INTRODUCTION

Decubitus ulcers have been a companion of man since his evolution. During ancient times, man’s life span was relatively short but with the tremendous strides of medical advancements the average life expectancy of modern man has been significantly increased. Along with this increase has been noticed a distressing frequency in the number of decubiti suffered by chronically ill patients, the elderly, patients in poor nutritional state, patients suffering with spinal cord injuries, brain injuries, and other traumatisms affecting mobility and sensation. The frequency of the lesions increases with age and usually shows a marked increase after the age of 50, especially in women (16). It is hard to believe that this era of modern medicine has indirectly been the cause of increase in this elusive complication.

Many writers have stated that the cost of medical care per decubiti has been between $2,000 and $10,000 and the patient requires extended care in already overcrowded and understaffed hospitals (6, 15, 18, 19). In addition to the above, the most serious results are the personal suffering and discomfort of this ordeal, not withholding the indignations and loss of self-identity and privacy sus-
tained during any hospitalization. Also, decubitus ulcers cannot be considered as only a minor complication, septicemia or toxemia, which may be fatal, can result from these ulcers.

Decubitus is a Latin term meaning "lying down," which is not a correct description of this complication because ulcers can be found over any tissue with an underlying bony prominence and a compressional surface such as a bed, wheelchair, cast, or brace. Decubitus ulcers are also referred to as "pressure sores," "trophic ulcers," and "bedsores" (2, 11, 18, 19). In general terms, the decubitus ulcer is frequently described as a tissue sore, developed in localized areas of necrotic tissue, formed on and/or below the surface over bony prominences subjected to pressure for some extended period of time.

In the layer of tissue over bony surfaces the subcutaneous fat layer is usually very thin and in some areas almost nonexistent. In this and the upper dermal layers, the arteries, arterioles, capillaries, venules, and veins must carry the life-giving substance, blood. Only in the capillaries does the exchange process necessary for life take place and at an average pressure of approximately 32 mmHg (12). Any imposed tissue pressure which partially or completely occludes the capillaries for an extended period of time will cause localized tissue necrosis leading to a decubitus ulcer. This condition is more often than not witnessed on the tissue of lying or sitting patients.

Decubitus ulcers usually form in areas where there is a relatively thin layer of soft supporting tissue. These areas include the occiput, ears, scapulae, elbows, sacrum, ischium, greater trochanters, knees, calves, malleoli, and heels (Fig. 1) (8, 16, 18, 19). Peterson et al. (16) recently surveyed a rather large sample of hospital departments and nursing homes regarding incidences of pressure sores. Their results showed that 67 percent were found on the dorsal side, around the hips and buttocks and 29 percent on the lower limbs. Very few were found above the level of the umbilicus. Of all afflicted areas the sacral was the most prevalent (15, 16, 18). On patients who suffered lesions, 25 percent had multiple sores.

Decubitus ulcers have been classified by Adams et al. (1) into four classes:

Class 1 — Primary, epidermal injury

Class 2 — Secondary, necrosis of skin and fatty tissue, excluding muscle.

Class 3 — Terminal, muscle necrosis and bone involvement

Class 4 — Neurotrophic, ulcers formed due to osteomyelitis, septic arthritis, and pathologic fracture.
This degree of acuity is not recognized by all. Some researchers distinguish bedsores as just superficial or deep. The superficial sores appear directly on the tissue surface, and the deep or malignant sores develop in the deep tissue and muscle and finally spread to the upper tissue layers.

In the past, pressure has been credited as being the major etiological factor in the formation of decubitus ulcers, but in the last two decades researchers have suggested that other factors may also
play a critical part in this problem. The following is an up-to-date list of decubitus ulcer causative factors (1, 15, 18):

1. Physical Factors
   a. Pressure
   b. Heat
   c. Moisture and Relative Humidity
   d. Friction
   e. Shear force
   f. Hygiene
   g. Local boney prominences

2. Nutrition
   a. General undernutrition
   b. Specific nutritional deficiencies

3. Anemia

4. Infection

**EFFECTS OF PRESSURE ON TISSUE**

In engineering, the term pressure is defined as "the force exerted by a load system on a unit area." For an "average man," 70 kgf weight, 170 cm height and 1.8 m² surface area (20), assuming the entire posterior surface to be a plane surface with the supporting area equal to 0.9 m² and the weight evenly distributed, the pressure would be approximately 5.7 mmHg or 0.11 lbf/in.² In actuality, this is far from being true because the weight is not evenly distributed and a much smaller area supports the body load on a normal bed or chair. The results are extremely large pressures applied to a few anatomical areas, medium pressures applied to some, and none applied to others.

Relatively large pressures applied to tissue can be sustained without harm, if the pressure is of short duration. When walking, the soles of an adult man are subjected to pressures of 500 mmhg or more, but the ischemic condition this creates is quickly relieved when the foot is raised and the blood allowed to flush the deprived regions (3).

The normal healthy person is especially aware of applied pressures through pain sensors which are located throughout his body. Experiments conducted by Trumble (22) showed that the tolerance to skin pressure over the dorsum of the foot is about 65 to 78 mmHg and may vary with a person's blood pressure. Clearly, healthy active people seldom exceed the tolerance limit, and if they do, it is only for a short period of time. For bedridden or wheel-
chair confined subjects extended periods of unrecognized high pressures may be disastrous.

According to Petersen’s (16) statistical survey, the distribution of lesion occurrences according to mobility are: 10 percent ambulatory, 37 percent wheelchair and 53 percent bedridden.

In the past half century many investigators such as Brooks and Duncan (3), Husain (7), Kosiak (9), and Lindan (14), all working with animals, have definitively proven that a time-pressure relationship for the formation of decubitus ulcers does indeed exist.

The extension of the findings of these researchers have been made by Kosiak et al. (10), Houle (6), Bush (4), and Lindan et al. (13, 14) who have proven that for sitting or recumbent subjects, on normal support materials, the maximum pressure under the ischial tuberosities far exceeds that needed for capillary occlusion.

One very interesting experiment conducted by Lindan (13) compared the pressure of a 306 lb man and a 97 lb female. The female showed higher pressures and greater areas of high pressure. The obese male showed greater areas of low and medium pressure.

Visual observations of human skin subjected to body pressure were made by Sachs and Miller (17). Pressure measurements of various anatomical regions along with body contact area tracings were made on 17 male and female subjects in the supine position. Sachs states that the reactive hyperemia reaction of the skin corresponds with the outline of the area of skin which blanches under pressure. He further states that the blanching sites and the outline of blanching areas correspond to those of decubitus ulcers. "Blanching is defined as the maximum or near maximum decrease in normal redness of skin as can be produced by applying sufficient pressure" (17).

Pressures of seven subjects were taken under the sacrum to define the minimum and maximum pressure required to produce blanching. They were 60 and 88 mmHg, respectively, very close to the adult average diastolic pressure and pain tolerance level.

A very important point made by Sachs (17) was that the body weight divided by the contact area (pressure) in no way predicts or even indicates what the maximum sacral pressure will be. This leads one to believe that the high pressures and their deviations may well be a function of the architecture of the skeleton and the topography of the involved bones.

Verhonick (23) and Goller (5) have been the only researchers involved in using thermography in examining tissue response to applied pressure. Verhonick made serial thermograms of the heels and knees subjected to body pressure for 40 and 50 minutes, respectively. After the body load was removed, the thermograms showed ini-
tial coldness followed by an elevated temperature and progressively increasing involvement area, and then cooling. Goller applied pressures of 259, 517, and 776 mmHg with a heated, variable size, Teflon cylinder. The pressures were applied for 3, 4, and 5 minutes upon the posterior calf of the leg, right zygoma, and dorsal surface of the thorax. His results on some subjects indicated an initial cooling period followed in a few minutes by a heating response. On other subjects he noticed immediate heating. The heating effect in both cases was similar to that described by Verhonick. In all subjects tested reactive hyperemia was noticed. Both researchers state that the “flushing” of the tissue (reddening) may be a way of defining those patients prone to the development of decubitus ulcers.

EXPERIMENT

In the spring of 1973 a patient lift bed was designed and constructed at the University of Virginia. The unique lift bed (Fig. 2) made possible the observation of human tissue subjected to body load. The supporting medium was a tough, high-tensile strength, 3 mil thick, polyester plastic film called Mylar®, the same material used by Sachs (17). The transparent film allowed for photographic and thermographic observations of a subject. The lift capacity of the bed was 300 lb and the subject support surface could be raised from 2 to 7 ft above the floor by an electromechanical system.

FIGURE 2.—Lift bed.
In addition to the patient lift bed an extremely thin and flexible pressure transducer and support hardware was designed. The pressure transducer and equipment are reported on in reference 21.

An experiment utilizing the lift bed, pressure transducer, and a thermography system (ThermIscope-Texas Instruments, Inc.) was designed to be focused primarily on the sacral tissue of 21 subjects (8 males and 13 females). Ages of the subjects ranged from 7 to 46 years with the majority of the subjects being college students. The experimental procedure was broken down into the following phases:

1. Information
   a. General Information
   b. Body measurements
   c. Room measurements-
2. Tissue equilibration, duration — 30 minutes
3. Reference thermogram
4. Loading of posterior tissue with body load
5. Reference and serial thermograms
6. Relieving tissue of body pressure
7. Thermographical observation of tissue reaction
8. Measurement of maximum sacral pressure with subject lying on Mylar film and on a polyurethane hospital mattress

The totality of the research was concerned with pressure, humidity and temperature measurements, and shear stress observations. Only the temperature (thermographic observations) will be reported on in this paper. Pressure, humidity, and shear stress results are published in reference 21.

The sequence of thermograming a subject was divided into three phases as described in the experimental procedure. They were a posterior, full body temperature reference thermogram with the subject standing (temperature range 96 to 86 deg F); a series of five or six 1 deg temperature differential thermograms starting at the highest measurable visible temperature and descending; and another full body temperature range reference thermograph. The thermograph series and last full temperature reference were taken approximately 25 minutes after body load was applied as subject reclined on Mylar. The third and final series was begun immediately after the body load was released. This series consisted of full body temperature thermograms taken at varying time intervals. The series continued until the sacral tissue region, registering the reactive hyperemia response, equalled or indicated a lower temperature than the initial reference thermogram taken while the subject was standing.
All three phases of thermograming can be seen in Figures 3 and 4 and are related as follows:

PHASE 1: (Fig. 3) Thermogram No. 1, initial reference thermogram

PHASE 2: (Fig. 4) Thermograms Nos. 1 through 5, series of five 1 deg temperature differential thermograms, No. 1 (93-92), No. 2 (91-90), No. 3 (90-89), No. 4 (89-88), No. 5 (88-87)

PHASE 3: (Fig. 3) Thermograms Nos. 2 through 6, series of standing subject undergoing reactive hyperemia, No. 2 — 0.5 minute, No. 3 — 1 minute, No. 4 — 3.0 minutes, No. 5 — 14.5 minutes, No. 6 — 20 minutes.

FIGURE 3.—Sequential thermograms of subject No. 14 standing.

RESULTS

Initial body reference thermograms indicated that for the subjects scanned a general posterior thermal body pattern does exist. A high skin and body temperature is noticed along the spinal column usually terminating at the lower lumbar and upper sacral level in some particular thermal pattern. Some subjects also show
FIGURE 4.—Thermograms of subject No. 14 on Mylar.
an elevated temperature area starting at the upper thoracic level of the spinal column and extending outward and then down on a diagonal, intersecting the spinal column at the mid-thoracic level. The hips and buttocks are usually very cool indicating poor vascular circulation and/or large concentrations of fat. Even though the thermograms showed general similarities, a unique vascular and tissue composition arrangement was apparent for each subject.

Thermograms taken of the same subject on different days, months apart, in similar environmental conditions, for most cases, show complete thermal similarity.

The 1 deg temperature differential thermograms taken with body load applied showed that in 18 out of 21 subjects the scapular region was warmer than the sacral region. In one case the sacral temperature was higher than the scapular temperature and on two other subjects they were the same. The scapular temperature on the average for the 18 subjects was from 1 to 2 deg F higher than that of the sacral.

The thermal patterns seen in the 1 deg series and the full body temperature reference thermograms while on Mylar, for most instances denote the general shape of the major load carrying bones of the body, especially the scapulae and sacrum. Also, the anatomical regions most accused of forming decubitus ulcers are the regions defined by the highest indicated temperatures.

After the body load is released and the subject assumes the standing position, a visible red flare usually develops quickly on the surface of the skin over the lower portion of the sacrum including the coccyx. This red flare becomes very intense in the first few minutes and then gradually diminishes and finally disappears. The grades of redness and exact time of disappearance are extremely difficult to discern with the naked eye. Nevertheless, the thermal flare response was still noticed in some cases long after the visual flare had been pronounced gone. This suggests that, if the redness is attributed to dilation of the pressure afflicted capillaries, then the disappearance of the visual flare means the capillaries are again back to normalcy in size and in the amount of blood they carry, thus ending the reactive hyperemia response. However, the continuance of a reduced but still detectable thermal flare strongly suggests that an elevated metabolic tissue rate, or some other phenomenon, is still taking place in this tissue.

The thermal flare as well as the visual red flare began almost immediately after body load was released. Within 1 minute a mottled thermal pattern was noticed followed by an intense thermal flare 1 minute later. The thermal flare for most subjects was well defined in 2 minutes after off-loading. Thereafter, the flare began to spread in
size reaching a maximum with reduced visible boundary definition. The flare then began to decrease in size and in temperature intensity, usually within the first 10 minutes of observation. It is proposed that the thermal mottling noticed in the first minute is caused by the infusion of blood into the blood deprived tissue area, and may well be the maximum thermal convective heat transfer response possessed by that anatomical region.

When comparing the initial reference thermogram against the first standing thermogram after load was relieved, a posterior body heating effect on 14 of the subjects and a cooling effect on two was noted. The thermal patterns of the remaining subjects appeared the same. The heating effect is attributed to the insulating qualities of the Mylar film which cause a low state of vasodilation.

The cooling effect is difficult to explain and may be related to the 30 minutes of tissue pressure. A more probable explanation would be the effect of room temperature and relative humidity. The average room temperature and relative humidity for all subjects were 71 deg F and 38.8 percent, respectively. The room’s condition for the two subjects in question was 74.5 deg F and 35 percent and 73.5 deg F and 48 percent. The first condition shows the greatest cooling effect. Of three other subjects having a room temperature similar to the second condition and a RH similar to the first condition, two indicated no thermal change, and the third showed only a slight heating effect. It is therefore proposed that the high room temperature and low RH caused an increase in the evaporative cooling rate of these two subjects, consequently lowering the thermal surface conditions of their bodies.

In an attempt to measure the maximum flare temperature difference, that is the difference between the initial standing reference thermogram and the maximum flare temperature observed on the CRT (cathode ray tube) during reactive hyperemia, for a similar anatomical area, it was found that the temperature change was as much as 12 deg F at 3 minutes decreasing to 10 deg F at 10 minutes and 1 deg F at 33 minutes. One of the subjects showing the cooling effect demonstrated a temperature difference of 6 deg F after 2 minutes.

The thermal flare patterns of 18 subjects are shown in Figures 5 and 6. The average flare area computed from enlarged photographs of the thermograms of all subjects is 5.1 in.². For males, 5.7 in.² and for females 4.7 in.². The average value of the females may be slightly low due to one 7-year-old participant. All thermograms were taken between 2 and 3 minutes after relinquishing body load. During this period of time most thermal flare patterns were well-defined, possibly signifying maximum vascular system involve-
ment. The time of maximum temperature is not known but is thought to possibly occur during the same time period.

When examining the thermal hyperemic response on the thermograms, the vertical distance from the buttock’s fold to the lowest and highest elevation of the flare was well-defined and considered as a possible indicator of sacral bone curvature. These upper and
lower dimensions averaged 6.4 and 3.8 in. for males and 5.9 and 3.2 for females. These dimensions indicate a bone structure parameter which may well be related to the pelvic differences known to exist between the species.

In reviewing the thermal flare patterns it is quite apparent that none is similar in shape and that they occur along the center line of
the body at the level of the sacrum and coccyx. It is universally
known by the medical profession that “decubitus ulcers form
over bony prominences.” These researchers strongly concur with
this statement and add that it is the shape, size, and topography
of the involved bones which are responsible for the thermal flares
and correspondingly the pressures which cause these lesions.

It was Sachs (17) who emphatically stated that blanched areas
were areas of reactive hyperemia and possible ulceration. Figure
7 shows the blanched sacral tissue area of subject No. 16 while on
Mylar and the thermal flare pattern of the same subject. This and
other similar observations extend Sachs’ statement to: blanched
areas are areas of reactive hyperemia and of increased thermal re-
response (high skin and body temperatures) and are areas of possible
ulceration.

The maximum sacral pressure on the Mylar film was 460 mmHg
found under subject No. 14, a 46-year-old female, 61.5 in. tall and
weighing 102 lb. This subject experienced the same maximum sacral
pressure as was found under subject No. 23, a 19-year-old male,
72.8 in. tall, and weighing 160 lb. On the hospital bed this subject
experienced a maximum pressure of only 46 mmHg. A palpation
test of the subject experiencing the lowest pressure yielded a flat
sacrum and coccyx with relatively few tubercles. A palpation test
was not performed on the female but it was noticed that she had a
protruding convexed sacrum. Her thermal flare pattern can be seen
in Figures 3 and 4 and is almost a perfect circle. Subject 23’s ther-
mal pattern is not shown.

The lowest pressure found on the hospital mattress was 38
mmHg, 6 mmHg more than what is needed to occlude the arterial
side of the capillaries. Therefore, it must be concluded that all sub-
jects participating in the experiment may be possible decubitus
ulcer candidates if they had to recline on this type of mattress, in
a confined manner, for an extended period of time.

The average maximum sacral pressure on Mylar was 185 mmHg
for females and 214 mmHg for males; on the hospital mattress, 68
mmHg for females and 67 mmHg for males.

The gluteal regions appeared on the reference thermograms as
areas of reduced temperature possessing thermal uniformity. After
loading this area for approximately 30 minutes with body weight
(subject standing), the gluteal regions on both sides of the spinal
column showed small faint localized warm spots over their en-
tire surfaces. It is suspected that these warm spots may have been
caused by either, or both, high localized compressive or shear
forces. To obtain a better idea of what takes place in the tissues of
the gluteal region and over the sacral-coccygeal region, a 1-in.$^2$ grid
Figure 7.—Blanched area and flare area comparison—on Mylar.
system was scribed on the skin over these regions on some of the subjects. Figure 8 shows subject No. 17 in the standing position and in the supine position on Mylar. Notice that the lines in most cases are markedly distorted, indicating that the skin and the underlying tissue are being severely compressed and stressed simultaneously. It may be reasonable to assume that the tissue being trapped between bone and film is being smeared around, and over, the bone. These manifestations can only lead to a severely complex compound tissue loading structure which changes drastically and continuously from one point to another.

**FIGURE 8.**—Tissue distortion on Mylar.

Another phenomenon noticed with all subjects more or less on the reference thermogram (subject in the supine position on the Mylar film) was the very distinctive mottled thermal condition of the gluteal regions, the triceps, the thighs and the calves. In the initial standing reference thermogram this condition was not observed. It is proposed that this phenomenon is caused by the body pressure and the fat deposits of the subcutaneous tissue. With the application of pressure, the blood supply to the loaded area is reduced or eliminated leaving the transfer of heat from the center of the body to the skin’s surface controlled primarily by conduction. It is therefore thought that the thermal resistance to heat flow caused by the local variation of the fat masses is responsible for
the thermal mottling. Some thermal mottling is noticed over the contact surface of the back.

CONCLUSIONS

1. Posterior body reference thermograms indicate that in general a similar thermal body pattern of humans does exist.

2. The buttocks, hips, and thighs of a nude subject are thermally cool regions, possibly indicating poor vascular circulation and/or large fat concentrations.

3. Thermograms of the same anatomical area on the same subject under controlled environmental conditions are thermally similar.

4. The scapular region is from 1 to 2 deg F hotter than the sacral region for subjects reclining on Mylar.

5. The 1 deg temperature differential thermograms and the reference thermogram while the subject is on Mylar, in many ways, denote the geometrical shape of the underlying bone structure, especially the bones of the scapulae and sacrum.

6. On the degree temperature differential thermograms, the anatomical regions most accused of being decubitus ulcer prone are the regions of highest temperatures: the scapulae, sacrum, elbows, and calves.

7. During reactive hyperemia, the visible red flare over the sacrum and coccyx becomes very intense in the first few minutes and then gradually diminishes. The thermal flare persists longer than the visible flare. The extended duration of the thermal flare over the visible red flare is attributed to a continued local elevated metabolic tissue rate caused by the previous engorgement of blood.

8. The thermal mottling seen in the first minute after releasing the load is believed to have been caused by the rapid infusion of blood and the dilation of affected vessels responsible for making up the blood flow debt which occurred during the period of ischemia.

9. A posterior body heating effect noticed immediately after the subject left the Mylar film has been attributed to the insulative qualities of the film. The cooling effect is more difficult to explain, but it is thought that the higher than average room temperature caused an increased evaporative cooling rate response of the two subjects either before getting off the film or immediately after getting off and therefore reduced the temperature of the skin.

10. The maximum reactive hyperemic temperature difference, the difference between the initial standing reference thermogram and the maximum flare temperature observed during tissue hyperemia, may be as high as 12 deg F.
11. Males on the average have larger flare patterns than females, 5.7 in.² and 4.7 in.², respectively. The flare areas were computed from thermograms taken 2 to 3 minutes after off-loading of tissue.

12. With the average distance from the buttock's fold to the highest and lowest thermal flare indication being lower for females (3.2 and 5.9) than for males (3.8 and 6.4), a relationship between the site or decubitus ulcer formation and the pelvic bone structure of the sexes may well exist.

13. No two thermal flare patterns are similar either in size or in shape. Thermal flare patterns occur along the centerline of the body at the sacrum and coccyx level.

14. It is concluded that it is the shape, size, and topography of the underlying bony structure which is responsible for the tissue pressure necessary to inflict the thermal flares.

15. Blanched areas are areas of reactive hyperemia and of increased thermal response and also areas of possible ulceration.

16. Maximum sacral pressure found beneath a reclining subject support surface is poorly related to weight and height but more to his size, shape, and the topography of the underlying bone.

17. Maximum sacral pressure found under all subjects on a polyurethane mattress exceeded the maximum normal capillary pressure and, therefore, all subjects participating in the experiment are possible decubitus ulcer candidates if they were to recline on the type of mattress used in the experiment for a period of time.

18. Thermograms taken during application of body load showed for many subjects thermal mottling of the gluteal regions, the triceps, the thighs, and the calves. Only slight mottling and, in many cases, no mottling was noticed over the contact surface of the back. The thermal mottling is thought to be caused by the local variation of the tissue fat masses and their conductive resistance to the flow of heat from the center of the body to the skin.

19. After body load was released, faint warm spots appeared over the gluteal regions, suggesting localized reactive hyperemia caused by localized compressive, shear, or other forces.

20. The distortion of the scribed grid system when loaded over the sacral and coccyx region indicates that the skin and tissue over these regions suffer from a severely compounded tissue loading phenomenon which changes drastically and continuously from one point to another.

REFERENCES