ABSTRACT

SOME HAZARDS OF PATIENT SUPPORT SYSTEMS
AND THEIR MITIGATION

This thesis is concerned with the efficiency of patient support systems, principally beds, and with the causes and prevention of pressure sores and similar disorders.

After reviewing the limitations of traditional hospital beds and the particular problem of pressure sores, the numerous methods for preventing these sores are examined. Novel support systems are shown to have their own limitations and hazards.

An improved general-purpose support system is advocated as a means of both reducing the incidence of pressure sores and avoiding various other identified hazards and disadvantages of contemporary general-purpose support systems. With this end in view the results of a series of experiments concerning force distributions at the patient/support interface are presented. The use of a novel system of mattress indenters has shown that much of the patient tissue distortion associated with pressure sores could be avoided by the use of stretchable mattress covers. The studies indicate that tangential forces at the patient/bed interface contribute to the development of ulceration, and a new method of measuring skin/support interface friction has been developed: the results of its use are presented here. These results indicate that the desirable coefficient of friction is approximately 0.4, and can be obtained (dry conditions) with at least five bedding materials.

Two further factors considered here are the water vapour permeability of bedding materials which have to be waterproof, and a possible replacement for the hospital drawsheet.
As a result of these studies a new patient support system, based on the King's Fund bedstead has been devised, and is described herein.

The results of the various investigations are collated and discussed.
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ABBREVIATIONS USED IN THE TEXT

DHSS  Department of Health and Social Security
NHS   National Health Service
P.S.P.S. Pressure Sore Prediction Score
P.S.S. Patient Support System
RNOH  Royal National Orthopaedic Hospital
μ     Coefficient of friction
W.V.P. Water Vapour Permeability
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CHAPTER 1.

TRADITIONAL SUPPORT SYSTEMS AND THEIR LIMITATIONS

1.1. Introduction

A system for the physical support of a patient may include a variety of equipment, such as walking aids and transfer trolleys, as well as beds and chairs. For the purposes of this treatise the term 'Patient Support System' is used to describe a patient's bed frame (bedstead), mattress, and mattress coverings, and some associated equipment. The research is chiefly concerned with patient support systems for hospitalized adults, and with a particular hazard – the pressure sore.

1.2. Development of the domestic bed

Primitive beds consisted of any available soft material piled on the ground (Everyman's, 1978). Skins, straw, leaves, even dry sand, have been used to provide a comfortable bed – especially in dry climates. In some parts of the world such beds are still used. The origin of the raised bedstead seems to be lost in the obscurity of Pre-history, although Mellaart (1964) has found that raised benches (for both sitting and sleeping) were used (c. 6000 B.C.) by the ancient citizens of Catal Huyuk, Turkey. It is probable that wooden bedsteads were in use at the same time, or shortly afterwards. The earliest wooden beds found in Egypt (c. 4000 B.C.) were light structures made of slatts and wicker, resembling the Indian 'Charpoy'. They used wood cut from the mid-ribs of palm leaves. Similar beds are still used in Zaire (Jenkinson, 1979). Some of the later, and more refined ancient Egyptian beds used a flexible mesh-work base stretched across a wooden frame (Wright, 1962). Except for a change in materials, this design of bedstead has changed little over the centuries (twentieth-century bedsteads use steel wires and springs rather than natural fibres). A design of such longevity suggests either a remarkably effective product, or a dearth of critical evaluation, although the truth may lie somewhere between these two extremes.
A flexible net stretched over a wooden frame is certainly an economical way of constructing a bed. The net will stretch, to some extent to provide some accommodation for the awkward protuberances of the human body. In a warm climate no further cushioning is required (viz, the Indian Charpoy). Early versions of the hammock were similarly ventilated, being made from a network of bark strips (Wright, 1962). Nevertheless, a cooler climate calls for better heat insulation beneath the body, and a great variety of soft materials have been used as mattresses on top of the flexible mesh-work base.

Straw seems to have been the most popular supporting material over the centuries; the now familiar mattress probably appeared when straw was first covered in fabric for convenient handling and to stop the pricking caused by cut straw ends. These first simple mattresses had the advantage that they could also be used to cushion a hard floor, poverty very often precluding the use of a bedstead.

Feather mattresses were popular in the nineteenth-century British home but many cheaper mattresses were stuffed with woollen flock (Blyth, 1873). Various other materials were in use as mattress fillings at this time, including corn, chaff, pine shavings, beech leaves and horse-hair. Both air beds and water beds were well-known, although they were not widely available. As the ordinary mattress became thicker and more resilient (horse-hair in particular) the mattress base could be made stiffer and hence more durable. Nevertheless, many manufacturers started to introduce elaborate steel springing arrangements for the mattress base, with the object of making the bed still more comfortable (Wright, 1962). The spring-interior mattress appeared in the early twentieth century (Gailani et al, 1958) and its rapid rise in popularity was probably due to the much-improved durability of steel springs, as compared with organic fillings (NHS report, 1968). The spring-interior mattress now has few rivals in the domestic-bed
Two such rivals, however, are Dunlopillo (Latex) foam, invented in 1928, and the more recent plastic foams, which were introduced into British hospitals in the nineteen-sixties (NHS report, 1968).

We have already mentioned the uncertain origin of the raised bedstead but, although necessarily speculative, the reasons for having it raised deserve consideration.

Marauding carnivores may have dictated the need for hammocks and other supports which were fastened to trees, but wet weather may also have prompted the development of a bed that was raised above cold, waterlogged, ground. In a crowded cave it would be prudent to have a raised bed, in order to avoid being trodden on by clumsy compatriots. Draughts are unlikely to have been a problem in most caves but primitive buildings, with ill-fitting doors and open fires, will encourage low-level draughts, thus providing a further reason for the raised bed. A bed raised on four legs is economical of materials and also has a certain advantage in deterring crawling insects and similar pests. In some parts of the world it may be necessary to isolate a bed from ants by placing each bed-leg in a container of noxious fluid. Other insects (notably the bed-bug) have adapted to wooden bedsteads and can escape destruction by hiding in the cracks and loose joints of the structure. In Britain the widespread use of iron bedsteads – following the Great Exhibition of 1851 – helped to control the bed-bug (Wright, 1962). In the second half of the twentieth century the wooden bedstead has become popular again, but 'Iron-rod' bedsteads are still used in many of the older British hospitals.

According to Wright, another innovation which helped to control the bed-bug was the introduction of cheap cotton bedding in the middle of the eighteenth century. Unlike wool and silk, cotton sheets can be boiled without ruining their texture. Bugs,
and other offending insects such as fleas, were presumably folded deliberately into the sheets, before being boiled to death. Long-lasting control of these pests was not, however, possible until the introduction of selective insecticides in 1939. Cotton sheets and pillow cases continue to be used on hospital beds, although polyester/cotton sheets are becoming popular for domestic use. It seems clear that the continued use of bed-sheets and pillow cases is influenced by the desire to avoid regular washing of mattresses, pillows and blankets. Even the 'Continental quilt', which is gaining in domestic popularity, has a washable cover.

In 1964 another unwelcome inhabitant of the domestic bed was revealed - the microscopic mite Dermatopagoides sp. (Voorhorst et al, 1964). This tiny animal lives in house dust and feeds on human dander (keratin rubbed off the skin). It has been found to be the chief cause of house dust allergies (e.g. asthma and allergic rhinitis) (Rao et al, 1975). The mite appears to live principally in bedding and mattresses, but hospitals have been found to be relatively free of contamination (Rao et al, 1975). The better hygiene in hospitals, particularly the regular changing of sheets and pillow cases, is thought to be responsible for this situation. Leeks (1973) and Sarsfield et al (1974) have suggested that domestic mattresses could benefit from an impermeable cover, which might reduce exposure to mites and their droppings. However, such an 'impermeable' cover needs to be water-vapour permeable in order to avoid heat discomfort. A suitable material is not yet available for domestic beds.

The continental quilt (mentioned above) may also prove to be a place where dust mites can hide away. These quilts may not, however, be as useful as blankets for patients who are nursed in buildings without thermostatic heating control; many British hospitals fall into this category. The particular advantage of blankets is that their numbers can be readily varied, to compensate
for varying ambient temperatures. Similar adjustments are often necessary when patients are either pyrexial or hypothermic.

Bolsters were used in ancient Greece, and pillows seem to have an equally long history. Pillows are particularly helpful in lateral sleeping positions to prevent the head drooping sideways. Perhaps the easiest and most primitive way of managing without such a support is to fold an arm under the head as many Indians still do (Mehta, 1980). In ancient Egypt rigid curved head-rests (Figure 1) were often used instead of pillows, and similar rests are still used in parts of Japan, Africa and the Pacific (Everyman's, 1978). Feather and down pillows slowly change their shape under the weight of the head, because the feathery particles act like a viscous fluid (Lowthian, 1975). This makes them very effective in preventing prolonged pressure on the sensitive soft tissues of the head. It is also possible to pat pillows into appropriate shapes (even when half-asleep) to provide adequate head support in a variety of sleeping postures (NHS report, 1968). Latex foam (sometimes called 'Sorbo') and soft plastic foams have been used in pillows in recent years, but they have not been widely accepted. Fillings of polyester fibre are said to be popular in the U.S.A. (Redford, 1966).

1.3. Supports for the sick

1.3.1. The height of the bedstead

Another reason for having a raised bed, not mentioned hitherto, is to ease the task of adjusting the bedding ('making the bed'), this being particularly relevant to the care of the sick. Before the nineteenth century most sick beds appeared to follow the domestic pattern (Gailani et al, 1958). The actual height of domestic beds seems to be a compromise between at least five considerations:-

a) A very high bed (about 70 cms.) will ease bed-making problems.

b) Beds higher than 53.3 cms. are difficult to climb into (Humanscale, 1974).
FIG. 1  AUTHOR'S IMPRESSION OF AN ANCIENT EGYPTIAN STONE HEADREST.

FIG. 2  A TRADITIONAL 'IRON-ROD' HOSPITAL BEDSTEAD AS USED, IN BRITISH HOSPITALS, DURING THE FIRST HALF OF THE TWENTIETH CENTURY.
c) A very low bed means that there will be fewer injuries from people (particularly children) falling out of bed.
d) A height of about 40 cms. facilitates using the bed as an occasional seat.
e) The higher the bed, the stronger and more expensive, the bedstead required.

Gailani et al (1958) record that the first steps to develop a bed specifically for hospitals were taken about 1880 and, following complaints from medical and nursing staff about bending over patients in bed, some 25 cms. were added to the height of hospital bedsteads at this time. High beds also became popular for military casualties, one such example being 90 cms. to the mattress base (Pearson, 1919). Sections of this bed's mattress, complete with its mattress base, could be removed, and the height of the bed allowed nurses to attend to the immobilised patient's posterior from below. From 1924 to 1937 U.S. standards recommended a height of 27 inches (69 cms.) for hospital beds excluding the mattress. A British standard of 1950 gave 24 inches (61 cms.) as the correct height. Adjustable beds started appearing in the late 1940's (Gailani et al, 1958) owing to changing medical attitudes in favour of early ambulation (Asher, 1947). A survey in New York's Mount Sinai Hospital (Weil and Parrish, 1958) showed that 46% of all hospital accidents resulted from a fall out of bed and the authors concluded that conventional 'Iron-rod' beds were too high for ambulant patients. A typical Iron-rod bedstead is shown in Figure 2. Many beds similar to this were manufactured in the first half of the twentieth century.

By 1963 the need for an efficient, adjustable-height hospital bed was becoming obvious and was one of the main reasons for the King's Fund design study of the General-purpose hospital bedstead, the report of which was published in 1967 (see Chapter 3).
The hazard of falling out of high iron-rod beds may have prompted manufacturers to produce adult cots for disturbed and demented patients, but these high-sided iron cages were later modified into more modest safety-rails, which could be attached to any bed as appropriate. Unfortunately, these rails were not so effective against determined wanderers and more serious accidents could occur when such patients either climbed over them or clambered over the foot end of the bed (Norton et al, 1962). Such safety rails (and some adult cots) are still in use, but their efficacy is questionable (Bergstrom et al, 1965).

1.3.2. Tilting the bed or its mattress

The surge of mechanical innovation in the late nineteenth century resulted in numerous variations of the iron-rod type of bedstead. An integral backrest was invented at this time, although upholstered backrests and articulating leg supports seem to have originated in the fifteenth century (Wright, 1962). Kamenetz (1980) shows a drawing of a primitive wheelchair, made for King Philip II of Spain, which had both an adjustable backrest and an adjustable legrest, so that it could double as a couch.

Gatch, an American innovator, introduced a backrest combined with a thigh support (c. 1890) for patients who are nursed seated-in-bed. His 'Gatch-Spring' base (see Figure 5) had, by 1920, gained wide acceptance in the U.S.A. (Gailani et al, 1958).

Apart from sitting-in-bed, patients may be nursed in a number of postures for specific purposes. A head-down tilt (loosely called the 'Trendelenburg' position) is frequently used when sliding traction is applied to the lower extremities or pelvis, so that the patient's body weight can act as a counterbalance. The same position may be used for postural drainage of the lungs (Henderson and Nite, 1978) and for emergency use in acute circulatory failure, or airways obstruction. The true Trendelenburg position is used for pelvic surgery and most
FIG. 3
AN EARLY MODEL OF THE GATCH-SPRING BEDSTEAD.
operating theatre tables can be speedily adjusted to this position by mechanical means. The majority of hospital beds are not so well equipped and, until the King's Fund bed became widely used (c. 1975), it was common practice, in British hospitals at least, for nurses either to lift the end of the bed onto 'blocks' or onto an 'elevator' (see Figure 4), although some elevators did incorporate a screw-jack mechanism for winding the bed into the tilted position. Some hospital beds also incorporated a screw-jack mechanism, together with a clutch, which enabled either the whole bed or just one end to be raised. Such mechanical works are liable to suffer from lack of maintenance (usually a lack of lubricant) and, consequently, their operation often called for considerable physical effort (Norton et al, 1962). The same problem occurs with a version of the Gatch-Spring bed known as the 'Fowler's bed', which also operates on screw-jacks.

Although the Fowler's bed is basically an Iron-rod bed design, its moving base sections were usually constructed from angle iron and, as with the early Gatch-Spring beds (Gailani et al, 1958), it was possible for nurses or patients to trap their fingers between the angle-iron and the main bed frame. A bed of similar pedigree is the 'Cardiac bed', which is still available (Nesbit-Evans, 1979) and which is operated by ratchets and worm-drives. The Cardiac bed can give the patient a full sitting position (lower legs vertical) as well as 'Fowler's' position (the bed shown in Figure 3 is adjusted to 'Fowler's' position) and both 'head-down' and 'feet-down' tilt. Unfortunately, its various mechanical parts can also trap the nurses' fingers and, in its usual form, it is higher than the ordinary ward bed, because of the clearance needed when the lower-leg section is vertical. Many other adjustable ('contouring') supports have been designed, some of which are discussed in later chapters.

When the special mechanisms just described are not available, the effort needed to lift an ordinary occupied bed
onto 'blocks' is often too much for one nurse. Nevertheless, in the author's experience, this can be essential when there is an emergency on a busy understaffed ward. Even if the nurse manages to get the bed onto its 'blocks', it will now be an unstable support which cannot either be moved or knocked. These particular problems have stimulated various people to invent sub-frames which fit under the mattress, thereby tilting a particular part as required (Rivlin, 1959; Savage, 1977). Maneuvering and storing these sub-frames when not in use creates obvious problems and may well explain why they have not become widely used.

A 'feet-down' tilt of the bed may be needed for skull traction or for allowing a patient to 'sit up' without flexing at the hip. Obtaining this position on an ordinary bed is, if anything, more difficult than the head-down tilt.

It is possible, of course, to motorize the bed so that various positions can be obtained without physical effort. One such bed, designed by Sanders (1936), could not only be used to obtain various postures and tilts, but could also rock the patient in similar fashion to a rocking-chair on a three-and-a-half minutes cycle. This type of bed is still available in the U.S.A. (Carpendale and Redford, 1980) and a 'rapid-rocking' version completes its rocking cycle in only a few seconds.

Some less elaborate motorized beds are designed to tilt into a near-vertical position so that a patient with limited mobility can simply step out of, or into, his bed. These beds are discussed further in Chapter 2.

There are many other motorized beds and some are capable of adopting a variety of postures. More than twenty years have passed since an American bed was being advertised which had eight distinct, motorized, actions: high prone (recumbent) position; early ambulation (low recumbent) position;
Trendelenburg and reverse Trendelenburg (feet-down); high Fowler position (seated-in-bed); low Fowler position; vascular position (the position adopted by astronauts at take-off); spinal hyperextension and reverse spinal position (the patient lying face-down). This bed (Hospitals, 1958) is only one of many similar American beds, but such sophisticated supports are conspicuous by their absence in most British hospitals. It is, of course, uneconomic to provide very elaborate supports for all hospital patients, when many such patients will only need a bed similar to their own. This basic bed need be little more than a cushioned platform on legs.

1.3.3. Dual-function supports

A cushioned platford on wheels is frequently used in hospitals for transferring patients between different hospital departments. Although this is normally called a trolley, it can be complex enough to need another name, such as 'Modular Stretcher' (Stryker, 1973) or 'Patient Transfer System' (Intensive Care, 1977). These trolleys have various accessories and may function as short-term beds. Robertson (1977) suggested that bedsteads should be mobile enough to serve as trolleys, so that the problems of transferring patients from trolley to bed and vice-versa can be avoided. This is especially pertinent in Intensive Therapy Units. However, special beds are now made for such units. These generally have a radio-translucent mattress base (made from structural plastic sheet or plywood) so that they can be used as x-ray tables (Hoskins, 1979).

Another type of bed, used in Maternity units, can double as an operating table. A special mechanism allows these beds to change the patient's position from 'supine' to 'lithotomy'.

Many special beds have been designed to ease the elimination problems of bedfast patients. Wright (1962) shows an illustration of an adjustable couch containing a commode pan which dates from 1896.
A few years earlier a special bed had been designed which facilitated the use of the contemporaneous bedpan (Gailani et al, 1958). By the middle of the twentieth century a flushable toilet had been installed in a hospital bed - according to Gailani et al (1958). Nevertheless, Carpendale and Redford (1980) were unable to find any kind of 'toilet-bed' operable by a patient which could be purchased in the U.S.A. The various toilet-beds which have been devised usually have the disadvantages of being both expensive and offensive. The latter problem arises from the difficulty of eliminating malodours, plus the lack of any aesthetic appeal. It seems that bedfast hospital patients in particular must still rely on bedpans or commodes. Urinal bottles (usually for men) are also in regular use.

Many other special supports have been devised for nursing the sick. However, most of these (water beds and air beds especially) have been designed either to eliminate or to ameliorate the particular hazard of pressure ulceration; they are discussed in Chapter 2.

1.3.4. The typical general-purpose hospital bed

1.3.4.1. Introduction

Although some special beds can be found in most hospitals, a standardized general-purpose bed is desirable for at least five reasons:—

a) costs are reduced when large quantities of the same design can be ordered,

b) nurse-training problems are reduced when ward equipment is standardized,

c) disputes and allocation problems (which patient has which bed?) are reduced or eliminated,

d) maintenance engineers, supplies officers and technicians can be more proficient in providing and maintaining a single design of bed,

e) a standard bed makes it possible to similarly standardize bed accessories (Bergstrom et al, 1965).
Similar reasons are behind the desire for standardized mattresses, lockers, chairs etc.

A general-purpose Patient Support System (P.S.S.) is necessarily a compromise between a complex support which can be readily adapted to suit any patient, and a 'basic' hospital bed. The latter type of bed is suitable for relatively-fit patients who are ambulant during the day and/or only stay in hospital for a few days. However, the increasing number of elderly people being nursed in general hospitals (Baly, 1980) suggests that a general-purpose P.S.S. should be a compromise biased in favour of the elderly and disabled. Such patients will (as a group) spend longer in their beds than relatively fit patients. In consequence, the characteristics of their support are more critical. The relatively-fit and/or short-stay patient is unlikely to have any problems in using a support which is biased towards the needs of elderly/disabled patients, but the latter patients are likely to suffer if the design of their P.S.S. is biased in favour of the fitter group of patients (see Chapter 2).

As mentioned above (1.3.1.) the King's Fund design study of the general-purpose hospital bedstead was biased in favour of elderly/disabled patients in that a variable-height bed does ease the transfer problems of such patients. However, the bedstead developed from the King's Fund Specification (King's Fund, 1967) was a radical departure from the traditional general-purpose bed. It is discussed in Chapter 3.

1.3.4.2. The bedstead and mattress

The typical British hospital bed used during the first half of the twentieth century was an iron-rod type with integral iron backrest which could be pulled-out (pivoted) from the head-end 'bow' of the bedstead; being adjustable in length, it gave back support at various angles. On some of these beds the head-end 'bow', complete with backrest, could be lifted off the bedstead to facilitate stretcher transfer of the patient.
Similarly, the 'bow' at the foot-end of the bed could sometimes be removed. Many of these 'traditional' bedsteads could not be dismantled in the way described. It was, nevertheless, usually possible to separate the mattress base from each (complete) bed-end - for storage and interchangeability. The most basic bedsteads had no integral backrest and either no castors or just two - on the head-end legs. Such bedsteads could still be purchased in 1979 (Nesbit-Evans, 1979) and many such supports are still in use in British hospitals.

Practically all of the traditional bedsteads have steel-link mattress bases tensioned by springs (Figure 2). This means that patients needing a firm support have to have 'fracture boards' pushed between their mattress and the mattress base (Hector, 1962).

The steel links of the mattress base can easily lose their rust-proofing and this can result in rust marks on the bedsheets. More seriously, the steel links, and splintering wooden fracture boards, can damage both the bedding and the hands of nurses, while they are 'tucking-in' the bedclothes (King's Fund, 1967). The length of these (adult) hospital beds appears to vary from about six feet (183 cms.) to seven feet (213 cms.) between the bed-ends; so that it is sometimes impossible to interchange mattresses. In addition, if neither of the bed's 'bows' can be lifted off it is difficult to find a suitable bed for the very tall patient who occasionally comes along. The width of the mattress base (and the mattress) is usually about three feet (91 cms.)

Norton (1964) maintained that the mattress should be developed as the upholstery of the bed instead of being seen as a "separate entity indiscriminately imposed upon it". Any hospital mattress is, however, unlikely to have a longer life than the bedstead on which it is used. In consequence it is prudent to make the mattress detachable, even if it is developed specifically for the bed in question.
The mattresses used on the typical iron-rod hospital bed (c. 1963) might be spring-interior, horsehair, or straw. Some latex foam mattresses were in use but, according to the author's experience, these tended to be reserved for patients at risk of pressure sores. However, Bliss et al (1966) record that latex foam mattresses (Dunlopillo) were in general use (1963-64) in the geriatric wards of the Whittington Hospital, London. In order to prevent soiling, most of the mattresses were completely covered in waterproof material: red rubber, polythene, or P.V.C. The typical contemporary mattress is discussed in Chapter 3.

1.3.4.3. The bedding

In the nineteen sixties, the bedding usually consisted of woven cotton sheets, woollen blankets and feather, or kapok, pillows (Pearce, 1971). Pillows were often fitted with thin polythene bags beneath their pillowcases. Cellular cotton blankets were being introduced: they withstood laundering better than the wool then available, and were considered to be less likely to cause cross-infection (King's Fund, 1959; Hector, 1962).

The bed-sheet covering the mattress, which is known as the 'bottom sheet', was normally placed directly over the waterproofed mattress cover. Next to this, across the central part of the mattress, was placed the 'draw mackintosh'; this being a waterproof sheet made from red rubber or polythene. The 'drawsheet' was made from cotton twill material and was placed to just cover the draw mackintosh. Some of these twill drawsheets were long enough to be 'drawn' from underneath the patient, when this part was slightly soiled. In this way a relatively clean part of the drawsheet could be used to replace a soiled part, which was then tucked under the mattress (Lowthian, 1973). However, disposable incontinence underpads were being introduced and these were tending to keep the drawsheet relatively clean, so that the 'drawing' function of the drawsheet was beginning to disappear (Pearce, 1971; Lowthian, 1977 B). The Ministry of Health report
on bed linen (NHS report, 1966) expressed the hope that the
drawsheet would be phased out, as disposable incontinence underpads
were improved, but this has not happened.

The NHS report (1966) could suggest only two reasons for
the use of drawsheets:-

1. to provide a fresh place for the patient to lie on,
   by 'drawing through' the sheet,
2. to protect the bedding from soiling.
The first of these reasons is difficult to understand unless the
term 'fresh' is a euphemism for 'clean'. It seems likely that
many of the nurses, who were consulted by the NHS committee
responsible for this report, were reluctant to be frank about
the practice of tucking soiled parts of the drawsheet under the
patient's mattress. In the author's experience, however, this
was usually done at times when it was essential to eke out the
very limited supply of bed-sheets. The second reason given in
the NHS report fails to explain why the soiling of a drawsheet is
preferable to the soiling of the bed's 'bottom sheet'. Though
it must be conceded that very little has been written about the
functions of the drawsheet; a fact which may be due to the
distasteful connotations already discussed.

The first mention of the drawsheet noted by the Oxford
English Dictionary (Supplement) (1972) is in 1870. Gailani
et al (1958) state that drawsheets were in use before 1700, but
were then made of leather. The Oxford English Dictionary (1961)
gives a helpful insight into the drawsheet's function by stating
that it is arranged to facilitate it being withdrawn; without
the disturbance entailed in making the whole bed. The same
dictionary says that the drawsheet is a folded sheet. Fernie
(1973) describes a 'double drawsheet' which is, in fact, a folded
ordinary sheet. However, it seems likely that fabric drawsheets
were originally made from salvaged parts of torn, or old, bed-
sheets. Most drawsheets used in English hospitals (since at
least 1963) have been purpose-made, and are somewhat smaller
than ordinary sheets, although there have been many local variations (materials and sizes) before the NHS report on bed linen (1966).

In the author's considered opinion, the main function of the drawsheet/mackintosh combination is to save time and effort when nursing patients who are incontinent. Even if the soiled drawsheet has to be completely removed, this can be done more quickly and easily than if the bottom sheet has to be changed. The latter procedure entails removing all of the bedclothes including pillows and backrest (if in use). A soiled drawsheet, on the other hand, can be removed simply by turning back the top bedclothes. When this is accomplished, the draw mackintosh, be it red rubber, polythene, etc. can be swabbed clean - before a new drawsheet is inserted. Any suitable piece of fabric, large enough to cover the draw mackintosh, can, in fact, be used as a make-shift drawsheet. It can be seen that this system manages to make good use of the available linen; in situations where the demand is great.

Some additional functions of the drawsheet appear to be:

a) for protecting the bottom sheet when haemorrhage, vomiting, wound discharge etc., is expected.

b) to minimise the disturbance of very ill patients when their bedding needs changing (for the foregoing reasons)

c) to turn the patient over (without lifting) by rolling him to one side and then pulling the drawsheet so that the patient is pulled to the centre of the bed; a long drawsheet being required (Henderson and Nite, 1978)

d) to prevent staining of the bottom sheet when long-stay patients have their meals in bed and wish to minimise their nurses' workload.
Despite these various functions, the drawsheet/mackintosh combination is not regarded as a means of contributing to the patient's physical comfort (Charnley, 1959; Norton et al, 1962; Fernie, 1973; Lowthian, 1975). Disposable drawsheets are also available (Lowthian, 1970 B).

Although drawsheets are not used on every hospital bed, many geriatric wards do appear to have them on every bed (Bliss et al, 1966; Lowthian, 1972 B). A point-prevalence survey, during the present study (April 1980) showed that 43 out of 97 orthopaedic hospital beds (44%) had drawsheets in position, whether occupied or not. This survey was conducted by the author - on a single day. Five wards were surveyed and, the range of drawsheet usage, over the five wards, was 11% - 79%; the lowest (11%) occurring on a rehabilitation ward.

1.3.5. Bed accessories and adjuncts

Hospital beds can have many accessories and adjuncts. Some of the more common of these are: bed curtains (or screens), bedtables, overhead pulleys (monkey poles), bed cradles (blanket supports), identification card holders, chart holders, urinal bottle holders, drainage bag holders, infusion stands, orthopaedic equipment, and cot-sides. The bedside locker can be considered as an adjunct; it needs to be accessible from the bed. The interaction of the hospital bed with these various accessories and adjuncts needs to be considered when a new bed is designed. It is, for instance, quite easy for a nurse to raise an adjustable-height bed, without noticing that the pull-out flap of a bedside locker is positioned over the mattress. A motorized bed may be even more dangerous in this respect: a constant-turning bed (see Chapter 2) has been known to tip over tables which are left too close to it and to pull wall fixtures away from the wall. It should also be appreciated that an overbed table needs to be adjustable in height if it is used with an adjustable-height bed.
From the viewpoint of the present study, an important accessory is the bed cradle. There are many different kinds of bed cradle, but a particular hazard of the traditional "Crimean" bed cradle (Andrews and Atkinson, 1975) is that it is placed on top of the mattress and can easily produce painful bruises, and abrasions, on a patient's legs. Many other kinds of cradles, and cradles combined with footboards, have been devised (Fripp, 1955; Norton, 1970) but they all seem to have the disadvantage of being awkward to 'park' during bed-making (Lowthian, 1976 B).

Another important accessory, when it comes to preventing pressure sores, is the overhead pulley. Versions of this device shown in early photographs suggest that the 'pulley' handle used to be suspended from a bracket fixed to the ward wall - above every bed (Nursing Times, 1980). Later pulleys were attached (removably) to the head-end of the bed; so that their use was not affected by moving the bed. The pulley handles were usually secured with steel chains.

The majority of hospital beds need to be capable of accepting orthopaedic equipment such as box frames or 'Balkan beams' from which pulleys and traction weights can be hung (see Figure 4). The clamps and screws, which often secure this apparatus to the bedstead, may be hazardous by presenting sharp edges, or by interfering with the normal operation of the bed.

Many other accessories, and their interaction with the hospital bed could be explored. There are, for example a variety of orthopaedic splints and traction arrangements which can adversely affect the efficacy of a support system, in its ability to prevent pressure sores. Some interactions which are thought to be particularly relevant to the present study are discussed in Chapters 2 and 3.

1.3.6. The problem of prolonged bed rest

Bed rest has, for centuries, been the natural inclination of the person who is very ill (Asher, 1947). But, according to
Browse (1965) it was in 1863 that the value of bed rest for various diseases was particularly emphasized by Hilton. Browse believes that this led to a general over-emphasis on the merits of bed rest. In the nineteen forties a campaign against excessive bed rest gathered momentum (Lancet, 1947) and surgeons started getting their patients out of bed as quickly as possible. Their main concern was to reduce the number of post-operative deaths resulting from atelectasis, thrombo-embolic infarction, peritonitis and ileus. Prolonged bed rest was implicated in the pathogenesis of all these complications. Asher (1947) particularly stressed the dangers of the bed and, apart from the afore-mentioned post-operative complications, suggested that too much bed rest could result in joint stiffness, muscle wasting, disuse osteoporosis, urinary calculi, retention of urine and incontinence, constipation, lethargy, and bed sores. Browse (1965) discussed these dangers in some detail, but also pointed out the value of bed rest in various conditions such as arthritis, cardio-vascular disease, tuberculosis, severe weakness and coma and certain orthopaedic conditions.

Browse also observed that there has been very little detailed research on the objectives and value of rest in bed. The same criticism can scarcely be made in relation to research on thrombo-embolic infarction. Nevertheless, Browse (1973) states that there is still no proof that either bed rest or position in bed are significant factors in the pathogenesis of pulmonary embolism (infarction). This complex problem of thrombo-embolism and position in bed is relevant to the pressure sore problem; it is discussed further in Chapter 2.

It seems clear, that where bed rest is necessary, every provision should be made for either optimising the patient's freedom of movement or ensuring that an immobile patient is regularly moved by nurses or mechanical means.
Complete bed rest, of more than three month's duration, is now comparatively rare in British hospitals (Scales, 1981). An interesting study by Deitrick et al (1948) showed that calcium loss from the skeleton begins to be quite serious after a few weeks of complete bed rest. Pace (1977) discussed the apparently similar problems associated with prolonged weightlessness, as experienced by Skylab astronauts.
CHAPTER 2.

THE PRESSURE SORE PROBLEM

2.1. Epidemiology

Bedsores were mentioned by Hippocrates (Withington, 1944) and have been found on ancient Egyptian mummies (Thompson Rowling, 1961). We have seen that the origin of the bed probably pre-dates ancient Egypt (Chapter 1.2.) and so it seems likely that bedsores have occurred since the bed was first invented, or perhaps before. Little, however, is known about the prevalence of bedsores (or 'pressure sores' as they are now usually called) before the twentieth century. A statement by Dannatt (1888) in an early nursing journal suggests that pressure sores were then a common nursing problem: "She (an efficient nurse) is careful to prevent and relieve bed-sores". Paget (1873) similarly implies that pressure sores were prevalent in the sick. However, the significance of these sores was not generally understood and they were often regarded as a component of terminal disease. This situation began to change when many 'terminal' patients could survive longer due to significant advances in medicine such as the introduction of penicillin.

The two World Wars created many paraplegics and, by the end of the second World War, pressure sores were seen as a major threat to the health and longevity of these patients. Munro (1940) found that 24% of 126 patients with spinal cord injuries developed bedsores at some time after their injury, but where the injury was thoracolumbar and relatively severe (in 26 patients) the incidence of sores was 54%. Unfortunately, Munro's definition of a bedsore suggests that many superficial sores were not included in his incidence figures. Kuhn (1947) reported that 85% of 113 spinal cord injured patients returning from the war had a history of decubitus ulcers. Berns et al (1957) found 58% of 31 spinal cord injured patients developed some skin breakdown.
Another group of patients with a high risk of developing pressure sores is the elderly. Bliss et al (1966) reviewed a previous survey (Norton et al, 1962) of 403 patients admitted to a geriatric unit. In this survey the patients were examined by research nurses, and the definition of sores was wide enough to include 'breaks in the skin' and 'blisters of the heels'. The 403 patients were examined (weekly) by the research nurses for up to six months and during this time 87 (22% of the 403) developed pressure sores. Norton et al (1962) also noted that 70% of new sores developed within two week's of a patient's admission. A comparable survey by Lowthian et al (1976) used a similar definition of pressure sores. This survey was also conducted by research nurses who examined 110 patients admitted to three different geriatric units. The patients were examined three times weekly for up to three weeks and 30 (27% of the 110) developed new sores. A few of these sores developed in patients who already had one or more sores when admitted, and these are counted in the 27% incidence figures. Such figures do not appear to have been included in the incidence figures given by Bliss et al.

The incidence of pressure sores in (British) orthopaedic wards seems to be similar to that in geriatric admission wards. Woodbine (1979) found that 12 (24%) of 49 patients admitted to an orthopaedic ward developed pressure sores within the seven-week period of her study. About half of these (49) patients were over 70 years of age.

The comparable surveys of Norton et al (1962) and Lowthian et al (1976) also studied the prevalence of (existing) pressure sores amongst geriatric patients on admission to a geriatric unit. In the earlier survey 12.3% (37 out of 300 patients) had existing sores while, in the later survey, 16% (18 out of 110 patients) had sores on admission.
The prevalence of sores in the community (including hospitalized patients) has been studied by Petersen and Bittmann (1971) in Denmark and by Barbenel et al (1977) in Glasgow. Both surveys were 'Point-prevalence' in that they looked at the situation on a single day in their respective areas. Petersen and Bittmann found that 43.1 (0.04%) of each 100,000 inhabitants had pressure sores, while the equivalent figure for the Glasgow area was 85.6 (0.09%) of each 100,000. It is likely that both surveys underestimated the true prevalence, as they relied on sores being reported by Health Service personnel directly concerned in patient care. A similar survey, but on patients only, was conducted at the Royal National Orthopaedic Hospital, Stanmore (Lowthian, 1979 A) on the 26th April, 1978. Of the 186 patients in the hospital on this day 13 (7%) had at least one pressure sore (see Appendix I). The equivalent figure in the Glasgow survey was 946 (9%) of the 10,751 recognized patients. However, the prevalence of sores increases with age, and an analysis of this relationship (recognized patients only) for both the Glasgow patients and the Stanmore patients was possible (Figure 5). Two small surveys at the Great Portland Street branch of the Royal National Orthopaedic Hospital, London, were included with the Stanmore figures. Figure 5 shows that there was good agreement between the surveys. Apart from a minor peak around 10 - 30 years (which seems attributable to patients with congenital spinal defects) the graphs indicate a definite increasing prevalence with old age. A histogram produced by Petersen and Bittmann (1971) and reproduced by Fernie (1973) correlates well with Figure 5.

As the number of very elderly people is expected to increase by 40% or more over the next 20 years (Norton, 1979; Baly, 1980), the prevalence of patients with pressure sores is expected to increase in proportion.

The most usual anatomical site for a pressure sore is over, or adjacent to, the sacrum. Other typical sites are the femoral trochanters (hips), the heels, and the ischial tuberosities.
FIG. 5 PREVALENCE OF PRESSURE SORES IN RELATION TO AGE.
The figures provided by Petersen and Bittmann (1971) and Lowthian et al (1976) have been combined in Figure 6 to indicate the anatomical distribution of pressure sores.

Pressure sores are, undoubtedly, a serious problem of health care, and they appear to be on the increase. When the 'pressure sores' suffered by lepers are taken into account (Brand, 1969) it can be seen that the problem is by no means confined to developed countries.

2.2. Aetiology and Pathology

Arnott (1833) and Paget (1873) both recognized that sustained pressure was a principal cause of bed sores, and Trumble (1930) suggested that quite moderate pressures would cause pressure sores if continuously applied over a long period. This was later confirmed (in dogs) by Kosiak (1959) who produced a graph correlating magnitude of pressure to duration of application. Reswick and Rogers (1976) reported that over 980 observations (human subjects) have tended to confirm the general shape of Kosiak's graph. Figure 7 is a pressure tolerance graph based on the work of Kosiak, Reswick and Rogers. The zone of uncertainty on this graph may be due to errors of measurement, or individual variations, or both. The posture of a patient must, however, be taken into account when considering the localised pressure that can be tolerated on a particular part of the body. For example, if a man stands upright with one arm over his head, his systolic blood pressure can vary from 40 mm Hg. (in his raised hand) to 160 mm Hg. in his foot. The same man's venous pressure will vary from zero in his hand to 70 mm Hg. in his foot (Browse, 1965). Capillary pressure is, of course, slightly higher than venous pressure and although there appears to be a lack of specific data on capillary pressure varying with posture, it seems likely that the same pattern of pressure variation holds good. Similarly, both lymph and tissue fluid pressures are likely to increase in the more dependant parts of the body.
FIG. 6 ANATOMICAL DISTRIBUTION OF PRESSURE SORES

'Sacrum' includes buttocks adjacent to sacrum.
FIG. 7 PRESSURE NECROSIS - THE RELATIONSHIP BETWEEN LOCALISED PRESSURE AND TIME OF APPLICATION.
Browse (1965) has also pointed out that the 'Valsalva manoeuvre' - causing raised intrathoracic pressure - may occur quite frequently in normal people while they are changing their position in bed, thus causing intermittent raising of vascular pressures. Similar variations in blood pressure occur under hormonal influences (Bell et al, 1980). More localised variations in vascular pressures are known to occur when muscles are contracted (Pegum and Fegan, 1967).

It should be appreciated that the kind of pressure which results in pressure necrosis (Figure 7) is localised (uniaxial) pressure. The failure to distinguish between this kind of pressure and encompassing (multiaxial) pressure has caused considerable confusion in the pressure sore literature. Aqualung divers can, for example, withstand a water pressure greater than 1 000 mm Hg. (Lowthian, 1977 A; Neumark, 1981) simply because this is an encompassing pressure which causes no distortion of soft tissues. On the other hand, a localised pressure of slightly less than 100 mm Hg. on the foot of an ambulant boy can cause pain (Trumble, 1930). Localised pressure distorts the soft tissues by squeezing them sideways - into regions under lower (atmospheric) pressure (Chow, 1974; Lowthian, 1977 A). At the same time most of the blood is likely to be squeezed out of the compressed region of tissue.

The external (localised) pressure needed to force all capillary blood out of an area of soft tissue is obviously related to the mean blood pressure of the individual (Trumble, 1930; Daly et al, 1976; Larson et al, 1979). Nevertheless, it should be recalled that intermittent variations in blood pressure can occur normally; and these may be sufficient to prevent prolonged ischaemia - even when localised tissue pressure is equivalent to the subject's mean capillary pressure. But the tolerance of tissues to prolonged periods of ischaemia is obviously important.
The careful work of Brooks and Duncan (1940) on the tails of rats showed that ischaemia caused by pressures just above the rat's mean blood pressure could be tolerated for 16 to 17 hours. Longer periods resulted in necrosis of the rat's tails. In similar experiments on rabbits' ears, Lindan (1961) found that a constant (uniaxial) pressure of 100 mm Hg. would initiate minor necrosis if maintained for 13 to 15 hours. The pressure clip used by Lindan probably resulted in more severe soft-tissue distortion than the pressurized rubber tube (plethysmograph) used by Brooks and Duncan, and this may explain their slightly different results.

Logically, those blood vessels (and lymph vessels) which have the lowest internal pressures will be the first to be emptied (their contents being squeezed sideways) when a localised pressure (such as Lindan's clip) is applied to soft tissues. Thus the lymphatics, venules and small veins should empty first - closely followed by the capillaries. If the compressing force is lower than the internal pressure in the arterioles these will not be emptied. However, the tissues themselves contain a great deal of fluid, in the form of lymph (tissue fluid) and ground substance gel (Gray's Anatomy, 1973). This fluid and gel will also be gradually displaced sideways as it is squeezed out of the numerous intricate pockets between groups of cells and tissue fibres (Elson, 1965). Increasing or prolonged pressures will produce more and more fluid/gel displacement (fat cells may also migrate) until there is little effective cushioning between the skin surface and the underlying bone.

Moreover, because increasing values of localised pressure (above local capillary pressure) are known to cause necrosis in progressively shorter periods of time (see Figure 7), an additional effect of this pressure - apart from the loss of fluid nutrients - has been postulated (Lowthian, 1970A).
Reichel (1958) had previously suggested that the sacral sores suffered by semi-recumbent paraplegics were attributable to a sustained tangential (shearing) force rather than pressure acting at right angles to the skin. Lowthian (1970 A) considered that the stretching and tearing of small blood vessels, suggested by Reichel, could, in fact, be caused by any (excessive) localised pressure with or without the contribution of tangential forces. Figure 8 shows that the anchoring effect of blood vessel anastomoses enables small vessels to be stretched and/or torn by the tissue-distorting effect of excessive localised pressure. When a sustained tangential force is added to the normal force the microvasculature is likely to be more severely strained (Figure 9). As already implied, this strain will gradually increase, under sustained loading, due to the viscoelastic nature of the tissues. Similarly, the elastic recovery of the strained tissue will be prolonged, in proportion to the duration of the distorting force (Gibson et al, 1976). Reactive hyperaemia (Lewis and Grant, 1925) appears to compensate, to some extent, for delayed elastic recovery by flushing previously-compressed tissues with an increased volume of blood (Brand, 1976 A).

Reichel's 'shearing' force is produced by static friction between the patient and his bedding, but Dinsdale (1974) working with swine, showed that kinetic friction (intermittently applied) would reduce the magnitude of the sustained normal pressure needed to produce cutaneous ulcers. Dinsdale's conclusion that kinetic friction increases pressure sore liability by a mechanical effect is supported by Lowthian (1970 A) and Comaish (1973). Comaish reasoned that repetitive kinetic friction causes blisters by a mechanical disruption of the skin structure - similar to fatigue fracture in metals. A similar hypothesis has been advanced by Brand (1976 B) to explain the sores which occur after excessive walking on insensitive feet. In all of these cases, with the possible exception of superficial friction blisters, there is stretching of the microvascular network; and such stretching appears to explain how the endothelial cells of capillaries become
FIG. 8 DIAGRAMMATIC SECTIONS OF A TOE - ON GROUND CONTACT - AND BEFORE.

- Load
- Bone
- Venules/capillary network
- Junction of epidermis & dermis
- Network of connective tissue fibres
- Flattened & stretched vessels (under phalanx) due to normal localised pressure.
FIG. 9 DIAGRAMMATIC SECTION OF A TOE UNDER A LATERALLY INCLINED LOAD.

(COMPARE WITH FIGURE 8)

Severe distortion & disruption of microvasculature due to inclined localised pressure.

Friction on ground preventing sliding of skin.
"separated by trauma", to use the words of Barton (1976) in pressure-damaged tissues. Zweifach (1964) mentions that venules have a particular predilection to injury and that both capillaries and venules are adversely affected when they are stretched with a microneedle. Stretching a capillary produces temporary stasis of blood, whereas similar stretching of a venule results in leakage of blood. When sufficient distortion, or disruption of tissue has occurred, we can expect many venules and capillaries to become overstretched; in the area of greatest tissue distortion/disruption. This may produce multiple venular/capillary thrombi in the affected region, as a result of either haemorrhage (inducing clotting in the vessels concerned) or platelet aggregation around tiny stretch-induced gaps in the vessels. Such thrombi, on the edges of pressure sores, have been found by Reichel (1958), Dinsdale (1973) and Barton (1976).

Astley (1940) was unequivocal in stating that a lack of blanching (of discoloured skin over a threatened pressure sore following finger pressure) indicates capillary thrombosis. When such thrombosis or 'microvascular occlusion' is extensive, it will lead to prolonged ischaemia, hypercapnia and subsequent necrosis (Dinsdale, 1973). Other tissue components, such as collagen fibres and lymphatic capillaries (Krouskop et al, 1978) can be damaged by the kind of tissue strains that result in microvascular occlusion; and such damage will increase the severity of the subsequent wound.

In summary, it seems clear that pressure sores are initiated by significant prolonged or repetitive distortion of subcutaneous tissues and/or skin. When the distorting force overcomes local capillary pressure, it produces local ischaemia, which is severely exacerbated and subsequently prolonged by stretch-induced thrombotic occlusion of the microvasculature, and the related mechanical disruption of various tissue components.
Endogenous factors undoubtedly influence a person's susceptibility to pressure sores, and one such factor (insensitive skin) has already been mentioned. If the subject's mean blood pressure is low, the foregoing discussion indicates that this also will increase the risk of pressure sores (Trumble, 1950).

Imposed (exogenous) factors must similarly potentiate the risk of pressure sores, immobilisation for fractured femur being just one example. These various endogenous and exogenous factors, which are thought to be involved in pressure sore aetiology, are summarized in an analysis chart (Figure 10).

The hypothesis advanced in this treatise is that the main cause of pressure sores is distortion of the skin and/or subcutaneous tissues, and that this must be either prolonged or repetitive to become pathological. Thus 'repetitive skin/tissue distortion' (Figure 10) can cause foot sores in healthy people who walk a greater distance than they are accustomed to; and lepers may develop serious sores from this cause (Brand, 1976 B) because of their 'loss of pain sensation'.

Sliding traction, combining with a bed surface which has a moderately-high coefficient of friction, will result in repetitive skin distortion and consequent erosion of the skin. Similar erosions (abrasions, excoriations or superficial sores) can occur as a result of repetitive friction attributable to uncontrolled spasmodic movements, such as occur with cerebral irritation after head injury.

Excessive massage (Figure 10) tends to disrupt the subcutaneous tissues (Dyson, 1978) and may thus contribute to pressure sore development. Excessive washing will remove the natural lubricants of the skin (sebum and other skin lipids) and thereby make it more vulnerable to erosion by tangential forces (see Chapter 5.)
FIG. 10 PRESSURE SORES - AN ANALYSIS
Tearing of the skin can be facilitated by a 'heat-retaining support surface' such as an impermeable mattress cover, which allows the skin to soften (macerate) due to local sweating. Incontinence can have a similar effect and may also excoriate buttock skin. A skin erosion has a high coefficient of friction (Lowthian, 1970 A) and this may result in 'adhesion at the skin/support interface' (Figure 10), which can also be caused by a moisture laden skin (Lowthian, 1976 A) resulting from incontinence or sweating.

Once the skin of a weak patient has adhered to his support surface any spontaneous movement is severely limited, so that prolonged tissue distortion of a discrete region of tissue may occur. If skin/support adhesion is combined with the tangential forces developed during the 'forward slide' (Lowthian, 1970 A) severe and prolonged tissue distortion is likely (see below 2.6.) High friction support surfaces, such as synthetic sheepskins, can dangerously prolong tangential forces even in dry conditions by anchoring the patient in one position (Lowthian, 1970 A, 1976 A; Denne, 1979).

Prolonged tissue distortion, with or without a significant tangential component, is particularly likely to occur when an immobilised patient has lost some, or all, of his pain sensation. General weakness and old age will also restrict movement, an obese or heavy patient being particularly at risk. However, a patient who is emaciated (Figure 10) is also at risk because he has little if any subcutaneous fat (which normally cushions bony prominences) and his skin can be severely distorted by the increased point-loading over his bones (Chow, 1974). Additionally, a wasted patient often has loose skin over his buttocks which can be severely compressed when it is trapped in folds under his sacrum (Lowthian, 1970 A). Unconsciousness or semi-coma (Figure 10) may exacerbate the latter effect (Lowthian, 1972 A). Creased bedding will cause a similar concentration of pressure. Severe tissue distortion may also result from skeletal abnormalities
such as bony tumours (Roaf, 1976) and spinal scoliosis (Lowthian, 1980). Contractures and hard supports are two of the more obvious causes of prolonged, or severe, tissue distortion.

Septicaemia has long been associated with pressure sores (Rupp, 1895). Groth (1942), Husain (1953) and Lindan and Hickman (1964) have suggested that circulating bacteria will multiply in subcutaneous tissues which have been traumatised by pressure insults. Thus, an abscess may form where a pressure sore might be expected. An elevated temperature will also predispose to pressure sores by increasing the metabolic rate of the susceptible tissues (Pathy, 1978). Local metabolism can be disturbed by interruption of nerve pathways (as in spinal cord injuries) but the effect of this trophic factor has long been disputed. Recent work by Manley and Darby (1980) suggests that neurectomy does play a limited role in pressure sore pathogenesis, by reducing the effectiveness of the local circulation (probably by interruption of the vasomotor nerves). Such a mechanism may help to explain the increased susceptibility of some multiple sclerosis sufferers (Scales, 1976).

Many other disturbances, of either local metabolism or general health, may increase pressure sore liability. Poor circulation, uraemia, severe malnutrition, negative nitrogen balance, diabetes mellitus, anaemia, dehydration and steroid therapy are just some factors which have been implicated by various authors (Lindan and Hickman, 1964; Berecek, 1975; Agate, 1977). It should be mentioned, however, that ACTH administered before a pressure insult occurs appears to strengthen the microvasculature. Although the mechanism of this strengthening has not been clarified, there does appear to be a reduced risk of necrosis (Lindan and Hickman, 1964; Barton and Barton, 1976). Agate (1977) supports Trumble (1930) in suggesting that a low blood pressure increases pressure sore susceptibility. Agate (1977) also stressed the importance of great vein thrombosis as a cause of pressure sores in the pressure areas affected by the thrombosis.
Figure 10 indicates those 'imposed' factors which can be readily modified by changes in support systems, or medical/nursing techniques, or both. In consequence, it is these factors, especially the hardness and friction/adhesion characteristics of the support system, which are the chief concern of the present study.

2.3. Definition of Pressure Sores

The classification and definition of pressure sores is a problem intimately associated with their pathogenesis. Barton and Barton (1973) suggested a classification depending upon thermographic evaluation of the sore. An 'indolent' sore exhibits little if any increase of skin temperature at the wound edge, and this is thought to result from occlusion of the surrounding microcirculation. A relatively innocuous sore caused by an abrasion in a healthy person shows a definite temperature difference between the wound edge and the surrounding skin. A third type of sore is termed 'hyperactive', because the temperature of the wound edge is about 6°C. above the level of the surrounding skin.

Unfortunately, thermographic evaluation is impracticable until the necessary equipment is readily available to health service personnel, and nurses in particular. Used alone, thermographic evaluation gives only a limited indication of a sore's severity.

Guttmann (1976) used a rather involved classification which included aspects of pathogenesis, making it rather too learned for general use. The same may be said of Shea's definition (1975). Another table of classification, developed by Bliss et al (1966) used thirteen gradings, although only two main types of sore were recognized: superficial and gangrenous. Lowthian et al (1976) reasoned that a sizeable break in the skin is normally more dangerous than a discoloured area beneath intact skin. The latter manifestation was consequently termed an
'incipient sore' and large blisters were included in this category. Any sores less than 6 mm in diameter were discounted. Non-incipient sores were open sores, and these could be classified as deep if the dermis was penetrated (Groth, 1942).

In a large-scale point-prevalence survey (Barbenel et al, 1977) an attempt was made to divide pressure sores into four grades:
1. skin discoloration
2. superficial
3. destruction of skin - no cavity
4. destruction of skin - cavity
In practice it was found that grade 1 (skin discoloration) was not specific enough.

For the purposes of the present study an agreed definition of pressure sores was produced. This followed discussion with hospital nurses at the time of the hospital survey of pressure sores (Appendix I). The new definition is designed to be comparable with that of Barbenel et al (1977) but is more specific (see Table 1).

Although human skin is a complex organ its main components are the epidermis (surface layer) and the dermis (cutis) which are keyed together by a special system of pliable pegs (Gray's Anatomy, 1973). These pegs are represented by a convoluted line in Figures 8 and 9. Blisters result from mechanical separation of the epidermis from the dermis (Dinsdale, 1973).

However, the main structural component of skin is the dermis. It is largely a dense network of collagen and other fibrous proteins (Fernie, 1973). A small break in this network (such as a needle puncture) is not serious, but a cut, or hole, measuring more than a few millimetres wide is difficult to heal, a fact which is supported by the spacing of sutures when a surgeon closes the skin. Any inadvertent strains of the skin will tend to enlarge a sizeable defect - thereby disrupting new tissue growth. This
Blood under the skin or in a blister, or black necrotic discolouration under the skin, measuring more than 5mm in diameter (longest measurement) or clear bullae more than 15mm in diameter.

A break in the epidermis, which may also include some damage to the dermis but without necrotic discolouration, and measuring more than 5mm in diameter.

Destruction of the skin (epidermis & dermis) without an obvious cavity, but possibly with some necrosis or necrotic discolouration - more than 5mm in diameter.

Penetration of the skin (epidermis & dermis) with a subcutaneous cavity (with or without necrotic tissue) more than 5mm in diameter.

Sizes of sores are judged using a special template (held just above the sore). Only those sores which overlap the smallest hole (5mm) are counted.

Sores* which overlap the 15mm hole are identified with a plus sign after their grade no: ____________________ +

Sores* which overlap the 50mm hole are identified with two plus signs: ________________________________ ++

(e.g. a grade 2 sore 60mm x 40mm would be graded: G.2.++)

N.B. Multifocal lesions are counted separately unless they are interconnected.

Any lesion which does not fit into these categories, such as persistant erythema with induration, is described in full.

*Including clear bullae.

**TABLE 1 THE 'STANMORE' DEFINITION OF PRESSURE SORES.**

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>CATEGORY</th>
<th>GRADE</th>
<th>ABBREVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood under the skin or in a blister, or black necrotic discolouration</td>
<td>Incipient</td>
<td>1</td>
<td>G.1.</td>
</tr>
<tr>
<td>under the skin, measuring more than 5mm in diameter (longest measurement)</td>
<td>Sores</td>
<td></td>
<td></td>
</tr>
<tr>
<td>or clear bullae more than 15mm in diameter.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A break in the epidermis, which may also include some damage to the dermis</td>
<td>Open</td>
<td>2</td>
<td>G.2.</td>
</tr>
<tr>
<td>but without necrotic discolouration, and measuring more than 5mm in diameter.</td>
<td>Sores</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Destruction of the skin (epidermis &amp; dermis) without an obvious cavity,</td>
<td>Open</td>
<td>3</td>
<td>G.3.</td>
</tr>
<tr>
<td>but possibly with some necrosis or necrotic discolouration - more than</td>
<td>Sores</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5mm in diameter.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Penetration of the skin (epidermis &amp; dermis) with a subcutaneous cavity</td>
<td>Open</td>
<td>4</td>
<td>G.4.</td>
</tr>
<tr>
<td>(with or without necrotic tissue) more than 5mm in diameter.</td>
<td>Sores</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
explains why penetration of the skin is regarded as the most serious grade of pressure sore. Such sores often start in subcutaneous tissue near to a bony prominence (Groth, 1942) and may take months to heal with conservative methods. They are usually associated with extensive microvascular occlusion (see above - 2.2.) It may be argued that this (grade 4) definition of a severe sore will exclude serious sinus sores (Guttmann, 1976) where the superficial part of a deep sore has prematurely healed, leaving some infected necrosis in the deep tissues. However, such a 'sore' might be better classified as an abscess resulting from a pressure sore.

Black discolouration (gangrene) under intact skin (Table 1, grade 1) may be just as serious as a grade 3 sore; if the skin breaks down shortly after such discolouration has appeared (Bliss et al, 1966). If, on the other hand, this lesion is carefully protected and the skin does not break, it is likely to be no more serious than a bruise (Norton et al, 1962). An open sore, of grade 2 or 3, is considered to be more serious than an 'incipient' sore because of increased discomfort and various complications: wound contamination and infection, further tissue damage - due to the sore adhering to the bedding or to an unsuitable wound dressing.

Excoriation, induration, and erythema of pressure areas are not graded due to difficulties of definition (see Appendix I). It is sometimes difficult to distinguish pressure sores from other lesions such as ischaemic ulcers of the feet and psoriasis plaques. Peripheral vascular diseases may make the heels and feet more susceptible to necrosis when they are subjected to tissue-distorting stresses, but the history, location and/or shape of the lesion in question will usually indicate its aetiology (Miller and Sachs, 1974). The relatively higher incidence of pressure sores in certain distal parts of the body (see Figure 6) may reflect the influence of peripheral vascular diseases; the
difference between the figure for 'elbows and arms' and that for 'knees and legs' should be particularly noticed, although other factors such as paraplegia may also influence the disparity between these two parts of the body.

The definition of pressure sores given in Table 1 will be used throughout the remainder of this treatise.

2.4. Recognition of patients at risk

A nurse caring for a number of patients needs to know which of these patients are most at risk of developing pressure sores, so that her limited resources (personnel and equipment) can be deployed to the best advantage. An understanding of pressure sore epidemiology and pathogenesis makes a nurse well-equipped for this task, but most nurses rely on their empirical experience of a variety of patients. Inevitably, this means that a nurse who is short on experience will be less able to identify patients at risk. Norton et al (1962) attempted to improve this situation with a scoring system based on 'general physical condition', 'mental state', 'activity', 'mobility' and 'incontinence' (Figure 11). Improvements to this scoring system were suggested by Bliss et al (1966) and Gosnell (1973). Lowthian et al (1976) attempted a more objective scoring system: The 'Bedsore Liability Score', which was further modified by Scales and Lowthian (1978-1980) for general ward use and for training nurses to recognise patients at risk. The chart of this system, which is known as the 'Pressure Sore Prediction Score', is shown in Figure 12. When the score is used for intensive care, training or research purposes, a key of 'Category examples' is consulted (Appendix II). The Pressure Sore Prediction Score (PSPS) is used in appropriate places throughout this treatise. In Chapter 6 an indication of its success in predicting pressure sores is shown in the form of a histogram. For an ordinary (typical) hospital PSS the danger level on the PSPS is thought to be a score of six.
Patients with a total score of 14 or less are liable to develop pressure sores.

**FIG. 11 THE 'NORTON' SCORING SYSTEM**
## Pressure Sore Prediction Score

Completed by:—  
Patient:—

<table>
<thead>
<tr>
<th></th>
<th>NO...</th>
<th>No, but..</th>
<th>Yes, but.</th>
<th>YES...</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unconscious?</strong></td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><strong>Very Ill?</strong></td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><strong>Incontinent?</strong></td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><strong>Sits up in Bed?</strong></td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><strong>Lifts up?</strong></td>
<td>YES... 0</td>
<td>Yes &amp; No. 1</td>
<td>NO..... 2</td>
<td></td>
</tr>
<tr>
<td><strong>Gets up and walks?</strong></td>
<td>YES... 0</td>
<td>Yes &amp; No. 1</td>
<td>NO..... 2</td>
<td></td>
</tr>
</tbody>
</table>

Total scores:  

* Able to lift own pelvis clear of support.  
Maximum score = 16  

NB For definition of terms see category examples.

**Fig. 12 The Pressure Sore Prediction Score**
2.5. Preventing pressure sores

2.5.1. Introduction

The author is aware of almost 200 devices, ideas and techniques for preventing pressure sores. A selection of these, with some grouping under collective headings, is given in Table 2. Although some of these ideas are not relevant to the present study, many are, necessitating some further selection in the discussion which follows.

 Practically all of the supports and preventative methods which will be discussed rely on one or both of the following principles:

 a) the static re-distribution of localised pressure, in either a uniform or non-uniform manner (e.g. a water bed provides uniform re-distribution of pressure, but skeletal suspension provides non-uniform re-distribution of pressure).

 b) the dynamic distribution of localised pressure; exemplified in supports such as 'constant-turning' beds and 'ripple' mattresses.

 In addition, some techniques aim to minimize the patient/support interface problems of shear (tangential forces); dynamic friction; and the 'microclimate' problem of heat/moisture accumulation (Scales, 1976 B).

 Two other basic principles for relieving local pressure from soft tissues are mentioned by Walker (1971): weightlessness and reduction of the body mass. As neither of these methods is very practical they will not be considered. It must be conceded, however, that a reducing diet may, in the long term, be a necessary measure for overweight patients who need to avoid pressure sores.
### Table 2

**A Selection of Devices, Ideas and Techniques for Preventing Pressure Sores.**

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Air-fluidised bed.</td>
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<td>2.</td>
<td>Bullitt bed.</td>
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<td>3.</td>
<td>Canvas slings.</td>
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<td>4.</td>
<td>Circ-O-electric bed.</td>
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<td>5.</td>
<td>Constant-turning bed.</td>
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<td>6.</td>
<td>Continuous bath.</td>
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<td>7.</td>
<td>Hey Groves' bed.</td>
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<td>8.</td>
<td>Low Air Loss Beds.</td>
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<td>9.</td>
<td>Molner's bed.</td>
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<td>10.</td>
<td>Mud bed.</td>
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<td>13.</td>
<td>Plaster beds.</td>
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<td>15.</td>
<td>Sawdust bed.</td>
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<td>16.</td>
<td>Shetrumpf bed.</td>
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<td>17.</td>
<td>Skeletal suspension.</td>
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<td>18.</td>
<td>Tilting beds (various).</td>
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<td>19.</td>
<td>Turning frames (various).</td>
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<tr>
<td>20.</td>
<td>Water beds (partial floatation).</td>
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<tr>
<td>22.</td>
<td>Water mattresses (various).</td>
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</table>

**SPECIAL MATTRESSES**

1. Air beds (Li-Lo's).
2. Air-water mattress.
3. Astec AP bed.
4. Balloon bed.
5. Bead Pillow mattress.
6. Burke mattress.
7. Clinifloat foam mattress.
8. Cubex mattress.
9. Dyson air-water mattress.
10. 'Egg-carton' foam.
11. Feather beds.
12. Foam packs.
15. Harris mattress.
17. Horsehair mattress.
18. Kent mattress.
19. Latex foam mattress.
20. Laminated foam mattresses (various).
21. Low Pressure air bed.
22. Lapidus Air-float.
23. Modular water mattress.
24. Polyfloat body pad.
25. Pneumatress.
26. Ripple mattresses (various).
27. Roho mattress.
28. Sectional foam mattress.
29. Seirex mattress.
30. Split mattress.
31. Ventile mattress.

**CUSHIONS AND MISCELLANEOUS**

1. ACTH injection.
2. 'Active' wheelchair cushions.
3. Adhesive felt.
4. Adhesive foam.
5. Air rings.
7. Bead bags.
8. Bed 'brackets' and cradles.
10. 'Bio-flote' pads.
13. 'Channel' cushion.
15. Dupic pad.
17. Dusting powders (various).
18. Elbow protectors.
19. Foam rings.
20. Foot-boards (various).
21. Gel pads (various).
22. Heel protectors (various).
23. Ischiectomy (surgery).
24. Leg supports (various).
26. Massage.
27. Methylated spirit.
29. Ointments (various).
30. Overhead pulley.
32. Polyester fleece.
33. Prone nursing.
34. Ripple cushions.
35. Roho cushion.
36. Spenco boots.
37. Sheepskins (natural).
38. Silicone sprays.
39. Soap rubbed in.
40. Seed bags.
41. Suspension seating.
42. Transfusions.
43. 'Tubipads'.
44. 'Turning' drawsheet.
45. 'U' ring.
46. Vitamins and proteins.
47. Vacuum bags.
49. Water cushions (various).
50. Zinc sulphate (oral).
2.5.2. **Manual turning**

If we accept that sustained pressure is the usual cause of pressure sores, then a patient who does not move himself (when bedfast) will need regular turning in order to provide pressure relief to each part of his body in turn. Most observers have found that regular manual changes of posture will, in fact, prevent pressure sores (Paget, 1873; Munro, 1940; Guttman, 1955; Norton et al, 1962) but the intervals between posture changes have varied from one to four hours, according to the susceptibility of the patients and the nursing care available. Unfortunately, nursing care, particularly skilled nursing care, tends to be a scarce commodity - particularly in units for the care of the elderly (Bliss et al, 1966; Lowthian, 1975). In consequence, posture-changing routines are seldom carried out as prescribed (Bliss et al, 1966; Lowthian et al, 1976).

Even the more flexible system advocated by Lowthian (1979 B) is unlikely to solve this problem - particularly in geriatric units - without the additional use of various aids. Perhaps correctly motivated nurses can prevent pressure sores regardless of the supports on which their patients are nursed (Eusanio, 1976), but such a view assumes that there is an adequate number of nurses and that their motivation is adequate. The fact that many pressure sores do develop in hospital (Norton et al, 1962; Lowthian, 1976 A; Petersen, 1976) would appear to show that this is not generally true.

It is often argued that pressure sores could, in former times, be prevented by good nursing care and that standards have been falling over the last few decades. Baly (1980) points out that this argument cannot really be resolved, because of the difficulty of equating the patients who get pressure sores today with the patients who escaped such sores many years ago. Moreover, many traditional nursing measures for preventing pressure sores have, in recent years, been seriously questioned. Although the traditional methods may have been of some benefit
for relatively young patients they are of doubtful benefit for elderly patients today. In particular, Norton et al (1962) and Dyson (1978) have shown that some traditional local applications, and massage of the pressure areas, can be harmful. Some other aspects of nursing care which are of questionable benefit have already been discussed (see above 2.2.)

Clearly, a sudden increase in the supply of skilled nurses, and their motivation, would have a salutory effect in reducing the incidence of pressure sores. If this greater number of nurses was able to provide regular manual turning (for all the patients they recognize to be at risk) this would almost certainly prevent pressure sores. On the other hand it would not, necessarily, optimise a patient's comfort - especially if his sleep is frequently disturbed by the manual turning (Bliss et al, 1966).

When bed-patients are considered, there are five main positions which can be utilised for varying the parts of the body subjected to pressure distortion. These are the Supine position (on the back and recumbent); the Prone position (face down and recumbent); the Left Lateral and Right Lateral positions; and the 'Upright' position (seated-in-bed). A patient may, however, be prevented from using some of these positions, e.g. a patient in sliding traction for fractured femur. Chairfast patients are also very restricted in the number of postures they can adopt.

As hospital mattresses tend to be relatively hard (see Chapter 4.2.4.) nurses usually try to provide better cushioning, on top of the normal mattress, when nursing patients at risk of pressure sores. Consequently, special cushions may be used on top of the mattress. Manual turning is often combined with nursing on pillows, which are specially arranged to avoid pressure on the vulnerable bony prominences. Special blocks
may be used under the pillows so as to ensure that the vulnerable prominences do not sag into the spaces between the pillows and finish up resting on the mattress (Rogers, 1978-79). The arranging of these pillows and 'packs' is a skilled job, calling for skilled nurses and, as has already been mentioned, such nurses are relatively scarce.

Patients with spinal diseases or injuries, who are particularly susceptible to pressure sores, are sometimes nursed in plaster of paris beds (Nissen, 1942; Powell, 1976) which have to be carefully made so as to avoid any pronounced distortion of the soft tissues. The plaster beds are usually made for support in the supine position. They are mounted on wooden frames so that bed pans can be placed underneath a special opening (Powell, 1976). Patients can be nursed in these plaster beds for many months without developing skin complications (Cope, 1939; Scales, 1976 B). Nevertheless, they tend to exacerbate many of the adverse effects of prolonged bed-rest (Chapter 1.3.6.) and they discourage spontaneous movement. The whole of a plaster bed (complete with patient) may, however, be given some mobility by counterbalancing it with traction weights (Nangle, 1951). A patient with strong upper limbs may then adjust the height and tilt of his bed as and when required. Moreover, an anterior plaster shell can be made, so that the patient can spend some of his time in the prone position. The technique of turning a patient while in a plaster bed involves strapping the anterior shell into position with the patient supine, and then turning the complete assembly through 180 degrees on the longitudinal axis. Three or more nurses are normally needed when performing this manoeuvre, but it has the advantage of keeping the patient's spine in a stable position. If a 'Margate turning frame' is used one nurse may be sufficient to turn the patient (Powell, 1976). Lifting and turning a spinal-injured patient who is not in a plaster bed or jacket may call for the co-ordinated skill of four people (Rogers, 1978-79).
2.5.3. Mechanical turning and rocking supports

The need for turning a helpless patient on either his longitudinal or transverse axis has stimulated the invention of many novel supports. A bed which allowed turning on either axis was designed by Bullitt (1897), but it does not seem to have been practicable at the time. Another bed which allowed patients to be turned 'head-over-heels' was apparently designed by Professor Hey Groves in the 1920's or earlier (Parry, 1960). A very similar support, which came to be known as the 'Big Wheel' was developed by the Stryker Corporation in America. The original Stryker frames were developed in 1936 and were designed to turn patients on their longitudinal axis into either the supine or prone position. Bliss (1964) reviewed a number of supports, some of which were intended to turn the patient automatically, while others were aids to facilitate turning by hand. Of these, only the Stryker frames have become extensively used, particularly in the U.S.A. By the 1970's the Big Wheel had become (officially) the 'Circ-O-lectric' bed. One of the most interesting features of this support is the way the mattress platform can be smoothly moved into a near-vertical position so that ambulant patients can simply step forward straight onto the floor (see Figure 13). Similarly, they can step back into the bed, operate the patient's control switch, and resume the horizontal position. The complexity of the Circ-O-lectic bed does, however, call for skilled nursing; the patient can be nursed at practically any angle (about the transverse axis) but unusual nursing positions produce special problems (Stewart and Wharton, 1976). Many special accessories are needed if the Circ-O-lectic bed is to be used to its maximum. Another motorized bed which allows the patient to have vertical egress and access was designed specifically for this purpose, and is consequently less expensive than the Circ-O-lectic bed (Egerton, 1979). It is particularly useful for patients who have little if any flexion at the hips and/or knees. Such patients are often at risk of pressure ulceration. The less complex Stryker 'frames', which turn patients laterally, appear to be more widely used in
FIG. 13 THE STRYKER CIRC-O-LECTRIC BED.
Britain than the Circ-O-electric. They are turned by hand, but only one nurse is required, because the patient can be 'wedges' between the posterior and anterior frames of this support as he is turned over (Stryker, 1972). This 'Wedge' frame is a useful support for the intensive nursing of specific patients. When surgery is required it can double as an operating table: it is much narrower than a normal bed. Unfortunately, its narrowness means that it will not accommodate very large patients. Although the mattresses used on these frames are shallower than normal, the ease with which the patient's position can be changed (supine to prone) tends to compensate for the relatively inferior cushioning. Nevertheless, pressure sores can occur, and many patients are alarmed by the turning manoeuvre.

Another bed for tilting the patient on his transverse axis was developed by Eve (1939), who also used it for his rocking method of artificial respiration. An interesting feature of this support was the use of a special accessory, shaped like a bed-cradle, to support the thighs and lower legs. When the bed was tilted feet-down this 'donkey', which was strapped to the mattress base, prevented the patient from sliding down the bed. Eve's bed could be locked in a particular position, but was thought to be especially beneficial when regularly rocked to an angle of approximately 30° each side of the horizontal. Nurses provided the motive power for rocking the bed and, apart from its usefulness in preventing pressure ulceration, Eve considered that it could be life-saving in cases of pneumonia, poliomyelitis, diphtheria, and other diseases affecting respiration. Motorized versions of Eve's bed have been designed, some of which are still in use (Tierney, 1981).

Just before Eve published his results, Sanders (1956) produced a sophisticated 'Rocking bed' which tilted the patient to roughly the same angles as Eve's bed, but was motorized and incorporated a 'Gatching' mattress base (see Chapter 1). Eve's bed did, however, score over Sander's bed in one novel respect:
it was claimed that Eve's 'donkey device could be used on its side, thereby allowing the patient to rest in a lateral Fowler's position (see Figure 14). This position may be unique to the Eve's bed. Many nurses do try to prop some of their patients into a similar position on an ordinary bed, but the unnatural position which results is both uncomfortable and dangerous (Lowthian, 1970 A). Eve's 'donkey' was probably abandoned a few years after its introduction, when such devices were suspected of encouraging venous thrombosis (see below 2.6.2.) Sander's rocking bed was later used by Whedon et al (1949) in a study of the metabolic effects of immobilisation. Three "normal healthy young men" took part in this study, which provided convincing evidence that the constant oscillating action of the Sander's bed could reduce the metabolic and physiological hazards of prolonged bed rest. Of particular interest was the finding that calcium less (estimated from urinary calcium) was only half that which occurred during immobilisation on an ordinary (fixed) bed. On both beds the lower limbs and pelvis of each volunteer were encased in heavy plaster casts.

Being convinced of the efficacy of manual turning for preventing pressure sores, Norton et al (1962) constructed a 'lateral tilting bed', which could tilt the patient along his longitudinal axis to 20 degrees on either side. A nurse-operated lever changed the bed's position. A similar device, which used two pneumatic bags placed under the mattress, came into use in the late 1960's. Called the 'Pneumatress', it used an air pump for inflating each bag in turn, thereby tilting the mattress a few degrees each way. A trial of this device by Stapleton (1979) suggested that it helped to prevent sacral sores, but it was later pointed out that use of the Pneumatress prevented the bed's backrest being used, and that this alone could account for the reduced incidence of sacral sores (Lowthian, 1979 C).

Various air beds have been designed to assist the manual turning of debilitated patients by allowing air to leak from one
FIG. 14  EVE'S ROCKING BED – AUTHOR'S IMPRESSION OF THE 'LATERAL FOWLER'S' POSITION.
(longitudinal) air cell into another as the patient presses against the first cell while attempting a turn. Bliss et al (1966) tested a particular mattress employing this principle and found it to be impracticable for those who might have needed it the most.

Another laterally-tilting bed introduced in the 1960's was the 'Stoke Mandeville Tilting Bed' (Guttmann, 1967) which was designed for spinal-injured patients. This bed is now known as the 'Egerton turning and tilting bed'. It is operated by electric motors – activated by patient or nurse – when a position change is required. Patients can be turned to an angle of about 60 degrees on either side of the horizontal. Head-down and feet-down tilting (15 degrees either way) is also possible. It will accommodate very large patients. Nevertheless, as the patient is not in a form-fitting mould, the higher angles of turn may result in some spinal movement as the patient slips into a slightly different position. In practice it may be found advisable to use carefully placed pillows on this support, so that the patient is not resting directly on the relatively firm mattress (Rogers, 1978-79).

The problem of ensuring spinal stability on laterally-tilting beds prompted Keane (1970) to develop a special support known as the 'Roto Rest', which incorporates upholstered 'cot-sides', head-restraints, and a special abduction support between the legs. With this device continuous lateral turning becomes possible. The optimum turning speed appears to be 35 degrees per minute and the maximum angle is 80 degrees from the horizontal. The slow speed enables patients to remain undisturbed while sleeping. A development of the 'Roto-Rest' is the 'Mini Co-Ro' (Figure 15). These constant-turning supports seem to be quite efficient at preventing pressure necrosis and they also appear to reduce the nursing workload (Lowthian, 1975). However, they restrict spontaneous movement, and their strangeness makes them unsuitable for many of the
FIG. 15 THE 'MINI CO-RO' CONSTANT TURNING BED (TREATMENT TABLE)

Arrows show where peak pressures occur (heels and hips) with net in a low position.

FIG. 16 NET SUSPENSION - THE LOAD/PRESSURE PATTERN

Sections through mannikin (shaded) show lack of support under waist (lumbar curve) while hips & shoulders are well supported on net.

FIG. 17 NET SUSPENSION - SPINAL SUPPORT PROBLEM
elderly patients who might otherwise benefit from them. The constant motion of these beds will probably help to prevent many of the complications of prolonged bed-rest (Chapter 1) and this suggests that they will prove useful for intensive care, as well as for the home-nursing of very disabled patients.

2.5.4. Suspension

Recently, another mechanical aid in turning a patient (on his longitudinal axis) was introduced, the 'Net' suspension bed (Gibbs, 1977). This novel support is really a hammock slung from the sides, which are rotatable poles, rather than from the ends. With this arrangement it is possible to roll up the hammock material on one side while simultaneously unrolling it on the other side; thereby turning the patient into a lateral position. The pattern of pressure distribution on this support is quite different from that on an ordinary mattress, especially when the net is allowed to hang in a low position. As shown in Figure 16, the main pressures on a patient's body are over peripheral prominences. The ordinary mattress tends to concentrate pressure on the midline of the supine patient.

Although the Net suspension bed can cause forced adduction of the legs and squeezing of the shoulders, it does relieve pressure from the sacrum and spinous processes, thereby permitting the healing of any sores in these areas (Lowthian, 1977 B). The synthetic fibre net (Nylon or Polyester) of this support stretches slightly, and so enables the patient's weight to be spread over a large area. Any pressure concentrations due to the strands of the net are dissipated by placing one or two folded blankets under the patient.

An earlier method of suspension nursing described by Rudd (1955) utilised canvas slings and a hydraulic hoist. Smart (1916) also mentions a device which used a canvas sheet, instead of a net, but this was probably less successful at distributing the patient's weight: like the net bed it used rollers to vary
the tension in the supporting canvas, but these were positioned at each end of the bed. In this orientation there would be no forces tending to adduct the legs and squeeze the shoulders but, also, no facility for turning the patient. The squeezing effect produced by the Net suspension bed is one of its disadvantages, and may also limit chest expansion in debilitated patients. Similarly, the spontaneous movements of such patients will be limited by the Net, when it is in a low position.

Unlike the earlier device mentioned by Smart, the Net suspension bed offers little support for a patient's spine (see Figure 17). Nevertheless, sitting up in the Net may be safer than sitting in an ordinary hospital bed (see below 2.6.) and it seems clear that the Net suspension bed will be a useful ancillary aid if used intermittently and with discretion, an ordinary mattress providing the main support for the patient (Lowthian, 1977 B).

Some recent versions of the Net bed dispense with the ordinary mattress base and mattress, so that the device becomes a special bed rather than an ancillary aid. Such beds are potentially dangerous, because it is difficult to perform cardiac massage on a net surface. It is for this reason that modern hospital beds need a rigid mattress base (Gainsborough, 1967). Other reasons for preferring a rigid mattress base are:

a) it provides better spinal support,

b) nurses find it easier to manoeuvre patients on a firm support.

Unfortunately, many special supports which aim to provide optimum load/pressure distribution ignore the need for a relatively rigid, and stable, platform under the patient.

The drastic measure of suspending a patient by wires or sharp hooks in his pelvic bones, tibiae, and clavicles (Bliss, 1964) appears to be extremely uncomfortable, restrictive and undignified. It is, nevertheless, still used in some countries, according to Petersen (1976).
2.5.5. Water beds

The earliest full description of a water bed for invalids appears to be that of Arnott (1833) who used a rubberized fabric (from Mackintosh and Co.) to cover a wooden bath, which was lined with metal foil. The rubberized layer was large enough to allow the patient to be substantially supported by water displacement, rather than the 'hammocking' effect of the fabric interface. Arnott also used a 'mattress' between the patient and the waterproof layer - apparently to insulate the patient from the cooling effect of the water. This cooling effect was eliminated in the continuous bath therapy used in Vienna (Riehl, 1930) by gradually replacing cooled water with fresh warmed water. Both of these 'water beds' seemed to be particularly useful in preventing and treating pressure sores, and it seems that the continuous bath therapy could be used for some weeks, or even months, despite the fact that the patient was nursed directly in the water. Riehl maintained that no cases of drowning had occurred, although he admitted that the presence of well-trained nurses was essential.

Paget (1873) found some practical difficulties in using Arnott's bed and considered that there were many cases, such as fractured neck of femur and acute inflammation of the knee, where water beds could not be used. By the early nineteenth century the water mattress seems to have largely replaced the deeper water beds (Smart, 1916). As these mattresses were only a few centimetres deep, much of the patient's weight was supported on the hammocking of their rubber covers. Nevertheless, they could be used on an ordinary bedstead and were undoubtedly easier to fill and maintain than was Arnott's bed. The hammocking effect also improved the patient's stability. The temperature of water mattresses was kept reasonably constant either by regular refilling with warm water, or by re-warming with hot-water bottles. Bliss et al (1966) mention that these mattresses fell into disuse after 1930. Judging from the experience of Bliss and her colleagues with such a mattress,
it seems likely that filling and maintenance problems were the chief cause of their demise.

However, both water mattresses and water beds refused to be forgotten, and by the middle of the 1960's improved technology made it feasible to introduce thermostatically-controlled water beds. Such beds appear to have been introduced in the United States of America and Britain at about the same time. The 'Water-immersion' bed (Russell-Grant, 1967) was designed so that a patient could "float on water" without getting wet. The waterproof bag enclosing the water was polyurethane-proofed nylon, and this was thin enough, and large enough, to allow the patient to sink into the water so that he almost floated. However, there is still some tension in the cover of a 'water-immersion' bed and this prevents a heavier-than-water patient (see below 2.5.6.) sinking completely below the water level. Spence et al (1967) found that a paraplegic dog, which bit a hole in its water bed, subsequently drowned. In consequence, the danger of such a bed leaking cannot be overlooked, very disabled patients being particularly at risk.

Pfaulder (1968) listed twelve disadvantages of water-immersion therapy, including most of the hazards of prolonged bed-rest listed by Asher (1947). Such hazards are of course most pertinent, because the rest induced by a water-immersion bed is closer to absolute rest. Further problems discussed by Pfaulder were:-

a) Hallucinations and nightmares,
b) difficult physical care on the unstable surface of the bed (patients needing a firm support are unlikely to be nursed on a water-immersion bed)
c) imbalance of fluids and electrolytes,
d) difficulties in ensuring that the optimum water temperature was maintained,
e) contamination of the water with algae and other micro-organisms (in later models this is minimised by using black materials to exclude light).
In the author's experience, the water-immersion bed seriously restricts spontaneous movements, and contractures are likely to be encouraged. Another serious problem with these beds is the fact that they cannot be tilted for physiological purposes (see below 2.5.6.) Yet another disadvantage with the water-immersion bed is that patients with any degree of urinary incontinence are likely to need urethral catheterization. Some further practical problems are the difficulties of cleaning, particularly of the bed surface, and the heavy weight of these beds which severely limits their mobility.

With some ingenuity it is possible to overcome some of the above-mentioned disadvantages, but such ingenuity usually relies on extra equipment and this calls for better training and more skill on the part of the hospital staff concerned.

It may be true that pressure-distortion is minimised on a water-immersion bed and that this makes it a good support for the intensive care of patients with deep pressure sores (grades 3 and 4) providing that they are not likely to suffer from the short-term disadvantages of the bed (Grahame, 1974).

Partial-floatation water beds have been described (Lowthian, 1977 B) which seem to be a good compromise between immersion beds and water mattresses. They suffer from many of the disadvantages already discussed, but to a lesser degree. However, because they are shallower than water-immersion beds, they can allow seated-in-bed patients to 'ground' on the hard base of the bed. On the other hand, if the volume of water is increased to prevent this 'grounding' the resultant tension in the cover can be sufficient to produce unacceptably high pressures on the patient's heels (Chow, 1974).

A novel support described by Schetrumpf (1972) can be loosely described as a water bed, although the patient is mainly supported by a mass of plastic balls floating on a tank of water.
This, it is claimed, makes thermoregulation unnecessary. Schetrumpf maintained that the support is comfortable and that its viscosity can be varied simply by adjusting the water level. This support appears to have promise for intensive, and high-dependency, nursing care but, in common with many water beds, is rather high-sided. This fact alone makes the Schetrumpf bed less than ideal as a general-purpose patient support system (P.S.S.)

2.5.6. Other fluid supports and air-beds

The specific gravity of pure water (1.0.) is very similar to that of the normal human body. Consequently, many a person floats in water with most of his body submerged. Some men, who have little adipose tissue, cannot (passively) float in water (Lanoue, 1964) and this suggests that many elderly and emaciated patients will also be "sinkers". This further suggests that a fluid of higher specific gravity than water would make a more satisfactory support for the human body. Such a fluid, with a specific gravity of 2.0. is used by Reswick and Rogers (1976) in the 'Rancho floatation Multifluidic Unresisting Displacement (MUD) bed'. This bed uses an oversized plastic enclosing sheet and is thermostatically controlled. In these respects it is similar to the water immersion bed. On the MUD bed, however, the supine patient is able to float with his hips and legs extended; and this tends to prevent the contractures which may be associated with water flotation. Floating in the prone position, on the MUD bed, is similarly less hazardous than it is on a water-immersion bed. The MUD bed poses no particular problem for incontinent patients, and catheter drainage is less complicated than on a water flotation bed. Nevertheless, the MUD bed is both heavy and expensive. Maintenance of the bed is rather involved, but nursing time appears to be reduced (Wilson, 1976).

A particular problem, which has already been mentioned and which is common to most liquid-filled beds, is the absence
of a tilting facility on the MUD bed. As mentioned in Chapter 1, there are a number of reasons for the 'head-down' tilt facility, but it is particularly useful for the emergency treatment of acute circulatory failure. A compartmentalized water mattress, such as that described by Carpendale and Redford (1980) can be tilted. This mattress uses two separate water cushions which are located in a 'foam frame'. Foam blocks of the same size as the water cushions are located in those gaps in the frame where pressure relief is less important. Devices of this type can be easily mis-used, when the various parts are incorrectly located.

Air is much lighter than either 'mud' or water, but it can be compressed sufficiently to support the weight of the human frame. The original air beds must have been invented many centuries ago (Wright, 1962) and were almost certainly made from animal skins carefully sewn together. Such beds must have been both expensive and unreliable. Blyth (1873) attributes the first air-bed to John Clark of Bridgewater, in 1813. However, the familiar camping mattress ('Li-Lo') was not a very practical proposition until the invention of vulcanized rubber in 1839. Hooper (1856) developed cellular rubber mattresses which were similar to modern 'Li-Lo' s and which could be filled with either water or air. More recently two 'Li-Lo' s have been stacked, so as to produce a deeper air-bed, in which the inflation pressure can be kept relatively low (McClemont et al, 1978-79). This allows a patient to sink down into the bed so that a large area of his body is supported on the rubberized fabric. Although this arrangement gives support similar to that of the partial flotation water beds, it tends to restrict loss of heat from the patient's body; air being a good insulator and the impermeable rubber restricting heat loss by evaporation from the body's surface. A particular advantage of this air-bed is the speed at which its inflation pressure can be adjusted, thereby facilitating both nursing attention and emergency care. It does not, however, appear to be suitable for nursing orthopaedic patients who need a relatively stable support.
Most air-beds rely on a tensioned envelope to contain the pressurized air, which means that there is, inevitably, some hammocking of the membrane supporting the patient. Unfortunately, a simple air-bed produces the same amount of tension and hammocking on each part of the body being supported. This tends to result in disproportionately higher pressures on small prominences such as the heels and elbows. One way of overcoming this is to have separate air cells inflated at various pressures. There is, however, a more dramatic way of solving this problem: the supporting membrane can be eliminated by using a continuous supply of pressurized air. With this system the patient and his support act as one giant pressure-relief valve. Scales (1961) has shown that this concept is a practical proposition, but the need for this unique support (the High Air Loss Bed System) has disappeared with the introduction of effective antiseptic treatment for extensive burns (Scales, 1978). The Low Air Loss Bed System (LALBS) was developed as a result of experience with the High Air Loss Bed System. The LALBS also uses a continuous supply of pressurized air, but this is contained in vapour-permeable sacs which leak, in a controlled way, so that the 'Microclimate' at the patient/support interface is optimised (Scales et al., 1974). The temperature of the air supply is thermostatically controlled, and the friction of the sac surface has a low enough value to encourage spontaneous movement by the patient. The sacs are arranged in five sets, each of which can be adjusted to its own pressure level. As the sacs are both detachable and washable, no under-sheets are needed. The support can also be contoured (like a 'Gatch' bed) and tilted both feet-down and head-down. This remarkably versatile support is, nevertheless, expensive, and calls for some special training in its use. It is not designed as a general purpose P.S.S. A recent version of the LALBS, known as the 'Mediscus Minor' (see Figure 18) can, however, be used on a standard hospital bed of the 'King's Fund' type (see Chapter 3).

Alternating pressure pads ('Ripple mattresses') were invented some time before the LALBS (Gardner, 1948) and many
FIG. 18 THE MEDISCUS MINOR AIR BED ON A KING'S FUND BEDSTEAD.

FIG. 19 LARGE-CELL RIPPLE MATTRESS (BACKGROUND) AND 'POLYFLOAT' FOAM MATTRESS - ON A 'PROFILA' CONTOURING BEDSTEAD (FOREGROUND).
versions of this device are now available. Since their introduction these pads have been used on top of the existing mattress, presumably on the assumption that ordinary general purpose mattresses are not very effective at preventing sores. At the same time, they are suitable for the majority of hospital patients, and so need not be discarded in favour of complete re-equipment with ripple mattresses. The original ripple mattress did, in fact, rely on the existing mattress being relatively compliant; their narrow air-cells were not designed to lift the patient completely away from the ordinary mattress surface. It was theorized that the pressure on a particular area of the patient's tissues could be reduced by increasing pressure on adjacent areas, thereby partially 'lifting' the region of tissue which coincides with a collapsed air-cell between the 'lifting' cells. After a few minutes, the areas 'lifted' were alternated so that all parts of the body, in contact with the mattress, could be given regular pressure-relief periods (Lowthian, 1970 A). Gardner et al (1954) reported that areas under collapsing cells could be seen to flush with blood as the localised pressure was relieved. Nevertheless, an evaluation of four different American ripple mattresses (Health Devices, 1972) concluded that, although ripple mattresses had been in use for over 20 years, there was no proof of superiority over other techniques. The journal was unable to recommend any alternating pressure system; chiefly because of the unreliability of the (American) devices they tested.

In Britain, however, Bliss et al (1966) had conducted a clinical trial of two types of ripple mattress, and they found an indication that a 'large-cell' ripple mattress could help to prevent pressure sores, particularly heel sores, when compared with normal ward care. Subsequently, a National Health Service report (NHS report, 1969) estimated that 4 000 ripple mattresses were owned by hospitals in Britain, and a further 1 360 were on hire. It seemed that there was a medical preference for the large-cell mattress (see Figure 19). The NHS report (1969)
also specified some functional requirements for devices designed to prevent and/or treat pressure sores; and these were chiefly concerned with ripple mattresses. It recommended an alternating pressure cycle lasting for between 5 and 30 minutes, and emphasized the need for secure electrical and pneumatic connections. However, by 1973, Lowthian et al (1976) found that the ripple mattresses being used in three geriatric units were mostly small-cell types, and only about 10% of patients thought liable to develop pressure sores were given these mattresses. Lowthian and his Research Nurse colleagues checked these mattresses on 51 occasions while observing the patients on them, and found them to be operating correctly on just 36 of these occasions. Lowthian (1977 B) concluded that ripple mattresses were declining in popularity - mainly because of maintenance problems. He suggested that, in maintenance terms, they were receiving a low priority compared to life-saving and diagnostic equipment. Bliss and Murray (1979) made out a strong case for preferring large-cell ripple mattresses to water beds, but they also stressed the still unsolved maintenance and training problems. Bliss and Murray found that more than half of the 51 ripple mattresses they examined were incorrectly installed, and few if any were intact and operating correctly.

Alternating pneumatic mattresses are still being developed (Newell et al, 1970; Lowthian, 1977 B) and, as stronger plastics and rubbers become available, many variations on the original design may become feasible. Some of the more recent designs allow air to leak from them, as with the LALBS, to optimise the micro-climate at the patient/support interface.

2.5.7. Particulate supports

An alternative form of floatation bed appeared in the 1960's: it became known as the 'Air Fluidised Bed' (Hargest, 1976). This device uses compressed air to fluidise a mass of glass spheres measuring 75 to 100 microns in diameter. The total weight of the beads is 900 Kgs. and they are separated from the
patient by either a porous sheet (continuous fluidisation) or a 'vinyl' cover (intermittent fluidisation). The specific gravity of the fluidised mass of beads is similar to that of the MUD bed, but without fluidisation they form a relatively rigid support similar to a plaster bed. This enables the intermittent version to be used for patients needing a firm and stable support, such as patients in traction for fractured femur.

With the continuously-fluidised version fluids leaking into the bed are rapidly evaporated and this is said to have a self-sterilizing effect. Nevertheless, two disadvantages of the Air Fluidised Bed (A.F.B.) are its initial cost and weight. The controls of the bed are simple to operate, but Hargest (1976) mentions that temperature control requires care, to avoid the potentially serious consequences of either under or over-heating the patient. Other hazards, or potential hazards, with the A.F.B. are:

a) the considerable evaporative water loss which is induced,

b) patients on certain drugs may develop hallucinations or extreme agitation (Hargest, 1976)

c) certain women think the fluidised bed is 'alive', or they find it erotic (Hargest, 1976).

Another fluidised bed similar to the A.F.B., but which uses graded sand, was described by Stewart (1976). Air fluidised beds do appear to have particular advantages for patients with multiple pathology (Thomson et al, 1980).

Loose dry sand without fluidisation can make a comfortable support, and must surely qualify as the oldest type of 'particulate' support (see Chapter 1.2.) Feather beds also qualify as particulate supports. Because the feathery particles of a feather bed (or pillow) are anisometric, they behave like a viscous fluid (Lowthian, 1975).

Although feather beds were much used in the nineteenth century, they were not popular in medical or nursing circles;
because feathers slowly migrated from beneath a patient's weight-bearing prominences the patient was liable to finish up with his prominences resting on the hard mattress base (Nightingale, 1859; Paget, 1873; Nursing Mirror, 1907). The same migratory effect takes place when feather pillows are used, but it is much easier to re-distribute a pillow's contents.

Sawdust beds (Hoffman et al, 1949) are similar to feather beds, but any soiled material is more easily removed and replaced. The association of sawdust with animals, and the fire risk of nursing patients directly on sawdust, seem to rule out its general acceptance as a P.S.S. However, the advantages of this system include:

a) low cost,
b) good heat-insulation and comfort,
c) the 'seated-in-bed' position is relatively safe,
d) 'skin-stretching' effects are eliminated.

Other pros and cons of this system have been discussed elsewhere (Lowthian, 1970 A).

Expanded polystyrene granules have been used in mattresses, cushions and 'bead-bags' in the hope that this material would provide inexpensive support - similar to that provided by chaff fillings (Gjerris, 1966). A small-scale trial of the bead filled cushion described by Gjerris was reported by Van Laer (1967), but it failed to provide convincing evidence of the benefits of this cushion in preventing pressure sores. Dench and Heath (1974) reported their experience with 'bead-bags', which had a filling of expanded polystyrene granules. These bags seemed to be useful for chairfast psychogeriatric patients. They were placed on special supports rather than normal chairs, and the debilitated patients could then be comfortably cocooned in the relatively large bead-bags. The apparent drawback with this system is the restriction of a patient's spontaneous movements. Nursing Times (1974) reported that Pauline Bretton had tested one of these
'bean-bags' (a synonym for bead-bags) and found that it was virtually impossible to move a patient who was supported by one: the nursing difficulty seemed to outweigh any supportive benefits of the bag.

By 1978 Beaufort Air-Sea Equipment (1979) had developed a bead-bag type of support using multiple pillows, which were each partially filled with expanded polystyrene granules. The pillows were designed to be removably attached to a waterproofed mattress cover for the full length of the bed. During the present study a clinical trial of this system (one patient) at the Royal National Orthopaedic Hospital (RNOH) showed that it also restricted the patient's spontaneous movements. It was difficult to ensure that this 'Bead Pillow Mattress' maintained good load/pressure distribution: when under load the granules have a high contact friction, which restricts their lateral movement and so limits their ability to act like a fluid. When not under load, the granules flow easily, but this makes it difficult to maintain the optimum distribution of the granules whenever the patient either moves himself, or is re-positioned on the bed. This is in contrast to feather pillows, which can maintain a shape, to some degree, because of their viscosity (discussed above). Any particulate or fluid-filled pillow/mattress which does easily change its shape by flowing under the influence of gravity is especially difficult to use in a tilted position (see 2.5.6. above).

Russell-Grant (1976) has described particulate mattresses filled with hollow polypropylene balls of about 10 mm in diameter. Clinical experience with these devices appears to be limited. Particulate mattresses filled with grain or seeds (see Chapter 1) will usually suffer from the same disadvantages as the plastic bead fillings but, in addition, they will encourage vermin.

2.5.8. Vacuum-bag supports

The use of semi-solid spherules (expanded polystyrene) in cushions, seems to have stimulated designers to develop
'Instant' casting bags - by evacuating air from impermeable bags filled with spherules (Povey, 1970; Nichols and Strange, 1972). While air pressure, inside and around these bags, is equalised, the granules will mould to the shape of the patient's body. Exhaustion of the bag, however, transforms it into a semi-permanent moulded seat. It is, in fact, possible to mix a quick-setting resin with the spherules, so that the moulded seat acquires a permanent set (Cuniffe, 1972).

These techniques should prove very useful for some very disabled patients - particularly those who are immobile though chairfast. Nevertheless, a rigid moulded mattress will suffer from the same disadvantages as plaster beds (see above 2.5.2.)

2.5.9. Gel and foam for mattresses

Both particulate supports and fluid supports can recover their original shape when a patient changes his position; but such recovery depends on gravity, elastic envelopes, or physical pounding ('puffing'). A gel, on the other hand, has inherent elastic recovery (Lowthian, 1977 B). Spence et al (1967) developed a silicone gel pad to simulate human adipose tissue: the natural cushioning of the body. As the gel material is, like water, incompressible, it is able to equalise pressure at each point of contact between the patient and the pad support, with the added advantage that it does not rely on gravity to recover its original shape. Nevertheless, it is possible for such gels to be overstretched (by localised pressure) so that they tear. To avoid this, Spence and his colleagues decided to enclose the gel in an elastic latex cover. As the gel was both expensive and heavy, its use as a complete mattress was considered impracticable; instead, it was made into a pad the size of a wheelchair cushion. A suitable soft foam surround enables this cushion-sized pad to be used on the bed to protect the vulnerable pelvic pressure areas (Nursing Times, 1975).

Various other gels, and gel substitutes, have since been developed, but they are mostly used as wheelchair cushions.
Using such cushions as inserts in a shallow foam surround has the disadvantage that a patient cannot be expected to stay in just the right position; he is particularly liable to slide off the pad when he is nursed seated-in-bed. In addition, the light foam surround is easily displaced when a patient is getting onto, or off, his bed.

Rubber can be regarded as a firm elastic gel, although it normally has insufficient compliance to be useful as a mattress. The situation is changed, however, when gas bubbles are introduced into the rubber: it becomes a relatively soft foam. Similarly, a synthetic rubber, such as polyurethane, can be foamed. Bliss et al (1966) conducted a clinical trial of some polyurethane foam mattresses which had recently become available. The trials suggested that these mattresses, which were made of laminated foam, helped to reduce the incidence of pressure sores in elderly patients when compared with normal ward care.

Munro (1940) found latex foam mattresses beneficial for spinal-injured patients. However, by 1968, the National Health Service Specification Working Group on Mattresses and Related Items were recommending polyurethane foam in preference to latex foam (NHS report, 1968). While admitting that latex foams had better elastic recovery than polyurethane (polyether) foams and were more durable, they considered that the slightly delayed elastic recovery of polyether foam was beneficial for some patients, and that polyether also scored over latex foil in respect of tear strength, porosity, resistance to ageing, and price.

The same working group suggested that hair mattresses should be phased out, to be replaced by polyether foam. They criticised spring-interior mattresses on the grounds of weight (20-22 Kgs.), and recommended an upper weight limit of 13.6 Kg. Nevertheless, in a later report (NHS report, 1969), the working group allowed an upper weight limit of 15 Kg. According to Grandjean (1980) the upper permissible weight limit for occasional
lifting (women) is 20 Kg., but this is reduced to 12 Kg. for frequent lifting. In the author's experience, mattresses are not frequently lifted by one nurse, but patients are frequently lifted by two nurses working together. Stubbs and Osborne (1979) give an upper weight limit (women over 18 years of age) of 22.6 Kg. for 'non-compact' loads. In practice, they found that individual nurses were often lifting 50 Kg. or more when handling 'non-compact' patients. By comparison, a mattress weight of 22 Kg. seems permissible. Moreover, too light a mattress will irritate nurses when its instability causes bedding to loosen too frequently (Bliss et al, 1966).

Amongst various other foam mattresses designed to prevent pressure sores are a laminated polyether foam mattress known as the 'Stoke Mandeville No. 4' (Lowthian, 1977 B), and a polyether foam mattress with special surface cut-outs to improve its compliance (Reswick and Rogers, 1976). This last mattress, known as the 'Polyfloat' is shown in Figure 19 without its cover.

2.5.10. Miscellaneous equipment for preventing pressure sores

As most pressure sores occur either in the pelvic region, or the heels (see Figure 6) it is not surprising that special cushions, designed to relieve pressure from these areas, have a long history. Gailani et al (1958) record that 'air cushions' began to be used in hospitals in the eighteenth century. Paget (1873) recommended large cushions, shaped like a horse-shoe, which were made of amadou (a form of tinder). Smart (1916) described how to make 'nests' from yellow splint wool for padding bony prominences such as the heels and elbows. She advocated that they should be bandaged into position. Smart also mentioned circular water cushions and air cushions. Newton (1938) stated that leather rings, stuffed with hair, moss or feathers, were used in the middle ages.

It seems logical that a ring-shaped cushion will restrict the circulation of blood and the drainage of lymph in the
superficial tissues positioned within the ring (Trumble, 1930; Munro, 1940; Guttmann, 1955; Walker, 1971; Snowden, 1979). During the present study the author found that a latex foam ring (designed as a pelvic cushion) produced peak patient/support interface pressures in the region of 40 mm Hg. However, the author's previous experience indicates that less compliant and smaller ring cushions can produce ischaemic pressures around small prominences such as the heels. Fernie (1973) shows a drawing (attributed to Dible) which indicates that particular branches of the posterior tibial artery are positioned where they must be compressed (to some extent) by any ring fashioned to fit over the heel. A 'horse-shoe' ring may, perhaps, avoid the ischaemia/congestion due to the use of a complete ring; but experiments by the author in 1969 showed that the ends of the horse-shoe tend to concentrate pressure on the patient's skin. This problem prompted the design of a 'Channel' cushion as an alternative to the popular ring design (see Figure 20). The prototypes of this device were promising, but some difficulties were encountered when it was used in a wheelchair. In addition it was not readily understood by the nursing staff (Lowthian, 1969).

The design and fitting of wheelchair cushions for patients at risk of pressure sores is now a specialised field of study (Chow, 1974; Reswick and Rogers, 1976; Manley et al, 1977), and falls outside the scope of this treatise. However, the principles of pressure redistribution, described by Manley et al (1977) involve modifying the shape of a patient's main support in order to either remove or reduce the normal loading on the patient's ischial tuberosities and coccyx. This is accomplished by transferring more loading onto the trochanteric shelves and the proximal parts of the thighs.

Mattresses have been similarly re-shaped in attempting to relieve pressure from the bony prominences. Paget (1873) described how a mattress could be divided into two halves - leaving a space of six inches between the halves - in order to remove
Plans of the cushion in two positions - relative positions of the ischia are shown in hatching.

Sketch of the cushion from beneath.

FIG. 20 THE 'CHANNEL' FOAM CUSHION - AN ALTERNATIVE TO 'RING' CUSHIONS.
pressure from the sacrum. Significantly, he added that in a case so treated, sores developed on the ilium and the trochanters. Kent (1953) made some special mattresses which had deep depressions centrally to relieve pressure from the sacrum and spinal cord. Although these depressions were merged smoothly into the main body of the mattress, they obviously relied on the patient staying in exactly the right position. This same problem of restricted movement occurs when a system of foam wedges - the 'Harris pressure-relieving mattress' - (Walker, 1971) is used to reduce loading on the spine and sacrum. Nevertheless, some means of partially relieving pressure on the midline of a patient's body would seem to be helpful, providing that it does not restrict the patient's free movement. This idea is explored further in Chapter 6.

The NHS final report on mattresses and related items (1969) described a sectional foam mattress, which was designed to provide varying degrees of compliance along the length of the mattress, each section being available in various hardnesses of foam. A similar 'split-foam' mattress is mentioned by Carpendale and Redford (1980). The NHS mattress design overcame the usual problem of lack of support at the various junctions between the sections, but it, like other sectional mattresses, can be easily mis-used; for example, very hard sections can be mistakenly placed under pressure-sore susceptible regions of the body.

Molnar (1972) produced a bed which took the concept of pressure redistribution a stage further. In Molnar's device, the normal mattress was replaced by a set of rigid but padded boards arranged transversely across the bedstead. Some of these boards ('crosspieces') were fixed, while others could be moved up and down, so reproducing the effect of an alternating pressure pad. The crosspieces were adjustable in various directions (to avoid susceptible areas of the body) and Molnar claimed that the bed was surprisingly comfortable. He seemed unaware that, some years previously, Bliss et al (1966) had constructed a similar device. A patient-trial with this latter device showed
that its alternating transverse bars caused increasing discomfort, and, by the twelfth day, had produced superficial skin loss corresponding to the positions of the transverse bars on the patient's body. Ripple mattresses appear to be able to avoid this effect by providing a smoother transition of pressure between inflated and deflated cells.

The plethora of devices used to reduce tissue pressures over the heels of bedfast patients reflects the little-appreciated fact that a simple homogenous mattress (such as a water mattress) cannot be adjusted to give optimum load/pressure distribution on every part of the body at the same time. In particular, if it gives good load/pressure distribution to a relatively large part of the body, such as the pelvis, it will fail to give similar support to a small part of the body which is under relatively high loading, such as the heel. The main reason for this failure has been well explained by Chow (1974), who shows a diagram to illustrate the extra resistance to compression caused by a block of foam which is larger than the rigid rod pressing into it. If the block of foam is of similar size, or smaller than the rigid rod, then there is no extra resistance attributable to hammocking and shear forces in the foam (see Figure 21). Clearly, the wider the load resting on a mattress the less serious will be the interface pressure due to the effects described. Hammocking is particularly serious when a non-stretch cover is used on a mattress. This is discussed further in Chapters 3 and 4.

Norton (1970) discussed some of the many devices designed to prevent pressure sores on the heels, and showed that the same solutions tend to recur in cycles over the years. Practically all of these devices rely on raising the heel off the mattress (for example see Figure 22), and Norton maintained that this limits the postures available to the patient, and can cause hyperextension of the knee joint as well as increasing the risk of pressure sores at the base of the spine. Norton's own solution was the 'Tubipad', a foam-lined tubular gauze sock
'L' represents the same load on a small prominence, such as the heel.

In 'A' the load is resisted by compression only (arrow 'C') — on a narrow block of foam.

In 'B' the load is resisted by compression ('C') shear ('S') and hammocking ('H') — on a wide block of foam, such as a mattress.

FIG. 21 THE RELATIONSHIP BETWEEN MATTRESS SIZE, SIZE OF LOAD, AND CONSEQUENT INDENTATION.

FIG. 22 A 'LENNARD' PAD IN USE — DESIGNED TO LIFT THE HEEL OFF THE MATTRESS.
which slightly improves the cushioning of the heel without significantly lifting it above the mattress surface. At the same time, the Tubipad appeared to reduce the coefficient of friction between the patient's heel and his bed surface, making for easier spontaneous movements. However, Bliss and McLaren (1967) found that Tubipads are difficult to keep in position, a fact which is borne out in this author's own experience. Bliss and McLaren also disliked the use of any bandages around the heel, believing that they encourage false confidence while discouraging regular inspection. Bandages and elastic stockings on the lower limbs can, in fact, be hazardous for bedfast patients who are suffering from peripheral circulatory disease. But, when such patients are ambulant, leg bandaging may be indicated because their circulation can be improved by the pumping acting of their leg muscles against the bandages (Abramson, 1978).

Walker (1971) mentions the 'Hilliam Sorbo sole'. This uses a nylon crepe stretch stocking, attached to a 30 mm thick 'sole' of latex rubber, the sole being cut slightly oversize so as to relieve pressure from the heel.

A special low-friction pad devised in 1970 (the 'Dupic' pad) can be placed beneath the heels and, as it is very shallow, it does not significantly raise the heels above the mattress surface (Lowthian, 1975). However, it would seem more logical to improve the friction characteristics and compliance of the surface of the hospital mattress, rather than have to rely on nurses remembering to use special devices for patients at risk.

The Dupic pad was designed principally as a means of preventing sores of the pelvic region. A controlled trial, in which it was tested against a synthetic sheepskin pad and a disposable incontinence pad (Lowthian et al, 1976) indicated that the incidence of pelvic sores was reduced: compared with results on the other two pads (see Table 3). The synthetic sheepskin pad was thought to be dangerous for bed patients
TABLE 3 DUPIC UNDERPAD TRIAL - PATIENTS WHO DEVELOPED PRESSURE SORES (2 - 3 WEEKS TRIAL).

<table>
<thead>
<tr>
<th></th>
<th>VENTAPAD *</th>
<th>DUPIC</th>
<th>POLYWEB **</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients:</td>
<td>28</td>
<td>28</td>
<td>22</td>
</tr>
<tr>
<td>Total patients</td>
<td>12</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>with pelvic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sores:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage</td>
<td>42.8</td>
<td>17.8</td>
<td>40.9</td>
</tr>
<tr>
<td>who developed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pelvic sores:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Synthetic sheepskin pad.

** Disposable incontinence underpad.
because of its relatively high coefficient of friction against
the skin. Friction tests by Denne (1979) have tended to
confirm the earlier findings of Lowthian (1976 A) in this respect.
Natural sheepskins may, however, be helpful for patients who do
not sit up in bed, as well as for wheelchair users (Lowthian,
1982). The ability of natural sheepskin to maintain low humidity
at the patient/support interface (Lowthian, 1970 A; Denne, 1979)
is particularly valuable when, in attempting to spread a patient's
weight large areas of his body become insulated against heat
loss (Lowthian, 1970 A).

A special pad designed by Dyson (1978) uses a row of P.V.C.
tubes, partially inflated with air, which incorporate a water-
filled section to dissipate the patient's body-heat. By precise
judgement of the volume of water used in these pads, Dyson is
able to keep a patient's skin at a comfortable temperature. The
benefits and possible drawbacks of this idea have still to be
fully explored.

Dusting powder is one of the simplest precautions against
pressure sores, in that it reduces friction at the patient/
support interface (Appeldoorn and Barnett, 1963), but it is
contra-indicated in the presence of incontinence (Lowthian, 1970 A).
The type of dusting powder employed is of some importance. Talc
can cause granulomas if dusted into open sores, and pneumoconiosis
is possible after intense exposure to talc dust. Unless the talc
is carefully sterilised it is liable to contain viable bacterial
spores, including Clostridium Tetani and Cl. Welchii (Martindale,
1977).

Although elbows are not as susceptible to pressure sores
as are heels (see Figure 6) patients who spend a long time in
bed may develop excoriated skin, or even incipient sores, through
resting on their elbows. Elbow protectors, which are similar to
heel protectors, may be helpful for such patients.
2.6. The seated-in-bed problem

2.6.1. General considerations

The physical discomfort caused by drawsheets has been mentioned in Chapter 1, but part of this discomfort appears to result from nursing the patient seated-in-bed. This posture produces a forward propulsive force (Gainsborough, 1967) which crumpled the top edge of the drawsheet (Lowthian, 1973) and so creates very uncomfortable creases. If the seated-in-bed patient does not lean backwards the forward (tangential) force can be avoided. In practice, however, sitting bolt upright is only possible for short periods: because of the tension it produces in the hamstring muscles (Gainsborough, 1967; Lowthian, 1970 A). The typical seated-in-bed posture, in British hospitals, is shown in Figure 23. Weak or insensitive patients nursed in this position tend to slide forwards and, being unable (or unwilling) to lift themselves, suffer from the effects of prolonged friction forces on their sacrum/buttocks and heels (Lowthian, 1970 A).

Logic suggests that the weak/insensitive patients who are susceptible to pressure sores should not be nursed seated-in-bed; but a survey in three geriatric admission units (Lowthian et al, 1976) showed that 47% of 95 patients admitted to these units, were nursed in sitting positions for long periods. Forty-two per cent of these patients subsequently developed sacrum/buttocks sores attributed to the 'Forward slide' effect.

Although some nurses may be unaware of the connection between sitting in bed and sacrum/buttocks pressure sores, the conclusion that must be drawn is that most nurses do connect the two things together. The author's experience indicates that most geriatric nurses believe that the benefits of having a patient seated-in-bed usually outweigh the pressure sore risk. The usual reason a nurse gives for a debilitated elderly patient being seated-in-bed is to prevent him becoming "chesty". In other words, to prevent pulmonary congestion. However, the potential benefits of this procedure are questionable and
FIG. 23 THE TYPICAL SEATED-IN-BED POSTURE USED IN MANY BRITISH HOSPITALS.
especially so if bed-tilting is used in attempting to sustain the seated position (see Chapter 3.2.) The author's observations in various geriatric wards suggest some secondary reasons why so many patients are nursed seated-in-bed:—

1. they are in a better position to feed, drink, and to reach their bedside lockers,
2. sitting up suggests that they are reasonably healthy,
3. lying flat makes them feel more vulnerable, particularly if a potential danger is at hand, e.g. a disturbed fellow patient,
4. their boredom is relieved by watching what is happening on the ward — watching television may also necessitate being seated-in-bed.

The weak/insensitive patients who are most likely to suffer from the adverse effects of the 'Forward slide' are often incontinent (Lowthian, 1976 A) and, in consequence, are usually nursed with no clothing between their buttocks and the bed surface. Some simple tests by Lowthian (1976 A) indicated that the coefficient of friction between buttocks skin and a typical hospital bed-sheet was, in dry conditions, low enough to allow a weak patient to slowly slide forwards from a seated-in-bed position. When, however, the patient/support interface was damp, the intensity of frictional resistance rose to a point where it could only be termed 'adhesion'. Lowthian (1970 A) found that urine (or water) did not act as a lubricant beneath the incontinent patient because it took only one or two minutes for this fluid to be largely absorbed: by the patient's bedding, or his skin, or both.

Unfortunately, typical cotton bed-sheets do not dry completely for some hours (Lowthian, 1976 A) which suggests that weak incontinent patients, who are left sitting in damp beds, will be virtually anchored in the position shown in Figure 23. Because of the tangential strains produced by this posture (see above 2.2.) the patient's subcutaneous tissues are liable to be the site of severe sacrum/buttocks pressure sores (Reichel, 1958).
As already discussed, the prolongation of these tangential forces increases the risk of serious tissue disruption/necrosis. A damp patient/support interface caused by sweating is likely to be equally dangerous (Charnley, 1959). Moreover, a waterlogged skin (macerated skin) is weaker, and more easily torn, than normal skin. Conversely, a very dry skin may be more easily cracked by tangential forces (Lowthian, 1980 B). Patients with congenital weakness of the skin are, of course, particularly at risk from these effects.

Nylon pyjamas appear to reduce the friction effects discussed above (Lowthian, 1976 A) but such pyjamas are pulled into tight creases at the patient's crotch - as he slides forward from a sitting position. Thus he may avoid sacrum/buttocks sores at the expense of developing Grade 2 sores on his genitalia.

Attempts to prevent the harmful effects of the 'Forward slide' have usually been concerned with preventing it altogether, by means of footboards or thigh supports (Fripp, 1935; Norton et al, 1962; D'Cruz, 1976; Gainsborough, 1967). Lowthian (1970 A) suggested that, providing patient/support friction was relatively low, the Forward slide enabled the weak patient to vary the portions of his body being subjected to physical stress and strain: as he gradually slipped from a sitting to a recumbent position. If the nurse was aware of this effect she could regulate the slide (perhaps by means of dusting powder and/or emollient creams) and then restore the patient to a sitting position, as and when necessary. This scheme had the virtue of ensuring that a near-immobile patient was, to some extent, kept moving. These, and other considerations, led to the development of the Dupic underpad.

The controlled trial of this pad (see above - 2.5.10.) suggested that the increased movement encouraged by a smooth bed surface did help to prevent pressure sores. Nevertheless, it was important to prevent tight bedding, at the foot of the bed,
from compressing the patient's feet as he slid forward into the recumbent position.

Some patients nursed on Dupic pads (during the controlled trial) developed an unusual excoriation of the buttocks which seemed to be caused by a 'slip-stick' effect on the knitted polyester surface of the pads. When the surface material was changed for one that was slightly smoother (knitted nylon) there were no further patches of excoriation attributed to this effect (Lowthian, 1979 D). Nevertheless, the increased frequency of the patient's slide 'cycle' was noticed by some of the nurses caring for these patients, and they complained of the number of times they had to re-position the patients.

Obviously, a bed surface which is too smooth will prevent a patient maintaining a desired position and may even be dangerous if it allows the patient to slide right off his support. The optimum coefficient of friction for the patient/support interface is discussed further in Chapter 5.

Another hazard of the Forward slide mentioned by Lowthian (1970 A) is the compression of loose skin-folds (see Figure 10) which is particularly likely to occur when a patient with loose skin slides into a semi-recumbent position.

However, this will be less hazardous if the bed surface has a comparatively low coefficient of friction. Similarly, a low friction surface enables weak patients to make minor (spontaneous) adjustments to their posture.

Gainsborough (1967) considered that some kind of thigh support was necessary in order to prevent the Forward slide. However, his own idea for an upper thigh support, to prevent the Forward slide, suffers from the disadvantage that it would tend to immobilise the seated-in-bed patient.
The use of a footboard may also tend to immobilise a weak or apathetic patient although D'Cruz (1976) showed that a footboard can provide physiotherapy for a comparatively fit patient. Footboards, however, have disadvantages when it comes to bed-making (see above Chapter 1.3.5.)

Air rings and foam rings (see above 2.5.10.) are often used to relieve pressure from a patient's sacrum - when he is nursed seated-in-bed. If such a patient is weak, and relatively light, the pelvic ring may act as an anchor, so that he is practically immobilised. The dangers of immobilisation have been discussed (Chapter 1.3.6.) and it seems clear that a weak patient who is anchored in a sitting position has fewer options for varying his position than has a similar patient who is nursed recumbent.

2.6.2. The venous thrombosis hazard

Gainsborough (1967) mentioned the 'Donkey' device, consisting of a firm pillow wrapped in a drawsheet, which was used to prevent the Forward slide. Gainsborough commented that this device had disappeared and hinted that it was harmful. However, some years later, the 'Donkey' was still being advocated by American nurses (Henderson and Nite, 1978).

The Donkey will obviously reduce the mobility of a weak patient, but a further hazard of the 'Fowler's position, which is the position produced by use of the Donkey, was postulated by Payling Wright (1947). She suggested that thrombosis of the peripheral leg veins could be caused by a flattening of the femoral veins (at the inguinal ligaments) when the hip is flexed to about 90 degrees - in the Fowler's position. The supposed slowing of the venous return, as a result of this flattening has, however, been challenged by the work of Calnan (1971) who found that deliberate partial obstruction of the iliac vein failed to produce a swollen leg - in dogs. Nevertheless, in the late 1940's and 1950's the case against the Fowler's position was identified
with the general case against bedrest as a therapy for all ills (Lancet, 1947; Wells, 1953).

Although the 'Gatch-spring' contouring mattress base was widely used in the U.S.A. from the 1920's, an examination of British nursing journals shows that the equivalent contouring base (the Fowler's bed) was still regarded as 'new' in 1946 (Nursing Mirror, 1946). The 'Fowler's Position' was, however, well-known at about this time (LeVay, 1947) and it seems that it was usually maintained by means of a Donkey - on an ordinary (straight) mattress base. A few years later, in the same nursing journal, Nicholson (1950) could say that nurses have noted, with relief, the decline in use of 'Fowler's Position'. Interestingly, in the U.S.A., where Gatch-Spring beds were already well-established, there appears to have been no similar decline in the use of Fowler's Position (Ganong, 1960; Bergstrom et al, 1965; Norton, 1970).

Although Fowler's Position is defined by Ganong (1960) as a seated-in-bed posture without a thigh support ('knee-break') in Britain it is associated with the Fowler's bed, which did have a 'knee-break'. In consequence, this treatise defines the Fowler's Position as seated-in-bed with the thighs supported on a 'knee-break'. The Gatch-Spring bed shown in Figure 3 is adjusted to this position.

If we accept that the years since 1950 have seen a fundamental difference, between British and U.S. hospitals, in the use of contouring beds; then, if the Fowler's Position does cause venous thrombosis, we should be able to see this reflected in a different incidence of this condition, between the two nations. Unfortunately, there are problems in diagnosing venous thrombosis (Abramson, 1978) which make this task impracticable. On the other hand, the fatal consequence of massive venous thrombosis (pulmonary embolism) is relatively easy to diagnose: after death. It is, in fact, the spectre of death caused by pulmonary embolism,
which makes doctors so anxious to minimise the occurrence of venous thrombosis.

The statistics for deaths due to pulmonary embolism are easily obtained and a comparison between the figures for England and Wales, and those for the U.S.A., reveal the interesting fact that the U.S. figures fell below the England/Wales figures at the very time when the Fowler's Position was declining in Britain (see Figure 24).

There are, of course, many possible influences on the figures under consideration. For example, the International Classification of Diseases coding for pulmonary embolism changed between 1948 and 1949 and this may have affected the number of American deaths reported as due to this condition (Smith, 1981). However, the same coding was used when obtaining the equivalent figures for England/Wales. Similarly, the sudden rise in the U.S.A. figures in the late 1960's may be linked to an increase in cardiovascular surgery.

Although it is difficult to be sure how many deaths from pulmonary embolism are linked with hospitalisation Figure 24 appears to show that the widespread use of Gatch-Spring beds is unlikely to cause an increase in deaths due to pulmonary embolism. However, motorised hospital beds became popular in America during the 1950's (Gailani et al, 1958) and, although these retained the Gatch-Spring position it was possible for the patient (or the nurse) to easily change his position - by pressing a button. This may well have discouraged the prolongation of a particular nursing posture.

Recent research suggests that venous thrombosis is ordinarily initiated by extensive tissue destruction at "some site in the body", which can be remote from the veins affected (Stewart et al, 1977). Surgery is obviously implicated by Stewart et al. Miller (1974) reported that as many as 30% of patients undergoing surgery may start developing a calf-vein
FIG. 24 DEATH RATES DUE TO PULMONARY EMBOLISM IN ENGLAND & WALES, AND U.S.A.
thrombus during their operation. In Miller's list of factors associated with a high risk of pulmonary embolism there is no mention of Fowler's Position, but there is a mention of excessive bedrest.

More recently Fenech et al (1981) found that four out of eleven patients with fractured neck of femur actually started to develop deep-vein thrombosis before operation, i.e. in the first few hours after their injury.

The work of Cockett et al (1967) suggested that the predominance of left-leg venous thrombosis is attributable to compression of the left common iliac vein, where it is crossed by the right iliac artery. If this is true we might expect prolonged nursing in the Supine position to increase the thrombosis risk; especially if a constipated bowel is resting on the iliac blood vessels. However, Calnan (1978) believes that the iliac vein compression hypothesis has not been supported by subsequent observations. Browse (1965) maintained that lateral postures are a potential cause of venous thrombosis; because of the upper leg pressing on the veins of the lower leg.

It seems safe to conclude that Fowler's Position is not, in itself, an important factor in the aetiology of venous thrombosis; although any nursing posture may be implicated if its prolonged use produces a severe restriction of mobility. Payling Wright (1980) feels that the modern practice of early ambulation and/or physiotherapy, in Britain, makes the question of nursing posture "far less important" than it was in 1947.

2.7. Treatment of pressure sores

In a review of pressure sore treatments Snowden (1979) listed 27 different, but current, techniques excluding surgical closure. Many more techniques can be added to Snowden's list, but the variety of recommended treatments must surely reflect our relative ignorance about the nature of wound healing (Schilling, 1968; Hunt and Dunphy, 1979).
An interesting experiment by Fernie and Dornan (1976) showed that novel treatments may influence the healing of pressure sores simply because they attract more nursing attention to the patient being treated. A placebo device, made by Fernie and Dornan, was thought, by the nurses, to be a special healing-ray machine. In fact it did nothing, but as the nurses were instructed to point this device at a pressure sore at regular intervals the consequent prevention of sustained pressure on the sore enabled it slowly to heal.

Most observers are, in fact, agreed that the patient's weight should not be resting for prolonged periods on a pressure sore of grade 3 or 4, while attempts are made to heal it. Exceptions to this rule are made in the case of some sophisticated supports such as the Low Air Loss Bed System (Scales et al, 1974), the water-immersion bed (Grahame, 1974), the Mud bed (Reswick and Rogers, 1976), the Air Fluidised Bed (Hargest, 1976) and the Roto-Rest bed (Keane, 1971). If a sophisticated support is not available it may be necessary to rely on pillow/pack nursing (Rogers, 1978-79) or on strictly-timed manual turning. However, in the author's experience, it is quite common to find patients being nursed directly on an open sore (grade 2) on an ordinary hospital bed. Such patients are usually receiving more pressure area 'care' than are patients without sores, but this can still result in them sitting on the sore for three hours or more at a time. During an early trial of the Dupic pad (Lowthian, 1972 B) it was found that certain patients with grade 2 pelvic sores, nursed directly on the smooth surface of the Dupic pad, showed more healing of these sores (over a few days) than did their matched counterparts who were nursed on paper-surfaced disposable pads. As this trial was designed to minimize the 'novelty bias' highlighted by Fernie and Dornan (1976) it seems likely that the better results on the Dupic pad were due to a reduction in adhesion between the patient and the pad (see Chapter 5). These considerations indicate that the surface coverings of a general-purpose P.S.S. need to be designed so as to minimize the adverse effects of direct contact with open pressure sores.
2.8. Summary of the pressure sore problem

Although pressure sores have been a problem of nursing care for several centuries their pathogenesis is complex and their development is often insidious. In the last few decades an increasing awareness that pressure sores are preventable has combined with various medical advances - preventing the early demise of many severely disabled/elderly patients - to produce a major problem for the health services.

A shortage of skilled nursing care, in hospital units where many patients are at risk, has exacerbated the pressure sore problem (Baly, 1980) and highlighted the need for a simple means of assessing the risk factor of hospitalized patients.

The manifest failure of the health-services to eradicate pressure sores, has resulted in the development of numerous preventive devices. The more sophisticated devices are expensive and are generally reserved for the most highly-dependant patients. In the author's experience, most General hospitals acquire a few special supports, such as the LALBS or water floatation beds, but rely on general-purpose P.S.S.'s for the majority of their patients.

Many new supports aimed at preventing pressure sores introduce new hazards and problems - for both patients and hospital staff. Continuing development of some of the sophisticated supports may make it possible to overcome these problems, and even to automate some aspects of nursing care. It has already been shown (Keane, 1971) that the mechanical turning of a patient can be less disturbing than manual turning. Nevertheless, many elderly patients will be frightened by strange-looking support systems (Bliss et al, 1966; Smith, 1976) and this will limit their use for a very large group of 'at-risk' patients.

Two recent reports (Carpendale, 1974; Steadman Steffal et al, 1980) suggest that when a novel support loses its novelty value, by evaluating it alongside other novel supports as well
as a 'standard' support, the 'standard' support tends to be preferred: by both patients and nurses.

Various aids such as sheepskins, bed cradles, pillows and packs, can be used on a 'standard' support for patients who are 'at risk' of pressure sores. Nevertheless, these aids themselves are often hazardous and in a busy ward situation many 'at risk' patients fail to be identified until they actually develop sores (Bliss et al, 1966; Lowthian et al, 1976).

While acknowledging the perennial need for an influx of skilled nurses - in hospital units where many patients are at risk of pressure sores - a particularly urgent need, it is suggested, is for an improved general-purpose P.S.S. Moreover, even if new developments in nursing organisation do improve the supply of skilled nurses (Baly, 1980) there would still be considerable scope for improving the 'standard' equipment with which nurses have to work (Scales, 1977).
CHAPTER 5.

THE CONTEMPORARY GENERAL-PURPOSE P.S.S.
- A CASE FOR IMPROVEMENT

3.1. Introduction

The typical general-purpose hospital P.S.S. (bed, mattress and bedding) has evolved over many years. Attempts to improve on this system must, therefore, recognize the many conflicting requirements which have squeezed the 'standard' system into its present form. Some of the fundamental requirements of a general-purpose hospital bed, which distinguish it from the typical domestic bed have been mentioned in Chapter 1. In brief these are:-

1. a waterproofed mattress, which enables nurses to quickly clean away excreta, blood, vomitus, pus, bile, wet plaster of paris, etc.
2. a bedstead with adjustable height which allows a floor to mattress-surface height of 51 cms. or less,
3. a head-down tilt facility,
4. a bedstead and mattress which allows for patients being seated-in-bed for prolonged periods,
5. special orthopaedic apparatus, such as 'Balkan beams' and traction pulleys, should be attachable to the bedstead.

In 1963 the Ministry of Health and King Edward's Hospital Fund formed a working group to study the design of hospital bedsteads. At about the same time the Ministry of Health formed a working group to prepare specifications for the standardisation of mattresses, and related items, for use within the National Health Service. A similar group looked into the standardisation of hospital bed linen. The main aim of the King's Fund study was to arrive at a specification which would give precise guidance to manufacturers on the requirements of a general-purpose bedstead; which could be mass-produced for hospitals.
While this study was in progress the United States health service was taking a critical look at their hospital beds: a conference of bed manufacturers and rehabilitation experts (Bergstrom et al, 1965) tended to confirm the desirability of a 'universal' bed which could be used in a variety of different situations.

A New Zealand bed manufacturer (Wright, 1975) observed that most manufacturers produce different beds for each, specific, nursing requirement; and that it would be more logical to produce one or two basic models, which could then be adapted (with various accessories) for each nursing requirement. The main arguments put forward, for this 'modular' concept, were that differing models become mixed in use so that special features are wasted (staff being unaware of the bed's capabilities); and special accessories are easily mixed or mislaid. Although work on this concept began in 1954, it was 1975 before Howard Wright Ltd. (Wright, 1975) were able to offer a basic bed unit which could be adapted to meet many different nursing requirements. Interestingly, some of this bed's chief design features were also features of the prototype general-purpose bedstead produced by the King's Fund design team.

The King's Fund team did not design a special mattress for their prototype bed, as a Ministry of Health 'Specification Working Group' had the task of investigating this aspect of hospital P.S.S.'s (NHS report, 1968). The fact that the development of an improved hospital mattress was pursued separately from the bedstead development has been described as "unfortunate" (Smith, 1976).

3.2. The King's Fund Bedstead

The distinctive feature of the King's Fund design is the cross-over 'scissors' mechanism which allows a hydraulic pump (operated by a foot pedal) to lift the bed, quickly and quietly, on just one bearing point (see Figure 25). The hydraulic
FIG. 25 AN EARLY VERSION OF THE KING'S FUND BED –
WITH VARIOUS ACCESSORIES.
mechanism also allows the bed to descend smoothly—from a high position—when a foot pedal is used to open a relief valve (Bretten, 1974). In the original design, the variable-height mechanism was attached to the mattress base platform at three points. One of these attachment points, at the foot-end of the bed, incorporated a spring-loaded adjustment mechanism, whereby a simple lever enabled the nurse to tilt the bed head-down; this being a one-handed operation (Thorne and Roberts, 1968). This was a big improvement on many previous tilting methods (see Chapter 1) and a tilt of 12 degrees could be obtained. If a foot-down tilt was required, the bed could be turned around; the bed-ends (bows) being removable and interchangeable.

With the mattress base platform level, the height of the bed could, in theory, be varied between 46 cms. (18 inches) and 91 cms. (36 inches) to the top of an uncompressed mattress. In practice, the height variation was approximately 50 cms. to 102 cms. (King’s Fund, 1967); this being principally attributable to the use of a thick mattress (180-195 mms.) When DHSS specification mattresses began to be used on the King’s Fund bed the practical variation in bed height was generally 52.5 to 90 cms. (including the uncompressed mattress) according to Hoskins (1979). Although the lower position is still a little high for some patients with short legs (King’s Fund, 1967) it represents a considerable improvement over fixed-height general-purpose bedsteads.

The various steel beams, which were used in the variable-height mechanism of the King’s Fund bed, had to be accommodated under the mattress base platform. They were set back approximately 10 centimetres, from each long edge of the mattress base platform, so as to allow some 'knee room' for nurses attending to bed-patients. Nevertheless, the King’s Fund report (1967) suggests that still more 'knee room' is desirable, in order to allow nurses to sit at the bedside with their knees under the mattress base platform. The relatively complex 'chassis' of the King’s Fund bed has to be dusted and this is obviously a more difficult task than
cleaning the 'chassis' of a more traditional bedstead. Cleaning
the floor beneath the King's Fund bed was, however, made easier
by giving the bed efficient, wheeled, castors: the diameter of
these rubber-tyred wheels being larger than the traditional
pattern.

The improved mobility of the King's Fund bed allowed it
to double as a patient-trolley. Thus it became possible to
reduce the patient-transfer difficulties discussed by Robertson
(1977) by using the bed as a trolley, when transporting patients
to various hospital departments for x-ray, operation, etc.
When a King's Fund bed needs to be stable; for example, when
a patient is getting out of bed; it is necessary to have
efficient brakes on the large castors. Such brakes were provided
on the King's Fund bed.

A time-honoured way of holding bedding during bed-making,
was on two upright chairs placed back-to-back (Hector, 1962).
The King's Fund bed made it unnecessary for nurses to run around
looking for chairs or underbed seats, when making beds: an
extendable platform, known as a 'bed stripper', was built into the
mattress base platform (see Figure 25).

All structural parts of the King's Fund bed were made from
steel, including the mattress base, which was a sheet of corrugated
steel. Gainsborough (1967) supported the use of this rigid base
on the grounds that it facilitates movement: by the patient, or
by the nurse, when changing a patient's position. He also pointed
out the value of a rigid mattress base in the event of cardiac
arrest; resuscitation being possible without removing the patient
from his bed. The steel sheet mattress base has, however, been
criticized by Scales (1976 C) on the grounds that it provides
inadequate ventilation for the mattress. For this reason steel-
mesh mattress bases are used on the King's Fund beds ordered for
the Royal National Orthopaedic Hospital (RNOH). Clinical trials
of new mattresses resting on these bases have shown that there is
no accumulation of water condensate on the steel mesh; but there is water condensate when the sheet steel bases are used. The steel mesh used on RNOH beds is rigid enough for both orthopaedic needs and cardiac resuscitation.

The use of a rigid mattress base, on the King's Fund bed, had earlier been criticized by the National Health Service Working Group investigating mattresses and related items (NHS report, 1968) on the grounds that it prevents adequate load/pressure distribution — with the shallow (10 cms.) mattresses recommended by the King's Fund design team. The NHS group considered that the traditional sprung mattress base is able to absorb the energy of sudden jars and impacts and, by assuming a hammock shape — under load — is able to ensure reduced pressures on the medial bony areas of the body: in the event of mattress failure. The NHS group concluded that a mattress thickness of 125 or 150 cms. would be needed on a rigid mattress base.

The authors of the King's Fund report (1967) had recognized the inherent problems of their bed's straight-base mattress platform for seated-in-bed patients, but considered that a slight head-down tilt would compensate for the tendency of the seated-in-bed patient to slide forwards and downwards in the bed. Gainsborough (1967) argued that this tilting manoeuvre increases pulmonary congestion by draining venous blood from the legs into the abdomen. In consequence, a patient who is sat up in bed in order to minimise pulmonary congestion, does not benefit.

The width of the King's Fund mattress base platform was set at a maximum of 97 cms. and its overall length was a maximum of 208 cms.; but there was provision to extend the platform a further 18 cms. in order to accommodate extra-tall patients. This was a significant improvement over traditional beds (see Chapter 1.3.4.2.)

The removable head-end and foot-end 'bows' slotted into position on the mattress base platform and the head-end bow
incorporated a traditional-style adjustable backrest (see Figure 25). Folding cot-sides were designed to be readily attachable and detachable from the mattress base platform. When folded down, the articulated rails of these cot-sides collapsed flat - to avoid any substantial protrusions below the mattress base.

Various accessories such as overhead pulley poles, Balkan beam equipment, and intravenous infusion poles, could be fixed to the King's Fund bed (see Figure 25) and this latter feature ensured that the bed could still function as a transfer trolley, while a patient was receiving intravenous therapy.

3.3. The mattress and bedding

The National Health Service group working on mattresses (NHS Report, 1968) produced a specification for a polyurethane foam mattress but this was not prepared specifically for the King's Fund bed.

The NHS Working Group investigated various mattress fillings before deciding, on balance that the advantage lay with polyurethane foam. Their decision was based on the potential comfort, low cost, durability, and low weight, of polyurethane (P.U.) foam. Small (1980) has found that hair mattresses have favourable indentation characteristics but, nevertheless, they are heavy and require regular turning/redistribution of their stuffing.

The NHS group did specify a spring-interior adult hospital mattress of lighter weight and shallower depth than those normally supplied (NHS report, 1969). However, they were clearly in favour of using P.U. foam rather than existing spring-interior mattresses and they also favoured P.U. foam for new mattress designs (NHS report, 1968).
The NHS group's specification for a general-purpose single adult hospital mattress (in P.U. foam) is particularly relevant to the present study. This was to be made from 'open-cell' flexible P.U. foam with a density of not less than 32 Kg. per cubic metre. Three different mattress widths were specified: 76 cms., 86 cms., and 91 cms.; the two wider mattresses having reinforced 'firm' edges made of denser foam. These firm edges were produced by bonding 5 cm. strips of reconstituted foam (chipfoam) to each long edge of the mattress 'core' (see Figure 26). The chipfoam used for this purpose had a minimum density of 64 Kg. per cubic metre. The hardness characteristics of the mattress core were carefully defined and measured by a British Standard method (B.S. 3667). This standard was later revised (B.S. 4443, 1972) and the foam mattress specification was also revised (DHSS Specification, 1978). The latter specification defines the general-purpose adult hospital mattress as 'Class 1'; 'Class 2' mattresses being for children and 'Class 2' for geriatric patients. The foam density of the Class 1 mattress was now set at 31 Kg. per cubic metre and the firm edges were to be 65 Kg. per cubic metre. The hardness of the Class 1 mattress was to be 110 - 140 Newtons at 40% indentation (see Chapter 4). It was specified that the narrower Class 1 mattress (76 cms.) should have 2.5 cms. chipfoam edges. The overall widths of the Class 1 mattresses were unchanged from the 1968 specification.

The DHSS specification (1978) also made it clear that the only difference between the Class 1 mattresses intended for a sprung mattress base and those intended for a rigid base, was the depth of the mattress: 10 cms. being specified for a sprung mattress base and 13 or 15 cms. for a rigid mattress base.

The NHS Working Group (NHS report, 1968) specified a proofed nylon mattress cover for their new foam mattresses. This has been modified slightly over the years, but the finalized specification was issued as a British Standard in 1976 (B.S. 5223,
FIG. 26  SKETCH OF DHSS SPECIFICATION MATTRESS SHOWING FIRM EDGES (LIGHTER SHADING).

FIG. 27  STRETCHED COVER ON A FATIGUED DHSS MATTRESS (30 cm. RULER ON COVER).
The nylon is a woven material and is waterproofed with a polyurethane resin possessing a degree of water-vapour permeability (see Chapter 5). The marbled brown pattern on the NHS Specification cover is now well-known in British hospitals (Geraghty, 1975). It is intended to present a pleasing appearance while masking any inadvertent stains due to incontinence, haemorrhage, etc. Another well-known feature of this cover is the fact that it fits tightly to the foam core; being made one centimetre smaller (in length and width). The mattress is completely covered in the waterproof material and the foam has to be squeezed down before the slide fastener can be closed. The aim of having such a tight cover is to prevent creases forming in the proofed nylon (NHS report, 1968). Unfortunately as discussed in Chapter 4, this feature increases the effective hardness of the mattress by exaggerating the 'hammocking' effect.

The estimated life of the NHS Specification foam mattress was six years (NHS report, 1968) after this the foam was likely to have fatigued (losing hardness and/or depth) to the point where it would fail to adequately cushion a patient. A random check by Lowthian et al (1976) showed that some 'Class 3' foam mattresses, which were used on rigid mattress bases, had deteriorated to this point after four years of constant use. It seemed likely that such deterioration normally went unnoticed by the ward staff of the hospital concerned. The most severe fatigue was, in fact, in the middle of the mattresses, and is likely to have been caused by prolonged use of the 'seated-in-bed' posture (see Chapter 2.6.) A photograph taken across the cover of a fatigued mattress (Figure 27) shows that the cover material has permanently stretched where the patient's weight has been concentrated. Such an area of stretched cover strongly suggests that the foam core of the mattress has also deteriorated. By sitting on one of these stretched areas, while allowing his legs to hang freely over the edge of the bed, the author discovered that the rigid base of the King's Fund bed could be felt (through the mattress) pressing on his buttocks. This centralised
fatigue may, perhaps, be delayed by regular turning of the mattress but this does not appear to happen, to any significant degree, on a busy ward (Lowthian et al., 1976).

It was anticipated that the NHS Specification mattress cover could be disinfected by swabbing with a disinfectant (NHS report, 1968). To this end the material was made as smooth as possible and was tested for its resistance to attack by commonly-used disinfectants. However, tests at a London hospital have shown that swabbing with disinfectants is a relatively ineffective means of removing the bacterial contamination from these covers (Nakhla, 1979). The covers can, however, be laundered to disinfect them, and this may be necessary on a Burns unit. Nevertheless, where this is done, the author has noticed that the laundered covers shrink after washing.

A more serious hazard with the NHS specification covers concerns their waterproofness. If contaminated fluid, such as urine, is able to penetrate a perforated cover it will not be easily detected and will tend to accumulate within the foam of the mattress. Personal communications from Jeneid (1978) and Ward (1979) indicated that the NHS specification covers lose their waterproofness as a result of abrasive wear. Stead (1979) detected Ps aeruginosa in contaminated fluid taken from within the NHS specification covers. When new, the covers are designed to withstand the pressure exerted by a 150 cms. head of water (NHS report, 1968) but it seems that hard use will abrade the covers - making them porous - after about two years.

The bed-sheets and blankets used on the traditional general-purpose P.S.S. (see Chapter 1) have continued to be used on the King's Fund P.S.S., although, in some hospitals, 'Duvets' have started to replace blankets (Chrisp, 1981). Drwsheets continue to be used on the King's Fund P.S.S. and they are particularly prevalent in Geriatric units (see Chapter 1). The problems caused by drawsheets and the seated-in-bed position have not been solved by the King's Fund P.S.S. design.
3.4. Suggestions for improving the general-purpose P.S.S.

3.4.1. Factors influencing general-purpose P.S.S. design

We have seen that there are many factors influencing the design of a general-purpose P.S.S., for hospital use. Some of the fundamental requirements are listed above (3.1.) To this list of requirements, which tends to differentiate the hospital bed from the domestic bed, we can add a further list of constraining influences, from the patient's viewpoint:

1. comfort for the patient without discouraging spontaneous movement,
2. the avoidance of micro-organic proliferation and pest infestation,
3. the need for a rigid mattress base (for fractures and cardiac massage),
4. the ability to absorb some energy when a patient stumbles, and partially falls, onto the mattress,
5. the avoidance of dangerous mechanical parts, which might collapse, prick, pinch, abrade, or otherwise harm the patient,
6. fire-safety,
7. the minimising of static electricity discharges - especially where inflammable gases are being used,
8. the provision of adequate ventilation - beneath the mattress - for heat comfort,
9. some degree of heat insulation to restrict heat loss in a cold environment (this assumes a lack of adequate environmental control - in old hospitals)
10. stability of the support surface, to avoid feelings of insecurity; the edges being particularly firm to facilitate transfers and sitting on the bed edge,
11. stability of the whole support - when it is not being moved,
12. stability while in motion,
13. innocuous, comforting, general appearance;
14. the avoidance of noise from mechanical parts,
15. the use of bed extensions for extra tall patients,
16. provision for the use of overhead pulleys, bed
   cradles, safety cot-sides, etc.
When the needs of hospital staff are taken into account an
additional list of constraints may be added:—
1. minimal cost and maintenance,
2. minimal training requirements — for using
   and maintaining the support,
3. durability and strength to resist 'wear and
   tear' during use, transport and storage,
4. minimal detachable parts, in order to avoid
   misplacement and loss,
5. minimal weight of detachable parts — such
   as the mattress,
6. minimal storage space requirements,
7. ability to be used (to some degree) as a transfer
   trolley, x-ray table, operating table, and
   physiotherapy couch,
8. provision for steering and braking the moving
   bed, plus being able to quickly discern the
   brake position,
9. minimal dusting/cleaning requirements,
10. provision for holding bedding during bed-making,
11. adjustments to the support should be possible by
    one woman working alone (King's Fund, 1967).

3.4.2. Problems of the contemporary (King's Fund) general-
        purpose P.S.S.

Although the King's Fund P.S.S. appears to meet many
of the requirements listed above, it does present some hazards for
patients who are either elderly, or disabled, or both. Out of the
various factors discussed above the following critical points seem
to emerge:—

a) the King's Fund one-piece mattress base, in rigid
   steel plate, fails to give adequate load/pressure
   distribution when pressure sore susceptible patients
   are nursed seated-in-bed; use of the integral backrest
   tending to produce severe tangential forces in the tissues,
b) the NHS specification mattress, when new, is too hard for the patients under consideration; the tight woven cover being chiefly responsible for this,
c) both the mattress core and the woven cover fatigue after approximately 4 - 6 years, and this allows patients to 'ground' on the rigid mattress base,
d) when new the mattress cover has poor permeability to water vapour and this results in sweating at the patient/support interface: in warm ambient conditions,
e) the mattress cover does become porous after approximately two years of hard use - producing a cross-infection hazard,
f) drawsheets and mackintoshes are frequently used on the King's Fund P.S.S. and this seems to increase both the patient's discomfort and his risk of developing pressure sores.

In addition, during the present study, it was discovered that the fire resistance of the NHS specification mattress needed to be improved (see Chapter 6).

The weak and debilitated seated-in-bed patient seems to be particularly affected by the above-mentioned deficiencies of this contemporary general-purpose P.S.S. If we assume that many such patients will continue to be nursed seated-in-bed, for the reasons given in Chapter 2.6., some means of making the general-purpose P.S.S. more suitable for these patients is imperative.

3.4.3 New developments

Since the development of the King's Fund bed some new contouring beds, exemplified in the Nesbit-Evans 'Profila' (Figure 19) have been introduced (Andrews and Atkinson, 1975; Lovthian, 1975). These new beds are similar to the older 'Fowler's bed'. The 'Profila', however, has a balanced mattress base which can be moved into different positions by the patient shifting his own weight. An easily-operated clutch keeps the mattress locked in position - until the patient wishes to change his position. In
this way the mechanical disadvantages of the Fowler's bed (see Chapter 1.3.2.) have been largely overcome; without introducing the complication of electrification.

The Profila, and similar contouring beds (Nesbit-Evans, 1979; Hoskins, 1979) are slightly less versatile than the King's Fund bed. In particular, the 'knee-break' section of the contouring mattress base invariably operates when the patient's backrest is in use. Thus, some patients who have to keep their legs straight (due to arthrodesis of the knee, or a similar problem) are unable to benefit from the adjustable backrest. A contouring mattress base which can, when necessary, be used without the 'knee-break' section is needed for orthopaedic hospital wards.

The author's personal experience suggests that contouring beds which have a three-section base tend to put uncomfortable pressure on the buttocks as the patient moves from a recumbent to a sitting position; the seat and backrest sections appear to act like giant pincers on the buttocks. The modern American Gatch-Spring bed appears to largely overcome this problem by using a four-section base, the extra section being under the buttocks. This section stays in position while the other sections move (Ganong, 1960) so that there is less chance of the pincer effect occurring.

A four-section contouring base, which is easily operated, and yet which retains all the advantages of the King's Fund bedstead seems to be a tall order. It is inevitable that a new bedstead of the type envisaged will be more expensive than the typical general-purpose P.S.S. currently employed in British hospitals. It is not, however, likely to increase the cost of the King's Fund bedstead by more than a factor of two (Layton, 1978). This makes it about one-fifth of the price of an equivalent motorised bed (Egerton, 1980).
FIG. 28 A TYPICAL HINGED MATTRESS DESIGNED FOR A
CONTOURING BED.
The mattresses used on the new contouring beds are usually hinged (see Figure 28) and this makes them less than ideal: the hinged portion giving poor support precisely where extra support is needed - under the patient's pelvis (NHS report, 1968). A mattress which will contour without being hinged is really required.

Other desirable features of an improved mattress, for use on the new bedstead envisaged, include superior compliance and greater durability. Both of these characteristics may be obtained if a stretchable mattress cover is combined with a foam core which has a slightly higher density than the NHS (DHSS) specification mattress foam. Any new mattress cover must, however, avoid the cross-infection hazard encountered with the DHSS specification covers, even though it has a high permeability to water vapour while remaining impermeable to liquid water (Scales, 1977).

Improving the cover system of the general-purpose mattress is unlikely to be very effective in reducing the incidence of pressure sores if traditional drawsheet/mackintosh systems continue to be used. The factors already discussed (see Chapter 1.3.4.3) suggest that the drawsheet will be difficult to banish; but a system which improves support surface compliancy, whilst retaining the practical advantages of the drawsheet, would appear to be a goal which is well worth pursuing.

3.4.4. Research Aims

The main aim of the project on which this treatise is based is to develop an improved general-purpose P.S.S., which will reduce the incidence of pressure sores. This new system should avoid the various faults in existing general-purpose supports without introducing new hazards and/or practical disadvantages. Although initially for hospital use the new system should be adaptable for home-nursing.
It was envisaged that the new system will be developed in three main stages:

1. development of an improved mattress, with its waterproof covering, which will optimise patient comfort and load/pressure distribution; this being usable on a contemporary hospital bedstead and with contemporary bedding,

2. development of an alternative to the bottom sheet/drawsheet system of mattress covering, which will overcome the disadvantages of this typical patient/support interface,

3. development of an improved contouring mattress base, which can be adjusted easily and speedily, and which will be usable with the new mattress/interface system.

This treatise concentrates on the first two stages of the P.S.S. development outlined above; the tests involved in determining the optimum characteristics of the mattress and patient/support interface; and with the actual development of the mattress system (stage 1).

The load/pressure characteristics of various hospital mattresses have been tested by others (NHS report, 1968; Fernie, 1973; Small, 1980) but it seems advantageous to develop a relatively simple method of such testing which will produce a pressure profile similar to that which occurs around a patient's body protuberances: as he rests on a mattress. This, in turn, should indicate the degree of tissue distortion which occurs.

Tests of the friction characteristics of some patient/support interfaces have been reported by Chow (1974), Lowthian (1976 A) and Denne (1979). However, such tests are fraught with difficulties because of the many variables which need to be controlled; particularly when human skin is one of the surfaces involved. A relatively simple, but repeatable friction test is required to evaluate new interface materials. It is undesirable to attempt
to evaluate these materials by using them directly against the skin of the patients concerned, because of the sustained tangential forces which can develop when weak/insensitive patients are seated (in bed) on a high-friction or 'adhesive' interface. Such a policy of 'patient evaluation' can increase the risk of these patients developing pressure sores.

Very little work has been done on the water vapour permeability (W.V.P.) of the typical hospital P.S.S., but Scales (1976 B) has pointed out that both patient comfort and the minimising of microbial proliferation (on moist skin) are two important reasons for obtaining the maximum possible W.V.P. This needs to be appreciated when considering the waterproofing of the new mattress.
CHAPTER 4.
LOAD/PRESSURE DISTRIBUTION ON THE
GENERAL-PURPOSE P.S.S.

4.1. Load/pressure measurement on mattresses

4.1.1. General methodology

A commonly used method of assessing the hardness of a mattress is to measure its loss of thickness with increasing load; the load being applied with a standard indenter (B.S. 4443, 1972). The indenter used is a flat circular plate - usually made of metal. Fernie (1973) used two such indenters, one was 50 mm in diameter and the other was 100 mm.

It is difficult to relate the results of such indentation tests to the pressures experienced, by various patients, on their body protuberances. In particular, the prominent weight-bearing areas of the human body are complex three-dimensional curves rather than flat discs. The peak pressures on these prominences must, ordinarily, be close to the apex of the prominence concerned (e.g. the femoral trochanters - in lateral nursing postures); and such pressures can be considerably higher than the pressures on the periphery of the prominence (see Figure 29).

When the body is floating freely in a concentrated saline solution - such as the Dead Sea - the pressures exerted around each weight-bearing prominence will vary only slightly; according to depth of immersion in the salt water; but, as we have seen (Chapter 2.2.) there is also a hydrostatic factor involved in the variation of pressure within the body tissues. In consequence, there is arguably no soft tissue distortion (Neumark, 1981) and, hence, no disturbance of tissue perfusion. If, however, the body is 'floating' on a high-density fluid, such as mercury, there will be only partial immersion of the weight-bearing prominences. The diminished area for supporting the body weight will increase pressure over the areas supported (pressure = force/area). In
Flat indenter on spring mattress

N.B. length of arrows indicates degree of interface pressure.

Patient sitting on spring mattress

FIG. 29 THE INFLUENCE OF A LOAD'S SHAPE ON INTERFACE PRESSURE DISTRIBUTION.
this circumstance the sudden pressure gradient – between the supported area and the peripheral area under atmospheric pressure – will produce soft tissue distortion. In Chapter 2 it has been argued that prolonged distortion of soft tissues is a principal cause of pressure sores. If this is so, a load/pressure test for mattresses should provide an indication of the degree of soft tissue distortion to be expected. We have seen that the removal of all tissue-distorting pressures is undesirable (Chapter 2.5.5.) but a mattress which gives a slow and smooth pressure gradient; from the apex of a weight-bearing prominence to its peripheral regions; would appear preferable to one which produces a sharp or irregular gradation of pressure.

Measuring pressures directly, at the patient/support interface, would seem to be the best method of checking the pressure gradients in question. Nevertheless, there are many practical problems in this approach. Firstly, it is difficult to get a 'standard' patient, as the patients most susceptible to pressure sores have very variable configurations; being either very lean or obese/heavy (Chow, 1974). Secondly, even minor variations in a patient's posture can produce considerable variations of localised pressure (Bell et al, 1974) so that continuous monitoring may be necessary (Robertson et al, 1980). Thirdly, the body's soft tissues are visco-elastic (Gibson et al, 1976) which makes it likely that the regions of maximum pressure under an immobile patient will be gradually changing. If the mattress being tested similarly changes its loading pattern with time under pressure, it becomes difficult to ascertain just what is happening at the patient/support interface.

A way out of this dilemma is suggested by one of the chief distinguishing features of an emaciated patient: a lack of subcutaneous fat and muscle. It is this feature which appears to make such patients particularly susceptible to pressure sores (Barton and Barton, 1981). If we assume that there is little or no soft tissue cushioning, over the bones of an extremely emaciated patient, a rigid indenter - shaped like such a patient - should provide a reasonable model of a patient who is highly susceptible
to pressure sores. The use of a rigid indenter should also allow the measurement of time-dependant changes in the pattern of load/pressure distribution; on various mattresses.

A patient with normal subcutaneous cushioning, or one who is obese, tends to have relatively low interface pressures; these being spread over a large area, due to his fat and muscle layers tending to conform to his support (Lindan and Hickman, 1964). In effect, a well-cushioned patient is able to smooth out the irregularities and bony prominences of his own skeleton; at least until the mobile components of his soft tissues have migrated away from the areas of maximum pressure (see Chapter 2.2.) If, however, we assume that our well-cushioned patient is observed at a fixed point in time, shortly after he has settled on the mattress in question, we can expect his body contours to be smooth and rounded: at the interface of his skin and his support.

It seems logical that a rigid indenter, which is smooth and rounded, can be used to model a well-cushioned patient; in the situation just described. It is well to remember, however, that even a well-cushioned patient will have relatively little subcutaneous cushioning over certain prominences - such as the heels. There may be little difference between an obese patient and an emaciated patient; when it comes to the cushioning over the heels.

Tests by Jeneid (1976) indicated that heel pressures (on a DHSS specification mattress) could be higher than 90 mm Hg., with the 'patient' in a semi-recumbent position. Such localised pressures should produce significant soft-tissue distortion. It is not surprising that the heel is one of the commonest sites for pressure sores (see Figure 6). An indenter in the shape of a heel would allow objective comparative tests to be conducted on various mattresses.

Since the properties of mattresses are temperature dependant they should be tested at a constant temperature. In consequence
the mattresses tested (discussed below) were placed in a temperature-
controlled room for 16 hours prior to testing (B.S. 4443, 1972).
They were then positioned on a King's Fund type of mattress base,
in the same room. The base was carefully levelled, and the
room temperature for all the tests was maintained at 18° - 22°C.;
the relative humidity being within the range 49% - 66%. These
same conditions were maintained for all the mattress indentation
tests.

Special rigid indenters were made for the comparative
load/pressure mattress tests; pressures being measured with
interface transducers. It was anticipated that the pressures
actually recorded would be slightly higher than the actual pressures
on human subjects.

4.1.2. Interface pressure transducers

When measuring patient/support interface pressures the
transducer used should not alter the shape of the interface.
Ideally, it should be no bigger than an acceptable surface irregularity
of the support. This might suggest a transducer which is as small
as a fine asperity produced by the weave of a linen sheet. Even if
such a small transducer is feasible it would need an impractically
high number of such transducers (in a suitable matrix) to check a
relatively small area of patient/support interface. Alternatively,
a single small transducer (positioned at selected points) could be
used, but the amount of re-positioning which would be needed, to
check even a small area of patient/support contact, would also
seem to be impractical.

As a large transducer will obviously change the interface
pressures it is attempting to measure, the only practical solution
to our problem appears to be a compromise; the chosen transducer
being as small and thin as is practical. It is possible, however,
to use inks or a microcapsular technique (Brand and Ebner, 1969)
to give an indication of the pressure distribution pattern at a
patient/support interface.
Ferguson-Pell et al (1976) described a number of small pressure transducers and discussed their drawbacks. They emphasized that pressure gradients can only be characterized with transducers having dimensions considerably smaller than the minimum radius of the curved body surface being investigated. Robertson et al (1980) described an electro-pneumatic transducer which was developed in co-operation with Talley Medical Equipment Ltd. The air capsule of this transducer is 28 mm in diameter with a welded flange around the air capsule (see Figure 30). The device is constructed from a sandwich of copper filaments and flexible P.V.C. sheet and, according to Robertson et al (1980) the maximal thickness of the capsule - where the filaments cross - is 0.52 mm. The welded flange around the capsule is of a similar thickness and is believed to act as a 'guard ring' which seems to improve the accuracy of the transducer by eliminating the so-called 'tent pole' effect. Fernie (1973) had argued cogently for the need of a thin flexible transducer, similar to the one later described by Robertson et al (1980).

Robertson et al initially calibrated their thin transducer using both water immersion and an air pressure chamber. They found errors of about one millimetre of mercury, over the range 11 - 158 mm Hg. However, by using a method of 'baseline' readings they found it unnecessary to calibrate the transducer. Instead, they taped the flanged edges of the transducer's capsule around the appropriate surface (e.g. a patient's heel) and checked the pressure necessary to overcome the resultant capsule distortion, before placing it under load. This 'baseline' reading was subtracted from the interface pressure reading, when the heel was placed on the support surface. They also checked for errors in the instrument by raising the pneumatic pressure in the capsule until the indicator light went out, and then dropping the pressure until it came on again. The difference between these two readings (the switch pressure) was considered acceptable if it was less than 1 mm Hg.
FIG. 30 SKETCH OF ELECTRO-PNEUMATIC TRANSDUCER USED ON THE MATTRESS TESTING PROGRAMME.

Pressure from mattress under test (arrows 'A') distorts transducer capsule and stretches its outer membrane (arrows 'B') thus increasing switch pressure (arrow 'C').

FIG. 31 DIAGRAM SHOWING EXTRA PRESSURE ON TRANSDUCER CAPSULE PRODUCED BY DISTORTION AROUND A SMALL INDENTER DOME.
This commercial sensor was still being developed during the present study, but it has been used for all of the interface pressure tests. The 'baseline' method (Robertson et al, 1980) was not used for tests in the present study; although the method of checking for faults in the instrument was used.

With the comparative method of testing used in the present study it is not essential to know the exact interface pressures. However, one of the indenters developed for this work (see below - 4.1.3.5.) used rigid domes 180 mm in diameter. The distortive effect of having the 28 mm transducer capsule pressed against such a dome is likely to increase its 'switch pressure' by stretching the outer membrane of the capsule (see Figure 31). In order to test the magnitude of this effect, a spare indenter dome (180 mm in diameter) was wrapped in a waterproof sleeve of transparent polyurethane rubber (this representing a mattress cover) and immersed in a water tank. A 28 mm pressure transducer was positioned inside the sleeve and rested on the outer surface of the dome. At depths below the water surface varying from 380 mm to 457 mm the transducer pressures were 12% to 14% above the pressures registered, at the same depths, when the transducer was surrounded by water. Similar tests, on the other two mattress indenters, have not been possible.

In the present experiments the 28 mm transducers were often found to be faulty. In particular, if two supposedly identical sensors were used, the results, on the same test, varied by as much as 25%. Eventually this problem was traced to the variable thickness of the contacts in the sensor capsule - a slight increase of thickness causing a rise in the pressure recorded. A more precise and robust transducer would have improved both the accuracy, and the total number, of test results in the present study.

4.1.3. **Mattress Indenters**

4.1.3.1. **Introduction**

Early in the present study it was decided to
construct three mattress indenters; one to represent an emaciated patient's torso; one to represent an average/obese torso; and the third to represent a normal heel. All three indenters would be transparent to allow direct visualisation of the pressure transducer positions and the behaviour of the various supports - under load.

Because of financial constraints it was not possible to construct special attachments for a universal testing machine (Small, 1980). The indenters were, instead, used as weight platforms. The use of fixed weights does, however, allow 'dwell' tests to be conducted, as is discussed below (4.2.3.)

4.1.3.2. The 'emaciated' torso indenter - construction and test procedure.

A human skeleton - normally used for teaching purposes - was utilized in constructing the emaciated torso indenter. After covering this skeleton with a flexible P.V.C. sheet, a four millimetres thick plaster of paris bandage was moulded over the posterior aspect of the skeleton - from the neck to the upper third of the femora. The resultant cast was then smoothed and modelled into a shape similar to the posterior torso of an emaciated patient in a supine position. After the cast had been strengthened it was used for producing a vacuum moulding in 'Perspex TX'. This clear moulding was then fitted with a flat sheet of 'Perspex' to act as a weight platform (see Figure 32). The completed indenter was strong enough to show no obvious distortion under a load of 25 Kg.

Calculations based on figures from 'Humanscale' (1974) and from weighing a very emaciated patient, suggested a weight of 22 Kg. for the trunk of an emaciated patient. The most prominent points on the 'emaciated torso indenter' (the sacrum and scapula blades) were expected to be the areas where the highest pressures would be recorded; with the indenter weighted. However, in view of the fact that pressure sores are much more prevalent over the sacrum (see Figure 6) a point over the proximal part of the sacrum
FIG. 32 SKETCH OF THE EMACIATED TORSO INDENTER -
SHOWING SACRUM MARKED FOR PRESSURE MEASUREMENTS.
was marked on the weight platform of the indenter, so that the weights could be centralized in the same position: for each test. The most prominent points of the indenter (sacrum, scapulae, iliac crests) were also marked, with indelible ink, for accurate location of the pressure transducers during the tests.

The chosen position of the weights, on the indenter platform, meant that the whole indenter tended to tilt towards its pelvic end (see Figure 33). If the height of the pile of weights was increased this exacerbated the longitudinal tilt. However, by using a maximum of two 10 Kg. weights it was possible to limit the variation of this tilt. The range of tilt angles, during the pilot studies, was $5^\circ - 14^\circ$ from the horizontal. Transversely, the platform was kept level; checks being made with a lightweight spirit level.

A 10 mm thick pad of expanded polythene 'Plastazote' was used to prevent the weights from damaging the indenter. This pad also enabled the weights to be slid sideways (with little effort) when adjusting the angle of the weight platform; the amount of shift, from the marked position for the weights, being recorded on each test. However, the coefficient of friction of the Plastazote was sufficient to prevent accidental slipping of the weights.

On most tests the emaciated torso indenter was placed in the centre of the mattress, so as to simulate the typical position of a patient. The mass of the indenter itself (2.55 Kg.) was added to the actual load used on the weight platform.

Each test with the emaciated torso indenter was preceded by a conditioning pre-load of 20 Kg., which was designed to simulate the placing of an emaciated patient on the mattress. Every placement of weights was carefully timed so as to ensure that each mattress was tested in the same way. It proved practicable to use just three different loads for the tests: 10 Kg., 15 Kg., and 20 Kg.
FIG. 33  DIAGRAM OF TILTING EMACIATED TORSO INDENTER DUE TO POSITION OF WEIGHTS ON WEIGHT PLATFORM.
Preliminary tests showed that the significant weight-bearing prominences were those corresponding to the sacrum and each posterior superior iliac crest. Accordingly, these three prominences were the only sites considered for the pressure transducers - in the pilot mattress tests. Nevertheless, it was reasoned that the sacral pressure, on an emaciated patient, is more significant that that on the iliac crests; because of two considerations. The first consideration is that sacral sores are more prevalent than those on the iliac crests (see Figure 6). The second consideration is that a slight lateral positional change, even a slight rolling motion, is sufficient to remove pressure from either iliac crest, whereas a considerable effort is needed, by a weak emaciated patient, to relieve pressure from his sacrum.

4.1.3.3. Emaciated torso indenter - pilot test results

The pilot tests with the emaciated torso indenter were mostly on the following mattresses:

1. A Dunlopillo latex foam mattress in its 'red rubber' cover - about 15 years old.
2. A DHSS Specification mattress Class 1, 150 mm deep (R/M 100635C Ext.2., Item 1E) - new.
3. A Stanmore spring-interior hospital mattress - newly reconditioned.
4. A prototype "Vaperm/ mattress (Mark 2) - new.

The Vaperm Mark 2 mattress was developed in the Department of Biomedical Engineering, Institute of Orthopaedics, Royal National Orthopaedic Hospital, Stanmore, before the author joined the staff. It is made of laminated polyurethane foam and has a "two-way stretch" vapour-permeable but waterproof cover. This mattress was subsequently succeeded by the Vaperm III, which was developed during the present study. A few pilot tests, using the emaciated torso indenter, were conducted on the Vaperm III; they are recorded in Chapter 6.
FIG. 34  EMACIATED TORSO INDENTER - TESTS ON VARIOUS MATTRESSES.
FIG. 35  EMACIATED TORSO INDENTER - TEST ON LATEX FOAM MATTRESS PLUS HOSPITAL COTTON BEDSHEET.
FIG. 36 EMACIATED TORSO INDENTER - TESTS ON STANMORE SPING-INTERIOR MATTRESS WITHOUT ITS P,V,C. COVER.
Results of the emaciated torso indenter tests are given in Figures 34, 35 and 36. Only three (sacral) pressures were recorded on each of the tests; there being one measurement at each indenter loading. The lines joining these pressure readings suggest the expected trace if many more (intermediate) indenter loadings had been used.

The higher traces on Figure 34 are results obtained on typical hospital mattresses. One set of readings shows the effect of an ordinary (cotton) hospital sheet used on a DHSS Specification mattress. The lower two traces are results from mattresses tested without their covers.

Figure 35 shows the trace obtained when the latex foam mattress (as used for the test shown on Figure 34) was covered by an ordinary hospital sheet. In Figure 36 two traces are shown, both were obtained from the spring-interior mattress - without its waterproof cover.

4.1.3.4. Discussion of test results.

On the DHSS Specification mattress sacral pressures appeared to change very little, as the load increased. One trace indicated less pressure with increasing load. However, this may be explained by peripheral prominences of the indenter sharing more of the total load - as they sink down and meet the surface of the mattress.

The sacral pressures on the DHSS Specification mattress, inside its cover, were almost three times as high as on the uncovered foam core of the same mattress. There is little difference between pressures on the DHSS foam core and those on the Vaperm Mark 2 foam core.

The traces for the latex foam mattress suggest that its shallowness (100 mm) combining with its age, was allowing the indenter to sink right through the fatigued core - onto the rigid mattress base.
The spring-interior mattress gave inconsistent results. This may have been due to the irregular (buttoned) surface of this mattress; even though the buttons themselves were avoided when the indenter was placed in position.

The problems of balancing the emaciated torso indenter, and interpreting its results, made it impracticable as a method for comparing the load/pressure distributive properties of different mattresses. It was considered that the small radii of curvature of the torso indenter's prominences called for a transducer of less than 28 mm in diameter. Thus only pilot tests were conducted with this indenter; the main comparative tests being with the 'three-domed' indenter and the heel indenter.

4.1.3.5. The three-domed indenter

The average/obese indenter (see above - 4.1.3.1.) was made from three identical Perspex hemispheres (180 mm in diameter) bonded to a flat Perspex sheet (Figure 37). It became known as the 'Three-domed' indenter. Although this indenter does not look like a normal torso it has the advantage of having just three bearing points, which are identical. The two domes which are relatively close together represent the buttocks of an average/obese patient, even though such buttocks would, ordinarily, be more oblate under load. A further consideration is that patients are often nursed in lateral positions, with much of their weight resting on one hip. The hip of an average/obese patient is roughly dome-shaped and most of the tissues around the hip are relatively firm. In other words, a single dome of the three-domed indenter would appear to be a tolerable model of the hip of an average/obese patient.

It was reasoned that weights placed at a pre-determined point, within the triangle formed by the apices of the three domes, would give the same loading on each dome. This would balance the indenter on the supports being tested and allow just one dome to be used for the interface pressure tests. Points were marked with indelible ink on the apex of each dome.
FIG. 37 THREE-DOMED INDENTER ON A VAPERM MARK 2 MATTRESS.

FIG. 38 THE HEEL INDENTER - IN TEST POSITION ON A LATEX FOAM MATTRESS.
According to Humanscale (1974) the maximum (95 percentile) weight of the human torso (U.S. subjects) is about 42 Kg. However, the more mamilliform shape of the three-domed indenter suggested that its contact area with a given mattress would be somewhat less than the contact area of an average/obese torso. This smaller contact area would increase the interface pressure (Pressure = Force/Area) above that expected with an actual torso of the same weight. In consequence it was decided that the maximum load used on the three-domed indenter would be in the region of 35 Kg. rather than 42 Kg. In practice (see below - 4.2.1.) it proved best to use the maximum (37.5 Kg.) loading to simulate a heavy patient sitting in bed.

4.1.3.6. The heel indenter

A tailor's model leg, which had been moulded in clear acetate sheet, was modified to produce the heel indenter. The leg was pivoted from a stand, which was placed on the floor, at the foot of the mattress under test. Weights were then placed on an integral weight platform (see Figure 38). It was recognized that the sharp curvature of the heel indenter would affect the accuracy of the 28 mm pressure transducer being used, but it was expected that comparative tests would be feasible even if absolute values were not obtained. The apex point of the heel, when in contact with the mattress - and with the leg horizontal - was marked on the acetate as a location point for the pressure transducer.

Early tests with this indenter showed that the pressures were unrealistically high (about 300 mm Hg. under a 2.5 Kg. load) and were consequently impracticable - even for comparative testing - because of the limited range (20 - 300 mm Hg.) of the Talley pressure sensor.

Although the model leg's heel was carefully smoothed and polished, to make sure that there were no small ridges which could produce concentrations of pressure, it was noticeable that
the size of the heel was slightly smaller than that of an actual (adult) human heel. Accordingly, it seemed best to increase the size of the heel by applying an even layer of material over the artificial heel, where it would be resting on the mattress. A carefully-sculptured rigid plastic onlay could have been made for this purpose; and an overall thickness of about four millimetres would have sufficed to produce a heel of realistic size. Such an onlay could also have incorporated an indentation to exactly fit the Talley pressure transducer; so as to minimize the transducer's effect on the shape of the heel/support interface (see Figure 39). Unfortunately, considerations of cost and time dictated that this approach was less practical than using a gelatinous onlay made from a reticulated flexible foam, which was impregnated with silicone gel ('Spenco Reusable Silicone Sheet'). This pad was easily moulded around the artificial heel and held in place with a thin sheet of polyurethane rubber. As both of these materials were transparent it was still possible to see the mark on the apex of the heel - while the indenter was under load. The gel pad tended to mould itself around the prominent parts of the Talley transducer, so that it acted like the special rigid onlay suggested in Figure 39.

Although this gel pad has good elastic recoil it also flows slightly under the loading used on the heel indenter. In consequence, it was decided that the heel indenter would only be used for comparative tests - at a fixed point in time - after the test load is applied. In addition, the heel indenter pad would be given time to recover its shape: after each mattress test.

4.2. Tests with the three-domed indenter

4.2.1. Test procedure

The central point on the three-domed indenter (between the three domes) which would equally distribute the load on each dome, was determined by placing each dome on a separate balance. Three 10 Kg. weights were stacked and then slid over the weight platform of the indenter until each balance registered the same
FIG. 39 DIAGRAM OF POSSIBLE MODIFICATION TO HEEL INDENTER.

FIG. 40 THREE-DOMED INDENTER ON A MATTRESS, SHOWING EFFECTS OF A TIGHT MATTRESS COVER.
weight— with the platform level. The pile of circular weights was then scribed around, to enable an indelible circle for subsequent weight-placing, to be marked on the platform of the indenter.

Initial tests, using pressure transducers under all three domes (at each apex) showed that, when the indenter was level, apex pressures on the domes were similar; particularly if the mattress under test was made of homogenous foam and uncovered. A mattress cover, however, produces a hammocking effect between the two domes representing the buttocks. This tends to shift the maximum pressures away from the apex of these domes (see Figure 40). If the mattress cover was relatively loose, or extensible, the pressure under a buttocks dome apex was often slightly lower than that under the apex of the third dome. When, however, a tight woven cover was fitted to the mattress the pressures under the buttocks dome apices could, at times, be slightly higher than that under the third dome. This paradox may have been due to the need to shift the weights slightly, in order to keep the platform level and counteract the 'bouyancy' produced by the tautness of the cover material between the closely-spaced buttocks domes. These problems of locating the maximum interface pressure were overcome by mapping the pressure distribution over a relatively large part of a single dome; rather than taking a single reading under each dome apex.

It was decided that the most useful test method was to use a single 28 mm pressure transducer to measure pressures at predetermined points, along a meridian, of one of the buttocks domes (see Figure 41). Although this involved re-positioning of the transducer, during each test, this seemed preferable to using twelve or more transducers positioned around the dome at the same time. The shape of the indenter/mattress interface would obviously be considerably affected by the presence of so many transducers, but a single 28 mm transducer was unlikely to produce a significant distortive effect over the surface of a 180 mm diameter hemisphere.
FIG. 41  INVERTED THREE-DOMED INDENTER SHOWING POINTS MARKED ALONG A MERIDIAN OF ONE OF THE 'BUTOCKS' DOMES.
In practice it was relatively easy to place the single 28 mm transducer under the dome apex - at the start of each test - and to ease it sideways while the indenter remained under load. In this way the transducer was moved under each measuring point, in a pre-determined sequence, until twelve pressure readings were completed: at each load-setting of the indenter. The transparent nature of the indenter also made it possible to eliminate inadvertant cover creasing and transducer twisting, before these effects could produce misleading pressure readings.

The pre-determined points on the dome meridian were spaced 15 mm apart and when the various readings were converted into a graph - using the meridian as a base line - a 'Profile' was obtained. This Profile was usually 'skewed'; in that the highest pressures were grouped towards the outer aspect of the buttocks dome. Comparing the 'Profiles' of various mattresses proved to be a useful way of visualising their relative effectiveness in load/pressure distribution. The test procedure was finalized as follows:

- **a)** the indenter was placed centrally on each mattress, but inclined at about 10° along its centre-line, so that the buttocks dome (used for measuring) was in a more-or-less central position; where, in fact, we could expect the hip of a patient to be resting - when in a lateral recumbent position;
- **b)** four 10 Kg. weights were placed on the indenter platform and immediately removed (conditioning pre-load)
- **c)** the transducer was placed under the apex of the measuring dome,
- **d)** four minutes after removing the 40 Kg. pre-load a 15 Kg. weight was placed on the indenter's weight circle and positioned until the platform was level (in most cases the amount of displacement from the centre of the circle was approximately 5 mm).
e) all the meridian pressure measurements were taken - within eight minutes - and the transducer was then re-positioned under the apex of the dome,
f) ten minutes after placing the 15 Kg. load it was increased to 35 Kg., the platform was levelled, and another set of readings was taken;
g) the transducer was returned to its apex position and, on occasions, the indenter was left undisturbed for two hours; following which, further pressure readings were taken - along the meridian.

The 15 Kg. load, plus the indenter's mass of 2.5 Kg., appeared to give maximum pressures which were very similar to those found under the buttocks of seated-in-bed volunteers using a DHSS specification mattress (Jeneid, 1976). The 35 Kg. load was used to simulate the effect of a very heavy patient sitting in bed.

4.2.2 The 'Pressure Profile'

Perhaps the most uncomfortable support imaginable would be a rigid surface such as a steel table having one or two sharp steel spikes on its surface. If the three-domed indenter was loaded to 17.5 Kg. and the apex of its measuring dome rested on a steel spike the resulting 'Pressure Profile' would be a single pressure measurement, of considerable magnitude. In order to avoid damaging the equipment this test was not actually conducted. However, a straight vertical line, of indefinite length would represent the Pressure Profile of this steel-spiked table; this particular 'Profile' being visualised as an isosceles triangle with a near-zero length base line (see Figure 42).

The most comfortable supportive situation is probably that experienced by astronauts in 'zero gravity' conditions. In this situation the Pressure Profile recorded by the three-domed indenter could be represented by a straight horizontal line at zero pressure; as shown on Figure 42. There would, in fact,
FIG. 42 THE PRESSURE PROFILE - THEORETICAL EXTREMES.
be zero interface pressure on every part of the indenter.

From the foregoing it can be seen that, on Terra Firma, the more comfortable the support the more closely will its Pressure Profile approximate to the zero gravity Profile. Conversely, a sharp Profile which approximates to a vertical line will represent the most uncomfortable support.

For a general-purpose P.S.S. we are not, however, looking for ultimate comfort, in one fixed position; but for the optimum comfort consistent with providing a firm mattress which both encourages spontaneous movement and gives good spinal support. In consequence, the best supports should produce a Profile of moderate height which has gently sloping sides - like a typical English hill.

Most of the Profiles produced on various mattresses were, in fact, roughly triangular and it seems reasonable to assume that, if various other points at the dome/support interface were to be measured, the resultant (three dimensional) Profiles would be roughly conical.

4.2.3. Three-domed indenter tests - results

The mattresses tested with the three-domed indenter were as follows:-

1. DHSS Specification mattress Class 1, 150 mm deep (R/M 100635C Ext. 2., Item 1E) - new
2. Stanmore spring-interior hospital mattress - newly reconditioned.
3. "Sharp" fire resistant spring-interior mattress - new,
4. Prototype "Vaperm" mattress (Mark 2) - new
5. Vaperm III mattress (see Chapter 6).

On some occasions absorbent pads and/or drawsheets were positioned on the mattresses being tested.
FIG. 43 PRESSURE PROFILES - all at 17.5 Kg. LOAD.
FIG. 44 PRESSURE PROFILES ON DHSS MATTRESS IN COVER ALONE.
FIG. 45 PRESSURE PROFILES ON DHSS MATTRESS IN STRETCHED COVER ALONE.
FIG. 46 PRESSURE PROFILES - VAPERM MARK 2 MATTRESS IN COVER ALONE.
FIG. 47. PRESSURE PROFILES - STANMORE SPRING-INTERIOR MATTRESS IN P.V.C. COVER ALONE.
FIG. 48 PRESSURE PROFILES ON DHSS MATTRESS PLUS HOSPITAL COTTON SHEET, DRAW MACKINTOSH, & TWILL DRAWSHEET.
FIG. 49 PRESSURE PROFILES ON DHSS MATTRESS PLUS HOSPITAL COTTON SHEET, DRAW MACKINTOSH, & 'KYLIE' DRAWSHEET.
FIG. 50 PRESSURE PROFILES ON 'SHARP' SPRING-INTERIOR MATTRESS IN INTEGRAL COVER ALONE.
FIG. 51  PRESSURE PROFILES WITH FAULTY TRANSDUCER - ALL AT 17.5 Kg. LOAD.
On all of the graphs the experimental point results are joined-up, by straight lines, to produce the Pressure Profiles. In some cases, the profile obtained is derived from the mean recorded pressures from more than one test - on the same mattress. Figure 43 in particular, shows the profiles obtained on the DHSS specification mattress (17.5 Kg. load) and that for the mattress in its cover alone is the mean of three tests. Similarly, the higher profile is the mean of two tests. In this case the DHSS mattress was covered with a hospital cotton bedsheet, a polythene draw mackintosh and a twill drawsheet.

Figure 44 shows the profiles obtained on the DHSS mattress at two different loadings, while Figure 45 shows a test, on the same mattress, in an area where the cover had just been slightly stretched by a previous test. Also on Figure 45 is a 'dwell' test resulting from the 37.5 Kg. load being in position for two hours.

Figure 46 shows the profiles obtained on the Vaperm Mark 2 at two loadings. The equivalent profiles for the Stanmore spring interior mattress and the DHSS mattress (covered with sheet and drawsheet) are shown in Figures 47 and 48 respectively. In the latter case the various sheets, which included a polythene draw mackintosh, were positioned on the mattress by an experienced nurse. When, on the same mattress, the drawsheet was replaced with the special 'Kylie' drawsheet, the resulting profiles were similar - Figure 49.

A special fire-resistant mattress, made by "Sharp" of Glasgow, and of spring-interior construction, produced a high profile which would not fit onto the vertical scale used for the other graphs. In consequence, this profile is shown on a reduced scale (Figure 50).

Figure 51 shows the profiles obtained, with a high-reading transducer (see above - 4.1.2.); the pressures being reduced by
25%. One unadjusted result is also shown. The shallowest of these profiles was taken on a Vaperm Mark 2 mattress covered with a very extensible knitted sheet; while the chain-dot profile was obtained on the same mattress covered with a Vincel/polyester (woven) sheet.

4.2.4. Discussion of Pressure Profile results

The results of the Three-domed indenter tests tend to confirm that those mattresses which, subjectively, seem soft and compliant, produce low profiles like gentle hills. Profiles which were relatively sharp and steep-sided, were produced on mattresses which appeared hard and unyielding.

Figure 43 indicates that maximum pressures on the DHSS mattresses are approximately twice those on the Vaperm Mark 2, and the addition of a bottom sheet and drawsheet - on the DHSS mattress - doubles the maximum pressures obtained. This tends to confirm the findings of Fernie (1973). The relatively steep sides of the DHSS mattress profiles show that interface pressures fall suddenly at a distance of 30-40 mm from the dome apex (17.5 Kg. load). When, however, the indenter loading is increased to 37.5 Kg., the interface pressure drop occurs slightly further out from the dome apex (Figure 44).

This sudden fall in interface pressure suggests a significant degree of soft tissue deformation; when a patient is nursed on the mattress in question. On one DHSS mattress test, where some pre-stretching of the mattress cover had occurred, the profile produced by a 37.5 Kg. load looked like a high plateau (Figure 45) while a 'dwell' test at the same loading showed that the profile had changed in appearance. The increased peripheral pressure indicated by this latter profile suggests that a heavy patient, seated on the mattress, could suffer from the effects of a ring of ischaemic pressure around his bony prominences. On the Vaperm Mark 2 mattress the 37.5 Kg. profile was relatively low and broad, and the 'dwell' test gave no suggestion of a 'Pressure Ring' effect (Figure 46).
However, the sharp and irregular profiles obtained on the two spring-interior mattresses (Figures 47 and 50) suggest that such mattresses are more hazardous than the DHSS mattress. In both cases, the indenter was placed to avoid areas such as mattress buttons, where the profiles may well have been even more sharp and irregular.

The 'dwell' test on the 'Kylie' drawsheet produced a profile suggesting a truncated cone with an inverted cone inserted in it— at the top. It seems likely that this would produce a severe pressure ring effect; on a heavy patient.

The profiles resulting from using 'bottom' sheets, on the Vaperm Mark 2 mattress (Figure 51) appeared to be only slightly higher than the profile obtained on the mattress without bedsheets, possibly because a thin sheet is easily pulled out from beneath the mattress, thereby reducing its hammocking effect. The profile for the 'stretch' sheet was only slightly lower than that for the woven sheet. This latter sheet (Hibbert, 1978) is discussed further in Chapter 5.

4.3 Tests with the heel indenter

4.3.1 The heel indenter procedure

The heel indenter was positioned at the foot end of each mattress being tested; the apex of the heel being 27 cms., from the mattress end. The model leg was fixed to a wooden bar, under the thigh portion, so that the whole device could be pivoted from a special stand, resting on the floor, at the foot of the mattress. A small wood platform, just above the knee of the model leg, was used for placing weights. A circle marked on this platform ensured that the weights were placed accurately.

Given that both the mattress and the weight platform were level, it was reasoned that a particular load, on the weight circle, would produce a standard load on the heel— where it rests on the mattress. Variations in mattress thickness and
hardness were accommodated simply by varying the height of the heel indenter's pivot point - on the special stand (see Figure 52).

According to Humanscale (1974) the mean weight of an adult male is 78 Kgs. and the percentage of the body weight represented by the lower legs and feet (man of medium build) is 11.9%. This suggests that the typical weight of an average man's lower legs and feet would be 11.9% of 78 Kgs. or 9.3 Kgs. Thus one leg and foot would weigh 4.65 Kgs.

The heel indenter represents a bed-patient's lower leg and foot in the supine position, with some of his leg's weight resting on the calf. If we allow for half of the 4.65 Kgs. to be borne by the calf, we would have a load of 2.3 Kgs. on the heel.

The weight of the heel indenter, minus its stand was, coincidentally, 2.3 Kg. When, however, the hollow leg was filled up to the knee with water (specific gravity similar to the body) the total weight was 4.55 Kg. This model leg was more slender than an average (female) leg, but the weight of water it contained (2.25 Kg.) may approximate to the lower end of the scale of loads, supported by a single lower leg and heel, when various patients are nursed supine. Hence the heel load (taken as half of 2.25 Kg.) would be 1.1 Kg. Such a heel load would, of course, be increased if the knee is flexed, or if the hamstring muscles are tensed.

In view of the above considerations the heel indenter was pivoted on its stand, and levelled, with its heel resting on bathroom scales. A series of weights were then placed on the weight platform and these produced a corresponding scale of registered heel weights. A total of five weights were used on the platform: 1 Kg., 2 Kg., 3 Kg., 4 Kg., and 5 Kg., which produced the following heel loads: 0.86 Kg., 1.3 Kg., 1.7 Kg., 2.125 Kg., and 2.54 Kg. This range, it seems reasonable to conclude, must approximate to the actual range of heel loads experienced by inactive bed-patients.
FIG. 52 ADJUSTABLE STAND FOR HEEL INDENTER.
Mattresses for testing with the heel indenter were prepared as for the other indenters. The actual test procedure was as follows:–

a) the indenter was positioned and levelled (27 cms. from the mattress end) in a position where one would expect a patient's heel to rest,

b) a conditioning pre-load of 8 Kg. was placed on the weight platform and immediately removed,

c) a 28 mm transducer was placed under the apex point of the heel,

d) a 1 Kg. weight (0.86 Kg. load on the heel) was placed on the weight platform, and levelled, within four minutes of placing the pre-load,

e) after checking the pressure at this load, the next weight was added – exactly five minutes after the 1 Kg. placing – and subsequent weight increases were made at five minute intervals thereafter.

4.3.2. Heel indenter results

The main use of the heel indenter, following the tests discussed below, was in comparing the DHSS mattress (Class I) with the Vaperm III mattress, and the relevant results as discussed in Chapter 6.

Apart from these later tests the three mattresses tested with the heel indenter were:–

1. The Vaperm Mark 2 – new
2. Stanmore spring-interior – newly reconditioned.
3. The DHSS mattress (Class I).

In each case the mattresses were tested in their covers, but without any bedsheets in position.

Figure 53 shows the graphs produced from the heel indenter results; the DHSS mattress trace being the mean of four tests.
FIG. 53 HEEL INDENTER TESTS ON VARIOUS MATTRESSES.

- DHSS mattress in cover alone
- Stanmore spring-interior mattress in cover alone
- Vaperm Mk. 2 mattress in cover alone
4.3.3. Discussion of heel indenter results

In accordance with the principle explained in Chapter 2.5.10, we should expect a small indenter to produce higher interface pressures than a large indenter — on a support of the same size — because of the extra 'hammocking' and shear forces involved. A mattress with a tight woven cover can be expected to exacerbate this effect, and this appears to explain the high pressures found on the DHSS mattress.

The trace on the spring interior mattress graph was prepared from measurements taken with the heel over an area which was free of mattress buttons. The mattress cover was much looser than that on the DHSS mattress. The stretch cover on the Vaperm Mark 2 mattress appears to produce minimum hammocking forces.

4.4. Interface pressures — clinical

During the project a number of pilot clinical trials were conducted; these being to compare the DHSS specification mattress to the Vaperm Mark 2 mattress. Some sample interface pressure measurements were taken while these patients were on the appropriate mattress, using the same 28 mm transducers as used for the indenter tests. It was anticipated that there would be a wide range of pressures recorded and this proved to be the case.

On the DHSS mattress the range of interface pressures was 15 - 110 mm Hg., from a total of 11 sample measurements. On the Vaperm Mark 2 the range was 20 - 90 mm Hg., from a total of 14 sample measurements. However, these measurements were made on various patients, in various postures, and at various parts of the anatomy. When just one posture (seated in bed) is considered and one anatomical site (the heel) the pressure measurements seemed to correlate with the indenter test results.

Five of the DHSS mattress measurements were taken on the heel; while the patient was seated in bed. On the Vaperm mattress
the equivalent figure was six measurements. The range of heel pressures on the DHSS mattress was 54 – 110 mm Hg. whereas the range on the Vaperm mattress was 24 – 82 mm Hg. The mean pressures were:

DHSS mattress – 81 mm Hg.
Vaperm Mark 2 mattress – 56 mm Hg.

It can be seen from figure 53 that the heel indenter results were usually somewhat higher than these figures, but the clinical figures appear to fit the general trend of the equivalent indenter curves.

4.5. General discussion

The emaciated torso indenter concept could, in theory, be taken further. A fully articulated manikin could be produced and its surface could be covered in a synthetic soft tissue. It is doubtful, however, that the cost of such an exercise is justified. It seems clear that the interface pressures on an emaciated patient's bony prominences are very similar to those on the heels of an average patient, (compare the range of pressures on Figures 3^ and 53). The heel indenter did produce repeatable results; a number of tests on the same support showing little variation.

The 'Pressure ring' effect, which appeared when some mattresses were tested by the three-domed indenter, was unexpected. It indicates that the highest interface pressures are not always found on the apex of the indenter – or bony prominence – which it represents. It does, however, appear to be associated with the hammocking effect of mattress-covering materials which are inextensible.

All of the indenters appear to produce interface pressures which, although useful for comparing different mattresses, are difficult to equate with the small number of clinically-measured pressures. However, the mean clinical pressure on the DHSS mattress (about 70 – 80 mm Hg.) suggests that a capillary blood
pressure of at least 80 mm Hg. will be needed to prevent localised pressure ischaemia, even if no appreciable tissue distortion occurs; when an immovable patient is nursed on this mattress. As discussed in Chapter 2.2., it seems unlikely that such a capillary pressure will be produced (by postural pressure variations) when a patient is either recumbent or seated-in-bed. On the Vaperm Mark 2 mattress, however, the mean clinical pressure (about 45 - 55 mm Hg.) may often be lower than the mean capillary pressure; on the heel of a seated-in-bed patient. Furthermore, Figure 7 suggests that localised pressures below approximately 50 mm Hg. are too low to produce a distorting effect sufficient to cause microvascular leakages (see Chapter 2.2.)

Patients who are not absolutely immobile, insensitive, or very weak, are usually able to make regular movements of their feet. Nevertheless, those patients who have some degree of immobility and/or insensitivity may not be able to move heavier parts, such as the pelvis. For such patients it behoves the designer to produce a support on which interface pressures, on the more susceptible bony prominences, will be below the anticipated capillary pressures.

Many patients at risk of pressure sores are nursed seated-in-bed (Chapter 2.6.) and this makes it particularly important to provide a support which adequately cushions both the heels and the sacrum. But various other requirements of a general-purpose P.S.S. dictate a relatively firm support. In consequence it may be necessary to accept interface pressures in the region of 60 - 70 mm Hg. In these circumstances patients will need to avoid prolonged tissue ischaemia by regular movements. A relatively firm support will, however, make such movements easier to accomplish (Lowthian, 1970 A).

Load/pressure test results on the Vaperm Mark 2 mattress (Figures 43, 46 and 51) suggest that this support should be compliant
enough to keep interface pressures below the critical levels, and its low pressure profiles indicate a minimal tissue-distortive effect. However, pressure sore susceptible patients who are seated-in-bed are liable to develop sores due to high tangential forces, which are not necessarily ameliorated by a compliant support.
5.1. **Interface design problems**

5.1.1. **Friction problems**

As discussed in Chapter 2, debilitated or insensitive patients who are nursed seated-in-bed, on a general-purpose P.S.S., are at risk of developing severe sacral/buttocks sores. It seems that a high level of friction between the patient and his support surface, particularly in damp conditions, is an important factor.

A contouring mattress base may provide the necessary improved support to prevent the sustained tangential forces associated with sitting in bed. Nevertheless, if such an improved support is not provided it is important that the patient/support interface is designed to avoid the hazardous effects of the 'Forward Slide'. Trials of the Dupic underpad (see Chapter 2.5.10.) have indicated that a low-friction interface design is possible. Moreover, a relatively low friction interface seems desirable for both the typical hospital bed and a contourable bed. Apart from preventing sustained tangential forces a low-friction bed surface (patient/support interface) enables weak patients to make small postural movements without lifting themselves. Similarly, spasmodic movements are less likely to cause self-inflicted erosions and sores; and nurses can more easily manoeuvre their patients.

A patient must, however, be able to maintain a desired position on his support (Chapter 2.6.1.) so that the interface must not be too slippery.

5.1.2. **Moisture problems**

Because a damp interface increases the coefficient of friction (Chapter 2.6.) such dampness must be either avoided or
minimised. One way of minimising this problem is to use a rapidly-drying interface such as a smooth nylon sheet stretched over an absorbent pad (Lowthian, 1973). This system appears to be beneficial where there is incontinence and seems to have some advantages when nursing a patient with Grade 2 open sores (see Chapter 2.7). Where sweat is the cause of dampness an absorbent pad may help by transferring moisture beyond the edges of the patient's body. This allows the moisture to evaporate and thereby cools the patient (indirectly) by means of the latent heat of vaporisation (Lowthian, 1970 A; Weiner, 1971).

Sweating may be induced by a waterproof mattress cover and/or a draw mackintosh and particularly when the mattress core is a good insulator, such as polyurethane foam. On a typical hospital bed the temperature of a patient's skin, in contact with the support surface, may rise to 35 or 36°C. (Scales, 1976 B). Sweat production starts when the skin temperature rises above 35°C. (Bell et al., 1980) and this can cause considerable discomfort at the skin/support interface; due to a lack of evaporation of the sweat produced. This, in turn, produces a humid microclimate, which encourages bacterial proliferation (Scales, 1976 B). Thus, although a waterproof mattress cover seems essential for hospital use (see Chapter 3) its water vapour permeability should be at least sufficient to prevent interfacial sweat accumulation in typical hospital conditions. Given sufficient permeability a patient can keep relatively comfortable, even if unable to move himself, as his water vapour is transmitted through the mattress and disperses in the air beneath and around his bed. In typical British climatic conditions sweat production is relatively low and, if the patient is not pyrexial or otherwise prone to hyperhidrosis, a mattress cover with sufficient water vapour permeability would seem to be a practical project aim. However, existing mattress covers and draw mackintoshes have very poor permeability to water vapour.

Even if existing mattress covers had good permeability to water vapour this would not help in relieving the discomfort.
experienced by incontinent patients sitting in their own excreta. Apart from the adhesion effects already mentioned, skin excoriation occurs when there is prolonged contact with urine and/or faeces. This is a well-known complication of stoma care (Wallace and Hayter, 1973). In the case of incontinent bed-patients it is usually prevented by regularly washing the patient and changing his soiled sheets (Norton et al, 1962).

The author's experience on a clinical trial (Lowthian et al, 1976) showed that urine incontinence was more prevalent than faecal incontinence (geriatric admission wards) and thin disposable incontinence underpads (about 3 mm thick - uncompressed) were often unable to prevent the first signs of skin excoriation. Nevertheless, when absorbent underpads of 5 mm or more in thickness were introduced it was difficult to find any skin excoriation, or maceration, attributable to prolonged contact with urine or faeces.

A highly absorbent pad such as the 'Kylie' drawsheet (see Chapter 4) may, however, encourage nurses to leave their patients too long - in a wet bed - so that bacteria can multiply in the stale excreta. This will increase the risk of cross-infection and objectionable malodours. These effects are particularly important when the patient/support interface succeeds in camouflaging the presence of stale urine. In the case of the DHSS specification mattress (see Chapter 3) the camouflaging is accomplished by the marbled pattern of its cover.

A hydrophobic synthetic fleece may camouflage urine by its lack of lateral absorption; the urine draining rapidly through the pile and into the drawsheet or 'bottom sheet' underneath. A nurse who is unaware of this effect may fail to find the dampened area beneath the fleece (Lowthian et al, 1976).

5.1.3. Crumpling and creasing problems

The crumpling and creasing of drawsheets and pyjamas has been mentioned in Chapter 2, but a loose disposable underpad
can also crease and crumple under the patient; the avoidance of this problem being one of the design aims of the Dupic underpad development (Lowthian, 1975).

A loose mattress cover made of heavyweight P.V.C. material, or red rubber, can produce dangerous creases under the patient (Scales, 1976 B). It was this problem which persuaded the NHS Specification Working Group to produce a tight mattress cover for the DHSS specification mattress (NHS report, 1968). Figure 54, which shows the three-domed indenter on a rubberized woven fabric ('red rubber' mattress cover) indicates the severe and extensive creasing which occurs when such a cover material is loaded by a patient's body. However, a weft-knitted fabric, as exemplified in the Vaperm mark 2 mattress cover, stretches evenly and very few creases are formed (see Figure 37).

The 'bottom sheet' covering the mattress may also crumple and crease under the patient, and especially if it is a typical woven cotton sheet on a mattress cover having a relatively low coefficient of friction (Scales, 1976 B). If, on the other hand, a tight woven sheet is unable to slip on the mattress at all it may increase the effective hardness of the support (see Chapter 4).

A smooth-faced stretch sheet may overcome these problems with the woven bottom sheet, but only if its elastic recovery is efficient enough to prevent loose creases forming: when a heavy patient temporarily leaves his mattress.

5.1.4. Miscellaneous hazards

Crumbs and small hard objects left in the bed can cause superficial skin trauma. The author once found a broken thermometer beneath an elderly patient. Although constant diligence on the part of nurses can avoid such hazards, a stretchable bottom sheet and mattress cover will serve to make small hard objects less traumatic; due to the avoidance of the hammocking effect (see Figure 55).
FIG. 54 THREE-DOMED INDENTER IN POSITION FOR LOAD/PRESSURE DISTRIBUTION TESTS - ON A LATEX FOAM MATTRESS.
A - Patient on a mattress with a stretchable cover.

B - Patient on a mattress with a non-stretch woven cover.

FIG. 55 EFFECTS OF SITTING ON A SMALL BLOCK OF WOOD ON TWO DIFFERENT MATTRESSES.
Traces of bleach or alkali left in laundered sheets have sometimes been blamed for skin problems (Green, 1976; McDougall, 1976) and it seems likely that inefficient rinsing can sometimes allow this to happen. Similarly, any new material used at the patient/support interface has to be carefully considered with regard to its possible effect on the skin; particularly for patients prone to allergies. A variety of creams and lotions may be applied to a patient's pressure areas (Lowthian, 1971; Green, 1976) and the interaction of these, with the interface materials, needs to be taken into account.

The modern plastics and synthetic materials which are now used in hospital P.S.S.'s can be a fire hazard, and particularly if patients are smoking in bed. It seems essential to have a mattress which will not burn when lighted cigarettes, or matches, are dropped onto it (Woolley et al, 1978). Modern plastics and synthetics can also be an explosion risk; due to discharges of static electricity in the presence of inflammable anaesthetic gases (Scales, 1978). Although this is a complex problem, high voltage discharges are more likely to occur when materials of dissimilar electrical characteristics are used together (Disher, 1972).

These miscellaneous hazards of the patient/support interface are discussed further in Chapter 6.

5.2. The measurement of tangential forces

5.2.1. Introduction

The concept of soft tissue 'Shearing' suggested by Reichel (1958) and discussed in Chapter 2, suffers from the fact that soft tissues lack homogeneity. Simple shear is easily demonstrated in homogeneous engineering materials such as steel, but tangential forces applied to soft tissue produce a complex pattern of stressing which can change dramatically and continuously, as we move from one area of the body to another (Trandel and Lewis, 1975). A transducer for measuring shear on one part of
the body (the thenar eminence of the thumb) has been devised (Bennett et al, 1979) and this does indicate that shear plus pressure is more dangerous than pressure alone; on this particular part of the body. However, Palmer (1979) maintains that shear stress in soft tissues has no special damaging qualities, but non-normal vectors can cause trauma by the way they stress tissue structures and blood vessels. Figure 9 (Chapter 2) suggests the mechanism whereby small blood vessels can be ruptured by 'non-normal vectors'.

The results of Bennett et al (1979) showed considerable 'run-to-run' variability and this suggests that their shear transducer would not be suitable for comparing the tangential forces produced when using various patient/support interface materials. However, Chow (1974) has pointed out that shear stress is directly proportional to normal pressure and the coefficient of friction (in the clinical situation of a patient sitting on a cushion). In consequence, it would seem best to assess interface tangential forces by means of friction tests rather than trying to measure shear in the tissues. It should, however, be possible to estimate the severity of soft tissue distortion, or shear, by correlating the interfacial friction of a given support with its load/pressure characteristics. Thus, a compliant support with a good pressure profile (Chapter 4) and a low coefficient of friction, should be very successful in preventing prolonged tissue distortion. Similarly, a low friction interface helps to prevent erosions due to intermittent tissue distortion resulting from spasmodic movements (see above – 5.1.1.) The 'skin-folding' effect and the 'skin-stretching' effect (Lowthian, 1970 A) are also discouraged by a low friction interface. All in all, a standard test of interface friction would appear to be a highly desirable research aim.

The typical components of the patient/support interface are debatable, but patients who are liable to develop pressure sores are often incontinent (Lowthian, 1976 A) and such patients
are often nursed without any clothing over their buttocks (Elphick, 1970). The popularity of the open-backed nightgown in geriatric units (Norton et al, 1962) appears to be due to the difficulty of removing damp nightdresses/pyjamas, coupled with the laundering problems, when a patient is frequently incontinent. It would, therefore, be particularly helpful to consider the patient's skin surface as the standard surface against which to test a variety of support surfaces. The relevant support surfaces should be those normally used on hospital beds, as well as new innovations.

5.2.2. Problems in measuring friction

The work of Amontons (1699) and Coulomb (1785) led to the well-known formula for the coefficient of friction: $\mu = \frac{F}{W}$ where $\mu$ is the coefficient, $F$ is the friction force and $W$ is the normal force (load). Coulomb also defined the difference between 'static' and 'kinetic' friction. The static coefficient is determined from the peak force needed to initiate sliding, while the kinetic coefficient represents the force needed for steady continuous sliding (Owens, 1968).

Naylor (1955) assumed that Amonton's law held for skin friction. He used a special oscillating device to investigate human skin friction over the anterior of the lower leg. Appledoorn and Barnett (1963) also assumed the validity of Amonton's law, but they decided that latex rubber was an acceptable model of the human skin surface; their tests being to estimate the frictional effects of various emollients. Nevertheless, latex rubber, and various other elastomers, have certain characteristics which seem to defy Amonton's law (Kummer, 1966; Owens, 1968). In particular, at low loadings, the coefficient or rubber appears to decrease as the load increases. It also seems that the coefficient decreases as the surface roughness increases (within limits). Whereas, for metal friction, the coefficient ($\mu$) is independent of surface roughness.
The essential difference between elastomer friction and metal friction appears to be due to the way elastomers deform under load, thereby changing their interface contact area. This also suggests that various polymers, which also deform easily when loaded, will behave similarly to elastomers (Owens, 1968). In the case of rubber it has been found that some degree of adhesion normally occurs between the rubber and the other surface; this effect increasing with time, if the materials are at rest. Because of this, the 'static coefficient' is not constant, but depends on the time that the two surfaces have been in contact - before a test begins (Kummer, 1966; Owens, 1968; Roberts, 1979).

Human skin is largely composed of polymeric fibres (collagen) and elastomeric fibres (elastin) with a covering of keratinized epidermal cells (Gray's Anatomy, 1973). In consequence, its friction characteristics might be expected to be similar to those of polymers and elastomers. Appledoorn and Barnett (1963) chose rubber as their skin model because certain characteristics seemed to apply to both materials. Firstly, their friction is relatively high and it is higher on smooth rather than rough surfaces. It is also higher in damp conditions than it is in either dry or wet conditions. Finally, the use of talc greatly reduces friction, whereas talc increases friction when used on a steel/steel interface. If it is assumed that human skin and rubber exhibit the same friction characteristics then it would seem pertinent to consider the following characteristic aspects of rubber friction:

1. The 'Ploughing' component of the friction force in metal friction theory (Bowden, 1944) is, in rubber friction theory, called the 'Hysteresis' component. Kummer (1966) showed that it is not very significant at low speeds, such as those experienced by a patient sliding on a bed. It is the 'Adhesion' component which accounts for most of the friction force.

2. Adhesion increases with time of contact, before sliding starts (Roberts, 1979).
3. 'Stick-slip' motion is, in some degree, likely to occur because rubber deforms elastically and its adhesion is time-dependant (Bowden and Tabor, 1954).

4. Adhesion increases with actual contact area, but the effect of load variation is more complex; depending as it does on factors such as interface roughness, material compliance, and sliding speed (Pascoe and Tabor, 1956; Kummer, 1966). However, the work of Shooter and Thomas (1949) and Naylor (1955) suggests that for loads of 400 g to 4 Kg. (and perhaps beyond) the frictional force (for rubber and skin) is proportional to load. For this range of loading, therefore, Amonton's law seems to hold.

5. A thin film of water at the friction interface increases adhesion - especially if the surfaces are hydrophillic (McFarlane and Tabor, 1950; Kummer, 1966).


8. A roughened surface reduces adhesion

9. An increase of temperature - within the clinical range - affects adhesion to some extent (Kummer, 1966)

10. Rubber exposed to air acquires surface contamination which reduces adhesion - it has to be cleaned prior to testing (Kummer, 1966).

Because there has been limited research on skin friction it cannot be assumed that all of the above characteristics will apply to skin. However, in the absence of evidence to the contrary, it is prudent to assume that they do; particularly those variables which are underlined.

It seems likely that the imprecise results obtained by previous investigators of skin friction (Naylor, 1955; Sulzberger et al, 1966; Spurr, 1976) were due to inadequate control of one or more of the many variables involved. This also applies to the tilted-bed sliding tests reported by Lowthian (1976 A).
An improved test of skin friction should control as many variables as possible. For instance, the time of contact before sliding begins can be the same for each test, and the loading on the interface can be standardized; at a load within the range 400 g. to 4 Kg. It should, however, be borne in mind that the test should model the conditions experienced by a weak hospital patient sliding forwards on his bed. If sufficient of the variables are controlled it should be possible to express the results using the standard definition of the coefficient of friction.

5.2.3. Development of a suitable test method

It was realised from the start that the tests would need to be conducted in a controlled environment. The ambient temperature, in particular, needed to be controlled. The size of the apparatus used was, consequently, limited by the size of the temperature-controlled room available. The small size of this room made it impractical to conduct tests on either patient volunteers or life-sized models. Nevertheless, it seemed that the tests would have relevance to the patient situation if the size of sample, and the loading employed, were similar to that of an actual body protuberance.

The range of normal loading on a patient's heel appears to be about 1 Kg. to 4 Kg. (see Chapter 4.3.1.) and this range meets the load requirements mentioned above. The surface area of the heel, when resting on a mattress, seems to be approximately 12 to 40 square cms. - according to the compliance of the mattress. It was decided to aim at developing a friction test sample with a similar area and loading.

Owens (1968) described various methods for the friction testing of polymers. Of these, two seemed suitable for the needs of the present project: the 'sled and plane' method and the 'capstan' method. The 'sled and plane' method seemed to be straightforward, and it also seemed suitable for a limited budget project.
Following the argument of Appledoorn and Barnett (1963) it was decided to try using latex rubber on the sled to model human skin. The 'plane' of this device was a heavy sheet of 'Float' glass, which was covered with a 2 mm layer of solid latex rubber with samples of bedding placed over this and secured with a strong clip. The sled itself was made from a carefully machined steel plate, curved upwards at each end, and secured to a 'Perspex' weight box. The sliding surface of the sled was a 4 mm layer of solid latex rubber bonded to the steel plate; the actual contact area measuring 11.5 x 7 cms. Although this area (80.5 sq. cms.) was larger than the target area, it seemed necessary in order to get sufficient weight in the sled; lead shot being used for this purpose. The finalized sled design (Figure 56) had wooden extension pieces on which was mounted a spreader bar carrying the traction cord. On the other end of the sled a counterbalance ensured that the sled's centre of gravity remained above the centre of the contact surface.

The extension arms and spreader bar enabled traction to be applied at the level of the sled/plane interface. Test runs showed that this arrangement ensured a smooth slide without rocking movements or lateral veer.

The traction cord was fed over a pulley so that weights could be used to supply the necessary traction force (see Figure 57, which shows the first sled design). Initially, a paint kettle was used to hold the weight, which was added gradually in the form of water - through a nozzle. When the paint kettle moved downwards the water supply was automatically cut. Unfortunately, the kettle would not hold sufficient water to move the sled - even on relatively smooth surfaces. It was also realised that the slow increase of weight, as water entered the kettle, would be different on each test sample and that this difference in the time of contact (before sliding begins) would affect the results (see above - 5.2.2.). A further problem was discovered when a dye test, with the sled loaded, showed that there was considerably
FIG. 56 FINAL DESIGN OF SLED USED FOR FRICTION TESTS - WITH 30 cm RULE ALONGSIDE.

FIG. 57 'SLED AND PLANE' FRICTION TEST APPARATUS - DURING A TEST.
less than 100% contact between the sled and the plane. It was assumed that this was due to the relatively poor compliance of the latex rubber. A softer rubber, however, would have allowed the sled to rock forward under traction.

Although these problems may have been resolvable, it was desirable to maintain the friction interface at skin temperature, rather than room temperature, in case the qualitative difference found on heated rubber surfaces is the same as the skin surface. Applying sufficient heat to this particular sled surface appeared to be impracticable. With all these problems to overcome it seemed better to abandon the sled and plane method in favour of the 'capstan' method. Results of the sled and plane tests which were completed are given in Appendix III.

The capstan method is used in the textile industry (Owens, 1968) and has been used for testing polymer films. When a fabric or film is pulled over a cylindrical surface the coefficient of friction at the fabric/cylinder interface is related to the tension \( T_1 \) in the fabric as it moves onto the cylinder and the tension \( T_2 \) in the fabric leaving the cylinder. When the contact angle of the fabric sample, around the cylinder, (in radians) is taken into account the coefficient of friction \( \mu \) can be calculated from the formula \( \frac{T_2}{T_1} = e^{\mu \sigma} \), where \( \sigma \) is the contact angle (Low, 1962; Owens, 1968).

Using a hollow cylinder made of heat-resistant glass as a 'capstan', it was possible to make a simplified heel model by bonding a 4 mm layer of solid latex rubber around the cylinder (see Figure 58). The width of this rubber strip was 6.3 cms. The device was fixed in a frame (Figure 59) and was heated by circulating warm water. The fabric test samples were draped over the cylinder, and slip was initiated by hanging a suitable weight on one side of the fabric. The flexibility of the fabric samples used ensured that there was good compliance between the samples and the capstan surface. The angle of contact was
FIG. 58  HOLLOW GLASS CYLINDER WITH BONDED-ON LAYER OF LATEX RUBBER - USED FOR "LATEX CAPSTAN" FRICTION TESTS.
FIG. 59 'LATEX CAPSTAN' IN ITS SUPPORT FRAME AND PREPARED FOR FRICTION TESTS.
FIG. 60 THE LATEX CAPSTAN - SHOWING WEIGHT TRAY, COUNTERWEIGHT, BACKING STRIP AND SAMPLE CLAMPS.
3.14159 radians (180°) which gives an area of contact (on the rubber strip) of 59.85 sq. cms. This system, known as the 'Latex capstan' is shown in Figure 60. With suitable cushioning the sample can be made to bulge around the capstan similarly to a heel resting on a soft mattress. In this way an assessment of the hysteresis (ploughing) component of the frictional resistance can be made.

Because of variations in the strength and extensibility of the fabric test samples it was necessary to use a backing strip cut from a strong, but compliant, woven cotton fabric. This was 30 cms. long and 6.5 cms. wide; each end being fixed in metal clamps. One of these clamps (on the traction side) also held the fabric sample. Both clamps could, however, be used to hold the sample (see below - 5.2.5.4.).

Figure 61 shows how the latex capstan system can be likened to a patient's heel sliding over a compliant support; the main differences being the greater angle of contact on the capstan and the three-dimensional curve of the heel. The method of connecting the weight tray and the counterweight, to the fabric backing strip, is shown on Figures 60 and 61. The counterweight was designed to balance the weight of the tray - on which the traction weights were placed.

Using this system a 'pre-load' of 1.3 Kg. (.65 Kg. on each side of the capstan) could be placed on the fabric sample for a fixed period (2.0 minutes) in order to overcome the 'contact-time' variable (see above - 5.2.2.). At the end of the two minutes the traction weight was placed carefully, and quickly, in the weight tray. A weight slightly lower than the estimated load needed was placed first and the sample was observed for movement. If there was none, the sample and weights were removed for two minutes. The second test repeated the procedure for the first, but the traction weight was increased by 0.5 Kg., and so on, until sliding occurred.
Diagram A - Heel pressing into, and sliding over, a mattress surface.

Diagram B - Same as 'A' turned through 90°.

Diagram C - Latex capstan system.

FIG. 61 SIMILARITIES BETWEEN THE CAPSTAN SYSTEM AND A HEEL SLIDING ON A MATTRESS.
The capstan method is inherently more stable than the sled and plane method and pilot tests showed that it gave repeatable results without any sign of 'stick-slip' motion. If, however, 'stick-slip' motion is required, it can be produced by incorporating a tension spring in the system (Owens, 1968).

It was realized that more information could be obtained from the capstan method if a mechanical drive, linked to a load transducer and recorder, were to be used to provide traction. Accordingly, a method was designed which allowed an 'Instron' universal testing instrument (floor model, TT) to be used; the capstan being fixed to the moving crosshead by a pulley and traction cord system. However, before this design was completed, a number of weight-placement tests were conducted on the latex capstan. These showed that rubber was less than an ideal model for human skin.

5.2.4. Lubrication problems of the 'latex capstan'

It seems likely that the skin's natural lubricant (see Chapter 2.2.) will enable skin to have a lower $\mu$ than that of un lubricated latex rubber. Early pilot tests on the 'sled and plane' system tended to confirm this and, accordingly, talc was dusted onto the rubber surface (in a standard way) to decrease the $\mu$. This seemed to have the desired effect, but only in dry conditions. When an attempt was made to simulate damp conditions at the friction interface it seemed that the mixture of talc and water gave very different characteristics to those encountered on damp naturally-lubricated skin (Lowthian, 1976 A).

However, it had been anticipated that the capstan method could be used directly on human skin, rather than rubber, if the supinated wrist took the place of the latex capstan. This area of skin is relatively free of hairs and is similar to skin on other parts of the body where sores often occur. The main friction tests were, therefore, 'Wrist capstan' tests using the author's left wrist. It would, undoubtedly, be even more
informative to conduct these 'wrist capstan' tests on various volunteers, but this was not attempted in the present study.

5.2.5. Details of the capstan friction tests

5.2.5.1. General conditions

All of the friction tests were conducted in the same ambient temperature/humidity conditions - as detailed for the load/pressure distribution tests (Chapter 4.1.1.). However, in the case of the latex capstan tests, the ambient temperature range was 19 - 23°C. The higher temperature was on one hot summer day and the usual range was 19 - 21°C. The humidity range was 42 - 64% R.H.; the lower figure being on one or two winter days: the usual range was 50 - 60% R.H. The temperature of the latex capstan was kept within the range 36 - 38°C. This temperature was taken at the friction interface with an electronic thermometer probe. The wrist capstan tests were conducted under very similar conditions of temperature/humidity, but the author's skin temperature varied over the range of 31.5 - 35.4°C. However, as the temperature at which sweating is induced falls within this range (see above - 5.1.2.) the effect of this (minimal) sweating on the coefficient of friction had to be taken into account. In consequence the wrist capstan tests, where the wrist temperature was more than 33.5°C., were considered as a separate group.

5.2.5.2. Pre-test cleansing

Both rubber and human skin appear to gradually develop a lower surface friction, when exposed to normal room air, after washing (Roberts, 1979; Spurr, 1976). The washing process seems to temporarily restore the intrinsic characteristics of these two materials – presumably by removing dust and oily contaminants (Roberts and Thomas, 1975) but washing also helps to remove any electrostatic charge on the surface (Roberts and Thomas). This is the rationale for cleaning the rubber, or skin surface, just prior to testing.
With the aim of keeping the friction tests as close as possible to the clinical situation it was decided to wash both contact surfaces (latex and skin) with soap and water. This was followed by drying with a clean towel. The washing procedure was standardised for each test and used unperfumed soap, a polyurethane sponge, and water at room temperature. The latter detail was designed to prevent the wrist skin temperature being raised to the point where sweating was significant. After washing, the latex capstan was left to dry completely (by air exposure of 4 minutes) in the temperature controlled room. In the case of the wrist capstan, however, the air exposure time was 5 minutes. Once the washing was completed, the capstan contact surfaces were not touched by hand before the test started (Owens, 1968).

5.2.5.3. Interface additives

In order to model the adhesive effect of a patient sitting on a damp support (see above - 5.1.1.) various methods of applying moisture, in a controlled way, were examined. The method finally chosen was to 'paint' on tap water using a clean bristle paint brush. This ensured that a controlled amount of water could be applied evenly, over the entire contact surface of the sample. Following this procedure the damp sample was left exposed in the temperature-controlled room for just 46 minutes. This allowed much of the moisture to evaporate. When such a sample was used on the author's wrist it did not look wet, but its cooling effect showed that it was, in fact, still damp. Pilot tests indicated that a very wet fabric had a low $\mu$, but the samples which were only slightly damp had a very high $\mu$. In order to avoid rapid drying, when a damp sample was placed on a warm capstan, a 50 micron layer of waterproof plastic film was placed above these damp samples, during the tests. In the clinical situation this can be likened to the plastic draw-mackintosh; which delays the drying of a dampened drawsheet (Lowthian, 1976 A). A pilot trial using fresh urine on a sample of cotton sheeting indicated that its adhesive effects were indistinguishable from tap water.
Talc was used to reduce adhesion on some of the early pilot tests on the latex capstan, but no other lubricants, powders, etc., were employed. There are, of course, many medicaments which nurses use on patients' skin (Green, 1976) but they were not included in the present study.

5.2.5.4. **Sample preparation**

Each fabric sample was cut to just overlap the latex capstan contact surface - on each side - and the same width of sample was used on the wrist capstan tests.

The method of hanging weights over the capstan is described above (5.2.3.). The test samples were held in one metal clamp; at the end of the strip where the traction weight was applied. It is possible, however, for both clamps to be used. In this way the test sample can be stretched by pre-determined amounts (see Figure 62). This method was not used in the current tests.

5.2.5.5. **Measuring the slide**

Both the latex capstan and the wrist capstan were marked at the point where the fabric samples broke contact with the capstan surface (the tangential point) on the counter-weight side of the sample. Once a test was started a corresponding mark was made on the edge of the test sample (before traction weights were applied) so that if there was any stretch in the fabric, which was not true slippage, it could be seen that the two marks were still in line. Only when the two marks separated could it be certain that the whole sample was moving around the capstan. This made it possible to detect very slow rates of movement. Pilot tests showed that the point of slippage was seldom, if ever, a sudden movement. In consequence, it became necessary to define minimal slippage as follows:—

The slowest observable slide (approximately 0.1 mm per second) providing that at least 5 mm are traversed in 1 minute, from application of the friction force (load).
Diagram A - Backing strip held to show shorter length of test sample (unstretched).

Diagram B - Release of backing strip shows stretching of test sample under 'pre-load'.

FIG. 62 THE CAPSTAN SYSTEM - METHOD OF PRE-STRETCHING TEST SAMPLE BY CLAMPING BOTH ENDS.
This definition might be termed the 'Minimal Velocity Coefficient'; its clinical analogy being found in the gradual 'Forward slide' effect (Chapter 2.6.)

Kummer (1966) produced a curve showing the relationship between the friction coefficient and sliding velocity — for rubber. This indicates that, within the clinical speed range under consideration (up to about 30 mm per second) adhesion increases with increasing speed of slide.

5.2.5.6. Limitations of the method

The wrist capstan tests were conducted with the author's hand extended: in order to stretch the tendons and skin on the inside of the wrist (see Figure 63). The sample fabric (and the backing strip) were placed on the supinated wrist so that the edge of the sample was just 7 cms. from the first skin crease at the edge of the palm. A particular advantage with the wrist capstan tests is the fact that the point of slippage can be detected by the volunteer's sensory nerve endings. With the capstan apparatus draped over the author's wrist (under the initial 1.3 Kg. loading) it was found that the area loaded was very close to a semi-circle, throughout the width of the contact area. Thus, it was feasible to use the formula $T_2/T_1 = e^{\theta}$ for calculating the coefficient of friction — as for the latex capstan tests.

The number of wrist friction tests attempted per day was limited by the discomfort which gradually developed and the desire to avoid pathological changes such as hypertrophy of the skin (Lowthian, 1982). In practice, there were no observed clinical changes in the author's wrist skin during the run of tests. The latex rubber did appear to deteriorate — its surface becoming slightly rougher — towards the end of its run of tests. The condition of the capstan was periodically checked by using a fresh piece of the 'Kylie' nylon facing. When dry (to all intents and purposes) this gave results which varied by $\pm \%$. 
FIG. 63 METHOD OF CONDUCTING FRICTION TESTS ON THE AUTHOR'S WRIST - THE 'WRIST CAPSTAN'.
The adjustable armrest (shown in Figure 63) was developed in order to adjust a volunteer's arm position to the correct height and angle, and to support his arm, when heavy weights are in use.

5.2.5.7. **Hysteresis tests**

As discussed above (5.2.3.) it is possible to cushion the capstan test samples in order to simulate a compliant support. Such cushioning was used in a limited number of wrist capstan tests, in order to estimate the relative importance of the hysteresis (ploughing) component of the friction force. The cushioning used was a 6.5 cms. thick layer of dressmaker's polyester fibre wadding. This had the same width and length as the backing strip, and was positioned between the test sample and the backing strip.

The cushioning material compressed to approximately 2 cms., when under load, and so produced a simulated 'Ploughing' situation (as shown in Figure 61) on the counter-weight side of the wrist.

Although the area of sample/capstan contact was increased by this technique, it was reasoned that this would produce only a slight increase in the friction force needed to produce a slide. Unless, of course, the hysteresis factor proved to be more significant than anticipated.

The hysteresis tests were conducted immediately after a 'standard' test; and using the same test sample.

5.2.6. **Test results – Latex capstan**

A number of friction tests on the latex capstan were conducted before the test procedure was finalized. The results of these tests are given in Appendix IV. The tests conducted with the finalized procedure were as follows:-
1. Nylon facing of the 'Kylie' drawsheet - 6 tests
2. Nylon facing of the 'Dupic' underpad - 2 tests
3. Ordinary (woven) cotton hospital sheet - 2 tests

All of these tests were in dry conditions and no talc was used to lubricate the latex rubber. The ordinary hospital sheet was freshly laundered, and had had an estimated 100 washes. The 'Kylie' was new, as was the Dupic underpad. Figure 64 shows the results of these various tests.

5.2.7. Discussion of latex capstan results

The fact that all of the six tests of the Kylie facing produced identical results suggests that the capstan method is more reliable than the sled and plane method (Appendix III). The nylon of the Kylie is brushed, whereas the nylon of the Dupic facing is smooth, and this may explain the slightly lower value of \( \mu \) of the Dupic facing. However, the relatively low value of \( \mu \) of the cotton sheet is more difficult to explain. In fact, the results of the wrist capstan tests appeared to conflict with these results.

5.2.8. Test results - Wrist capstan

Some wrist capstan tests (on the author's wrist) were conducted in 'dry' conditions, in that the samples were left in the testing room for at least 16 hours prior to testing (see above - 5.2.5.1.) and were dry to the touch. Tests in 'damp' conditions are defined above (5.2.5.3.). The following tests were conducted:

1. Nylon facing of the 'Kylie' drawsheet (new) - 1 test 'dry'
2. Nylon facing of the 'Dupic' underpad (new) - 3 tests 'dry'
3. Ordinary (woven) cotton hospital sheet (about 100 washes)
   - 7 tests 'dry', 4 tests 'damp', and 1 test 'extra dry'
   (see below).
4. Polyester/Vincel (woven) hospital sheet (about 60 washes)
   - 2 tests 'dry'.
FIG. 64 RESULTS OF FRICTION TESTS ON LATEX CAPSTAN - DRY CONDITIONS.
5. Cotton twill drawsheet (new) - 2 tests 'dry'.
6. Cotton twill drawsheet (about 100 washes) - 4 tests 'dry'.
7. Nylon/Viscose/cotton knitted stretch sheet (flame-retarded and new) - 2 tests 'dry' and 2 tests 'damp'.
8. Nylon facing from a 'Polyweb' disposable underpad - 1 test 'dry'.

Some additional tests were conducted before the test procedure was finalized - they are given in Appendix V.

Where two or more tests were conducted on the same material, the results appeared to be largely consistent. The actual results are given in Figure 65; the large dots representing the mean coefficient of friction ($\mu$) of the material/skin interface. However, when the samples were dry, there was only one case (cotton sheet at higher wrist temperatures) with a range of coefficients: 0.50 to 0.52. The results given are all 'rounded-up' to two decimal places.

One test on the cotton bedsheet (see above - 'extra dry') was conducted with a quilted bag of dessicated silica gel crystals laid on the backing strip. This was done in an attempt to dry the cotton/wrist interface below the level of the ambient humidity (57% R.H.). The result (Figure 65) was a $\mu$ of 0.48. Immediately after this test a second test was conducted, using the same materials, except that the silica gel bag was sealed in a thin polypropylene bag. The resulting $\mu$ was 0.50. As well as the 'standard' wrist capstan tests, hysteresis tests were conducted on the following materials:

1. Nylon facing of the 'Dupic' underpad - 1 test 'dry'
2. Polyester/Vincel hospital sheet - 1 test 'dry'
3. Cotton twill drawsheet (new) - 1 test 'dry'
4. Cotton twill drawsheet (about 100 washes) - 2 tests 'dry'
5. Nylon/Viscose/Cotton knitted stretch sheet (flame-retarded and new) - 1 test 'dry' and 1 test 'damp'.
FIG. 65 RESULTS OF FRICTION TESTS ON AUTHOR'S WRIST - STANDARD CONDITIONS.
FIG. 66 RESULTS OF HYSTERESIS TESTS ON AUTHOR'S WRIST.
The results of these tests, alongside the relevant 'standard test' results, are given in Figure 66. They are presented in terms of the load needed to initiate a slide, instead of the coefficient of friction.

5.2.9. Discussion of wrist capstan results

As with the latex capstan tests, the results of the wrist capstan tests indicate that consistently repeatable results can be obtained; and the various standardisation precautions appear to be justified.

The importance of the wrist skin temperature is indicated by the relatively high $\mu$ on the cotton bedsheets when the wrist skin temperature was in the range $33.6^\circ C - 35.4^\circ C$ (see Figure 65). This strongly suggests that it is the effect of increased adhesion caused by small amounts of moisture produced by the sweat glands. This conclusion is supported by the work of Naylor (1955) and Sulzberger et al (1966). In addition, the reduced coefficient obtained by the drying effect of the silica gel crystals suggests that, beyond an undefined value $\mu$ will not be high because of interface moisture but will, instead, gradually diminish as more and more of the remaining moisture is removed by drying.

Spurr (1976) found that finger tips cleaned in hot water acquire a higher value of $\mu$ as the temperature of the water rises. It seems likely that this is caused by either sweating due to the heat, the greater uptake of hot water by the epidermal cells, or the more efficient removal of skin lipids, or, possibly, to a combination of these factors. In consequence, in the temperature range normally encountered by the patient's skin, it seems that an increase of skin temperature is likely to cause an increase of interface friction rather than the decrease indicated for rubber (Kummer, 1966).

As the water used for washing a patient's skin is usually warmer than room temperature, it is likely that the friction
results of the wrist capstan tests are slightly lower than the maximum friction effects encountered in the clinical situation being modelled.

The two transverse lines across the chart of results (Figure 65) indicate the optimal range of interface friction. This is necessarily speculative but, in dry conditions, clinical experience suggests that smooth cotton sheets have an acceptable \( \mu \) against skin (Lowthian, 1970 A) and experience on an underpad trial (Lowthian et al, 1976) has shown that the friction characteristics of the Dupic facing (\( \mu \) of 0.38) are normally acceptable to patients. A coefficient of friction less than 0.38 is, however, likely to cause a positional instability which would be unacceptable to both nurses and patients.

From the tests so far completed, the bed-surface materials which seem to be the most acceptable are:

   a) The Dupic underpad facing.
   b) The Polyweb disposable underpad facing.
   c) The Polyester/Vinse1 sheet.
   e) The Kylie facing.

Nevertheless, in damp conditions, none of the materials may be acceptable (in the clinical situation) unless they can rapidly lose the moisture they have imbibed. This latter condition suggests that the Dupic, Polyweb, and Kylie will be more acceptable than the other products. However, the Polyweb underpad tends to form uncomfortable creases when it crumples (Lowthian et al, 1976) and the Kylie seems to have poor compliance (see Chapter 4). New drawsheets also have relatively poor compliance; being stiffer than well-worn drawsheets. This may explain the somewhat paradoxically lower value of \( \mu \) of the new drawsheet (Figure 65) which, being somewhat inflexible may have a smaller area of actual contact against the author's wrist. This 'new' drawsheet had been laundered once or twice and this makes it unlikely that
a special finishing treatment was responsible for the lower value of $\mu$.

As discussed above (5.2.1.) the optimum interface needs good compliance as well as a low coefficient of friction (0.38 - 0.50) and the tested products which seem best to fulfill these requirements are the Dupic underpad, the Nylon/Viscose/Cotton knitted sheet and, to a lesser degree, the Polyester/Vincel sheet.

The results of the hysteresis tests appear to confirm that the increased 'Ploughing' effect produced by sliding over a compliant support will not significantly increase the value of $\mu$ (see figure 66). In damp conditions, however, there may be increased adhesion due to an increase in the contact area of the material with the skin.

It is possible to compare the wrist capstan results with the results of Spurr (1976) on the coefficient of friction of fingertips. His range of results ('dry' conditions) was approximately 0.40 to 0.55. He did not, however, use bedding materials for these tests. Naylor (1955) found that the value of $\mu$ for skin against Polythene, in dry conditions, was approximately 0.50 to 0.60. In damp conditions the value rose as high as 1.10. These figures suggest that the wrist capstan test produces realistic results; although the shape, size, texture and temperature, of the wrist used may affect the results obtained. This difficulty might be overcome by conducting tests on a number of volunteers; so that the mean and standard deviation can be obtained - for each material tested.

Nevertheless, the wrists of adults are relatively similar in size, because they are short of the normal soft tissues which are responsible for most size variations: muscle and fat. It was not possible to find a suitable synthetic skin for the friction tests, which might have made wrist tests unnecessary, but any artificial skin will gradually roughen; as more tests are
performed. Living skin is not so likely to alter its surface characteristics; if discomfort is avoided and time is allowed for pressure-relief between tests (see above - 5.2.5.6.)

Many more friction tests are necessary for a clear understanding of the optimum interface friction in various clinical conditions and, although total environmental control was not possible in the current series of tests this would be essential for conducting tests at various ambient temperatures and relative humidities.

5.3. Water vapour permeability - the 'Microclimate'

5.3.1. Introduction

The reasons for a waterproofed hospital mattress have been mentioned in Chapter 1.3.4., and Chapter 3. However, it seems essential for the proofing to be very permeable to water vapour; in order to minimise temperature discomfort, and sweating, at the skin/support interface.

Currently, many hospital mattresses have the DHSS specification mattress cover discussed in Chapter 3. The proofing of this cover withstands a 150 cms. head pressure of water (NHS report, 1968) but its water vapour permeability (W.V.P.) is not defined. On many hospital beds a waterproof draw-mackintosh is also used and this is usually a thin sheet of polythene (Pearce, 1971). Although, in practice, this material has been found more comfortable than the traditional red rubber it has a very poor water vapour permeability (Norton et al, 1962; Scales, 1977). Thin polythene sheeting is also used for the backing sheet of many disposable incontinence underpads (Lowthian, 1970 B). In consequence, an incontinent patient may have no less than four layers of impervious material beneath his lower trunk and pelvis; the fourth layer being the underside of the mattress cover. On a typical King's Fund bedstead we can count another impervious layer: the corrugated steel mattress base.
If, however, the incontinent patient is raised above the first impervious layer by, for example, a thick underpad, there is less chance of his pelvic skin becoming waterlogged and macerated (see above - 5.1.2.) Nevertheless, although such a pad may also help to absorb sensible perspiration, it is hardly suitable as a general method for continent patients.

Charnley (1959) considered that the impervious layers of a hospital bed were particularly harmful for pyrexial patients and he recognized that the area of cotton sheet on which such a patient was resting would quickly reach 100% R.H. Scales (1976 B) described the damp and sticky skin condition which results when an average patient is lying on a hospital bed. He pointed out that such conditions are conducive to bacterial proliferation. In addition, the moisture-laden epidermis becomes weaker and more extensible (Wildnover et al, 1971); it adheres to the support surface (see above - 5.2.9.) and, in consequence, blisters are readily produced by tangential forces (Sulzberger et al, 1966).

A sticky microclimate, at the patient/support interface, seems to be encouraged by immobility rather than activity (Clark, 1974). Although cold ambient conditions, and patients with low metabolic rates, may avoid such stickiness because of greatly reduced perspiration. There are, of course, many relatively fit and/or short-stay hospital patients, as well as pyrexial patients, who neither have low metabolic rates nor reside in cold wards. Some of these patients will also have periods of relative immobility, for example, after an operation. In consequence, it seems essential to improve the W.V.P. of the general-purpose P.S.S.

5.3.2. The critical W.V.P.

Redbourn and Rees (1972) concurred with Weiner (1971) in suggesting that an average man, at rest, produces insensible perspiration at a rate of approximately 11g./M²/hour: from his skin surface. This figure assumes that the man's body surface
area is 1.8 $\text{m}^2$, while the ambient temperature is in the region of 20 - 25°C. At higher temperatures sensible perspiration becomes apparent, and the critical temperature appears to be 32 - 33°C. (Scales, 1978; Chao et al, 1979).

At high rates of sweating the average man may lose (through the skin) about 69g. of moisture per metre squared per hour (Weiner, 1971). Maximum rates of sweating, however, may produce 800g./$\text{m}^2$/hour (Clark and Cox, 1974).

If we assume that Weiner's figure of 69g./$\text{m}^2$/hour is realistic for a near-immobile patient who is either very warm or slightly pyrexial, the daily skin moisture loss may be in the region of 1,656g./$\text{m}^2$ (69g. x 24 hrs.). In equivalent terms Weiner's figure for normal (insensitive perspiration) skin moisture loss is 264g./$\text{m}^2$/day. Burgh and Windsor (1944) gave a figure of 235g./$\text{m}^2$/day for normal skin moisture loss, at an ambient temperature of 24°C. and a relative humidity (R.H.) of 50%.

Recently, Denne (1979) estimated that a typical wheelchair-bound patient will lose approximately 600g./$\text{m}^2$/day through his skin. We may conclude that the proofing of a patient's support should have a W.V.P. of at least 300g./$\text{m}^2$/day. However, because a mattress is usually a very good insulator it produces a relatively-high interface temperature (see above - 5.1.2.) which suggests that 600g./$\text{m}^2$/day is the minimum figure for the W.V.P. of a proofed mattress cover. For very warm conditions (or pyrexia) however, a W.V.P. of 1,700g./$\text{m}^2$/day may be required.

5.3.3. W.V.P. tests on mattress covers

During the research work on which this treatise is based a number of waterproof materials were tested for W.V.P., by Smith and Nephew Ltd. The method of testing was by the Payne's Cup Method (Payne, 1936). The tests were conducted with a differential R.H. (across the film) of 100%; the ambient temperature being 37°C. Waterproofness was determined by the
sample showing no failure under a hydrostatic head of 140 cms. - for 15 minutes. All the materials passed this test.

5.3.4. W.V.P. test results

The materials tested for W.V.P. were as follows:

1. Polyurethane resin on woven nylon (SNF 1275) from Smith and Nephew Ltd.
2. Soft polyurethane resin on knitted nylon (P.071) from Courtaulds PLC.
3. Hard polyurethane resin on knitted nylon (P.072) from Courtaulds PLC.
4. DHSS specification cover (polyurethane resin on woven nylon).
5. 'Simpla' P.V.C. mattress cover (50 microns thick).
6. 'Platilon' U01 polyurethane film (50 microns thick)
7. " U01 " " (30 " " )
8. " U01 " " (25 " " )
9. " U04 " " (50 " " )
10. " 'U04 " " (30 " " )

All of the materials tested were new and unused except for one sample of U01 (50 microns film) which had been in use as a mattress cover for seven months.

The results of these tests are given in Table 4, which also shows the number of tests and the results which these (mean) figures are based on. The Smith and Nephew material (SNF 1275) was tested frequently - as a control for the tests of the other materials.

5.3.5. Discussion of W.V.P. test results

The mean W.V.P. of a single layer of the DHSS specification mattress cover (433g./m²/day) indicates that it will not quite meet the specification outlined above (5.3.2.) Moreover, because that proportion of a patient's water vapour which disperses downwards
<table>
<thead>
<tr>
<th>Material</th>
<th>yes</th>
<th>N/A</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SNF 1275</td>
<td></td>
<td></td>
<td>520,490,470,</td>
<td>490</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>530,440,410,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>500,400,540,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>500,430,480,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>530,520,510,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>570.</td>
<td></td>
</tr>
<tr>
<td>P.071</td>
<td></td>
<td></td>
<td>1890,2030,</td>
<td>1938</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2040,2020,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1780,1870.</td>
<td></td>
</tr>
<tr>
<td>P.072</td>
<td></td>
<td></td>
<td>720,715,575,</td>
<td>720</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>695,775,860.</td>
<td></td>
</tr>
<tr>
<td>DHSS mattress cover</td>
<td></td>
<td></td>
<td>430,480,440,</td>
<td>433</td>
</tr>
<tr>
<td>(one layer)</td>
<td></td>
<td></td>
<td>400,420,426,</td>
<td></td>
</tr>
<tr>
<td>Simpla P.V.C. cover</td>
<td></td>
<td>50mc.</td>
<td>250,220,175,</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>140,170,180.</td>
<td></td>
</tr>
<tr>
<td>U01 — new</td>
<td></td>
<td>50mc.</td>
<td>835,780,760,</td>
<td>770</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>730,755,765.</td>
<td></td>
</tr>
<tr>
<td>U01 — in use for 7 months</td>
<td></td>
<td>50mc.</td>
<td>930,910,900,</td>
<td>888</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>860,930,890,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>820,860.</td>
<td></td>
</tr>
<tr>
<td>U01 — new</td>
<td></td>
<td>30mc.</td>
<td>1030,1020,</td>
<td>1042</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1010,980,990,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1040,1080,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1140,1080,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1050.</td>
<td></td>
</tr>
<tr>
<td>U01 — new</td>
<td></td>
<td>25mc.</td>
<td>1350,1300,</td>
<td>1298</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1330,1412,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1290,1260,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1125,1320.</td>
<td></td>
</tr>
<tr>
<td>U04 — new</td>
<td></td>
<td>50mc.</td>
<td>790,710,790,</td>
<td>751</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>770,710,660,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>790,790.</td>
<td></td>
</tr>
<tr>
<td>U04 — new</td>
<td></td>
<td>30mc.</td>
<td>820,820,840,</td>
<td>844</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>810,900,810,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>850,900.</td>
<td></td>
</tr>
</tbody>
</table>

N/A = Not applicable.  
* W.V.P. results in g./M²/24 hrs/  
mc. = Microns.  
37°C./100% R.H.  

TABLE 4 W.V.P. TEST RESULTS ON WATERPROOF MATTRESS COVERS.
through the mattress will have two layers of cover to traverse, the effective W.V.P. of the mattress may be somewhat less than 433g./m²/day.

Charnley (1959) and Norton et al (1962) considered that P.V.C. sheeting had a W.V.P. which made it superior to 'red rubber' and polythene sheeting. However, the 'Simpla' mattress cover is made of thin (50 microns) P.V.C. and its mean W.V.P. was only 190g./m²/day. Nevertheless, as this cover is fixed onto the mattress like a fitted sheet, it leaves a large area (beneath the mattress) which is not proofed; so allowing the free passage of the water vapour which has passed through one layer of the cover.

All of the materials which were investigated as possible mattress covers in the list above (5.3.4.) were made into prototypes which left most of the mattress underside free of proofed material. The code numbers of these prototype covers are:-

1. SNF 1275
2. P.071
3. P.072
4. U01 (50 microns)
5. U01 (30 microns)
6. U01 (25 microns)
7. U04 (30 microns)

'SNF 1275' was used on the Vaperm Mark 1 mattress (see Chapter 6) and was a non-stretch material. Some modern waterproof materials, such as 'Goretex' are also non-stretch and have very high W.V.P.'s. Goretex has a W.V.P. of about 11,000g./m²/day (unspecified test conditions) according to Geisow (1980).

Nevertheless, a mattress cover needs to be relatively inexpensive and (preferably) it should be extensible; so as to avoid the hammocking effect (see Chapter 4).
A very extensible cover (P.071) was produced by Courtaulds for the Vaperm Mark 2 mattress (see Chapter 6). The mean W.V.P. of this cover (1938g./M$^2$/day) was more than sufficient to satisfy the theoretical requirements already discussed. Nevertheless, the cost of this cover (£25 in 1979) made it a doubtful proposition unless it had good durability. Unfortunately, clinical experience showed that its life expectancy was no more than two years. A more durable resin was tried on the same cover material (P.072) but its W.V.P. was less than half the value of the P.071 cover.

Some German polyurethane resins, from Platebonne, (U01 and U04) were relatively inexpensive if used without a knitted fabric substratum. Their W.V.P.'s were satisfactory at the thinner gauges, and they seemed strong enough to last for some months in hospital service. The thinnest film (25 microns) proved to have unsuitable mechanical properties, but the 50 micron film (mean W.V.P. of 1042g./M$^2$/day) seemed suitable as a 'short-life' mattress cover.

5.3.6. Heat comfort—personal and clinical trials

Although the W.V.P. tests are a useful indication of the heat-comfort to be expected on a particular mattress cover, they cannot substitute for clinical trials.

Accurately monitored and objective tests would involve complex measurements of patient temperature and mobility, temperature and relative humidity at the patient/support interface, and ambient temperature and humidity. The limited scope of the present study precluded such tests, but the author tested various mattresses, and their covers, on his own bed. These trials were unavoidably subjective, but some pilot clinical trials tended to support the personal trial results. The ambient temperature was checked evening and morning, by the author; during the personal trials.
<table>
<thead>
<tr>
<th>Surface upwards</th>
<th>Height tested</th>
<th>Temp.</th>
<th>Impression</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2/P.071 cover/FTS/CP</td>
<td>29</td>
<td>16-20?</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>Domestic spring-interior mattress/PVC/Py.C/CP</td>
<td>1</td>
<td>18?</td>
<td>Hot &amp; sticky</td>
</tr>
<tr>
<td>Stoke Mandeville No. 4 mattress/DHSS/Py.C/CP</td>
<td>2</td>
<td>16?</td>
<td>Hot &amp; sticky</td>
</tr>
<tr>
<td>V2/P.072 cover/FTS/CP</td>
<td>1</td>
<td>16</td>
<td>Hot &amp; sticky</td>
</tr>
<tr>
<td>V2/P.071 cover/U01 (50 microns) drawmackintosh/HCS/CP</td>
<td>1</td>
<td>16</td>
<td>Hot &amp; sticky</td>
</tr>
<tr>
<td>V2/Py.C/U01 (50 microns) cover/HCS/CP</td>
<td>1</td>
<td>16</td>
<td>A little sticky</td>
</tr>
<tr>
<td>Domestic spring-interior mattress/U01 (50 microns) cover/HCS/Nylon pyjamas</td>
<td>1</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>VIII/FTS/U01 (25 microns) cover/HCS/CP</td>
<td>4</td>
<td>16-18</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>VIII - as above, but with 10 mm foam pad under HCS</td>
<td>2</td>
<td>16</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>VIII/FTS/U01 (25 microns) cover/FTS/CP</td>
<td>2</td>
<td>20</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>VIII/FTS/U01 (30 microns) cover/Py.C/10 mm foam pad/CP</td>
<td>2</td>
<td>16</td>
<td>Satisfactory</td>
</tr>
</tbody>
</table>

**KEY:**
- CP = Cotton pyjamas.
- FTS = Knitted nylon/viscose/cotton sheet.
- DHSS = DHSS specification mattress cover.
- HCS = Hospital cotton sheet.
- PVC = Simpla P.V.C. mattress cover.
- Py.C = Polyester/cotton sheet.
- V2 = Vaperm mark 2 mattress.
- VIII = Vaperm III mattress.

**TABLE 5** AUTHOR'S IMPRESSIONS OF HEAT COMFORT ON VARIOUS SUPPORTS AND INTERFACES.
<table>
<thead>
<tr>
<th>Code No.</th>
<th>Diagnosis</th>
<th>Interface</th>
<th>No. of nights tested</th>
<th>Time of year</th>
<th>Impression</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2 (1)</td>
<td>Diabetes - elderly and incontinent</td>
<td>V2/P.071 cover/FTS</td>
<td>22</td>
<td>Jan.</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>T2 (2)</td>
<td></td>
<td>RT-F/U01 (50 micron) cover/FTS</td>
<td>190</td>
<td>Jan.-Aug.</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>T2 (3)</td>
<td></td>
<td>RT-F/PVC/FTS</td>
<td>&gt;2</td>
<td>Aug.</td>
<td>&quot;Sweaty&quot;</td>
</tr>
<tr>
<td>T2 (4)</td>
<td></td>
<td>RT-F/U01 (30 micron) cover/HCS</td>
<td>70</td>
<td>Nov.-Jan.</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>W1 (1)</td>
<td>Young Quadraplegic</td>
<td>VIII/FTS/U01 (25 microns) cover/FTS/Cotton nightdress</td>
<td>120</td>
<td>Jul.-Nov.</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>W1 (2)</td>
<td></td>
<td>VIII/FTS/U04 (30 microns) cover/FTS/Cotton nightdress</td>
<td>&gt;30</td>
<td>Nov.-Dec.</td>
<td>Satisfactory</td>
</tr>
</tbody>
</table>

**KEY:**

FTS = Knitted nylon/viscose/cotton sheet.
HCS = Hospital cotton sheet.
RT-F = Relyon "Triple-foam" mattress.
V2 = Vaperm mark 2 mattress.
VIII = Vaperm III mattress.
PVC = Simpla P.V.C. mattress cover.

**TABLE 6** PILOT CLINICAL TRIALS FOR HEAT COMFORT - VARIOUS SUPPORTS AND INTERFACES.
5.3.7. Heat comfort trials – results

The various combinations of mattresses and covers which were slept on by the author, and the subjective results of these trials, are given in Table 5.

The results of the pilot clinical trials (heat comfort) are given in Table 6.

5.3.8. Heat comfort – conclusions

The trial results tend to support the use of the W.V.P. measurement as a good indicator of the heat comfort to be expected from a particular patient/support interface.

The P.071 cover was normally comfortable, even on a 20 cms. thick foam mattress, on all but the warmest nights of the year. Most of the other mattress covers tested, including the DHSS specification cover, produced heat discomfort regardless of the mattress used; at ambient temperatures of 16° – 26°C. Both of the thinner U01 covers, 25 microns and 30 microns in thickness, caused very little heat discomfort and, when a 10 mm thick foam pad (similar to a Dupic underpad) was used to separate the author from the U01 covers, the result was very similar to sleeping on the P.071 cover. These trials, on the foam pad, took place on a later Vaperm mattress (see Chapter 6).

These various tests and subjective trials suggested that the 30 micron U01 film would have adequate W.V.P., when used in the form of a 'fitted sheet' mattress cover, and particularly if the patient is separated from the film by a soft porous pad, some ten millimetres thick.
6.1. Pedigree of the system

6.1.1. Beginnings of the concept

The Vaperm P.S.S. was originally conceived by Scales (1978) as a cost-effective way of providing, for the majority of hospital patients, some benefits of the Low Air Loss Bed System. In particular, he was concerned to improve the W.V.P. of the typical waterproof mattress cover, and the ventilation of the rigid type of mattress base. It was anticipated that such improvements, together with a relatively soft foam mattress core, would reduce the risk of pressure sores.

The first mattress in this development programme (the Vaperm Mark 1) was made from a soft grade of urethane polyether foam and was covered in a proofed nylon fabric (SNF 1275) from Smith and Nephew Ltd. This has relatively good W.V.P. (see Chapter 5) but, being woven nylon, it produced a hammocking effect similar to that found on the DHSS mattress (see Chapter 4). The Vaperm Mark 2 had a laminated foam core, made by Dunlop PLC, and a knitted cover with 'two-way' stretch. This cover was produced by the Courtaulds group and was proofed with a polyurethane resin (P.071) as mentioned in Chapter 5.

While these mattresses were being developed, Professor Scales was actively encouraging the development of a rigid but ventilated mattress base (Scales, 1980); this being designed for the King's Fund bed (see Figure 25). Figure 67 shows a ventilated 'Weldmesh' base which was detached from its bedstead, for load/pressure distribution tests.

6.1.2. The Vaperm Mark 2

The Vaperm Mark 2 laminated mattress core was specially shaped to enable the uppermost layer of the mattress cover to be
FIG. 67 THE VAPERM MARK 2 MATTRESS ON VENTILATED 'WELDMESH' BASE USED FOR LOAD/PRESSURE DISTRIBUTION TESTS.
slightly wider than the mattress core (see Figure 67). This humped shape was produced by using relatively soft foams so that, when accommodating a load, the 'hump' could be easily compressed. This enabled the slightly wider cover to conform to the shape of the patient (load) without hammocking. Even more accommodation was provided by the stretchable nature of the cover.

The lack of excess cover material on the DHSS mattress exacerbates the hammocking effect (see Chapter 3) and its firm chipfoam edge resists compression by a taut cover; so that an even more severe hammocking effect is produced. Nevertheless, the need for firm edges on a hospital mattress was accepted by Scales (NHS report, 1968) and such firm edges were incorporated in all of the Vaperm mattresses. Most of the Vaperm Mark 2 mattress core was, however, made of relatively soft foam (Dunlopillo urethane polyether foam D.14).

The core measured 200 x 90 x 15 cms., but the humped portion was 2.5 cms. deeper. As mentioned in Chapter 5, the underside of the mattress was porous – it was covered with woven calico.

Some prototypes of these mattresses became available in 1977 just before the author became involved in the Vaperm development programme.

6.1.3. Pilot trials of the Vaperm Mark 2

A number of pilot clinical trials were conducted on the Vaperm Mark 2 and some of these were randomized controlled trials. The control being the DHSS specification mattress (Class I) 15 cms. deep. It is not intended, however, to discuss these trials in detail, as the number of patients involved was relatively small and the Vaperm Mark 2 was phased out during the development of the Vaperm III P.S.S. The pilot trials have been discussed in detail elsewhere (Scales and Lowthian, 1978–1980). Nevertheless, some details of the Vaperm Mark 2 clinical trial conditions were used for later pilot trials of the Vaperm III (see below – 6.3.4.).
Moreover, the Vaperm Mark 2 trials enabled the Pressure Sore Prediction Score (see Chapter 2.4.) to be put to the test.

Twenty nine patients nursed on the Vaperm Mark 2 were observed three times weekly for a maximum of three weeks. Nine patients randomly allocated to DHSS mattresses were similarly observed. At each observation the Pressure Sore Prediction Score (P.S.P.S) was calculated and recorded. In this way, the mean P.S.P.S. for each patient's trial period could be correlated to the development of new or more serious sores. Although only nine patients were nursed on the DHSS mattress their mean P.S.P.S.'s were spread over the fairly wide range of 5 - 10.8. The histogram based on this range of P.S.P.S.'s (Figure 68) suggests that patients nursed on this support are at risk of sores when their P.S.P.S. is six or more.

On the Vaperm Mark 2 the range of mean P.S.P.S.'s was 2.6 to 13.5. The histogram derived from this range of means is shown in Figure 69. This indicates a steady increase of pressure sore risk with increasing scores, and suggests that the P.S.P.S. is a useful method of assessing such risk amongst orthopaedic patients at least.

The small number of patients nursed on the DHSS mattress make it difficult to draw firm conclusions from the histogram in Figure 68. Nevertheless, there is a suggestion that the Vaperm Mark 2 mattress reduced the risk of sores by a matter of one or two points on the P.S.P.S. scale.

6.1.4. Practical drawbacks of the Vaperm Mark 2

Although the pilot trials of the Vaperm Mark 2 were promising the mattress was found to have some practical disadvantages. In particular, the special cover (see above - 6.1.1.) was expensive and, in warm humid conditions, the resin coating tended to delaminate and tear. Its effective life proved to be
Patients with new or worse sores: 0 5 1 1 0
Total patients: 2 5 1 1 0

FIG. 68 RELATION BETWEEN PRESSURE SORES AND MEAN P.S.P.S.- PATIENTS NURSED ON DHSS MATTRESS (CLASS I).
Patients with new or worse sores: 0 1 2 3 1
Total patients: 8 10 6 4 1

FIG. 69 RELATION BETWEEN PRESSURE SORES AND MEAN P.S.P.S.- PATIENTS NURSED ON VAPERM MARK 2 MATTRESS.
less than three years. Washing the covers, at a disinfection temperature of 71°C, was impracticable.

It has been mentioned that the P.071 cover avoided the hammocking effect because of its stretch characteristics. However, a sustained load caused the fabric to remain stretched when the patient took his weight off the mattress. Loose folds of fabric then formed in the stretched area and, when the patient resumed his original position, he had to sit on creased folds of the cover fabric.

During the development of the Vaperm P.S.S. new fire-safety standards were being developed for foam furniture (Woolley et al, 1978) and a simple ignition test on the Vaperm Mark 2 (a lighted match on its cover) indicated that it would not meet the new safety requirements.

6.2. The Vaperm III

6.2.1. The general concept

The practical difficulties encountered with the Vaperm Mark 2 prompted a close investigation of the many conflicting requirements of a general-purpose hospital P.S.S. and much of this treatise is derived from the results of this investigation.

An obvious area for improving the Vaperm concept was the development of a more practical mattress cover. The pilot trials of the Vaperm Mark 2 indicated a number of ways in which improvements could be made.

It seemed clear that the new mattress should be usable on a contouring mattress base; and this suggested a relatively shallow mattress without a hinged section (see Chapter 3.4.3.) which would, nevertheless, bend into the Fowler's position shown in Figure 3. At the same time the overall firmness of the mattress should be sufficient to provide good orthopaedic support.
The depth of the mattress, at its long edges, needed to be 130 mm, or less, so that there would be no particular transfer problems on a King's Fund bed - in its lowest position (King's Fund, 1967).

Pressure tests under the heels (see Chapter 4.4.) indicated that the ends of the mattress needed to be relatively compliant, compared with the main body of the mattress.

The pilot trials of the Vaperm Mark 2 also showed that nurses were reluctant to nurse some patients without the ubiquitous pelvic ring cushions; particularly when these patients were seated-in-bed and were wasted around the buttocks. This emphasized the need for some means of sacral pressure relief to be incorporated into the mattress. The foam core of the mattress also needed to be particularly fatigue-resistant: it could not rely on a woven cover absorbing some strain by the hammocking effect.

By October, 1978 it was possible to produce a preliminary performance specification for the new mattress (Appendix VI). The rigid but ventilated mattress base (see above - 6.1.1.) was retained for use with the Vaperm III mattress, but new mattress coverings were needed; particularly to avoid the possibility of contaminated fluid being trapped within the mattress (see Chapter 3.3.).

In order to try and phase out the drawsheet and its hazards (see Chapter 1.3.4.3.) it was decided to explore a new bed-surfacing concept which would be as convenient, but less hazardous, than the drawsheet/mackintosh system.

6.2.2. The mattress core

A mattress core to meet the new specification (Appendix VI) was designed in co-operation with Dunlop PLC and Courtaulds PLC.

As the core needed to be relatively shallow it was recognized that very resilient foam, of relatively high density, would be needed
to provide adequate support for patients seated-in-bed. Such foam would also make the mattress relatively firm. The uppermost layers, however, would need to be softer and more compliant, so that a thin patient's bony prominences could be adequately cushioned. To elaborate, a thin patient is usually light, although the point loading on his bony prominences is high. Thus his prominences tend to sink into the soft compliant foam; although the broad expanse of his body is supported without any significant deformation of the mattress. Experience gained by the Dunlopillo branch of Dunlop PLC suggested that the flexible foams chosen for the uppermost layers should have a hardness in the range of 70 - 120 Newtons and a density of 30 - 35 Kg./m$^3$ (Ludman, 1978).

Following some personal pilot trials it was decided that the soft compliant layers would be best confined to the upper third of the mattress. At the foot end of the mattress, however, the middle layers of relatively firm foam were contoured so as to provide pressure relief for comparatively sharp bony prominences: i.e. the heels. This contouring, in the form of shallow grooves, was at both ends of the mattress, so as to allow the mattress to be turned (in the horizontal plane). But the contouring was designed to be relatively unresponsive to a broad body protuberance such as the head (see Figure 70). In this way it is possible to keep the mattress surface free from noticeable bumps and grooves, although the heels tend to find their way into the softer areas over the foot-end grooves. A similar but shallower groove, in the central area of the mattress core, was designed to provide some pressure relief over the sacrum and spinous processes of thin and emaciated patients.

The new mattress was designed to fit a King's Fund bed and, consequently, it measured 200 cms. in length and 87 cms. in width. For very tall patients, a mattress extension may be necessary (see Chapter 1.3.4.2.) and this could be made of the same type of foam as used for the upper layers of the mattress: it would not be liable to either excessive loading or prolonged use. It would
FIG. 70 VAPERM III MATTRESS - METHOD OF PROVIDING PRESSURE RELIEF FOR HEELS WITHOUT COMPROMISING HEAD SUPPORT.
FIG. 71  SKETCH OF SECTIONED VAPERM III MATTRESS.

- Short-life vapour-permeable waterproof cover
- Surface layers of compliant foam
- Firm Chipfoam edge
- Firm resilient foam with pressure-relieving channels and ventilation holes
- Stretch cover
- 87 cm.
have the same width and shape as the mattress and would extend the mattress length by about 20 cms.

The use of relatively dense foams, in the lower two-thirds of the mattress, gives the core sufficient resilience and weight (13 Kgs.) to enable it to bend to fit the shape of a contouring bed (see Chapter 3.4.3.) without the need for special hinges. The weight of the mattress also helps to keep the bedclothes in position, although it is still light enough for occasional lifting by one nurse (see Chapter 2.5.9.).

Pilot trials by the author, on various foam mattresses (Chapter 5.3.6.) indicated that their heat-insulative effect might be critical in warm ambient conditions. Accordingly, the new mattress core was ventilated by means of regularly-spaced holes in the firm layers of foam.

Although most of the foams used in the new core were not flame-retardant, it was recognized that the uppermost layer should be able to resist flame ignition. The special "cold-cure" foam chosen for this layer has the required property by virtue of its ability to melt and drop away from the ignition source (Ludman, 1978). The finalized core design is shown in Figures 70 and 71.

6.2.3. The mattress covers

The high cost of producing the proofed fabric cover of the Vaperm Mark 2 prompted the adoption of an alternative cover, which would be inexpensive enough to be discarded after a short period of use. A thin pliable film of polyurethane rubber (Platilon U01) was found to be a suitable material to make into a waterproof mattress cover and, as mentioned in Chapter 5, a 30 microns film had sufficient water vapour permeability for the purpose. An additional advantage of a 'short-life' cover was the ability to discard the cover, between patients, should there be any danger of cross-infection.
The first covers in 30 micron U01, made in 1979, cost £2 each and this made the 'short-life' principle a feasible proposition. There appeared to be no contraindications to using this material as a mattress cover. Pilot trials, in clinical use, have suggested that its average service life is in the region of eight months.

The film cover is made in the form of a fitted bedsheet, so that a large area of the bottom of the mattress remains uncovered. A flame-retardant fabric sheet is bonded to the underside of the mattress core, but this is porous (for ventilation of the mattress) and has integral cloth handles — for lifting the mattress. The presence of this bonded-on sheet makes it very difficult for the mattress to be used, inadvertently, upside-down.

A knitted fabric stretch cover (also porous) was developed, in co-operation with Courtaulds PLC, to cover the top and sides of the mattress; this being used directly over the foam of the mattress core and beneath the waterproof film cover. It protects the foam from tearing due to rough handling and also has a chemical treatment to impart flame retardant properties. As this 'Basic' cover contains absorbent cellulosic fibres it easily stains — should urine find its way through a damaged film cover. Such a stain can be seen through the transparent film cover, and this enables the nurse to identify the leak, change the film cover, and wash the Basic cover.

The absorbent fibres of the Basic cover also help to prevent fluid entering the foam core. Should this happen, however, the fluid can quite quickly disperse, by evaporation, through the porous underside of the mattress. In other words, it does not become a reservoir of pathogenic microbes (see Chapter 3.3.)

When the new mattress assembly was tested for flame retardancy it was found that the mattress covers, in combination with the top layer of the mattress core, enabled the mattress
to pass "Source 5" (a burning wooden crib on the mattress surface) of the D.O.E. flammability specification 10 (D.O.E./P.S.A., 1978). When the crib had burnt itself out the mattress surface was self-extinguished (Poole, 1981).

Clinical experience with the new mattress has shown that the pliable film cover is so thin that creases forming in it, during use, are not noticed by the patient. Neither this cover, nor the Basic cover, appear to have any harmful effects on a patient's skin. There was, however, some initial concern about creases forming in the Basic (knitted) cover (see above - 6.1.4.) when a patient changed his position on the bed. It was reasoned that this might be averted by ensuring a high coefficient of friction at the foam core/Basic cover interface. The rationale of this approach was the assumption that the mattress foam and the cover would stretch (under a load) and recover, in unison. Experience to date has shown that creases do not seem to form in the Basic cover, even after patients have been bedfast for many weeks.

The Basic cover is designed to last the life of the mattress core, but it can be replaced. Fatigue tests (Ludman, 1978) suggest that the new mattress will have an average life of about eight years.

The effect of the new cover materials on the static electricity produced by bed-making was considered. Tests by Courtaulds (Poole, 1981) compared the Vaperm III assembly with the DHSS specification mattress and cover. The results showed no significant difference between the two systems. An ordinary cotton sheet was used on each assembly.

6.2.4. The bedding

As discussed in Chapter 5, the bedding used on a hospital mattress needs to have fairly precise friction
characteristics. Fortunately, the woven cotton bedsheets normally used on hospital beds do (when dry to the touch) have suitable characteristics. Nevertheless, the slightly lower coefficient of friction found on the special knitted sheet (see Chapter 5.2.8.) makes it marginally better for covering the new mattress assembly.

The stretch characteristics of the knitted sheet do allow folds of the material to collect under a patient, similarly to the P.071 mattress cover (see above - 6.1.4.) but, in the case of the stretch sheet, the folds are relatively innocuous. However, without some means of anchoring the stretch sheet to the mattress corners, it would crumple too easily under tangential forces. This would seem to make it an unsuitable material to use in the form of a drawsheet.

As discussed in Chapter 5, a resilient porous pad, some 10 mm thick, is needed to improve the microclimate at the patient/support interface. If such a pad is placed directly on the Vaperm III's film cover no draw mackintosh is needed and, providing that similar pads can be used to cover the remainder of the waterproof cover, the conventional 'bottom sheet' is not required. This system preserves the W.V.P. benefits of the mattress assembly.

A system using just three overlapping pads was devised by the author and has since been patented (U.K. patent application 8020164). As shown in Figure 72 the central pad of this system can be removed without disturbing the other pads. It can be rolled up, and replaced, in a similar manner to the traditional drawsheet. Each pad is identical, in order to minimise both sorting problems and production costs. The flaps which 'anchor' the pads under the mattress are designed to resist tangential forces produced by the 'Forward slide' and positioned to avoid producing a hammocking effect - on the vulnerable body protuberances. The 10 mm foam inside the pads gives extra interface cushioning
Head-end pad folded over mattress end.

Central pad pulled sideways.

Triangular tuck-in flaps.

Quilted foam pad.

FIG. 72 SKETCH OF DRAWSHEET REPLACEMENT SYSTEM ON A VAPERM III MATTRESS.
and both sides of the foam are covered with the knitted sheet fabric mentioned above. A 'non-return' hydrophobic layer might also be fitted, as on the Dupic underpad (Chapter 2.6.1.).

As this system dispenses with the need for bottom sheets, drawsheets and draw mackintoshes, it should, if used for selected patients, prove to be economically acceptable.

Pilot trials of the first prototypes have given an indication that the system will be appreciated by both nurses and incontinent patients.

6.3. **Tests and trials of the Vaperm III**

6.3.1. **Load/pressure tests**

The layered and contoured structure of the Vaperm III mattress core made it necessary to conduct various load/pressure tests. Some of these were to judge the effectiveness of the special interior grooves ('Soft-strips') while others were to test the main areas of support. All of the tests were on new mattresses.

The conditions for the load/pressure tests were the same as those described in Chapter 4.1.1.

Some tests were conducted with the emaciated torso indenter, some with the three-domed indenter, and some with the heel indenter.

6.3.2. **Load/pressure test results**

Only two tests were conducted with the emaciated torso indenter; both being on a Vaperm III complete with covers. One of these tests was with the 'sacrum' of the indenter over the central 'soft-strip', while the other was on the main 'seat area' of the mattress. Figure 73 shows the 'sacral' pressures recorded on these two tests and, for comparison, the equivalent results on the DHSS mattress (see Chapter 4.1.3.3.) are also shown.
FIG. 73 EMACIATED TORSO INDENTER TESTS ON VAPERM III MATTRESS IN COVERS ALONE, AND DHSS MATTRESS IN COVERS ALONE.
The three-domed indenter was used for the following tests under the 17.5 Kg. load:

1. Mattress core covered with Basic cover and film cover - over central soft-strip (one test).
2. Mattress core covered as above, plus an ordinary hospital 'bottom sheet' made of woven cotton - over central soft-strip.
3. Covered mattress core (as above) but with a drawsheet replacement pad in place of bottom sheet - over central soft-strip (one test).
4. Mattress core covered as above, except that a fitted stretch sheet was used as the bottom sheet - over central soft-strip (one test).
5. Mattress core, with covers only, but on the main seat area, and not over a soft-strip (one test).

The pressure profiles resulting from these tests are shown in Figures 74, 75 and 76.

The tests completed with the three-domed indenter loaded to 37.5 Kg. were as follows:

1. Mattress core with covers only - over central soft-strip (one standard test and one 'dwell' test).
2. Mattress core covered as above, plus an ordinary 'bottom sheet' made of woven cotton - over central soft-strip (one standard test).
3. Covered mattress core (as above) but with a drawsheet replacement pad in place of bottom sheet - over central soft-strip (one standard test and one 'dwell' test).
4. Mattress core covered as above, except that a fitted stretch sheet was used as the bottom sheet - over central soft-strip (one standard test and one dwell test).
5. Mattress core with covers only, but on the main seat area, and not over a soft-strip (one standard test and one dwell test).
FIG. 74  PRESSURE PROFILES ON VAPERM III MATTRESS - all at 17.5 Kg. LOAD.

KEY:

--- = Mattress in covers alone.

--- = Covers + cotton sheet.

-- = Covers + drawsheet replacement pad.

N.B. Profiles taken with dome over central soft strip.
FIG. 75 PRESSURE PROFILE ON VAPERM III MATTRESS PLUS COVERS AND FITTED STRETCH SHEET - 17.5 Kg. load.

N.B. Profile taken with dome over central soft-strip.
FIG. 76 PRESSURE PROFILE ON VAPERM III MATTRESS IN COVERS ALONE - 17.5 Kg. LOAD.

N.B. Profile taken with dome on seat area - avoiding central soft-strip.
The pressure profiles resulting from these tests are shown in Figures 77, 78, 79, 80 and 81.

The heel indenter was used for the following load/pressure tests:

1. Mattress core with covers only - 27 cms. from foot end (four tests).
2. Mattress core covered as above, plus an ordinary cotton 'bottom' sheet - 27 cms. from foot end (one test).
3. Mattress core covered as above, except drawsheet replacement pad in place of bottom sheet - 27 cms. from foot end (one test).
4. Mattress core with covers only, but on main seat area, and not over a soft-strip (one test).

The mean result of all four tests on the mattress, in its covers alone and over a soft-strip, are given in Figure 82. Standard deviations are given for each load. Also shown on this figure is the curve for the DHSS specification mattress (see Chapter 4.3.2.) and the result of the one test on the seat area of the Vaperm III.

Figure 83 shows the result of the one test on the drawsheet replacement pad and the one test on the cotton bottom sheet.

6.3.3. Discussion

The results of the emaciated torso indenter tests need to be interpreted in the light of the reservations expressed in Chapter 4.1.3.4. Nevertheless, it seems clear that an emaciated patient's bony prominences will be under less pressure on the Vaperm III than they will be on the DHSS specification mattress. Figure 73 also suggests that the central soft-strip of the Vaperm III will reduce sacral pressure; when an emaciated patient is positioned in the centre of the mattress. Similarly, the heel indenter tests shown on Figure 82 suggest that the foot-end soft-strips will reduce heel pressures.
N.B. Profiles taken with dome over central soft-strip.

'Dwell test'

FIG. 77 PRESSURE PROFILES ON VAPERM III MATTRESS IN COVERS ALONE - 37.5 Kg. LOAD.
N.B. Profile taken with dome over central soft-strip.

FIG. 78 PRESSURE PROFILE ON VAPERM III MATTRESS PLUS COVERS AND HOSPITAL COTTON BEDSHEET - 37.5 Kg. LOAD.
N.B. Profiles taken with dome over central soft-strip

FIG. 79 PRESSURE PROFILES ON VAPERM III MATTRESS - WITH COVERS AND DRAWSHEET REPLACEMENT PAD - 37.5 Kg. LOAD.
N.B. Profiles taken with dome over central soft-strip.
N.B. Profiles taken with dome on seat area - avoiding central soft-strip.

FIG. 81 PRESSURE PROFILES ON VAPERM III MATTRESS IN COVERS ALONE, BUT SEAT AREA - 37.5 Kg. LOAD.
FIG. 82 HEEL INDENTER TESTS - VAPERM III & DHSS MATTRESSES.
**Fig. 83: Additional Heel Indenter Tests - Vaperm III.**

- In covers + cotton sheet over 'soft-strip'
- In covers + drawsheet replacement pad over 'soft-strip'

Pressure in mm Hg.

Load in Kg.
The pressure profiles resulting from the three-domed indenter tests were similar to those on the Vaperm Mark 2 mattress (see Chapter 4) at the 17.5 Kg. loading. When, however, the 37.5 Kg. loading was used on the indenter, the firmer layers of the Vaperm III indicated their presence by producing a steeper profile than that of the Vaperm Mark 2 (compare Figure 77 with Figure 46). Nevertheless, a comparison with the profiles for a DHSS specification mattress at 37.5 Kg. loading (Figure 44) and a spring-interior mattress under the same loading (Figure 47) suggests that the Vaperm III will produce less tissue distortion than the more traditional mattresses.

The various 'dwell' tests on the Vaperm III indicate that there is no pressure-ring effect; as seen with some other supports (Chapter 4.2.4.)

The drawsheet replacement pad appeared to make only a slight difference to the pressure profiles produced on the Vaperm III (see Figures 77 and 79).

6.3.4. Pilot clinical trials

6.3.4.1. Trial design

During the Vaperm Mark 2 clinical trials (see above - 6.1.3.) some of the hospital nurses developed an obvious bias against the 'control' (DHSS specification mattress) and, in consequence, it was impracticable to use this control for a definitive clinical trial of the Vaperm III. Pending a decision on controlled trials in other hospitals, the Vaperm III prototype mattresses were used for a number of pilot clinical trials at the Royal National Orthopaedic Hospital, Stanmore (RNOH).

The pilot trials were confined to non-ambulant patients who scored 6 or more on the Pressure Sore Prediction Score. Nine pilot trials were undertaken. Eight were in the wards of the accident unit of the RNOH, and one was in a rehabilitation ward. The patients were nursed under similar conditions to those used
on the Vaperm Mark 2 trial (see above - 6.1.3.) The bottom sheets used were either ordinary cotton sheets or the special fitted stretch sheets. Drawsheets were not allowed but, as the special drawsheet replacement system was not then available, Dupic underpads or disposable underpads were used to cope with incontinence problems. Large foam rings and similar cushions (for use under the pelvis) were not allowed, but pillows were sometimes used under the lower legs. The beds were all straight-based traditional or King's Fund types, with rigid ventilated bases. There were no restrictions on the use of backrests. In all cases, the patients had no clothing over their buttocks while in bed.

Unless a patient left the trial for some reason, such as transfer to another hospital; the trials lasted for three weeks. The author examined the patients three times weekly and took photographs of any pressure sores. A number of other details were checked at the same time. These included:

1. The type of bed and mattress base,
2. bed accessories in use, and whether or not the bed backrest was in use when the patient was approached,
3. whether the Dupic underpad was in use,
4. the patient's age, diagnosis, treatment etc.
5. temperature,
6. Pressure Sore Prediction Score,
7. sensory loss below the waist,
8. any spontaneous comments on the support,
9. whether or not the trial conditions were correct.

A simple questionnaire was used at the end of each trial, to ask patients if they were comfortable on the mattress, and a follow-up observation was made one week after each patient stopped using the Vaperm III. Two patients, however, continued to use the new mattress beyond the end of their trial period.
6.3.4.2. **Trial results**

Four of the pilot trial patients had no pressure sores when admitted to the trial, but the remaining five did have such sores. In consequence, the trial results were assessed on the incidence of new sores or the worsening of existing sores; or the converse.

One patient had to be excluded from the results tables, because the nursing conditions imposed for the trial were frequently overlooked. Another patient was on the trial for only four days and another for 18 days. However, both of these latter patients were included in the results. The one excluded patient had heel sores on trial entry, but did not develop any further sores during her trial.

The characteristics of the eight accepted patients are shown on Table 7. The mean P.S.P.S. is an indicator of either new sores developing or existing sores deteriorating (see Figure 68) but a score assessed at the second observation of a trial seems to be more reliable for predicting sores in new admissions who are free of existing sores (Norton et al, 1962; Lowthian et al, 1976). Accordingly, both the mean and second observation scores are given— for each patient. The new admissions without sores were patients V1, V2, and V9.

The random observations of patients occurred during the daytime, so that an estimated 100% use of the bed backrest does not necessarily mean that it was in use during the night.

Only one patient (V6) used the Dupic underpad (one observation) and the same patient also used a disposable underpad (one observation).

The results of each patient trial, in terms of pressure sore incidence or existing sore deterioration, are given in Table 8. Also shown on this table are the 'Follow-up' results.
<table>
<thead>
<tr>
<th>Code No.</th>
<th>V1</th>
<th>V2</th>
<th>V3</th>
<th>V9</th>
<th>V4</th>
<th>V5</th>
<th>V6</th>
<th>V8</th>
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<td>Sex</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>F</td>
<td>F</td>
<td>M</td>
<td>F</td>
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<tr>
<td>Age in years</td>
<td>52</td>
<td>77</td>
<td>24</td>
<td>74</td>
<td>92</td>
<td>60</td>
<td>54</td>
<td>68</td>
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<tr>
<td>PSPS at second observation</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>8</td>
<td>9</td>
<td>11</td>
<td>7</td>
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<tr>
<td>Sores at start of trial</td>
<td>nil</td>
<td>nil</td>
<td>nil</td>
<td>nil</td>
<td>1 (pelvic)</td>
<td>1 (pelvic)</td>
<td>3 (pelvic)</td>
<td>1 (ankle)</td>
</tr>
<tr>
<td>Degree of sensory loss below waist</td>
<td>nil</td>
<td>nil</td>
<td>some</td>
<td>nil</td>
<td>nil</td>
<td>some</td>
<td>nil</td>
<td>nil</td>
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<tr>
<td>Days on trial</td>
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<td>21</td>
<td>21</td>
<td>18</td>
<td>21</td>
<td>4</td>
<td>21</td>
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<tr>
<td>Mean PSPS</td>
<td>5.3</td>
<td>6.3</td>
<td>9.4</td>
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<td>7.6</td>
<td>9</td>
<td>11</td>
<td>6.4</td>
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<td>Maximum recorded temp. (°C)</td>
<td>36.7</td>
<td>36.6</td>
<td>36.9</td>
<td>37.4</td>
<td>36.8</td>
<td>39.8</td>
<td>38</td>
<td>37.4</td>
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<tr>
<td>% of time in bed (estimate)</td>
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<td>100</td>
<td>95</td>
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<td>100</td>
<td>75</td>
<td>63</td>
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<tr>
<td>% of time backrest in use *</td>
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<td>93</td>
<td>18</td>
<td>100</td>
<td>88</td>
<td>91</td>
<td>100</td>
<td>90</td>
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</tbody>
</table>

Main diagnoses:
- V1 - Compound fracture of leg.
- V2 - Fractured pelvis.
- V3 - Quadraplegia.
- V4 - Removal of hip pins.
- V6 - Hip replacement.
- V8 - Arthritis.

V9 - Bilateral femoral fractures.

V5 - Quadraplegia.

TABLE 7 CHARACTERISTICS OF ACCEPTED PATIENTS (VAPERM III PILOT TRIALS).
<table>
<thead>
<tr>
<th>Code No.</th>
<th>V1</th>
<th>V2</th>
<th>V3</th>
<th>V9</th>
<th>V4</th>
<th>V5</th>
<th>V6</th>
<th>V8</th>
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</thead>
<tbody>
<tr>
<td>New sores</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1 -</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>pelvic (G.2)</td>
<td></td>
</tr>
<tr>
<td>Existing pelvic sores</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>which healed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>N/A</td>
</tr>
<tr>
<td>Other existing sores</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>which healed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1 -</td>
</tr>
<tr>
<td>ankle (G.2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ankle (G.2)</td>
</tr>
<tr>
<td>New sores at</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'follow-up'</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>not</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>seen</td>
<td></td>
</tr>
<tr>
<td>&quot;Mattress uncomfortable?&quot;</td>
<td>No</td>
<td>No</td>
<td>-</td>
<td>not</td>
<td>No</td>
<td>Not</td>
<td>Yes,</td>
<td>Not</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>really</td>
<td>asked</td>
<td></td>
<td>on existing sore</td>
<td>asked</td>
<td>No</td>
</tr>
</tbody>
</table>

N/A = Not applicable.

**TABLE 8** RESULTS OF PILOT CLINICAL TRIALS ON VAPERM III MATTRESS.
(where applicable) and answers to the crucial follow-up question: "Has this mattress been in any way uncomfortable?" No patients made adverse spontaneous comments on the Vaperm III. One patient (v8) made a spontaneous comment that the mattress was very comfortable, and another patient (v9) exclaimed "Oh that's better!" as soon as she was placed on the Vaperm III. This latter patient had previously been on a spring-interior mattress (for two days).

The two patients who continued using the Vaperm III beyond their trial period did so because the ward nurses objected to the new mattresses being replaced by the usual (spring-interior) ward mattresses.

6.3.4.3. Discussion

Although the clinical trials were very limited, the results obtained suggest that the Vaperm III P.S.S. is well-accepted by both patients and nurses: it appears to be both comfortable and practical. Only one of the eight patients developed a new sore, but this patient (v6) had the highest P.S.P.S. (11) and already had five pressure sores. His new sore (G.2.) developed from an existing G.1. sore.

None of the four patients without sores, on trial admission, developed any sores during the trial, even though their P.S.P.S.'s ranged from 6 to 10 (second observation). Moreover, one of these patients (v.2.) developed a G.2. buttocks sore one week after being taken off the Vaperm III mattress. One patient's existing G.2. buttocks sore healed during the trial period. It was treated by covering it with an adhesive polyurethane film (Op-Site).

One of the patients who spent longer than 3 weeks on the Vaperm III (v5) had an indwelling urethral catheter and, because a suitable hanger was not available, the drainage bag for the catheter was frequently pinned to the bottom sheet over the mattress. After four months use by this patient the short
life waterproof cover was checked. There were numerous pin-
holes in each side of the cover, but no holes or tears extended
onto the sitting area of the cover: it was still usable.

The other patient who remained on the Vaperm III for more
than the three weeks trial period was on sliding traction, to
both legs, for 17 weeks. After this she was allowed up in a
chair. She developed no sores during her 17 weeks in bed and,
on examination, the new mattress appeared to be in good
condition. In particular, there were no creases at all in the
Basic (fabric) mattress cover.

Following the first nine pilot trials of the Vaperm III
the nursing staff were convinced of its benefits and 60 of the
new mattresses were ordered, for general use in the R.N.O.H.
Subsequently, it has been decided to replace all R.N.O.H.
mattresses on adult beds with Vaperm III mattresses. There has
also been a bed replacement programme in operation for the last
two years, and all of the new beds have rigid 'Weldmesh' bases
(see above - 6.1.1.)

A report on the development of the Vaperm III and its
advantages when compared with the DHSS specification mattress
(Class 1) was published in the Lancet (Appendix VII).

6.4. Conclusions and further developments

The Vaperm III P.S.S. was developed to partially fulfill
the research aims defined in Chapter 3. It seems to meet the
requirements of the first development stage (Chapter 3.4.4.) in
that the mattress is a suitable replacement for the traditional
and DHSS specification mattresses. It is anticipated that the
use of the Vaperm III mattress, on a King's Fund bed with a
ventilated mattress base (see above - 6.1.1.) will provide a
general-purpose P.S.S. which will improve patient comfort, and
avoid the particular practical hazards of the contemporary P.S.S.
(Chapter 3.4.2.)
The optimum surface coverings (bottom sheet) for the Vaperm III mattress have still to be developed, but friction tests (chapter 5) indicate that polyester/Vincel sheets or Nylon/viscose/cotton stretch sheets are more suitable than traditional cotton sheets. The new drawsheet replacement concept (see above - 6.2.4.) should overcome the drawsheet hazards discussed in chapter 2.6., but is not yet available.

The third development stage of the research aims (Chapter 3.4.4.) to develop an improved contouring mattress base, is in abeyance due to a lack of funding, but pilot tests suggest that the new mattress will perform well on existing contouring beds (see chapter 3.4.3.).

The use of fatigue-resistant foams in the new mattress make 'grounding' on the mattress base less likely than on the DHSS specification mattresses (see Chapter 3.4.2.) but, as a precaution, a note to test the mattress every five years, is fixed to the underside of the Vaperm III. The foam construction of the Vaperm III means that it is radio-translucent so that, if necessary, radiographs can be taken through the mattress.

The relatively low cost of the waterproof film cover of the Vaperm III suggests that it has potential for domestic use; particularly for enuresis sufferers (Lowthian, 1973) and for preventing dust mite contamination of mattresses (Chapter 1.2.). The inherent simplicity of the Vaperm III makes it suitable for situations where skilled nursing is not available. Its appearance will not alarm the anxious patient.

If required, sophisticated pressure sore prevention aids, such as ripple mattresses and net suspension beds, can be used on the Vaperm III P.S.S.

Being a vented system, the new P.S.S. lends itself to modifications involving air supply or extraction. Improving
the treatment of pyrexial patients, particularly in warm climates, could be accomplished by using a mechanical blower to force a stream of cool dry air into the core of the mattress; the mattress being suitably covered to allow the slow escape of this air, as it is warmed by the patient's body.
Summary

A one-day prevalence survey at the Royal National Orthopaedic Hospital, Stanmore, showed that 12 of the 186 in-patients (6.5%) had a pressure sore which was defined as 'open'. When allowance is made for three patients admitted for the treatment of pressure sores, and for other patients who were severely disabled, most of the other sores were located in the buttocks/sacral region. This suggests a correlation with the semi-recumbent nursing position so often used for bed-patients in hospital.

The average age of the population studied (44.2 years) suggests that the prevalence of pressure sores in hospitals which have fewer juvenile patients, may be higher than was found on this survey.

Introduction

A one-day point-prevalence survey of pressure sores was carried out at the Royal National Orthopaedic Hospital, Stanmore, on 26th April, 1978. The object was to gain an indication of the typical prevalence of pressure sores in this special orthopaedic hospital; which information was necessary in order to plan a proposed comparative trial of patient support systems.

The Royal National Orthopaedic Hospital, Stanmore, tends to specialize in certain fields, notably in scoliosis correction and hip replacement. The hospital has 301 beds, including 16 beds on a 5-day ward: all were included in the survey.
Methods

The survey was carried out by three of the hospital nursing officers and a research assistant who was also a nurse. The nursing officers each covered two or three wards for which they were normally responsible and the research assistant covered one ward in each of the areas for which the various officers were responsible. The wards were informed of the date of the survey on the 21st April and were asked to place coloured stickers on the beds of all their patients who were known to have pressure sores, or were 'non-ambulant' (including patients who could only walk with help or aids) on the day in question. Patients with a sticker on their beds and any other non-ambulant patients, were examined by the survey team. Wednesday was chosen as the day for the survey so that patients who normally went home for the weekend could be included; and so that the results of the survey could be compared with the recent pressure sore survey in the Greater Glasgow Health Board (Jordon & Clark, 1977).

Pressure sores were defined similarly to the Greater Glasgow study (see above) but each grade of sore was given a more detailed description. The definitions were as follows:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>CATEGORY</th>
<th>GRADE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood under the skin or in a blister,</td>
<td>Incipient</td>
<td></td>
</tr>
<tr>
<td>or black necrotic discolouration under the skin,</td>
<td>sores</td>
<td>1</td>
</tr>
<tr>
<td>measuring more than 5 mm in diameter (longest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>measurement)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>or clear bullae more than 15 mm in diameter.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A break in the epidermis, which may also include</td>
<td>Open</td>
<td></td>
</tr>
<tr>
<td>some damage to the dermis but without necrotic</td>
<td>sores</td>
<td>2</td>
</tr>
<tr>
<td>discolouration and measuring more than 5 mm in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>diameter.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Destruction of the skin (epidermis and dermis) without an obvious cavity, but possibly with some necrosis or necrotic discolouration—sores more than 5 mm in diameter.

Penetration of the skin (epidermis and dermis) with a subcutaneous cavity (with or without necrotic tissue) more than 5 mm in diameter.

Although persistent erythema is often regarded as a "grade 1" sore (Bliss et al., 1966; Delateur et al., 1976) the practical difficulties of distinguishing between reactive hyperaemia; skin excoriation due to incontinence; healing skin; and skin infections (e.g. candida); would have probably caused considerable disagreement between the observers, as indeed was found to be the case when the unqualified term "skin discolouration" was used in the Greater Glasgow study (Jordan & Clark, 1977). Skin discolouration (other than black necrotic discolouration or haemorrhage) is particularly difficult to diagnose when the development of the discolouration has not been observed and when the patient in question is dark-skinned.

Sizes of the various sores were judged by means of a template (supplied to all the observers) which was held just above the lesion being measured. Sores which failed to overlap the smallest hole on the template (5 mm diameter) were not counted. Sores which overlapped the second largest hole on the template (15 mm diameter) were counted as medium-sized sores and a large sore was one which overlapped the largest hole on the template (50 mm diameter). These three size limits were the same as previously used, in a survey by Lowthian (1976). The position of each sore was also noted.

The survey started at 7.30 a.m. and was completed at 2.0 p.m. The principal diagnosis, age and sex of all in-patients,
was noted, as was the number of patients examined and their mobility.

The four members of the survey team reached agreement on the definition of sores before the survey started. Photographs of the various grades of sore (taken in 1974-75) were used for this purpose. Additionally, where there was any doubt about the grade or size of a sore reported, the patient concerned was reviewed by the team leader – no disagreements were discovered.

Results

The total patients in the hospital, at the time of the survey, was 186. Twenty-nine of these patients (15.6%) were aged 70 or over, (50% of the Glasgow survey population were aged 70 or over), 80 patients (43%) were under 30 years of age.

According to the survey definition 13 patients (7%) had at least one pressure sore. However, not all of these patients had 'open' sores (Grades 2, 3 or 4). The Greater Glasgow survey, referred to above, found that 8.8% of the 10,751 patients surveyed had at least one sore of grade 2, 3 or 4; and these three grades are considered to be roughly equivalent to the definitions used in the present survey. The number of patients with a sore (or sores) of grade 2, 3 or 4 – in the present study – was 12 (6.5% of 186).

It is assumed that the ward nurses notified (by means of a bed-sticker) all of their patients who had pressure sores and that none of the patients who were not notified (ambulant patients) had any sores. The Glasgow study (see above) also relied on ward nurses notifying all of their patients who had sores. Thus, the prevalence figure found on the present survey (6.5%) seems comparable with the Glasgow survey figure of 8.8%, although the populations studied were not really equivalent. The total patients that the nursing officer/research assistant survey team actually examined (on the present survey) was 153.
The total number of sores recorded was 28, but 13 of these were on one patient, who had been admitted to treat pressure sores acquired elsewhere.

The well-known association of age with pressure sores was supported by this study: of the 29 patients aged 70 or over, 4 (13.8%) had at least one pressure sore.

Poor mobility is another factor associated with pressure sores and of the 13 patients with sores 4 were bedfast and 8 were chairfast. It should be appreciated, however, that these figures do not suggest that chairfast patients are more liable to develop pressure sores than are bedfast patients, as many of these sores may have started whilst a now chairfast patient was confined to bed.

One hundred and eight of the 186 patients were female and 6 of these had pressure sores. Of the 78 male patients 7 had sores. These figures are too small to suggest any significance in the larger proportion of male patients with sores.

Table 1 shows the principal diagnoses of the 186 in-patients, and the number in each group who had pressure sores. It can be seen that the majority of sores were found on patients who had spinal injuries, M.S., T.B. spine, or Spina Bifida. Three of these patients had been admitted to hospital specifically for treatment to sores they had acquired elsewhere - all three were being treated on Low Air Loss Beds (Scales, 1976).

Ten out of the total 28 sores were located on the buttocks: three were over the sacrum; three were over the femoral trochanter; and a further two were over the outer ankle malleolus. The remaining 10 sores were in various sites, such as the knee, calf, tibial tuberosity, perineum and medial ankle.
The number of sores in the different size categories (small, medium and large) is shown in Table 2. The majority of sores were less than 50 mm in diameter (longest parameter).

Nine of the ten buttocks sores were grade 2 sores and five of these were medium-size. Most of the other medium-size sores were on the one patient, referred to above who had a total of 13 sores.
<table>
<thead>
<tr>
<th>PRINCIPAL DIAGNOSIS (GROUPS)</th>
<th>NO. OF PATIENTS</th>
<th>NO. OF PATIENTS WITH SORES</th>
<th>NO. OF SORES IN VARIOUS GRADES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>G.1</td>
</tr>
<tr>
<td>Scoliosis</td>
<td>22</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Total Hip Replacement</td>
<td>16</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(Recent)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee Replacement,</td>
<td>12</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>and other Implants,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>or Removals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg Amputation and</td>
<td>10</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Similar Patients</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>undergoing Rehabilitation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spinal Injury (including</td>
<td>15</td>
<td>5*</td>
<td>1</td>
</tr>
<tr>
<td>M.S. and T.B. Spine)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fractured Femur</td>
<td>13</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>(or Neck of Femur)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Congenital Dislocation of</td>
<td>11</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Hip</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spina Bifida</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Diabetes Mellitus</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>General Orthopaedic</td>
<td>82</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>and Accidents</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Including one patient with 13 sores

**TABLE 1:** DIAGNOSES ASSOCIATED WITH PRESSURE SORES
<table>
<thead>
<tr>
<th>SORE GRADE</th>
<th>NO. OF SORES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SMALL</td>
</tr>
<tr>
<td></td>
<td>(6-15mm)</td>
</tr>
<tr>
<td>GRADE 1</td>
<td>-</td>
</tr>
<tr>
<td>GRADE 2</td>
<td>5</td>
</tr>
<tr>
<td>GRADE 3</td>
<td>2</td>
</tr>
<tr>
<td>GRADE 4</td>
<td>1</td>
</tr>
<tr>
<td>TOTALS</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 2: Sizes of Sores

Discussion

The small number of patients found to have sores makes it difficult to draw any firm conclusions from this survey, but if we allow for the fact that most of the deep sores (grades 3 and 4) were found on severely disabled patients (in various locations) the majority of the remaining sores were superficial (grade 2) and located over the buttocks. This suggests that the 'forward slide' phenomenon (Lowthian, 1975; Scales, 1976) was a significant factor in producing the sores in question.

Although some of these buttock sores may have started before the patients concerned entered the hospital, at least four were known to have been acquired since admission.

Apart from the Low Air Loss Beds mentioned above, most of the hospital beds were either of the traditional iron-framed type, or of the 'Kings Fund' type; and the integral backrests of these beds were frequently in use, without the benefit of the thigh support provided on a 'gatched' bed (Lowthian, 1975). The
greater number of buttocks sores, as opposed to sacral sores, found on this survey; contrasts with the relatively high proportion of sacral sores found on other surveys (Lowthian, 1976; Jordan and Clark, 1977) but this may reflect the fact that these latter surveys looked at a significantly older population and elderly people often lose much of their intrinsic buttocks cushioning (subcutaneous fat and muscle) thereby making their sacrum bear the brunt of the 'forward-slide' effect.

The oft-expressed view that pressure sores start on the operating theatre table does not seem to be supported by this survey, as only one of the 16 patients who had recently had a hip replacement had a sore and this particular patient was reported to have been sore before the operation.

No heel sores were found, but this was not surprising in view of the abundant supply of bed cradles in this hospital and the practice of placing pillows under the lower legs of patients who are severely disabled (Bliss et al, 1966).

The relatively low prevalence of sores found in this survey is probably due to the average age of the population studied (44.2 years) and a particularly strong nursing emphasis on pressure sore prevention. Further one-day surveys may be necessary to indicate the influence of seasonal changes on pressure sore prevalence.

References


Acknowledgements

This survey owes much to the active support of both Professor J.T. Scales and Miss M. O'Hare (Principal Nursing Officer). The involvement of Miss A.M. Allen, Miss M.J. Ives and Miss J.R. Thomas was greatly appreciated, as was the willing co-operation of the ward nurses.
APPENDIX II

PRESSURE SORE PREDICTION SCORE.
CATEGORY EXAMPLES FOR HIGH DEPENDANCY CARE AND RESEARCH

UNCONSCIOUS

"No": Fully conscious and orientated.  
      Fully conscious and slightly confused.

"No, but..": Confused/withdrawn.  
              Excessive sleeping.  
              Semi-conscious at times.

"Yes, but..": Rouseable - responds to commands or pain.

"Yes": Deeply unconscious.  
      Does not respond to pain.

VERY ILL

"No": Fairly good general condition - awaiting minor operation.  
      Awaiting discharge home.  
      Minor local, or mental disease.  
      Disease confined to upper extremities.

"No, but..": Elderly and thin or obese.  
             Restricted movement of lower extremities.  
             Recent operation under G.A.  
             On steroids.  
             Pyrexial.  
             Anorexic.  
             Arthritic.  
             Diabetic.  
             Some neuropathy.  
             Active skin disease.  
             Circulatory/arterial disease.

"Yes, but..": General condition could be worse.  
              Fair general condition despite severe injuries to lower half of body.  
              Severe injuries to chest/abdomen/arms/face, only.  
              Young paraplegic.  
              Active hemiplegic.  
              Well established chronic disease/disability (e.g. Parkinsonism).

"Yes": Seriously or critically ill.  
       Terminal (acute) illness.  
       Paraplegic - recent onset, or elderly.  
       Hemiplegic - recent onset.  
       Tetraplegic.  
       Emaciated and cachectic.  
       Severe general infection.  
       Severe M.S.  
       Iliac artery/vein thrombosis.  
       Severe uraemia.  
       Severe injuries especially to lower half of body.  
       On narcotic analgesics.  
       Leprosy.
INCONTINENT ? ..........................................................

"No": No incontinence, or no 'accidents' recently. Indwelling catheter or stoma, but no leaks or accidents recently.

"No, but.." Occasionally wets the bed or spills urinal. Occasional accidents with attached urinal. Occasional leaks from indwelling catheter or stoma. Occasional faecal accidents.

"Yes, but.." Small amounts at infrequent intervals. Urine only and infrequent. Faecal only and infrequent. Faecal only and infrequent, although has some leaks from catheter/urinal.

"Yes": Continual dribble/leak of urine or faeces, or both. Frequent urine, faecal, or double incontinence.

SITS UP IN BED ? ..........................................................

"No": Bedfast, and nursed flat. Only sits up when in a chair (short periods).

"No, but.." Occasionally sits in a chair. Sits in a self-propelled chair for long periods, but nursed flat in bed.

"Yes, but.." For short periods only, although spends long periods sitting in a fixed chair. Lies down for long periods.

"Yes": Sits up in bed most of the day. Sits up both day and night.

LIFTS UP ? ..........................................................

"Yes": Lifts all of body clear of support. Easily lifts pelvis clear.

"Yes and No" Can only lift pelvis with some effort, and soon tires. Seldom lifts self. Can lift with help. Lifts slightly - shuffles into new position.

"No": Unable to lift pelvis. Can neither help with lift nor shuffle.

GETS UP AND WALKS ? ..........................................................

"Yes": Fully ambulant. Slight impediment. Uses walking aids with no difficulty.
"Yes and No" Has difficulty walking with aid. \# Walks with help and encouragement. \# Soon tires. \# Can only walk to toilet.

"No": Bedfast or chairfast. \# Stands and shuffles – with help and encouragement.
APPENDIX III
'SLED AND PLANE' FRICTION TESTS

Twelve tests were conducted with the Sled and Plane friction test apparatus (Figure 57) before it was abandoned in favour of the 'Capstan' apparatus. The Sled and Plane tests were conducted in a temperature-controlled room; the sample materials being preconditioned as described in Chapter 4.1.1. The range of ambient temperatures during the tests was 18°C - 21.4°C. The relative humidity varied from 47% to 57%. The results of the twelve tests are given below.

<table>
<thead>
<tr>
<th>TEST</th>
<th>INTERFACE</th>
<th>SLED WT. (Kg.)</th>
<th>INITIAL FORCE (Kg.)</th>
<th>FORCE TO INITIATE SLIDE (Kg.)</th>
<th>OBSERVED SLIP-IN 15 MINUTES</th>
<th>CALCULATED ( \mu )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>warp-knit Polyester (40 denier) against latex (dry).</td>
<td>3.5</td>
<td>0.67</td>
<td>&gt;1.63</td>
<td>nil</td>
<td>?</td>
</tr>
<tr>
<td>2</td>
<td>as above but talc on latex</td>
<td>2.0</td>
<td>1.17</td>
<td>1.43</td>
<td>32 mm</td>
<td>0.72</td>
</tr>
<tr>
<td>3</td>
<td>as above</td>
<td>2.0</td>
<td>0.89</td>
<td>1.43</td>
<td>18 mm</td>
<td>0.72</td>
</tr>
<tr>
<td>4</td>
<td>Polythene against talced latex (dry)</td>
<td>2.0</td>
<td>0.67</td>
<td>0.67</td>
<td>20 mm</td>
<td>0.34</td>
</tr>
<tr>
<td>5</td>
<td>smooth knitted nylon/viscose/cotton sheet against talced latex (dry)</td>
<td>2.0</td>
<td>0.89</td>
<td>1.11</td>
<td>5 mm</td>
<td>0.56</td>
</tr>
<tr>
<td>6</td>
<td>as above</td>
<td>2.0</td>
<td>0.67</td>
<td>1.0</td>
<td>5 mm</td>
<td>0.5</td>
</tr>
<tr>
<td>7</td>
<td>Terry Towelling against talced latex (dry)</td>
<td>2.0</td>
<td>0.89</td>
<td>1.27</td>
<td>29 mm</td>
<td>0.64</td>
</tr>
<tr>
<td>8</td>
<td>as above</td>
<td>2.0</td>
<td>0.89</td>
<td>1.13</td>
<td>10 mm</td>
<td>0.57</td>
</tr>
<tr>
<td>9</td>
<td>as above</td>
<td>2.0</td>
<td>0.89</td>
<td>1.46</td>
<td>10 mm (approx)</td>
<td>0.73</td>
</tr>
<tr>
<td>10</td>
<td>as above</td>
<td>2.0</td>
<td>0.89</td>
<td>1.68</td>
<td>50.5 mm</td>
<td>0.84</td>
</tr>
<tr>
<td>11</td>
<td>as above</td>
<td>2.0</td>
<td>0.89</td>
<td>1.43</td>
<td>83 mm</td>
<td>0.72</td>
</tr>
<tr>
<td>12</td>
<td>as above</td>
<td>2.0</td>
<td>0.89</td>
<td>1.57</td>
<td>28 mm</td>
<td>0.79</td>
</tr>
</tbody>
</table>
A number of pilot tests were conducted with the latex capstan apparatus (Figure 60) before the test procedure was finalized. The ambient temperature during these tests was in the range 19°C. to 22.5°C. and the relative humidity varied from 50% to 60.5%. The temperature of the capstan was in the range 36°C. to 37.5°C. The results of these various tests are given below. Unless otherwise indicated, all tests started with a capstan 'pre-load' of 1.3 Kg.

<table>
<thead>
<tr>
<th>TEST</th>
<th>INTERFACE</th>
<th>FORCE TO * PRODUCE SLIDE (Kg.)</th>
<th>CALCULATED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Smooth knitted nylon/viscose/cotton sheet against talc'd latex (dry).</td>
<td>2.2</td>
<td>0.47</td>
</tr>
<tr>
<td>2</td>
<td>As above</td>
<td>2.5</td>
<td>0.50</td>
</tr>
<tr>
<td>3</td>
<td>As above</td>
<td>2.2</td>
<td>0.47</td>
</tr>
<tr>
<td>4</td>
<td>As above</td>
<td>2.4</td>
<td>0.49</td>
</tr>
<tr>
<td>5</td>
<td>As above</td>
<td>2.6</td>
<td>0.51</td>
</tr>
<tr>
<td>6</td>
<td>As above</td>
<td>2.5</td>
<td>0.50</td>
</tr>
<tr>
<td>7</td>
<td>As above, but no talc on latex.</td>
<td>3.6</td>
<td>0.60</td>
</tr>
<tr>
<td>8</td>
<td>Cotton hospital bedsheet against talc'd latex.</td>
<td>3.3</td>
<td>0.57</td>
</tr>
<tr>
<td>9</td>
<td>As above, but with water sprayed on bedsheets.</td>
<td>3.3</td>
<td>?</td>
</tr>
</tbody>
</table>

* Minimal slide as judged by careful observation.
<table>
<thead>
<tr>
<th>TEST</th>
<th>INTERFACE</th>
<th>FORCE TO PRODUCE SLIDE (Kg.)</th>
<th>CALCULATED</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Aluminium foil against latex without talc (dry). (3.3 Kg. 'pre-load').</td>
<td>&gt; 5.8 (foil broke)</td>
<td>?</td>
</tr>
<tr>
<td>11</td>
<td>Polythene against latex without talc (dry). (3.3 Kg. 'pre-load').</td>
<td>&gt; 7.0 (polythene stretched)</td>
<td>?</td>
</tr>
<tr>
<td>12</td>
<td>As above, but back to the 1.3 Kg. pre-load.</td>
<td>&gt; 5.0 (polythene stretched)</td>
<td>?</td>
</tr>
<tr>
<td>13a</td>
<td>Cotton hospital bedsheet against latex without talc, but water sprayed on bedsheet - drying for 4 hours at room temperature.</td>
<td>7.6 0.81</td>
<td></td>
</tr>
<tr>
<td>13b</td>
<td>Same test after drying for 5.75 hours.</td>
<td>6.5 0.76</td>
<td></td>
</tr>
<tr>
<td>13c</td>
<td>Same test after drying for 7 hours.</td>
<td>4.8 0.68</td>
<td></td>
</tr>
<tr>
<td>13d</td>
<td>Same test after drying for 21 hours.</td>
<td>3.5 0.59</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Cotton hospital bedsheet against latex without talc (dry).</td>
<td>4.3 0.65</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>As above</td>
<td>4.3 0.65</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>As above</td>
<td>4.3 0.65</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Smooth knitted nylon/viscose/cotton sheet against latex without talc (dry).</td>
<td>2.4 0.49</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>As above, but with talc on latex.</td>
<td>2.2 0.47</td>
<td></td>
</tr>
</tbody>
</table>
Pilot tests with latex capstan, continued.

<table>
<thead>
<tr>
<th>TEST</th>
<th>INTERFACE</th>
<th>FORCE TO PRODUCE SLIDE (Kg.)</th>
<th>CALCULATED</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>'Kylie' surface against latex without talc (dry).</td>
<td>3.9</td>
<td>0.62</td>
</tr>
<tr>
<td>20</td>
<td>Cotton hospital bedsheets against latex without talc (dry).</td>
<td>4.5</td>
<td>0.66</td>
</tr>
<tr>
<td>21</td>
<td>'Dupic' surface against latex without talc (dry).</td>
<td>4.4</td>
<td>0.65</td>
</tr>
<tr>
<td>22</td>
<td>'Kylie' surface against latex without talc (dry).</td>
<td>4.6</td>
<td>0.66</td>
</tr>
</tbody>
</table>
APPENDIX V

PILOT 'WRIST CAPSTAN'

FRICTION TESTS

Just three wrist capstan tests were conducted before the test procedure was finalized. One test was with the wrist at 33.4°C. and the other two with a wrist temperature of 34.3°C. Ambient temperature was in the range 22°C - 23°C. and relative humidity was 54% - 55%. The test at the lower wrist temperature was the only one where ether meth was used to clean the wrist skin.

Water at room temperature was used for cleaning the wrist in the other two tests, which piloted the damp procedure for the wrist capstan tests. All three tests used a 1.3 Kg 'pre-load'. Details of the three tests are given below.

### TESTS AT WRIST TEMP. BELOW 33.5°C.

<table>
<thead>
<tr>
<th>TEST</th>
<th>INTERFACE</th>
<th>LOAD NEEDED FOR SLIDE (Kg.)</th>
<th>CALCULATED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>cotton hospital sheet on skin cleaned with ether meth (dry)</td>
<td>2.0</td>
<td>0.45</td>
</tr>
</tbody>
</table>

### TESTS AT WRIST TEMP. ABOVE 33.5°C.

<table>
<thead>
<tr>
<th>TEST</th>
<th>INTERFACE</th>
<th>LOAD NEEDED FOR SLIDE (Kg.)</th>
<th>CALCULATED</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>cotton hospital sheet on skin - sheet sprayed with water - drying for 15 minutes</td>
<td>2.8 (? sample dried out)</td>
<td>0.53</td>
</tr>
<tr>
<td>3</td>
<td>as above, but waterproof film above sample - drying for 15 minutes</td>
<td>&gt; 3.4 (wrist stinging)</td>
<td>?</td>
</tr>
</tbody>
</table>
APPENDIX VI

PRELIMINARY PERFORMANCE SPECIFICATION
FOR GENERAL-PURPOSE SINGLE
ADULT HOSPITAL MATTRESS CORES.

1. Application

This mattress core should be suitable for the majority of adult hospital patients in the U.K. It is not intended for high-dependancy care or intensive care applications, e.g. for patients at high risk of developing pressure sores. The mattress core should be used on a rigid mattress base which provides adequate ventilation, and should also be usable on a contouring mattress base.

2. Principal requirements

The patients requiring this mattress may be conveniently grouped into two categories:

a) Short-stay, or long-stay patients who are relatively mobile, and are not confined to bed for long periods.

b) Medium-stay, or long-stay patients who are relatively immobile, and are confined to bed for long periods.

Category "a" patients form the bulk of hospital admissions, but the requirements of their support are less critical than those in category "b", where the side-effects of bed-rest are more prevalent.

In medical, surgical, and orthopaedic wards category "a" patients and category "b" patients are often mixed together and it is difficult to ensure that these different types of patient are nursed on different mattresses. In consequence, a general-purpose mattress should be suitable for both categories of patient; although some special supports (such as beds and mattresses designed to assist the healing of pressure sores) will be necessary for patients needing intensive or high-dependancy nursing care.
A mattress which is ideal for category "b" patients may be somewhat softer and accommodating (for pressure sore prophylaxis) than the ideal mattress for category "a" patients. It may also have special characteristics to make sitting in bed more comfortable. Category "a" patients are likely to be more concerned with general comfort for sleeping, the heat dispersion properties of the mattress, and adequate spinal support. These, and other considerations, indicate the principal characteristics we should look for in a good general-purpose hospital mattress:

i) Surface softness - to allow adequate weight distribution - particularly for thin and emaciated patients.

ii) Sufficient overall firmness to allow weak and/or heavy patients to easily change their position *.

iii) Correct support for the lumbar spine.

iv) Sufficient insulation to prevent chilling, but adequate water vapour permeability to prevent over-heating and sweating problems.

v) Sufficient flexibility to allow its usage on a contouring mattress base.

vi) Ability to absorb the energy of sudden impacts (e.g. a patient falling onto his bed).

vii) A relatively soft foot end, to give improved weight distribution over the heels, and allow slight knee flexion: for seated-in-bed patients.

The latter characteristic implies that both ends of the mattress should be softer than the central section (to allow for the mattress being turned around). The softening should be concentrated in narrow strips across the width of the mattress; each strip being softest at its centre and gradually becoming firmer towards each edge; where its hardness will match the hardness of the rest of the mattress. These transverse soft-

* Smoothness of the mattress surfacing (bottom sheet) will help in this respect - to some degree.
strips should be confined to within 38 cms. of each mattress end. They must not substantially weaken the mattress so that it would fail to give adequate support to a relatively wide load, such as the head (on a pillow). Optionally, the central section of the mattress core may contain a longitudinal soft-strip (along its centre-line) with similar properties to the transverse soft-strips. This longitudinal soft-strip may stop where it meets the transverse soft-strips (at each mattress end) but there must be no sudden increase of hardness at these junctures **.

3. Safety, and other requirements

i) Both long edges of the mattress should be firm enough to prevent them being compressed into a wedge shape, under the weight of a seated patient, or visitor.

ii) The mattress should have a low flammability, especially its surfacings and, as far as is consistent with cost and ultimate disposal (incineration) it should not contribute significantly to the adverse affects of a hospital fire (in terms of either a heat source, or a toxic smoke source).

iii) All materials used should be non-toxic and hypoallergenic.

iv) The mattress should not contain material such as steel wire, or other very hard and/or potentially sharp materials, which could injure a patient if the mattress is incorrectly constructed, or prematurely fails. Metals used close to the mattress surface are also contra-indicated where diathermy apparatus may be used.

v) As the central part of the mattress can be expected to fail (lose hardness and allow the patient to "ground" on the mattress base) after some years,

** This longitudinal strip is designed to relieve pressure on the sacrum and spinous processes of very thin and emaciated patients.
both the year of manufacture and the interval at which the mattress should be tested for failure (e.g. every five years) should be indelibly indicated on the mattress core.

vi) Any need for frequent turning and/or pounding the mattress should be eliminated by ensuring that the mattress core material does not migrate and set, under prolonged loading. In the case of a foam core, the compression set should not exceed 6% (75% deflection).

vii) If the mattress is not designed for use both-ways-up, this fact must be clearly indicated: preferably, the shape of the mattress core should, in itself, make the correct orientation obvious.

viii) The mattress core should have sufficient tensile strength to resist the normal wear and tear of handling; and also the shearing force imposed when patients slide themselves up the mattress (by pushing with their heels).

ix) Maximum depth of the mattress – at its long edges – should be 150 mm.

x) Overall weight of the mattress should not exceed 13.6 Kg.

4. Disinfection

The mattress should be capable of disinfection by DHSS approved methods.
Hospital Practice

VAPERM PATIENT-SUPPORT SYSTEM: A NEW GENERAL PURPOSE HOSPITAL MATTRESS

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Summary
Most mattresses used in British hospitals have certain disadvantages in relation to patient comfort, pressure-sore liability, ward hygiene, and flammability. An improved waterproof but water-vapour-permeable flame-retardant mattress system (Vaperm) has been developed. Extensive laboratory studies and clinical trials indicate that, with normal nursing care, the disadvantages of the standard mattress are largely overcome.

INTRODUCTION
Pressure sores are one of the most undesirable and expensive conditions in the care of patients. They represent a drain on National Health Service bed occupancy and work load which, in monetary terms, we estimate at more than £150 000 000 annually. The work reported here started in now the D.H.S.S., was developed some 15 years ago. It has been widely used in the King's Fund type bed provides limited ventilation of the skin and moisture trapped between the mattress and the base tends to corrode the bed structure.2

The mattress recommended by the Ministry of Health,5,6 now the D.H.S.S., was developed some 15 years ago. It has certain disadvantages, particularly when used on the King's Fund type of bed frame. The D.H.S.S. specification mattress has a uniformly dense polyurethane foam core, the sides of which are reinforced with reconstituted foam. This core is enveloped in a polyurethane-coated woven nylon non-stretch cover secured by a zip fastener.3 According to Payne's cup method of measurement, the water vapour permeability of one layer of the fabric is in the region of 400 g/m²/24 h at 37°C and 100% relative humidity (RH) when the fabric is new. The box construction of the cover reduces this value. Experience with water-vapour-permeable films used as wound dressings and skin cover indicates that a permeability of at least 1000 g/m²/24 h at 37°C and 100% RH is required to maintain the normal skin condition and at the same time provide comfort. The proofing of the nylon fabric may break down after two or three years of service, especially in the central area corresponding to the pelvis. This allows fluids such as urine and exudate to accumulate within the mattress, with the formation of a reservoir of pathogens.4,10 Furthermore, normal ward cleansing of intact mattress covers with chemical disinfectants does not rid them of pathogens.11 Since creases in a woven fabric are uncomfortable, the D.H.S.S. specification mattress cover is made to fit tightly over the foam core but tight woven covers produce a "hammocking" effect, which increases the effective hardness of a mattress.12 After 4–5 years of continuous use, when the nylon fabric has stretched and the foam has undergone core fatigue, the pelvis of a patient seated in bed can sink through the mattress, so that his tissues are supported largely by the rigid mattress base.12 In addition, unless a special fire-retardant cover is fitted, the type of mattress normally used on the King's Fund type of bed may be a potential fire hazard (see section on flammability).

An improved low-cost patient-support system must take into account: patient comfort; the need to "contain" tissues and distribute load over a maximum support area to prevent high local pressures and undue distortion of vessels; the need to provide a disposable water-vapour-permeable waterproof conforming cover for the core of the support structure; support for the spine in the recumbent patient; resistance to fatigue of the structure; fire hazard; reduction of nursing effort; and capital outlay.

Development of the 'Vaperm' Patient Support System

The appropriate mechanical properties of a patient-support structure cannot be achieved with a block of foam of uniform density. The foam core of the vaperm is a composite structure made from fatigue-resistant polyurethane foams of five densities (fig. 1). It has pressure-relieving channels inside the core to give improved load/distribution pressure over vulnerable bony prominences—heels and sacrum—without...
Creating an uneven mattress surface. The pressure-relieving channels for the heels are present at both ends of the mattress, so that either end can be put at the head of the bed. The design provides adequate head and lumbar-spine support. The superficial layer is a flame-retardant foam, and the undersurface of the foam core is covered with a flame-retardant fabric.

The primary mattress cover, which is a washable stretch fabric of knitted construction, is composed of cellulosic and synthetic fibres. The construction of the fabric allows it to follow the deformation of the foam under body load. The stretch fabric is treated with a flame-retardant agent ('Pyrovatex').

A disposable polyurethane film ('Platilon U.01') cover is used over the stretch cover; it is 30 µ thick and under normal conditions has a useful "life" of a year. Although this disposable film is waterproof, the water-vapour permeability as tested by the Payne's cup method is more than 1000 g/m²/24 h at 37°C and 100% RH. Since this cover is confined to the top, sides, and periphery of the under surface of the mattress, it allows adequate ventilation through the mattress. Fluid penetrating a damaged disposable cover will show up on the fabric cover. The disposable film cover can then be replaced and the fabric cover washed. Although the mattress is light, it is stable on the bed and the design permits it to be used on a contouring base.

A water-vapour-permeable mattress must be supported on an open-mesh base. We cooperated with bed manufacturers in the investigation of various steel mesh bases. A suitable base, which provides adequate ventilation and rigidity, is shown in fig. 2. Most beds can be easily modified in the hospital by the manufacturers. The base must be attached in such a manner as not to interfere with the attachment of cot sides. 3-4 cm² plastic-coated weld mesh has proved satisfactory provided that the cross-section of the wire used and the method of attaching the mesh to the bed frame is such that when the frame is walked on, as can occur when beds are in store, the mesh is not disturbed.

Fitted sheets of the same construction as the fitted primary mattress cover are preferred. Studies done at Stanmore show that creasing of the sheets is greatly reduced and patients find them more acceptable as regards comfort than traditional hospital sheets. The purpose of the mattress will be defeated by the use of non-stretch and tucked-in draw sheets which, though widely used, are to be deprecated.

Assessment of Properties of the Vaperm

A separation indicator pad system has been used throughout the development of the vaperm to compare the pressures exerted on the patient by the various patient-support systems. Load/pressure distribution studies (fig. 3) with a 50 mm diameter rigid domed indenter to represent heel load show that, with increasing loads, the vaperm has lower pressures/unit area than a standard 125 mm D.H.S.S. mattress (class 1). A three-domed indenter (fig. 4) (hemispherical domes of 17 cm diameter, two representing the buttocks with centres 20 cm apart and a third on the midline between the other two and with its centre 31 cm from the centre of each) was used with a 17.5 kg load, which was found by experiment to yield interface pressures very similar to those recorded under the buttocks when volunteers were tested on an equivalent (D.H.S.S.) mattress. This indenter was placed in the seat area and showed that the vaperm has better compliance than, and a peak pressure approximately half that of, the D.H.S.S. mattress (fig. 5).

We have conducted several pilot trials in the Royal National Orthopaedic Hospital (R.N.O.H.) during the past...
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