surfaces. Duration is addressed via turning and weight shifting frequency as well as with the use of dynamic surfaces that actively redistribute pressure on the body surfaces. This article shows that preventative interventions must be targeted to both magnitude and duration and addresses the rationale behind several common clinical interventions—some with more scientific evidence than others.

**Key words:** body posture, clinical interventions, postural supports, pressure magnitude, pressure ulcers, prevention interventions, support surface, tissue loading, turning frequency, weight shifting frequency, wheelchair.

## INTRODUCTION

The formation and underlying causes of pressure ulcers (PUs) are quite complex, with multiple influencing factors. However, by definition PUs cannot form without forces, or pressure, on tissue. Because tissue loading is the defining characteristic of PU formation, it naturally garners significant attention in research in PU prevention strategies.

Research has clearly demonstrated that the damaging effects of pressure are related to both its magnitude and duration. Simply stated, tissues can withstand higher loads for shorter periods of time. Kosiak first demonstrated this characteristic 50 years ago by applying varying loads to the trochanters and ischial tuberosities of dogs for varying periods of time [1]. High loads for short durations and low loads for long durations induced ulcers, with the time-at-pressure curve following an inverse parabola. Reswick and Rogers tried to extend this animal research into clinically relevant information, and using combinations of interviews and interface pressure measurements (IPMs), determined a pressure-time relationship that was similar to that of Kosiak [2].

Using the premise that both the magnitude and duration of loading are important, we can diagram a simple model of PU development (**Figure 1**) that illustrates the reasoning behind certain clinical interventions. Pressure magnitude is managed by the selection of support surfaces and postural supports as well as body posture upon supporting surfaces. Duration is addressed via turning and weight shifting frequency as well as with the use of dynamic surfaces that actively redistribute pressure on the body surfaces.

**Abbreviations:** IPM = interface pressure measurement, Mobility RERC = Rehabilitation Engineering Research Center on Wheeled Mobility, PU = pressure ulcer, SCI = spinal cord injury.

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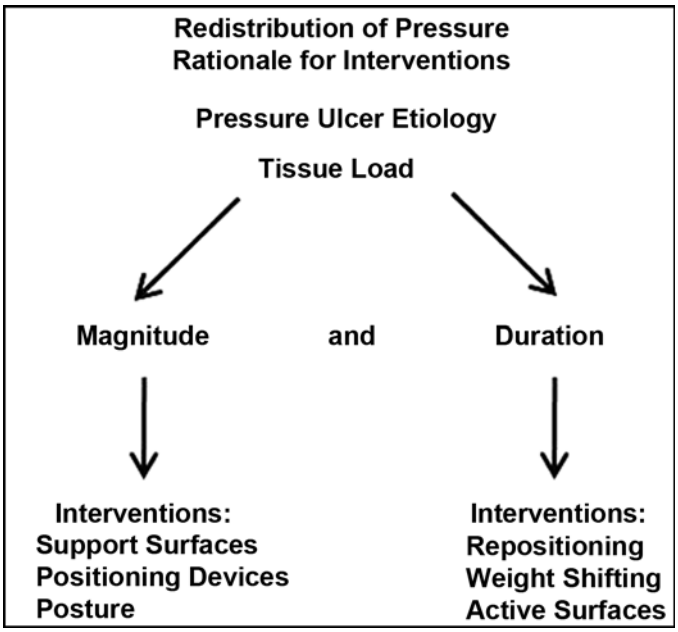


**Figure 1.**
Rationale for redistribution of pressure.

This article reviews the evidence supporting clinical interventions that address the magnitude of pressure and the duration of that pressure. Within this article, "support surfaces" will refer to devices designed for horizontal (mattresses, overlays) and seated (wheelchair cushions) postures. The term "pressure" will refer to the force or load exerted over an area of the body or on a localized area of the body surface.

## CONTROLLED EXPERIMENTS OF TISSUE LOADING

A fairly extensive amount of research has applied loads to tissues and monitored physiological outcomes. For obvious reasons, research with animal models uses controlled loading to create PUs or tissue necrosis, whereas human studies are limited to indirect measures, such as the effect of loading on blood flow.

### Tissue Response to Loading in Animal Models

As mentioned previously, Kosiak undertook seminal research by applying loads to the trochanters and ischial tuberosities of dogs [1]. Loads ranged from 100 to 500 mmHg, and durations ranged from 1 to 12 hours. Kosiak monitored animals for 14 days postischemia to determine the occurrence of PUs. Dinsdale applied pressures between 45 and 1,500 mmHg for 3 hours to swine with and without paraplegia [3]. Normal pressure was combined with friction in half the specimens. The results indicated that no necrosis occurred with normal pressures below 150 mmHg, but in combination with friction, tissue changes could be seen after loading with 45 mmHg. Daniel et al. also studied swine with and without paraplegia [4]. Using an indenter to apply load at the greater trochanter, they found that application of 200 mmHg for 15 hours did not induce a PU. Ulcers were obtained by applying 500 mmHg for 4 hours and 800 mmHg for 8 hours.

Linder-Ganz and Gefen exposed rat hind limbs to pressure magnitudes of 86, 262, and 525 mmHg for 2, 4, and 6 hours, respectively [5]. They used finite element modeling to calculate internal stresses and concluded that tissue damage occurred with 13 kPa of internal stress applied for 6 hours and 40 kPa of internal stress applied for 2 hours. Both conditions represent an approximate stress application rate of 80 kPa/h.

While this is not a comprehensive list of animal PU etiology research, collectively the studies illustrate results obtained by applying different loads over different durations (**Table**). The use of different sizes and shapes of indenters, different loading parameters, and different animal models explains why a range of magnitudes and durations are linked to PU development. Despite these differences, the evidence suggests that both magnitude and duration of loads must be considered in PU prevention and validates the simple intervention model in **Figure 1**.

### Blood Flow Response to Loading in Humans

While research has clearly shown a relationship between pressure magnitude and duration and tissue damage, these studies have not defined a critical magnitude above which ischemia occurs. Many studies have used controlled experimental approaches for determining the pressure at which blood flow to tissue ceases with significantly varying results. Lassen and Holstein found that the pressure required for vascular occlusion approximated diastolic pressures when the measured skin approached heart level [6]. Holloway et al. loaded the forearm and found that blood flow decreased as external pressure approached mean arterial pressure and that occlusion was reached at ~120 mmHg [7]. Ek et al. found "weak positive correlations" between blood flow during

**Table.**
Examples of animal pressure ulcer models highlighting different loading parameters.

| Author | Animal Model | Loading Conditions | Outcome |
|---|---|---|---|
| Kosiak [1] | Canine trochanter and ischial tuberosity | 100–500 mmHg over 1–12 h | Proposed inverse magnitude-duration relationship. |
| Dinsdale [2] | Swine with and without spinal injury | 45–1,500 mmHg over 3 h with and without friction | Loading at 45 mmHg in the presence of friction-induced damage. |
| Daniel et al. [3] | Swine with and without spinal injury | 200 mmHg for 15 h, 500 mmHg for 4 h, 800 mmHg for 8 h | No damage at 200 mmHg for 15 h, but damage under other conditions. |
| Linder-Ganz & Gefen [4] | Rat hind limbs | 86, 262, and 525 mmHg for 2, 4, and 6 h, respectively | Tissue damage occurred with loading rate of 80 kPa/h. |

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loading at the heel and systolic blood pressure [8]. Loading at the sacrum did not result in the same relationship with blood pressure. Sangeorzan et al. determined that 71 mmHg was needed to occlude flow over the tibialis anterior (a "soft" site) but only 42 mmHg occluded flow over the tibia (a "hard" site) [9]. Bennett et al. measured occlusion pressure at the thenar eminences of nondisabled subjects and found that 100 to 120 mmHg was necessary to occlude vessels in "low shear" conditions and 60 to 80 mmHg was needed in the presence of "high shear" conditions [10]. Barre viewed the literature and concluded that a critical pressure is necessary to occlude blood flow and that while this threshold is related to vessel pressure, it appears to vary widely [11].

The animal and human studies contribute important information to the field of PU research by identifying tissue's response to external loads. However, the results are very hard to apply clinically. Controlled loading at specific anatomical sites simply does not generalize to the person lying in bed or sitting in a wheelchair. For example, the magnitudes and durations of loading used to induce damage in animals greatly exceed those deemed acceptable in clinical environments. This apparent discrepancy does not invalidate either the research or the clinical interpretation of the findings. Rather, these animal tests inform us about the mechanism of injury and the complex relationships between the variables involved when supporting the human body in sitting or lying positions.

To date, research has not identified a specific threshold at which loads can be deemed harmful across people or sites on the body. Tissue's tolerance to load varies according to the condition of the tissue and its location, age, hydration, and metabolism. All the factors common to PU risk assessment tools tend to influence how the tissue distributes the loading and its ability to withstand load.

## EVIDENCE SUPPORTING CLINICAL INTERVENTIONS

### Support Surfaces

Support surfaces attempt to redistribute forces away from bony prominences, thereby reducing the magnitude of loading at these at-risk sites. In general, creating successful support surfaces is challenging because of the differences in individual risk factors, as well as the complicated nature by which force is distributed throughout tissue. For example, when a person sits on a cushion, normal loading works in combination with shear and frictional forces to induce complex tissue distortion. Consequently, myriad support surface designs exist that have benefit for some people, but for the most part, no single surface is optimal for all persons. Two very general categories of support surfaces can be defined: reactive surfaces that respond to the load placed upon them and active surfaces that dynamically alter the body–support-surface interface. Although active surfaces serve as a duration intervention, their primary role as a support surface (thus affecting magnitude of loading) makes it natural to present them together with reactive support surfaces.

Judging the effectiveness of support surfaces is done with both direct and indirect methods. Indirect methods use physiological means such as blood flow, tissue oxygenation, and interface pressure to judge performance. Direct methods follow a group of patients over time to determine PU occurrence. Direct methods are more valuable but are harder to administer and are limited in the number of interventions that can be investigated (i.e., types of surfaces).

In their systematic review focused on randomized controlled trials with PU development as an outcome, Cullum et al. used the term "constant low-pressure support surfaces" to describe the myriad foam, air, water, and elastomeric mattresses, overlays, and cushions [12]. Their review of the literature concluded that these surfaces outperform standard hospital mattresses in preventing PU formation. Comparisons between different constant low-pressure surfaces did not result in definitive outcomes. In other words, differences across the more common reactive surfaces have not been demonstrated in terms of PU outcomes.

Studies on wheelchair cushions are not as common as those on mattresses, but informative evidence is still available. Indirect measures, specifically interface pressures, comprise the bulk of studies on cushions [13–16]. Researchers have shown that high seated interface pressures were associated with PU occurrence [17–19]. Therefore, despite the limitations in IPM as a less accurate representation of localized loading [5,20–22], it can be useful in selecting cushions.

Because active surfaces vary loading of particular regions of the body, they intend to alter both the magnitude and duration of loading. Active surfaces are available for both mattresses and wheelchair cushions, with mattresses being used and studied more frequently. In part, this is the result of a funding decision in the United States by the Centers for Medicare and Medicaid Services to not pay for powered wheelchair cushions for PU prevention. Evidence on commercially available active cushions is limited to secondary outcomes [16,23]. Because the secondary measurements vary throughout the cycle of active cushions, the results of such studies are hard to apply clinically.

Studies of active mattresses and overlays are more common than those of cushions and have used both direct and indirect outcomes. Two recent systematic reviews do a very thorough job of covering the literature on alternating pressure mattresses so the details will not be repeated here [12,24]. Cullum et al. focused exclusively on direct outcomes (PU development), while Vanderwee et al. extended their review to include studies with indirect outcome measurements and alternative study designs. But both groups reached the same conclusions: alternating pressure air mattresses are better than standard hospital mattresses but their benefit over constant low-pressure mattresses is unclear. Furthermore, differences across types of alternating pressure air mattresses were not demonstrated. Active surfaces also provide increased potential for mechanical problems and user error compared with some alternatives. One major limitation of most of the reviewed studies, as pointed out by Cullum et al., was that turning schedules were not controlled. Therefore, it is possible that nurses made a point to turn patients on the standard mattresses more frequently than those on the active surfaces because of a perceived need for increased intervention. If true, than comparable outcomes could come with the benefit of reduced clinical intervention time for the active surface, but research to evaluate this possibility is needed.

### Interventions for Reducing Duration of Loading

The body's motor and sensory systems are responsible for ensuring that we move periodically to change our posture. This may be in the form of discomfort eliciting movement or subconscious postural shifts or fidgeting. Many studies over the years have monitored movements in chairs as metrics of comfort and function [25–28], thereby establishing a base of knowledge about sitting as a dynamic activity. Many people at risk of developing PUs are either unable to effectively reposition themselves or are not provided with the sensory feedback that elicits movements. Therefore, that loss of mobility and sensation are identified as risk factors within every PU risk assessment scale is not surprising.

We use this information to target movement as a means of redistributing pressure and altering the duration of loading on tissues. Clinically, this includes turning schedules for patients who are in bed and weight shifting strategies for those who are seated.

### Turning Frequency

In a study on PU prevention interventions, Richardson et al. found that manual repositioning was the most commonly used intervention and that it was also the most expensive [29]. The idea of necessary repositioning has appeared throughout literature and textbooks since the

1800s [30]. Evidence that some repositioning is necessary can be found across decades of literature.

In the United States, common practice requires that at-risk patients be repositioned at least every 2 hours if consistent with overall patient goals [31]. Despite efforts by a number of researchers to identify the origins of this practice, or at the very least identify evidence supporting the 2-hour turning practice, no strong scientific support exists [30,32–33]. In fact, earlier texts often included suggestions that the turning schedule depend on the magnitude of loading and condition of the patient.

Therefore, the standard practice of using the same turning schedules independent of support surface is not reflective of earlier work. Recent evidence demonstrates the need to account for the support surface in determining the optimal turning schedule. Defloor et al. showed that 2- and 3-hour turning schedules resulted in the development of PUs in 14 to 24 percent of patients lying on standard mattresses. A 6-hour turning schedule for patients lying on a viscoelastic mattress resulted in similar outcomes, but a 4-hour turning schedule for patients lying on a viscoelastic mattress significantly reduced stage II PUs. Other research suggests that turning may need to occur more frequently than every 2 hours and that sufficient pressure reduction surfaces are needed in addition to turning [32,34–36]. Recently, Vanderweet al., using a pressure-reducing mattress, found no difference between repositioning patients every 4 hours and alternating between 2 hours in lateral and 4 hours in supine [36]. In both interventions, more than 16 percent of participants developed a PU. Additionally, two studies of secondary outcomes demonstrated that redness and oxygen reduction while lying in bed occurred in less than 2 hours [37]. Furthermore, in studies on turning, patients who are able will change posture between scheduled repositionings. As a result, these subjects are exposed to more position changes than offered by the intervention, which may mask a need for more frequent repositioning in those unable to reposition themselves [36]. The necessary repositioning frequency may be so high that implementation is impractical for immobile patients [32].

## Positioning Devices and Posture

The entire premise behind turning is obviously to reduce the amount of time different body surfaces are exposed to loading. Operationally, many facilities sequence between supine and two side-lying postures. The loading at specific body surfaces is highly dependent on the resulting postures and any positioning devices used. For example, side lying may expose a malleolus to damaging loading but proper positioning of the lower limbs and judicious use of positioning devices can effectively reduce loads from this bony prominence (**Figure 2(a)**). Adopting a supine posture with the head of the bed elevated alters loading on the buttocks, which is why it is a controversial posture. Elevating only the head of the bed increases both the normal and frictional forces on the sacrum [38–39]. Mechanics suggests that as the head elevates, more of the upper-body weight will be transmitted through the buttocks to the supporting surface. In addition, the tendency to slide is increased as the trunk support is inclined. The complication is that it is a functional posture, adopted so people can converse with others, read, and eat, to name a few activities. Some of the frictional forces can be counteracted by raising the foot of

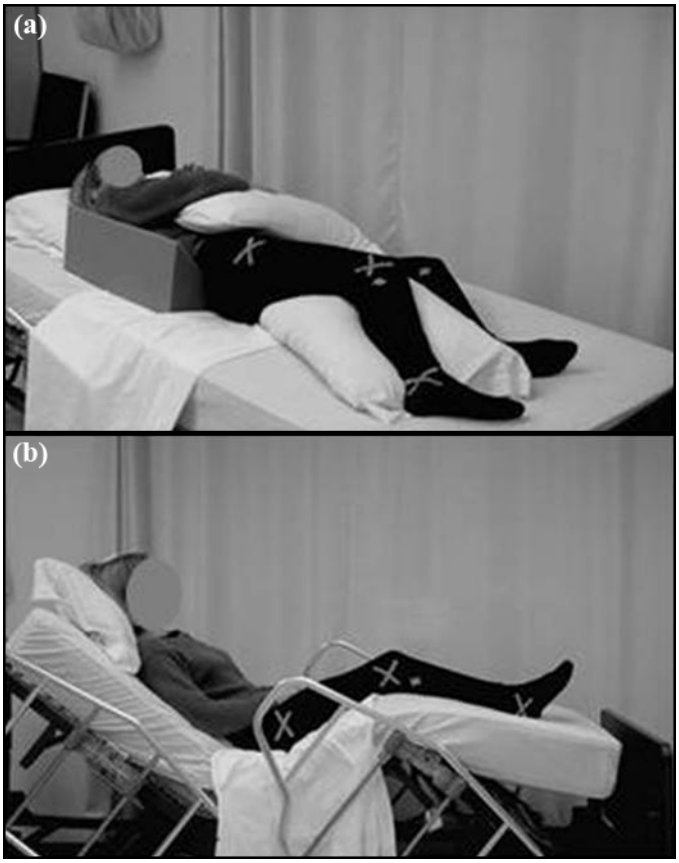


**Figure 2.**
**(a)** Use of positioning devices to redistribute pressure and **(b)** raising foot of bed counteracts sliding tendency.

the bed, but this will not reduce the normal forces on the buttocks [38] (**Figure 2(b)**).

The seated posture also affects how loads are redistributed. Sitting on a sling seat with a pelvic obliquity induces asymmetric loading on the ischial tuberosities, not to mention contributing to postural instability (**Figure 3(a)**). A slouched, kyphotic posture is typified by posterior pelvic tilt, a posture that loads the sacrum and coccyx while seated (**Figure 3(b)**) [40–41].

In summary, body posture and positioning have a direct relationship to loads on specific body sites, which is why posture must be considered when devising PU prevention strategies.

## Weight Shifting

Wheelchair users are often at high risk of developing sitting-acquired PUs. Persons with absent or diminished sensation and/or mobility are always at high risk of PUs [42–43]. A variety of maneuvers to shift body weight off the buttocks are taught to wheelchair users at risk of PUs. They can push down on the seat or armrests to lift the buttocks off the cushion surface (**Figure 4(a)**), lean forward to rest their trunk upon the lower limbs (**Figure 4(b)**), or lean to one side and then lean to the opposite side (**Figure 4(c)**). Persons who use power wheelchairs and cannot independently perform these maneuvers are sometimes prescribed variable position wheelchairs that incorporate powered tilt and/or recline to redistribute weight off the buttock area (**Figure 5**).

Most guidelines that suggest weight shift or pressure relief frequency have been developed for persons with spinal cord injury (SCI) because of the effect of SCI on sensation and mobility. For the SCI population, recommendations for weight shift frequency have typically ranged from 15 to 30 seconds every 15 to 30 minutes to 60 seconds every hour [44–47]. Based on the wide range of these guidelines, one can infer that they were based on a combination of clinical experience, clinical insight, and research findings.

In addition to weight shift frequency, one must also consider the duration for which a weight shift is held. In other words, not only do wheelchair users have to perform weight shifts regularly, they must attend to the duration of these maneuvers. The ability to sustain a weight shift is dependent on myriad factors, including functional ability, strength, flexibility, and postural control [46]. A 2003 study measured tissue perfusion to investigate the length of time required for tissue to reperfuse in an SCI cohort ($n$ = 46) [48]. The mean duration of weight shift required to return transcutaneous partial pressure of oxygen to unloaded levels following upright sitting was 1 minute 51 seconds (range = 42–210 seconds). This finding suggests that the

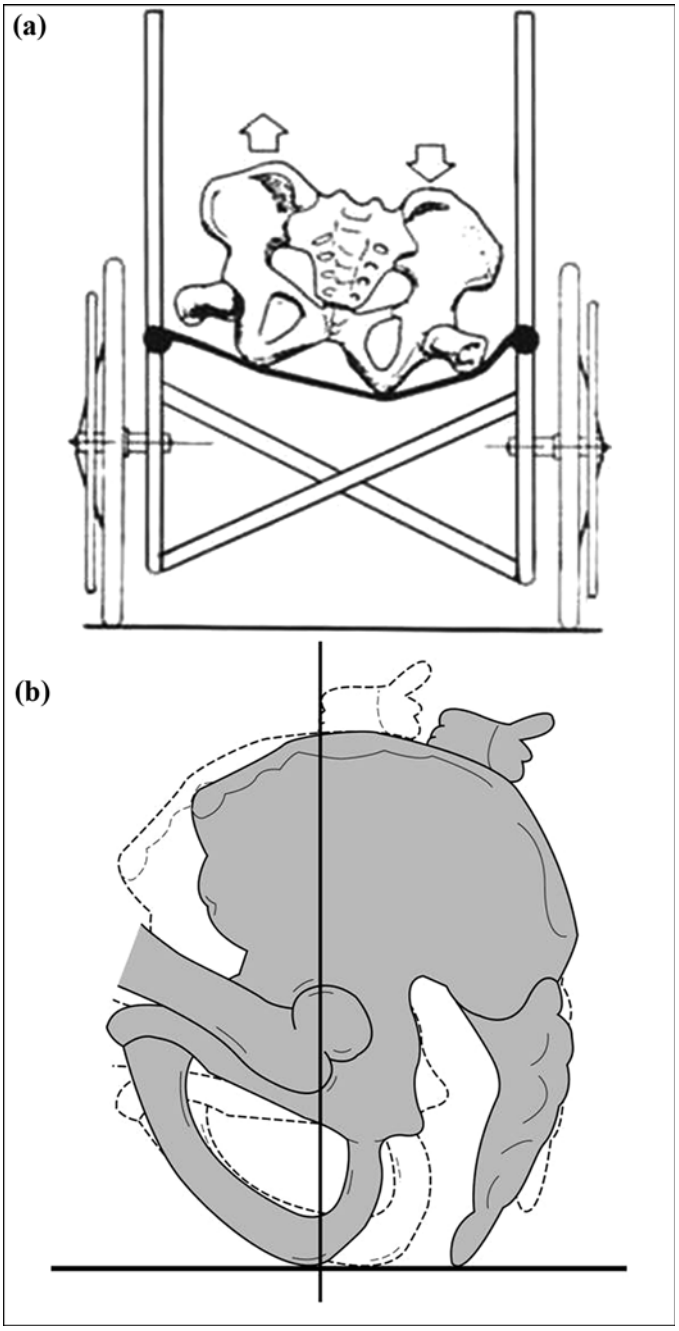


**Figure 3.**
**(a)** Pelvic obliquity from sitting on sling seat and **(b)** posterior pelvic tilt loads sacrum and coccyx.

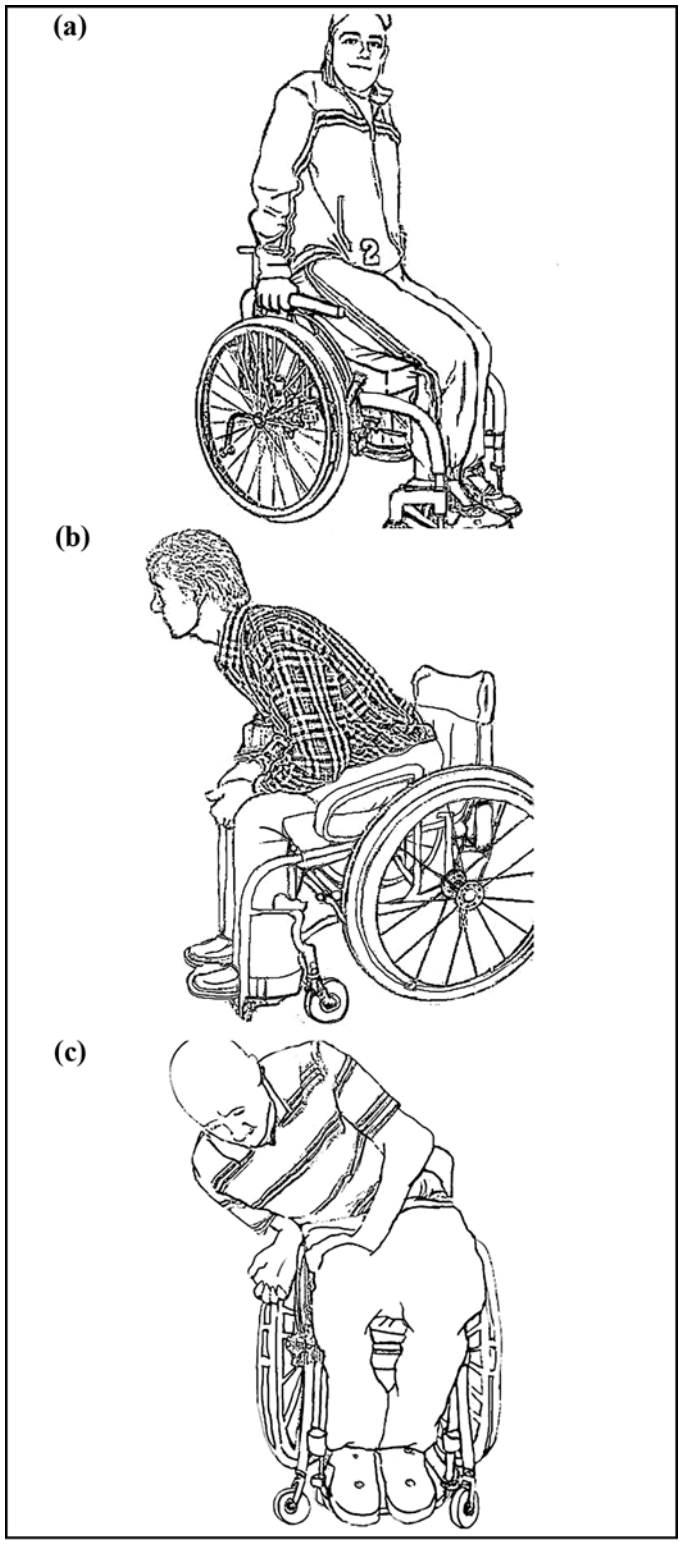


**Figure 4.**
**(a)** Push-up weight shift, **(b)** forward-lean weight shift, and **(c)** side-lean weight shift.

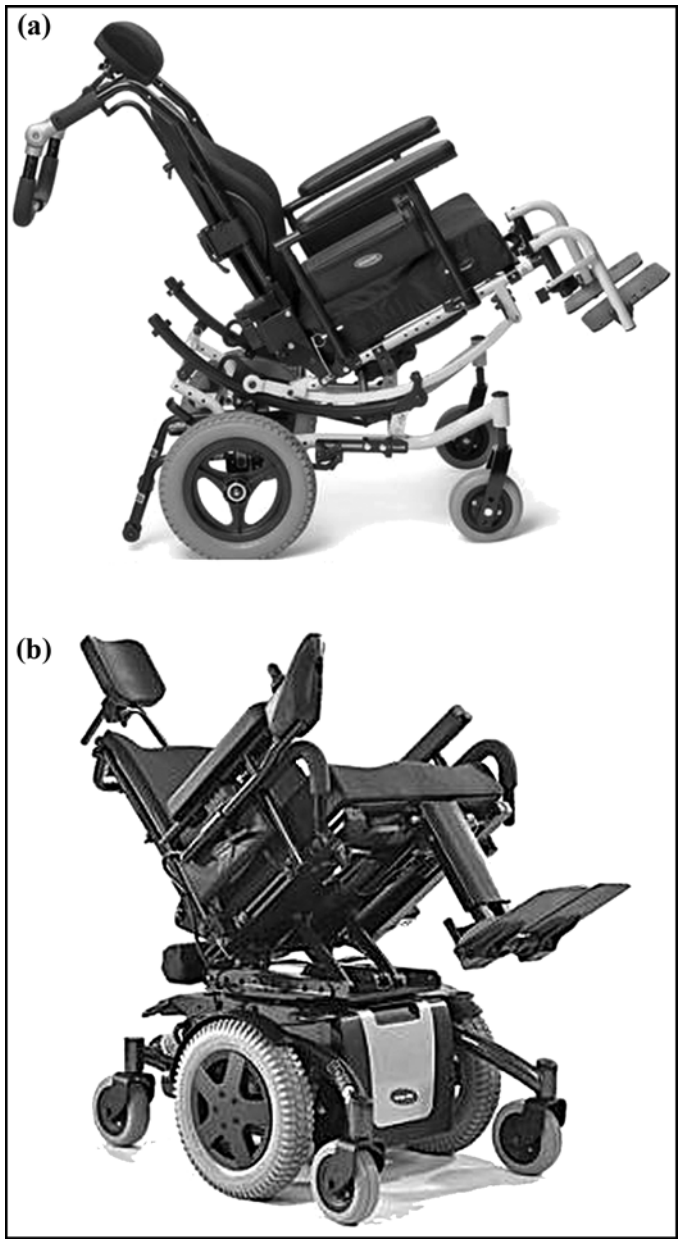


**Figure 5.**
**(a)** Manual Tilt-in-Space wheelchair and **(b)** Power Tilt-in-Space wheelchair. Images used with permission. © Invacare Corporation.

duration of weight shifts currently recommended (i.e., 15–30 seconds) is inadequate. Further, this suggests that the common practice of sitting push-ups is not sustainable for many to achieve reperfusion. Consequently, the authors supported the use of alternate, sustainable methods of weight shift, namely forward lean, lateral lean, and rearward tilt. Partial weight shifts may also allow for better sustainability by persons with SCI.

Three recent studies investigating PU prevalence in an SCI cohort considered weight shift behavior as a potential risk factor [49–51]. None of the studies found weight shift behavior or frequency of weight shifts to be associated with PU occurrence. However, each of the studies used self-report to measure weight shift practices. Further objective analyses are needed to determine the role of weight shifts in PU prevention.

## CONCLUSIONS

The review of research corroborated the clinical interventions commonly used for load redistribution but also identified areas of uncertainty. As with all means of prevention, some interventions are better supported than others and some interventions have a legacy quality to them and little else. Nonetheless, several clinically oriented suggestions can be made.

### Support Surface Assessment

Selections of mattresses, overlays, and cushions should be based upon assessment. Research is clear that individual factors can contribute to PU susceptibility, and all the PU risk assessment scales are based upon individualized evaluation. Research has also shown that individualized evaluation improves the selection of mattress [52] and wheelchair cushions [53]. Long-standing evidence supports the use of seating clinics to select and prescribe wheelchair cushions [54]. One of the benefits of this type of individualized evaluation is its educational aspect in informing patients and clients about skin health and proper equipment use.

### Interface Pressure

Interface pressure can be used to identify areas of unacceptably high pressures and to ensure a site is adequately off-loaded during posture changes or a weight shift. We advocate for use of pressure mapping to rule out products rather than as a sole means to prescribe a particular product [21]. For example, if the interface pressure under the ischial tuberosity is deemed too high for a particular person by a clinician, then the clinician should deem that product unacceptable. That said, one cannot infer that published IPM values will generalize to other clients or patients. Another useful role for IPM is assessing how posture or position changes influence loading on tissue. Repositioning in bed or while seated is necessary to unweight different parts of the body. IPM can offer visual feedback to clinicians, patients, and clients as they sequence through different postures.

### Weight Shift and Turning Frequency

Periodic repositioning is an important preventative measure. Patients and clients who can independently redistribute pressure should be educated to do so and taught strategies to ensure compliance. Persons who cannot reposition must rely on others to set and follow a routine. Evidence on how often a weight shift should be performed and evidence behind turning schedules is limited. The odds are that repositioning frequency is not the same for all people and surfaces. This can be inferred by the wealth of evidence indicating the individualized nature of PU risk and supports the approach that repositioning frequency should reflect the person, his or her equipment, and the environment of use.

- Standard hospital beds are poor support surfaces. Ample evidence has shown that standard mattresses are inadequate to prevent PUs. Even relatively "low tech" mattresses and overlays offer better prevention [12].
- Increasing activity has many health benefits, including tissue health. In a study of more than 600 persons with SCI with and without a history of recurrent PUs, Krause and Broderick identified behaviors that were shown to be protective [50]. These behaviors included a healthy lifestyle, fitness, and exercise. Putting people into equipment and postures that permit functional activity addresses the key PU risk factor of immobility. We should promote reaching, leaning, and moving as a means of promoting functional independence and maintaining skin integrity.
- The European and U.S. National Pressure Ulcer Advisory panels have recently released their joint *International Pressure Ulcer Guidelines for Prevention and Treatment*. The document addresses both PU prevention and PU treatment by assessing many clinical interventions.
- When reviewing conflicting literature, pay close attention to external validity. Literature regarding pressure redistribution and support surfaces is often equivocal and may be contradictory. This can occur because of differences in methods, measurements, and subjects. When reviewing literature, pay attention to how the studies reflect your clinical situation. Perhaps some studies better reflect your patient mix or techniques.

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*Study concept and design*: S. Sprigle, S. Sonenblum.
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