PRESSURE SORES: CAUSATION AND COST, BIOMECHANICS AND PREVENTION

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INTRODUCTION: PRESSURE SORES

The load bearing skeletal system and the vital organs of the body are isolated and protected from the external environment by a continuous layer of skin and subcutaneous tissue. In consequence when we stand, sit or lie, the areas of skin which are in contact with the supporting surface are subjected to both normal and tangential force components of the body weight. Those forces compress and deform the layers of soft tissue through which they act, and such deformation may interfere with the cutaneous capillary blood supply, which, if maintained, leads to tissue death and the formation of a pressure sore.

It is thus apparent that man is not designed to remain immobile for long periods of time. His natural reaction to imposed immobility is to randomly make small adjustments in posture or position whether he is awake or asleep, the "fidgeting" being partly stimulated by the feeling of discomfort caused by localised tissue ischaemia. Unfortunately the chronically ill, the aged, and the immobilised have lost this protective mechanism, and these patients are most liable to suffer from pressure sores.

Traditionally, the prevention of pressure sores has been considered as a nursing problem and the presence of sores as a manifestation of inadequate nursing care. However, the increasing numbers of immobilised and handicapped patients worldwide have focused more attention on the problem and it is now accepted that some of the factors in pressure sore aetiology are inadequately understood.

Basic research is being carried out worldwide into the effects on soft tissue physiology of mechanical stress, inadequate nutrition, chemical irritants, and moisture. In addition, devices to prevent sores developing in the chronic patient are being developed.

This paper describes the biomechanics of pressure sores in the sitting and bed-bound patient and discusses some of the techniques which are now available for sore prevention.

INCIDENCE

The incidence of pressure sores in the patient community has only been investigated relatively recently and information is still somewhat scant. Data currently available includes the results of definitive surveys conducted in a large hospital population in Cape Town (Manley 1978), in the total patient community in Glasgow (Barbenel *et al.* 1977) and in the total population of the county of Aarhus in Denmark (Petersen and Bittman 1971). It was shown by all three surveys that the overall incidence of patients with pressure sores is about 9% of the total patient population, although the incidence increases significantly with increase in patient age. In Cape Town, for example, about 20% of the patients surveyed were over retiring age and this 20% had about 50% of the pressure sores found. The Glasgow survey produced the most dramatic age related data, as in the total patient community of that city (hospital patients plus home based patients) 65% of the patients surveyed were over retiring age, and these patients contributed 83% of the pressure sores recorded. Other factors found to predispose to pressure sores were incontinence, immobility and unconsciousness. However, all results showed that the strongest single predictive factor was age. An interesting result which emerged from the Cape Town survey was the disparity in pressure sore incidence among different racial groups. It was shown that in the general hospital population the ratio of caucasian to negroid patients with sores was about 20 : 1, a result which still requires a satisfactory explanation.

THE BIOMECHANICS OF PRESSURE SORES

Soft Tissue Mechanics

In mechanical terms, human tissue is a visco-elastic material; that is, it has an elastic component and also a viscous or flow component. Thus, when a load is applied to an area of skin, the material undergoes an immediate initial deformation through its elastic component and with time the viscous component allows the initial deformation to increase without increase in the applied load. This phenomenon is known as creep, and deformation of tissues is said to be time-dependent.

The effects of forces upon human soft tissues and skin have been extensively studied in the laboratory (Fung 1972, Kenedi *et al.* 1975, Gibson *et al.* 1976). The simplest test is to apply a tensile force of known magnitude to a parallel sided specimen of skin and measure the longitudinal elongation and simultaneous lateral contraction of the specimen. If the force is increased in incremental steps the type of curves shown in Fig. 1 can be plotted. Curve A is longitudinal percentage elongation ("strain") plotted against applied force. The curve shows that a skin specimen undergoes a large initial deformation on the application of a small force. As applied force increases each incremental step produces progressively smaller increases in specimen deformation. Eventually a relatively linear region is reached where extension or lateral contraction increases linearly with applied force. Complete removal of the force from the tissue specimen allows the specimen to return to its original length, although the recovery process does not occur instantaneously, and the original length may not be regained for some hours.

Once the specimen has returned to its original resting dimensions the experimental procedure can again be repeated. However, the force/strain curve now obtained is shown by curve B in Fig. 1. This curve shows that

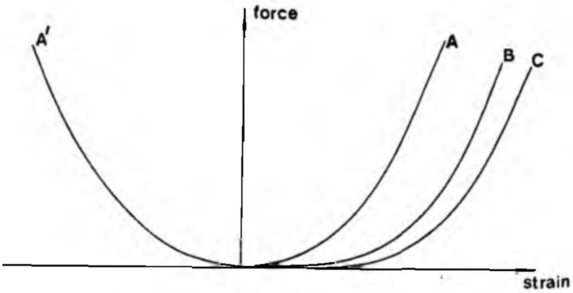

Fig. 1

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the first loading cycle has apparently given the specimen greater compliance, and an increased deformation can now be observed at each step in the second loading procedure. Unloading and then reloading on a third occasion will again produce an apparent change in mechanical characteristics (curve C) but thereafter the tissue exhibits stable characteristics and is said to be pre-conditioned (Daly 1966, Finlay 1970, Starke 1971).

Laboratory studies like these have clearly shown that the magnitude of soft tissue deformation depends not only on the magnitude of the applied load, but also upon time of application and the repetitive nature of the loading cycle. Such results have obvious clinical implications.

Finally, an understanding of pressure ischaemia demands that the loading profiles applied to soft tissue during sitting, lying, or walking must also be studied. When we lie, sit, or stand our body weight is not evenly distributed across the area of skin in contact with the support surface. The body is not a rigid structure, and therefore the force applied at the body/support interface in one area will differ from the force applied at the interface at an adjoining area. In engineering terms the critical measure is not simply the magnitude of applied force but the ratio of this force to the surface area over which it acts. This ratio is known as the stress and is a measurement of force intensity. In the clinical world, stress is usually loosely referred to as "pressure" and reference is made to the pressure between a subject and support surface. "Interface pressure" is usually measured and specified in millimetres of mercury (mmHg) and this common usage will be adhered to in this article. It is generally accepted that sores can be prevented if the interface pressure at a bony prominence is less than mean capillary blood pressure (30 to 40 mmHg), as under this condition capillary blood flow is maintained and not arrested by the applied load.

PREVENTION OF SORES

THE RECUMBENT PATIENT

The projected area of support of a supine patient when divided by his body weight yields an average pressure of around 20 mmHg, which is well below mean capillary blood pressure (30 to 40 mmHg). Thus, if a patient is evenly supported over the complete posterior of the body, pressure sores will not occur. The simplest method of achieving a whole body support situation is to "float" the body in a suitable fluid, and some successful prevention devices use this flotation principle. Other approaches use shaped elastic foam to remove loads from bony prominences, or high compliance elastic foam to equalise support pressures. Mechanical devices which compensate for the patient's inherent lack of mobility and spontaneous movement by shifting the body weight at regular intervals can also be used with success.

Liquid Support (Flotation) Beds

Probably the simplest form of liquid support system is the "water flotation bed" which consists of a tub filled with warm water, the surface of which is covered with an extremely loose fitting sheet of synthetic rubber or vinyl. Because of the looseness of the sheet the patient literally floats in the water and is supported by hydrostatic pressure alone. However, if the water surface is covered by a tight sheet or membrane, the patient is supported by a combination of hydrostatic pressure and membrane tension. Membrane tension support is known as "hammocking", and is a potential problem in all types of fluid support systems, as the soft tissues are then subjected to both shear forces and increased

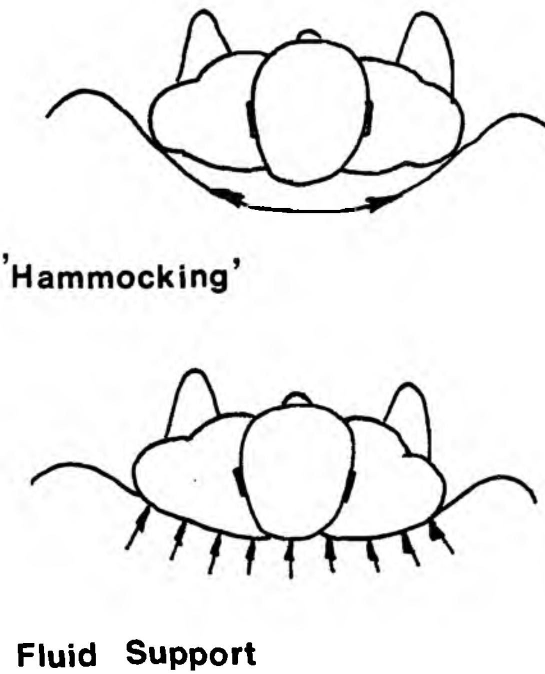

Fig. 2

interface pressures. Correct hydrostatic support and the incorrect membrane tension support are shown schematically in Fig. 2.

An inherent disadvantage of the water flotation system is the unnatural posture adopted by the patient; floating in a three-quarter submerged position with hips and knees flexed and face just above the surface. In addition, the body is only marginally stable in the water and nursing operations are difficult on the unstable platform offered by the water surface.

A development of the water bed first described by Reswick (1972) is known as the "Rancho flotation bed" or "mud bed" in which the containing tub is filled with oilwell drilling mud. Again the surface of the supporting fluid is covered with an extremely loose fitting vinyl sheet and the patient is supported by hydrostatic pressure. Oilwell drilling mud has a density approximately twice that of water and therefore the body only sinks half as far into the supporting medium. The greater density and viscosity of mud compared to water ensures that stability is markedly improved and that the patient floats in a more comfortable position. Fig. 3 compare the "floating" position of patients in both water and mud beds.

One of the practical problems which arises in the use of liquid support beds is the weight of the bed once it has been filled with the supporting fluid. For example, a mud bed which contains about 250 litres of mud weighs in excess of 500 kg. In addition, the temperature of the supporting liquid must be carefully controlled to ensure that the patient is not heated or cooled.

Air Support Systems

Two major types of air support systems, known as high air loss and low air loss beds, have been developed. The high air loss bed was developed primarily for the treatment of major burn injuries and the patient is supported by a high volume flow of temperature controlled air at low pressure. The air is passed into the base of a coffin shaped box which contains the patient,

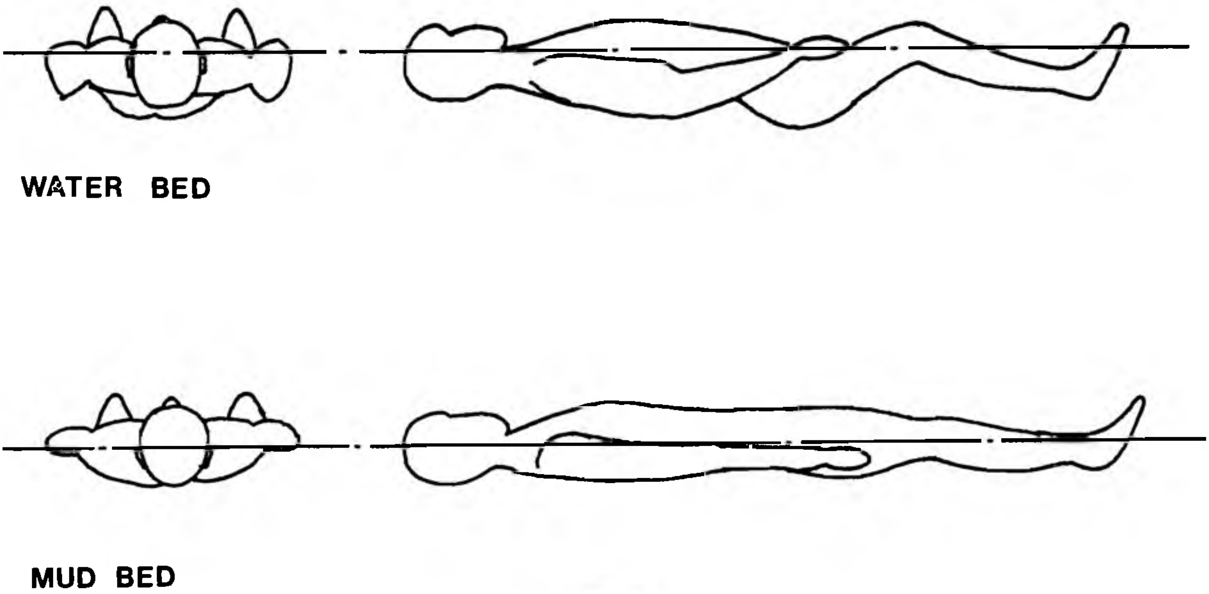

Fig. 3

and as the air exits to the atmosphere, the patient's body is lifted clear of all supporting surfaces and "hovers" in the box. The system has some application in pressure sore prevention but is unpopular with patients, noisy and difficult to manage.

The low air loss bed (Scales 1976) was designed specifically for prevention of pressure necrosis. The bed is constructed of 21 air sacs fabricated from a microporous polyurethane coated nylon fabric which is permeable to water vapour but which is impermeable to air. Moisture collecting between the patient's body surface and the sac permeates the membrane into the air space, the volume flow of air through each sac and the moisture removal from the patient's skin surface being controlled by a system of outlet valves. Body weight is supported by the 21 sacs, the pressure in each sac being adjusted to suit a particular area of the patient's anatomy. Typical pressures are: head, trunk, and seat group of sacs — 20 mmHg; thigh — 10 mmHg; calf and foot — 6 mmHg.

Finally a quasi-fluid bed "the Fluidised Sand Bed", requires brief consideration (Stewart 1976). The bed consists of a box or tray full of fine sand, the base of the tray being constructed of a steel micropore mesh. In operation a patient is placed on a sand surface and air is passed from a blower into the base of the tray to generate a "quicksand" effect. The patient sinks slowly into the sand and when a suitable body contour has been formed the supplied air is switched off, and the patient is supported by a surface which is in intimate contact with the body. The interface pressures obtained by this method have not been published, but the sand bed is said to be very successful in preventing sores.

Dynamic Support Surfaces

The fluid support beds described above attempt to achieve an acceptable static redistribution of pressure and thus allow the patient to lie in one position for long periods of time. Dynamic support surfaces relieve pressure ischaemia by constant adjustments in the posture of the patient, and thus attempts to replace the normal physiological "fidgeting" response to imposed immobility. In their simplest form they are a standard bed and mattress fitted onto a "rocker" arrangement, but such turning beds are unpopular and of little benefit. The more acceptable type of dynamic support surface is the so-called "ripple mattress", variations of which can now be obtanied from several manufacturers. The ripple mattress consists of a multicellular or multitube air mattress, about 75 mm thick, the tubes being progressively inflated and deflated with air to produce a ripple effect. Ripple mattresses are relatively inexpensive, simple to use, and often extremely effective in preventing sores.

THE SITTING PATIENT

It has been shown that the highest interface pressures encountered while sitting occur between the support surface and the ischial tuberosities, and peak pressures in the order of 300 mgHg have been measured in this area from subjects sitting on a wooden chair (Manley *et al.* 1977). Even when a patient is sitting on a soft foam cushion, capillary occlusion may still occur as the interface pressures beneath the tuberosities is often in excess of 100 mmHg. Additionally, if there is a tendency for the buttocks to slip forward in the chair, frictional or shear forces will further deform the loaded tissues and cause further occlusion of capillaries.

Numerous methods have been proposed for preventing sores in sitting patients and many different types of seat cushions or pads are now available. Cushions designed for long-term sitting can be subdivided into passive or active categories, the passive cushion attempting to redistribute statically the "natural" interface pressures while the active cushion provides a constantly changing patient/support contact area and thus cyclic tissue loading. Cushions which fall into the passive category including flotation pads which may be filled with air, water, or silicone fluid; bean bags consisting of cloth envelopes filled with dry macrospheres (usually polystyrene beads); gel pads of silicone or vinyl gel enclosed in an impervious envelope or in closed cell foam; elastic foam cushions of latex or polyurethane; visco-elastic foam cushions which attempt to provide greater stability than the purely elastic variety; and custom-made vacuum formed seats which attempt to provide the maximum patient support contact area. Active cushions are usually of the ripple seat or alternating pressure pad variety, in which air or a support fluid is pumped through linked chambers or pipes to move body weight cyclically from one area to another. Active devices prevent the prolonged application of excessive interface pressure rather than reduce the magnitude of peak loads on the sitting area.

Both passive and active systems have achieved some success in preventing sores. Problems with support devices in the passive category include the instability, floppiness and weight of fluid and gel pads, the heat retention properties of bean bags, and the expense and maintenance requirements of vacuum formed seats. In the active category, ripple type seats are cumbersome and require extensive modification to a wheelchair (including the addition of a power supply): as they can be expensive to buy and maintain they are not suitable for the majority of wheelchair users.

The simplest and least expensive sitting support surfaces are constructed from elastic (or visco-elastic) foam, and a large variety of pressure relief cushions constructed from foam materials are commercially available. Most of these cushions attempt to provide a sitting surface which conforms to the patient's body shape, but conflicting design requirements mean that high foam density and resilience are required to prevent "bottoming out" of the cushion, and a low foam density is required to provide both a "soft feel" and good conformability. Consequently, many foam cushions are laminated from two or more materials of different densities to provide a compromise solution; this is not totally effective in preventing sores.

A foam cushion which has shown itself to be very effective in both preventing and healing sitting sores is the Paracare cushion developed at Conradie Hospital (Manley *et al.* 1977). The cushion is constructed from expanded polyurethane elastic foam of high density which prevents "bottoming out" of the pelvis onto the wheelchair seat and a cut-out under the ischii ensures that most of the load which would have been carried by the tuberosities is now carried on the "trochanteric shelf" and thighs (Fig. 4). In early designs of the Paracare cushion the cut-out was custom-fitted to the anatomy of the individual patient to ensure that loading was completely removed from the tuberosities, but subsequently it has been shown that the ischii can safely withstand an interface pressure of about 40 mmHg. A block of low density foam is now fitted into the cut-out so that the tuberosities carry a small proportion of body weight, and this weight sharing between the trochanteric shelf and ischii has allowed the fitting procedure to be simplified so that only three sizes of cushion cut-out now need be constructed.

A complete Paracare cushion is shown in Fig. 5. The raised front portion of the cushion structure ensures that the maximum possible load is transferred to the "safe" weightbearing area of the thighs, while the curved base fills the sag in the wheelchair hammock seat and prevents distortion of the cut-out dimensions on the upper surface. The complete cushion is fitted with a two-way stretch fabric which prevents abrasive wear of the foam and reduces soiling of the cushion.

In addition to the Paracare cushion, patients at Conradie are also supplied with a shaped backrest which is designed to ensure a no-load condition on the sacrum, coccyx, and vertebral processes. The backrest also ensures that the patient's ischii are positioned

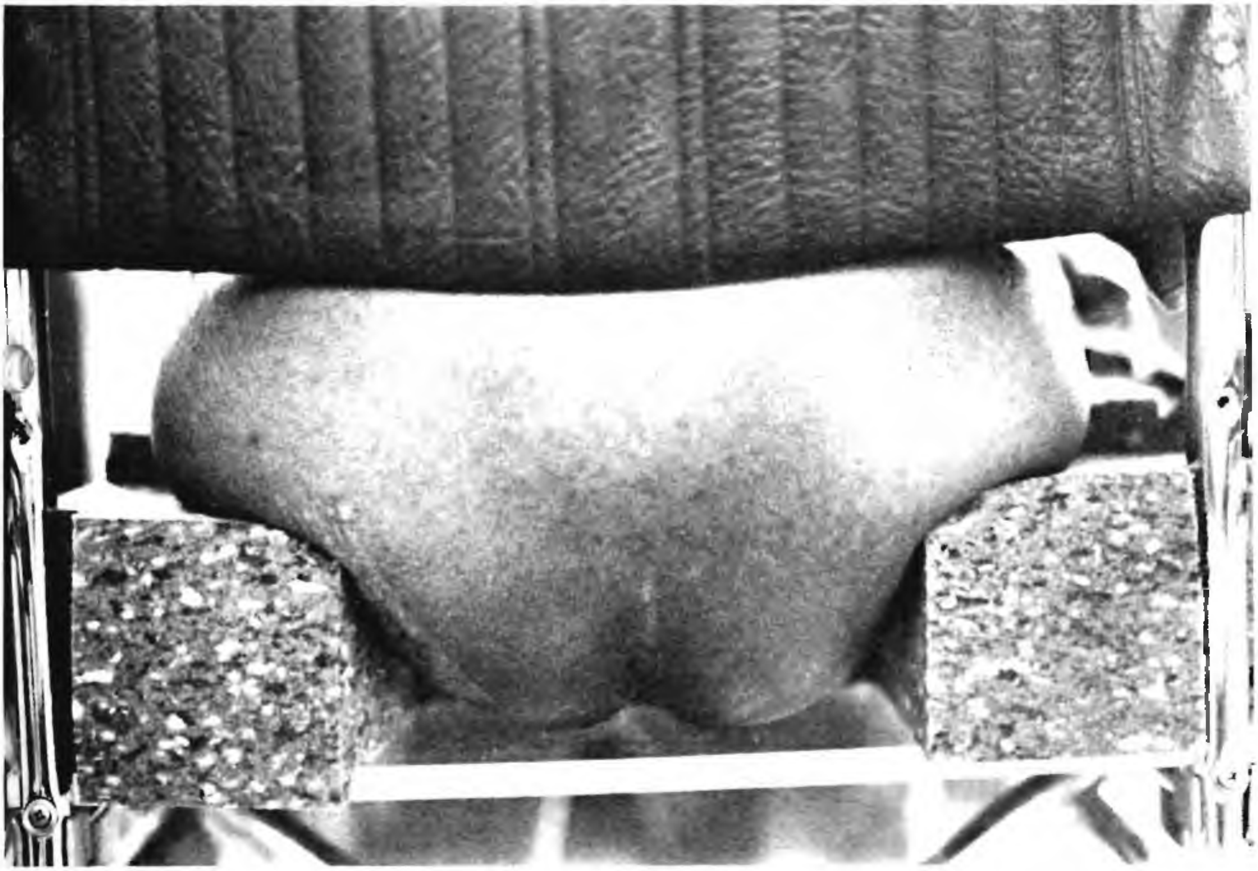

Fig. 4

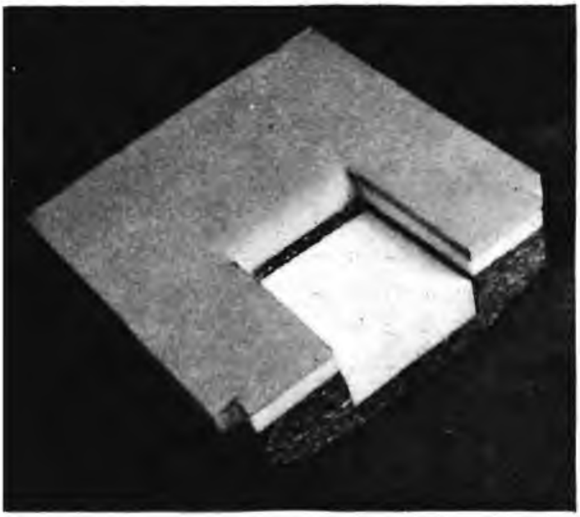

Fig. 5

correctly in the cushion cut-out, improves patient posture in the chair and provides lateral stability for patients with a high level of spinal lesion. Lumbar support is also provided for improved patient comfort, and the backrest is again covered in two-way stretch fabric. Location to the wheelchair is by elastic tapes, over the wheelchair handles and by "Velcro" tapes to the rear of the cushion cover. A complete Paracare seating system is shown in Fig. 6.

CONCLUSION: REHABILITATION AND COST BENEFITS

The rapidly growing worldwide population of handicapped and helpless people has led to an escalation in health care costs. The United States, for example, now spends about 18% of its gross national product on health care, and the average cost to society for each patient treated has approximately trebled in the last eight years (Kenedi 1977). There are now clear indications, particularly in the "caring" societies, that the financial and manpower demands of the health care services may very soon outrun the resources that can be allocated to them. In consequence, health care must become more cost effective, and patients must be rehabilitated and reintegrated into society at the earliest possible stage in their treatment. It is evident that pressure sores, whether due to prolonged bedrest or to prolonged sitting can only delay the rehabilitation process, and active steps taken at the earliest opportunity to prevent sores must increase the cost effectiveness of medical care.

Fig. 6

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