
Tissue Interface Pressure and Estimated Subcutaneous Pressures of 11 Different Pressure-Reducing Support Surfaces

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■ ABSTRACT

This pilot study examined the pressure-reducing properties of 11 different pressure-reducing devices as compared to a standard hospital mattress. Mean trochanteric and heel pressure readings were obtained on each surface from 13 healthy adult volunteers by using an electropneumatic pressure transducer (Gaymar, catalog # PSM1). Mean trochanteric pressures ranged from 37.2 mm Hg to 55.1 mm Hg on the pressure-reducing support surfaces as compared to 83.6 mm Hg on a standard hospital mattress. Mean heel pressure readings ranged from 28.1 mm Hg to 62.1 mm Hg on the pressure-reducing support surfaces as compared to 93.9 mm Hg on the standard hospital mattress. While pressure-reducing support surfaces were found to yield significantly lower mean pressure readings than the standard hospital mattress, none of them is capable of preventing tissue ischemia if the subcutaneous pressure is three to five times higher than the interface pressure.

Current demographic trends show that the elderly comprise an increasing percentage of the overall population. This group constituted 11.3% of the U.S. population in 1980 and will account for 13.1% of the population in the year 2000, and 21.7% of all Americans by the midpoint of the 21st century (Lusky, 1986).

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The "graying" of America is creating opportunities for healthcare marketing. Many older Americans are living well into their eighties and are enjoying relatively good health. Those over 85 years of age have the highest incidence of dependency and health problems. One quarter of this

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population is institutionalized. Many of those who live in the community are alert and independent, while others require supportive services. In the decades to come, these elders will be using inpatient hospital services, long-term care, and community-based home and hospice services (IAET Strategic Planning, 1989). One of the challenges of healthcare will be to meet the needs of the growing elderly population.

Many rural hospitals are closing throughout America. The burden of care will be greater for those hospitals which survive. Therefore, hospitals must be managed as a proprietary business. All healthcare clinicians will need to develop skills to provide cost-effective, quality care for patients. Maintaining the integrity of an elder's skin through the evaluation and choice of an appropriate pressure-reducing support surface is one example of skilled care that will be required.

The United States' dermal wound care market is a \$2 billion business and covers approximately 26.5 million wounds, ulcers, and burns. Another \$4 billion is spent annually on pressure ulcer treatment. Eight billion dollars is now spent annually in nursing homes for skin care products (IAET Strategic Planning, 1989).

One area that can cut health costs and enhance the patient's well-being is the prevention of pressure ulcers. Healthcare providers need to be educated not only in the use of pressure-reducing support surfaces but must also be able to distinguish support surfaces that will promote comfort and reduce pressure.

■ LITERATURE REVIEW

One measure of the pressure-reducing capability of a support surface is the interface pressure measurement. The literature review includes the most pertinent articles on measuring tissue interface pressure on various pressure-reducing support surfaces. The prevention

and treatment of pressure ulcers has been the subject of speculation and research for many years. Focus on treatment is an exercise in futility if one does not understand causative factors. Using the microinjection method, Landis (1930) established the average capillary blood pressure to be 32 mm Hg at the arteriolar end and 12 mm Hg at the venous end. Landis' work led to the belief that internal or external force applied to

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bony prominences of greater than 32 mm Hg can contribute to capillary closure and cause tissue hypoxia resulting in pressure ulcers.

This is supported by numerous authors (Berecek, 1975; Husain, 1953; Kosiak, 1959; Lindeman, 1961; Maklebust, Mondoux, & Sieggreen, 1986) who have identified sustained pressure as the primary cause of soft tissue necrosis. Seiler and Stahelin (1986) emphasized that without relief of localized pressure no healing is possible and all other treatment measures are ineffective.

Because pressure is the primary cause of pressure sores, the major emphasis of prevention is an adequate reduction or relief of external pressure. Both the amount of pressure on the soft tissue and the length of compression time must be considered. Husain (1953) believed that

low pressure maintained for long periods of time was more damaging than high pressure for short periods. Kosiak (1959) found a parabolic inverse relationship between duration and intensity of pressure required to cause tissue necrosis.

A primary goal for the immobilized patient is the prevention of pressure ulcers according to Olson (1967). She refers to such aids as air-filled or water-filled alternating pressure mattresses, turning frames, and oscillating beds as possible ways to prevent pressure ulcers. The Roto Rest was marketed in the early 1970s as an aid in preventing the tissue breakdown caused by immobility (Keane, 1970).

It has become routine practice to reposition immobile patients at two-hour intervals although it is often difficult for caregivers to maintain this schedule on an around-the-clock basis. In lieu of this, there has been a proliferation of new pressure-reduction products introduced to the marketplace. Parish, Witkowski, and Crissey in 1983 stated that there were more than 140 different products designed to assist with or eliminate the task of turning patients. Currently, there are even more.

In an effort to objectively assess pressure reduction capabilities, several studies have compared the amount of pressure reduction offered by various products. The efficacy of static and dynamic pressure-reducing mattress overlays was compared by Whitney, Fellows, and Larson (1984) on a population of matched groups of patients who were in bed 20 out of 24 hours a day. The two overlays used in the study were a four-inch polyurethane convoluted foam pad and an alternating pressure (AP) pad consisting of 134 three-inch diameter air cells with a 2+ lift. The patients' skin condition did not significantly differ on the two products. The authors acknowledged that most patients had very little skin breakdown on either surface, making it difficult to detect differences between the two study

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groups. The investigators based their findings on clinical observation, not on tissue interface pressure measurements.

Krouskop, Williams, Krebs, Herszkowicz, and Garber (1985) evaluated the pressure reduction capabilities of seven mattress overlays by comparing tissue interface pressure measurements during recumbency. Thirty subjects were rotated onto each support surface and tissue interface pressure readings were recorded at the scapula, trochanter, and sacrum of each individual. When compared to the standard hospital mattress, there was significant pressure reduction on each of the therapeutic mattress overlays with the exception of the two-inch convoluted foam pad. The effectiveness of the mattress overlays were independent of the subject's body build.

Wells and Geden (1984) compared the body support pressures when 15 male paraplegics were placed on a water bed, foam overlay, and standard hospital mattress. Readings were taken at five-, 20-, and 35-minute intervals. The major findings were that the water bed yielded significantly lower occipital, scapular, and sacral pressures than the foam and standard hospital mattress. Analysis of pressure measurements on a particular mattress by site over time indicated no significant time effect.

Daechsel and Conine (1985) studied the incidence of pressure ulcers in 32 chronic neurologic patients using two different types of surfaces, an alternating pressure mattress and a silicone mattress. No significant difference in the efficacy of the two products was found. The investigators did not directly measure tissue interface pressure, but based their findings on clinical observations.

Maklebust and colleagues (1986) compared the pressure-reducing capabilities of six support surfaces intended to relieve pressure: a) the Clinitron bed, b) the Mediscus bed, c) the Ergerton net suspension bed, d) the Sof•Care bed cushion, e) the Biogard flotation mattress, and f) a

two-inch convoluted foam pad. The subjects consisted of 13 healthy volunteers who were rotated onto each sleep surface. Tissue interface pressure readings were taken at the sacrum, trochanter, and heel of each subject using an electropneumatic pressure transducer. Of the six support surfaces in the study, only the Clinitron air-fluidized bed, the Mediscus low-air bed, and the Sof•Care bed cushion reduced pressure below 32 mm Hg. One finding of particular importance was that heel tissue interface pressure measurements consis-

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tently were greater than 32 mm Hg on each sleep surface evaluated.

Maklebust, Sieggreen, and Mondoux (1988) compared the pressure relief capabilities of the Sof•Care bed cushion, the Clinitron air-fluidized bed, and a standard hospital mattress. Sixty-four healthy volunteers were rotated onto each sleep surface. Tissue interface pressure readings were taken over the sacrum, trochanter, and heels of each subject by utilizing an electromagnetic pressure transducer. Both the Sof•Care bed cushion and the Clinitron bed readings differed significantly from the standard hospital mattress. There was no statistical difference between the Sof•Care bed cushion and the Clinitron bed in the ability to relieve pressure over the sacrum, trochanter, or heel. Tissue interface pressure readings under the heels were greater than 32 mm Hg on both the Sof•Care and Clinitron surfaces.

Jester and Weaver (1990) evaluat-

ed 34 pressure-reducing support surfaces. These support surfaces were divided into five categories for the purposes of reporting findings: 1) special overlays, 2) air mattresses 3) foam mattresses, 4) mattress, and 5) specialty beds. The subjects consisted of 10 volunteers who were low risk, because high-risk patients could not be transferred to multiple surfaces just for the purpose of clinical evaluation. Tissue interface pressure readings were obtained on the sacrum and trochanter of each subject utilizing the Scimedics Mercury Pressure Manometer. Results were validated through the use of the Gaymar Electric Pressure Manometer. Findings indicated that the trochanteric interface pressures were higher than the sacral interface pressures for the majority of support surfaces. The support surfaces that produced interface pressures less than 32 mm Hg for both the sacrum and the trochanteric measurements were: First Step (KCI), Clinicare (Gaymar), Koala, Iris 10,000, Maxi-float, and all the specialty beds tested (Kinair, Biotyne, Therapulse, Fluid Air, Mediscus, Skytron, Ortho-derm, Flexicare, Clinitron).

It is difficult to make decisions about the correct support surface to purchase. Literature reports of interface pressure measurements need to be interpreted cautiously due to the difficulty of obtaining measurements while maintaining consistency throughout all subjects (Fraulini, 1990). Another consideration is the relationship of interface pressure to internal pressure over a bony prominence.

Le and colleagues (1984) used a silicon pressure sensor to measure the scalar pressure distribution within the tissues near the trochanter and the ischium. Their findings reveal that the internal pressures are three to five times greater than the pressures at the surface of the skin. Sangeorzan and colleagues (1989) investigated the differences in the tolerance of skin to mechanical loading over the tibia and the tibialis

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anterior muscle in healthy volunteers. They used the levels at which subcutaneous partial pressure of oxygen ($TcPO_2$) reached zero as an indication of the intolerance of cutaneous circulation to external pressure. They found that skin over bone more rapidly developed a higher subcutaneous pressure and lower value of $TcPO_2$ than did skin over soft tissue. The results of their study suggest that subcutaneous pressures are a more accurate indicator of the pressure actually applied to cutaneous circulation. These findings suggest that interface pressures may not be the best indicators of effective support surfaces. Yet most clinicians do not have the ability to measure the internal $TcPO_2$ over bony prominences. Therefore, interface pressure measurements were used in this study to estimate the subcutaneous pressure near the bony prominence of the trochanter.

■ CONCEPTUAL FRAMEWORK FOR PATIENT CARE

To maintain a state of health, the individual must constantly adapt to internal and external stimuli. Failure to adapt healthfully may lead to an alteration in physiological integrity which may be exhibited as a pressure ulcer. Utilizing assessment skills, clinicians can identify patients at risk for alterations in skin integrity, specifically those at risk for the development of pressure ulcers.

In order to maintain physiological integrity, individual patients must adapt to meet the nutritional, elimination, oxygenation, activity and rest, and protective needs of the body (Andrews & Roy, 1984). One way to assist individuals at risk for the development of pressure ulcers to adapt healthfully is through the selection and use of an appropriate pressure-reducing device. The first step in the selection process was a pilot study to identify interface pressures of 11 support surfaces.

■ DESCRIPTION OF THE PILOT STUDY

The purpose of the pilot study was to examine the pressure-reducing properties of 11 pressure-reducing support surfaces as compared to a standard hospital mattress. These support surfaces included Akros, Bio Gard, Geomat, KCI III, KCI First Step, KCI Fluid Air, Koala Kare, Roho, Sof•Care, Tender Cloud, and Tender Flo III.

It was hypothesized that each of the 11 pressure-reducing support surfaces would yield significantly lower trochanteric and heel interface pressures than a standard hospital mattress.

The study was conducted at a private, 252-bed hospital located on the coast of the Gulf of Mexico. A three-day inservice education program was provided to educate area nurses and physicians about the use of pressure-reducing support surfaces in the prevention and treatment of pressure ulcers. During the three days, data were collected on 13 healthy adult volunteers. Nine subjects were male and four were female.

A researcher-designed data collection sheet was used to record demographic data and tissue interface pressures obtained from each subject. Trochanteric and heel interface pressures were measured utilizing

an electropneumatic pressure transducer (Gaymar, catalog #PSM1). Pressure readings obtained from the Gaymar pressure manometer have previously been validated by Jester and Weaver (1990) using a Scimedics Mercury Pressure Manometer.

Subjects were asked to empty their pockets of all items and after removing their shoes, were posi-

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tioned horizontally on each of the 11 pressure-reducing support surfaces and a standard hospital mattress. A pressure sensing device consisting of a one-inch square inflatable plastic bladder attached to an aneroid pressure gauge, was positioned between the subject's trochanteric prominence or heel and the surface being evaluated. Three consecutive

MEAN TROCHANTERIC PRESSURE READINGS ON 11 PRESSURE-REDUCING SUPPORT SURFACES AND A STANDARD HOSPITAL MATTRESS

Support Surface	Mean	SD
Akros	49.0	12.6
Bio Gard	50.8	10.6
Geomat	55.1	15.6
KCI III	38.3	3.6
KCI First Step	38.4	9.8
KCI Fluid Air	32.5	3.5
Koala Kare	37.2	5.3
Roho	36.1	4.7
Sof•Care	38.4	2.8
Tender Cloud	41.0	4.7
Tender Flo III	51.8	7.4
Standard Mattress	83.6	11.1

TABLE • I

TISSUE INTERFACE PRESSURE

MEAN HEEL PRESSURE READINGS ON 11 PRESSURE-REDUCING SUPPORT SURFACES AND A STANDARD HOSPITAL MATTRESS

Support Surface	Mean	SD
Akros	53.4	11.5
Bio Gard	62.1	9.4
Geomat	60.7	11.7
KCI III	46.7	9.0
KCI First Step	58.6	16.9
KCI Fluid Air	28.1	3.5
Koala Kare	58.9	16.2
Roho	43.3	6.5
Sof•Care	60.6	14.9
Tender Cloud	62.1	8.0
Tender Flo III	54.0	11.7
Standard Mattress	93.9	7.2

TABLE • II

ESTIMATED SUBCUTANEOUS PRESSURES ON 11 SUPPORT SURFACES AND A STANDARD HOSPITAL MATTRESS

Support Surface	Trochanter			Heel	
	x3	x5	x3	x5	
Akros	147	245	159	265	
Bio Gard	153	255	186	310	
Geomat	165	275	183	305	
KCI III	114	190	141	235	
KCI First Step	114	190	177	295	
KCI Fluid Air	99	165	84	140	
Koala Kare	111	185	177	295	
Roho	108	180	129	215	
Sof•Care	114	190	183	305	
Tender Cloud	123	205	186	310	
Tender Flow III	156	260	162	270	
Standard Mattress	252	420	282	470	

TABLE • III

pressure readings were obtained at each site on each device by an enterostomal therapy nurse and pressure readings recorded. A mean of the three pressure readings at each site was computed for use in data analysis.

All subjects volunteered to participate in the study. Each was informed that about one hour of his/her time would be needed and subjects were assured of anonymity and confidentiality. Institutional Review Board and hospital approval were obtained for the study.

RESULTS

Subjects ranged in weight from 110 to 250 pounds with a mean weight of 186 pounds (SD = 40.8). Mean height of the subjects was 69.2 inches (SD = 4.0) with a range of 60 to 73 inches. Mean trochanteric interface pressures on each pressure-reducing support surface and the regular hospital mattress are summarized in Table I and mean heel interface pressures are summarized in Table II.

A repeated measures analysis of variance with a post hoc comparison of means (Scheffe) revealed that all 11 pressure-reducing support surfaces yielded significantly lower trochanteric pressure readings than heel pressure on a standard hospital

mattress ($F [11, 132] = 38.3, p = .000$). Similarly, a repeated measures analysis of variance with post hoc comparison of means (Scheffe) revealed that all 11 pressure-reducing support surfaces yielded significantly lower heel pressure readings than heel pressure on a standard hospital mattress ($F [11, 132] = 29.83, p = .000$).

Additionally, a significant positive correlation was found between height of the subject and trochanteric pressure on the Geomat device ($r [10] = .563, p = .05$) and between height of the subject and heel pressure on the KCI First Step device ($r [10] = .672, p = .05$). Significant positive correlations were also found between weight of the subject and heel pressure on the KCI First Step ($r [10] = .605, p = .05$), the Tender Cloud ($r [10] = .714, p = .01$), the Koala Kare ($r [10] = .786, p = .01$), and the Geomat ($r [10] = .797, p = .01$).

To estimate the subcutaneous (internal) pressures of the tissue closest to the trochanter or to the heel bone each of the interface pressures was multiplied by 3 and by 5. This provides the lowest and the highest estimated pressure reading if the internal pressure is three to five times greater than the surface pressure as suggested by Le et al. (1984). Refer to Table III for estimated internal pressures.

DISCUSSION

Numerous factors including nutritional status, incontinence, immobility, and mental status, as well as prolonged pressure between a bony prominence and an underlying object, have been associated with the development of pressure ulcers. Pressure-reducing support surfaces that redistribute pressure at bony prominences over the larger surface area of the entire body are one adjunct to assist in the arduous task of preventing and treating pressure ulcers.

In this study, trochanteric and heel pressure readings were signifi-

task of preventing and treating pressure ulcers.

In this study, trochanteric and heel pressure readings were significantly lower than those on a standard hospital mattress; this supports continued use of pressure-reducing support surfaces. Mean heel pressure readings, however, were found to be consistently higher than mean trochanteric pressure readings on all surfaces with the exception of the KCI Fluid Air bed. While the number of layers of clothing between the trochanteric prominence and testing surface differed from the number of layers of clothing between the heel and testing surface among subjects in this study, these differences in mean trochanteric and heel pressures cannot be overlooked. Differences in the amount of pressure exerted over different bony prominences suggest that differing interventions are appropriate for each bony prominence.

The significant correlations found in this study between height of the individual and heel pressure as well as weight of the individual and heel pressure additionally suggest that interventions and use of pressure-relieving support surfaces may need to be adjusted for different-sized individuals. While the exact amount of pressure reduction necessary for the prevention of pressure ulcers is unknown, it is interesting to note that with all support surfaces except KCI Fluid Air, all mean pressure readings, although significantly lower than pressure readings on a standard hospital mattress, were consistently higher than the average capillary blood pressure of 32 mm Hg reported by Landis (1930). Until an optimum pressure reading level can be agreed upon, it would be prudent to use a pressure-reducing support surface and to select a support surface for at-risk patients which maximizes pressure reduction at all bony prominences.

Calculating the estimated subcutaneous (interior) pressures at three

and five times the interface pressure provides inordinately high pressure estimates. These high pressures presumably have the potential to cause closure of all arteriolar and venous circulation at the site of pressure. Whether one subscribes to the school of thought that below 32 mm Hg is a safe pressure reduction or to the school of thought that down to zero mm Hg is the only safe pressure reduction, these estimated pressure readings are alarming. This leads to the conclusion that only zero pressure at periodic intervals will prevent occlusion of the microcirculation. Zero pressure is obtained by turning patients off the pressure points at intervals, thus adding increased importance to the time-honored standard of turning patients every two hours.

Determining the appropriate pressure-relieving support surface for a specific patient, however, is not a simple matter of comparing reported pressure readings for various support surfaces. A more controlled study, using a larger sample more representative of the at-risk population, is required to confirm and support the findings of this pilot study. Also, the relationship between interface pressures and subcutaneous pressures need to be studied and integrated into prevention and management of pressure ulcers.

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