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While a "Special Article" will rarely if ever follow the format of a scientific article, it will invariably have been reviewed by members of the Journal's Editorial Board, and by ad hoc reviewers selected for their experience and stature in the disciplines concerned. The fact of its publication may be taken as evidence that the article obtained some strong (though not necessarily unanimous) support in the review process.

The Effectiveness of Preventive Management in Reducing the Occurrence of Pressure Sores

THOMAS A. KROUSKOP, P.E., Ph. D.
PHILIP C. NOBLE, M.S.
SUSAN L. GARBERT, O.T.R.
WILLIAM A. SPENCER, M.D.

The Institute for Rehabilitation and Research in the Texas Medical Center
1333 Moursund Avenue
Houston, Texas 77030

INTRODUCTION — Many conferences and workshops held in recent years have demonstrated that seating, whether for pressure relief or for postural control, is not only an area of major concern but one of tremendous controversy. At the Institute for Rehabilitation and Research (TIRR) in Houston, in conjunction with the Texas Rehabilitation Engineering Center, efforts have been directed since 1975 toward increasing our own understanding of the causes of pressure sores and on the development of clinical programs and technological advances that have the potential to help prevent them.

Pressure sores are a severe and potentially life-threatening complication for many individuals with physical disabilities. In 1968 the Veterans Administration estimated that 50 percent of all quadriplegic veterans will require hospitalization because of pressure-related problems during their lifetime and more than 30 percent of the paraplegic population will have a similar fate (1). It was also estimated by the VA that approximately one-fourth of these persons will die as a direct consequence of pressure sores (1). The magnitude of the problem is further emphasized when an analysis similar to those done by Robinson in Canada (2), Noble in Australia (3), and Motloch in California (4) is performed on the problem in the U.S. Using the assumptions and data from these analyses, the medical costs associated with curing pressure sores in the U.S.A. are estimated to exceed $2,000,000,000 per year. This estimate is consistent with the information presented in the Technology Section of the NIHR long range plan 1981-1986, which emphasized that the effects of pressure on tissue is a high priority area for research and demonstration activities.

The social costs associated with pressure sores are even greater than the medical costs. These costs include: (i) time lost from a productive vocation with its attendant economic impact on individual and family, (ii) time lost from school, which has far-reaching and long-term impact because the disabled person's vocational potential is limited, which generates long-term dependency, (iii) loss of time from the family which can have a significant psychological impact on the person's social development, and (iv) loss of general personal independence and productivity that ultimately contributes to a serious loss of self-esteem and self-worth. Moreover, problems that result from these social factors may contribute to the fact that the suicide rate among persons with severe disabilities is significantly higher than that associated with the general population.

There are also many other groups of disabled people who are threatened with the debilitating effects of pressure sores, besides those with spinal cord injuries. These groups include:

1. Persons such as stroke patients who suffer from limited physical and personal mobility.
2. People with demyelinating neurological diseases, such as multiple sclerosis.
3. Trauma patients confined to intensive care units for extended times.
4. Victims of malnutrition and birth defects such as spina bifida.
5. The geriatric population confined to nursing homes.

The most commonly cited causes of pressure sores included:

1. Prolonged sitting during daily activities, particularly during travel and in recreational activities such as card playing and video games.
2. Use of old deteriorated wheelchair cushions.
Background for the Clinical Program Development

At home or work, prevention of pressure sores and treatment of the early stages of pressure-induced tissue damage are extremely difficult for even conscientious patients. Our understanding of the sore's etiology is not complete and what understanding does exist has not been transferred widely to practical solutions that accommodate daily activity patterns. Similarly, technological aids that effectively reduce an individual's risk of developing a sore are not widely disseminated and utilized.

Pressure ulcers are characterized by an open wound where tissue necrosis has increased in response to externally applied loads. Classical treatment involves providing complete relief from pressure to the affected area, which often necessitates long periods of hospitalization to avoid infection and other complications, e.g., phlebothrombosis.

The normal structure of skin and the physiological processes involved in maintaining healthy tissue are fairly well understood, but in contrast, the exact causes and mechanisms of soft-tissue breakdown resulting in pressure sores are not as certain. During normal activities such as sitting, lying, and leaning against another surface, relatively small volumes of flesh are compressed between the internal bony skeleton and the external surface. Since most of the body weight is carried by the skeleton, extremely high tissue stresses can be generated. Classically, decubitus ulcers are assumed to be caused by pressure-induced vascular ischemia resulting in tissues being deprived of oxygen and nutrients as the nonrigid walls of blood and lymph vessels collapse under pressures that are higher than that of the fluids inside. Also, mechanical deformations of the flesh due to high levels of sustained load (or more moderate, repetitive forces) are of importance in producing tissue damage (5).

During the last 25 years, a number of scientific studies have advanced our knowledge of the factors involved in the formation of pressure sores and have provided a basis for improving preventive techniques. Most of these studies have focused on the biomechanical aspects of pressure sore formation, but more than a decade ago investigators began to appreciate that tissue breakdown was probably a multidimensional process. The variables identified include such factors as pressure, shear loading, general metabolic condition of the person, local tissue integrity and viability, age, edema, repeated pressure, altered sensation, neurotrophic effects, and psychological or psychiatric factors.

Clinical Program

While the above considerations apply in varying degrees to all persons who are immobilized as a result of disability or disease, the traditional acute-care approach to pressure sore management does not provide a mechanism for using much, if any, of this information to ameliorate the problem. In the past, the approach to pressure sore management has consisted of medical and surgical treatment of the sore once it became clinically significant. Moreover, the concept of an individualized pressure management program was virtually nonexistent due to the lack of technical expertise necessary to assess patient needs and prescribe equipment that was consistent with the individual's lifestyle. Consequently, the acute-care model of service delivery was associated with a remarkably high recurrence rate of pressure sores within the population at risk.

The Institute for Rehabilitation and Research (TIRR) in Houston is a hospital specializing in the comprehensive rehabilitation of persons with severe neuromuscular disabilities, primarily spinal cord injury. Prior to 1974, our experience was typical of many similar facilities: 32 percent of patients, based on the percentage of visits, admitted for the treatment of pressure sores returned with a recurrent breakdown within 24 months of discharge. These statistics were not only startling but they produced great dissatisfaction with the then current pressure sore treatment model. Therefore, in 1975, the Institute, in conjunction with the Rehabilitation Engineering Center, started to develop a program of pressure sore management that emphasized prevention rather than treatment.

The core of this approach has been the integration of research results into service and educational activities that result in (i) effective patient assessment, (ii) individualized equipment prescriptions, and (iii) increased awareness by the patient and the patient's family of their responsibilities for pressure sore prevention. Functionally, the program can be divided into three areas of activity: Clinic, Education, and Research.

The Clinic: designing the individual patient's program—The clinic is where the patient contact is first made with the multidisciplinary team who are responsible for designing the individual's program. The team consists of a plastic surgeon, nurse, engineer, occupational therapist, social worker, and of course the patient himself. In the clinic, the individual's history is recorded and insights into his lifestyle are sought. It is important to know if the person lives alone. Is he dependent or independent in his activities of daily living? What are his work and social activities? Does he drive? Who assists him with his care? At this point, it is...
decided whether the person needs a pressure evaluation to determine cushions for immediate and long term use.

The pressure evaluation pad (Fig. 1), developed at the Texas Rehabilitation Engineering Center, provides the information for use in prescribing needed wheelchair cushions. This device has been modified over the years so that it has become a clinically useful tool (Fig 1). This instrument is used to identify the maximum pressure situated at any point on the body contact area, without requiring a prior judgment of the location of the maximum pressure level. Valuable information about the pressure distributions and, hence, the uniformity of weight distribution are also obtained from the evaluation. This assessment in combination with the clinical patient data enables an appropriate cushion to be selected for each individual, and makes it possible for the final cushion of choice to be checked to ensure that pressure is relieved in susceptible areas—instead of simply being transferred to other areas where it may cause tissue damage.

Following this evaluation, the person’s other equipment needs are reviewed and the recommended devices are ordered. These might include sitting-time alarms, beds and mattresses, bath and shower aids, and transfer aids.

**Education: an extended series of scheduled follow-up contacts for the patient and family, and inservice-training sessions for the health care team**—The second phase of the program consists of two types of educational activities: One is directed toward the patient and his family and is used during the acute rehabilitation process for new patients and following surgery for sore repair. Numerous practitioners have stressed the importance of self-care and self-responsibility in pressure sore prevention, and the tissue pressure management program has developed a series of presentations in which patients and/or family members interactively learn about skin checks, the importance of diet and good personal hygiene, risks in daily activities, choice of clothing, sitting tolerance, and stress management. In contrast to the short-term, unscheduled interactions between the disabled person and the health care professionals that are characteristic of the acute medical treatment model, the prevention program requires an extended series of scheduled follow-up contacts. These contacts are used both to reinforce the information provided in the education sessions and to maintain the adequacy of the devices that were provided in the initial assessment.

The second facet of the education activities is directed to members of the health care team and concentrates on the development of keener awareness of practical pressure management measures. This component utilizes the clinical departmental inservice-training session to convey the latest research findings and clinical experience of other programs.

**Results: Human, Medical, Financial**

Over the last 6 years, the pressure management program has played an increasing role in the rehabilitation of individuals with spinal cord injuries. Referrals now come from the hospitals within the Texas Medical Center and surrounding areas and the other centers throughout the United States. Since its inception in 1977, more than 600 individuals, representing more than 1500 patient visits, have participated in
the program, and through the development of the clinical
and educational services, the recurrence rate of pressure
sores has been markedly reduced. Prior to the start of
the program, some 32 percent of the patients treated for
pressure sores at TIRR returned with repeated tissue breakdown
within a 2-year period. With the commencement of a clinic
specifically directed toward pressure sore prevention, this
recurrence rate dropped to 11 percent in the period following
1977 and 9 percent in the period after 1978. The introduction
of psychological counselling and an active education pro-
gram to promote improved self-awareness and conscious-
ness of pressure damage has now reduced the recurrence
rate still further, to a rate of only 4 percent following 1980
(Fig. 2).

To assess the influence of any program which attempts to
prevent pressure sores, it is necessary to consider many
factors, which impact far beyond the cost of medical care
and lost income. As pressure sores are a major impairment
to the independence and self-esteem of many disabled indi-
viduals, the impact of a prevention program must be as-
sessed in terms of its effect on the quality of life of the
individual, and not simply the increased economy of medical
care. Nonetheless, the hard economic yardsticks of medical
and insurance costs can be applied to the pressure manage-
ment program to examine its effectiveness in savings to
both medical service providers and to the patient undergo-
ing treatment. The cost of treatment of pressure sores has
been shown to vary greatly, depending upon whether surgi-
cal closure of the ulcer is undertaken and upon the duration
of the hospital care needed to effect complete healing of the
initial sore or the surgical site. (57) Several authors have
attempted to take these factors into account through de-
tailed analysis of the hospital costs of individual patients
treated for pressure sores or through calculation of the dura-
tion of hospital stay for larger populations of individuals
having such treatment. Based upon this work, the "average"
cost of pressure sore treatment varies form $20,000 to
$30,000 in 1982 dollars. (3,4,57) To estimate the cost savings
associated with the pressure management program at TIRR,
the conservative estimate of $20,000 per pressure sore has
been assumed. On this basis, and the base rate of 32 percent
pressure sore recurrence rate observed in 1976, it has been
calculated that the reduced recurrence rate is equivalent to a
total cost savings ranging from $600,000 per annum in the
first year of the program's operation to $1,900,000 per an-
num in 1980 (Fig. 3). The total savings over the period 1976–
1980 amounted to $5,600,000. The impact of this reduction is
further accentuated when the social, educational, and voca-
tional costs associated with pressure sores are also
considered.

Discussion

The experience at TIRR has justified the initial postulate
that each person requires an individualized program of edu-
cation and equipment prescription which is compatible with
his lifestyle. In the specific instance of wheelchair cushions,

FIGURE 2
Recurrence of pressure sores in patients treated in the Pressure
Management Program (2-year followup).

clinic records show that although different types of cushions
meet the diverse needs of the broad population of wheel-
chair users, some cushions, e.g., water/foam flotation cush-
ions, are not well accepted by users in the long term. Other
cushions, notably those manufactured from viscoelastic
foams, while meeting with a high level of user acceptance
appear to have an unusually high association with skin irrita-
tion and tissue breakdown. These observations influence
the interpretation given to static pressure measurements
taken at the patient/cushion interface and guide the recom-
mendations given to patients and physicians concerning the
most suitable wheelchair cushion for each individual.

To further assist the process of wheelchair cushion pre-
scription, the records of cushions prescribed in the pressure
management clinic have been examined in an attempt to
establish a correlation between variables characterizing the
wheelchair user (body weight and build, gender, level of
spinal cord lesion). No significant correlations have been
found between any single patient-variable and the wheel-
chair cushion ultimately prescribed within the clinic. This
observation is consistent with the experimental data of
Garber and Krouskop. (58) Based upon this present analysis,
however, it has been possible to narrow the range of cush-
ions considered for a particular individual, the final selection
being made upon the basis of a pressure evaluation and

*The Pressure Evaluation Pad is scheduled to become commer-
cially available the latter part of July, 1983, through Knights-
bridge Medical, Inc., 16139 Rudgewick Lane, Spring, Texas 77373.
consideration of lifestyle factors including postural stability, continence of bladder and bowel, and the cost of possible alternative cushions. The cushion prescription process is summarized in Table 1. For male wheelchair users, the pressure evaluation initially investigates the suitability of the ROHO air cushion and a resilient polymeric foam cushion, the individual's neurological status, body weight and continence generally influencing the ultimate prescription. In the case of female wheelchair users, the Bye-Bye Decubiti air cushion is also considered, body weight and continence again being critical factors affecting cushion selection. From previous experience, this range of alternatives is found to meet the requirements of 80–90 percent of the individuals using the service. Other types of cushions are also selected, based upon additional considerations and the patient's prior experience and preferences. In many cases, the cost of the cushion influences the cushion actually used by the patient—regardless of the recommendation of the clinic staff.

In closing, the technology and knowledge developed in the Tissue Pressure Management Program has led to a new independence for many disabled individuals. For these people, not only has the vulnerability to pressure sores been reduced, but there has emerged a new continuity in family life, social life and vocation potential.

APPENDIX

The scientific studies which have advanced our knowledge of the factors involved in the formation of pressure sores have also provided a basis for improving preventive techniques. Most of these studies, as noted in the preceding article, have focused on the biomechanical aspects of pressure sore formation. A number of investigators have studied blood flow and tissue mechanics in attempts to quantify the relationship between externally applied loads and the internal stresses that result in cessation of blood flow. In Kosiak's classic study the variables governing soft tissue breakdown were extended to include "time at pressure." While Kosiak’s relationship between "time at pressure" and breakdown has considerable variance associated with it, the clinical significance was shown by Rogers et al. in the early 1970's. As these early studies became well publicized, investigators began to appreciate that tissue breakdown was probably a multi-dimensional process. The variables identified included such factors as pressure, shear loading, general metabolic condition of the person, local tissue integrity and viability, age, edema, repeated pressure, altered sensation, neurotrophic effects and psychological or psychiatric factors. Unfortunately, most studies have isolated for examination only one or two of the variables, leaving the other variables uncontrolled or assumed to be constant—even though other investigators have identified them as significant contributing factors during their studies. For example, the age, metabolic condition, and levels of general neuro-endocrine stress in subjects (human and animal) have not been controlled in most studies. The shape of the load applicator has only recently been structured so as to control the shearing load that is ap-
TABLE 1: Wheelchair Cushion Prescription Strategies

<table>
<thead>
<tr>
<th>For Male Patients:</th>
<th>For Female Patients:</th>
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<tbody>
<tr>
<td>Compare ROHO and Foam Cushions</td>
<td>Compare ROHO, Foam and Bye-Bye</td>
</tr>
<tr>
<td></td>
<td>Decubiti Cushions</td>
</tr>
</tbody>
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**Relative Indications**

- **Lower Level Spinal Cord**
  - Lesion: ROHO
- **Increasing body weight**: Foam
- **Incontinence**: ROHO

- **Decreasing body weight**: Bye-Bye Decubiti
- **Increasing body weight**: Foam
- **Incontinence**: ROHO or Bye-Bye Decubiti

Although other types of cushions are also selected, the three shown here have been found to meet the requirements of from 80% to 90% of the individuals using the service described in this paper, the authors report.
plied. Consequently, it is difficult—often impossible—to compare the results obtained in one laboratory directly with the results from another. General trends may be noted, but valuable specific values are often found to be incompatible.

Many studies have been designed with animal models. Typically, the animals have been subjected to various externally applied pressure loads using indentors having very different geometries. As a result, substantial data have been collected indicating that pressures ranging from 20 mm Hg upwards are necessary to produce tissue breakdown. Several studies have been conducted to elucidate the relationship between externally applied pressure and cessation of blood flow in a region. Although most of this work has been done with animals, several investigators have made analytical studies of soft tissue oxygenation. One of the most widely used models is based on the Krogh Cylinder. These studies have produced useful information for determining where, when, and how long blood flow will cease after an area has been loaded with externally applied pressure. Unfortunately, the magnitude of the pressure and load duration times typically derived from these studies are inconsistent with conditions existing in a hospital or nursing home setting. The animal studies indicate that "healthy" tissue can withstand pressure of 300 mm Hg for periods up to 18 hours with reversible damage. Consequently, investigators have started to look for additional factors causing blood cessation and/or tissue damage.

Bennett and Lee (37) and Reichel (38) have researched the role of shear stress. Their work indicates that shear forces can add significantly to the effect of externally applied normal forces in occlusion of blood flow in soft tissues. Bennett theorized that in addition to shear forces produced by friction, the shear resulting from large variation in compressive forces will produce severe mechanical stress in the soft tissues. His experimental work convinced him to conclude that shear force plays a significant part in the occlusion of blood vessels, but that large compressive forces must already be applied in order for a suitable shear condition to develop. His work indicates that the pressure level capable of disrupting blood flow can be reduced by one-half by the...
presence of significant shear forces.

Brand (5) has contributed most to our knowledge about the effects of repetitive stress on soft tissue breakdown. Rats have been used as the model animals to study the effects of low-magnitude pressure loads as a cause of soft tissue breakdown in several such studies.(5,43) In Brand’s experiments, repetitive subcritical loads were applied to the rat’s foot pad over a period of 3 weeks in different patterns. These loadings created necrotic areas in the soft tissue that had characteristics similar to those of pressure sores. Of particular importance was the finding that during the stressing of soft tissue, introduction of rest intervals followed by restressing caused the soft-tissue region to hypertrophy and become capable of bearing much greater external loads than before. Based on Brand’s work, design criteria have been developed and used in the fabrication of shoes for persons with insensitive or severely deformed feet as found in leprosy, peripheral neuropathies, and peripheral vascular disorders associated with diabetes.

From the results of many of the blood-flow studies, Reddy, Krouskop, and Newell (44) hypothesized that the accumulation of waste products, as well as deficits in metabolic nutrient supply, in a region of tissue may be a primary factor in producing pressure sores. Analytical and experimental studies have been conducted to investigate the effects of altered lymphatic drainage on the formation of pressure sores.

An analytical study (45) has also been conducted on the role of interstitial fluid on pressure sore formation. The results have been used to provide a basis for understanding the “time at pressure” phenomenon noted in the earlier work done by Kosiak and Reswick and Rogers.

Several investigators have noted the influence of psychosocial factors on the incidence of decubiti—the individual’s responsibility for his or her own skin care, satisfaction with the activities of life, and self-esteem all having some correlation with the risk of skin ulceration.(11,17) An individual’s own understanding of the causes and risks of skin breakdown, combined with a positive attitude towards health and independent living, are also expected to influence heavily the effects of potentially dangerous mechanical factors in everyday life.

Susceptibility to pressure sores is also related to the general medical condition of the individual.(3) Incontinence, for example, has long been associated with decubitus ulcers. In the Greater Glasgow Health Board Survey (46) it was found that, while 3.7 percent of fully continent patients had significant pressure sores, the incidence rose to 15.5 percent and 39.7 percent among those with urinary and fecal incontinence respectively. The observation must be attributed in part to the susceptibility of moist skin to maceration through direct trauma or exposure to pressure. Wet skin is also more likely to adhere to clothing and bed linen, thus enhancing the generation of substantial shearing forces. An additional factor in the case of fecal incontinence is mechanical attrition of the epidermis combined with the introduction of infection into any breach of the body defenses.

Poor nutrition, resulting in loss of weight and reduced padding of the bony prominences, is another important factor.(47,48) The body’s normal tissue integrity is dependent upon a correct nitrogen balance and vitamin intake.

Hypoproteinaemia leading to edema causes the skin to become less elastic and more susceptible to inflammation as the rate of oxygen transfer from the capillaries to the tissue is reduced, thus compromising the skin’s vitality.

The role of skin temperature and perspiration in the process of soft tissue breakdown has recently become an active area of pressure sore research (49-51). The soft tissue may be modelled as an enzyme-activated chemical engine wherein slight changes in the operating temperature environment, particularly temperature increases, produce dramatic effects by increasing the metabolic demands of the cells in the local region. A rise of 2 to 3 degrees Fahrenheit can change the metabolic demands by an order of magnitude. Similarly, the use of hypothermia to reduce the metabolic demands of a region, and the use of temperature as a predictive tool, have been explored in several laboratories. In a number of studies, infrared thermography has been employed to study thermal changes in the skin related to the effects of repetitive stresses and to monitor the rate of healing of established pressure sores.(43) Mahanty and Roemer (50) have been involved in similar work and have contributed new knowledge in how temperature affects soft tissue breakdown.

Recently, several investigators (52-54) have studied changes in collagen metabolism following spinal cord injury, and the possible interrelation of these changes with susceptibility to soft-tissue breakdown. At this time, studies in that area remain speculative, and yet the qualitative information provided to date serves as a useful framework for the development of a model of pressure sore etiology. One such model has been proposed by Krouskop et al.(56) and is based upon the following information.

(i) Soft tissue may be represented as a matrix composed of cells, vascular networks, and interstitial fluid supported by a network of collagen and elastin fibers which characterize the gross mechanical properties of the tissue, working together as parallel springs transmitting loads between the external surface of the tissue and the underlying skeletal surface (Fig. 4a).

(ii) Collagen breakdown and synthesis is very sensitive to many physiological factors, including the concentration of oxygen and trace elements such as copper within the tissue. When suitable biochemical conditions are not present, a collagen triple helix forms which is not stable at body temperature and is water soluble.

It is hypothesized that the capacity of soft tissue to support mechanical forces without inflammatory or necrotic changes is fundamentally related to its inherent elastic properties, which determine the extent to which force applied externally to the skin will be dissipated within subdermal tissue layers. In conditions which affect the elastic properties of soft tissue, it is further hypothesized that collagen within the soft tissue is progressively broken down and washed out of the subdermal matrix, leaving an increasing proportion of the load-dissipating function of the tissue to the elastin fibers (Fig. 4b). As more and more collagen is lost from the tissue, the increasing stress placed upon the vascular and lymphatic elements causes a reduction in the availability of nutrients essential for all metabolism, in associ-
When a sufficient volume of interstitial fluid and ground cells and maintaining a localized hydrostatic state of stress. This normally performs the function of separating to the displacement of interstitial fluid and ground substance has been removed from a region under pressure, the cushioning effect is lost and cell-to-cell contact may occur. Contact stresses under these conditions may then become high enough to cause distortion and rupture of the cell membranes. (27, 55) When damage does occur and the lymphatic system is unable to cleanse the region of toxic intracellular materials, the remaining cells in the region may be poisoned causing a larger necrotic area to develop.

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