Bulletin of Prosthetics Research
BPR 10-34 (Vol. 17 No. 2) Fall 1980
Pages 5–11

Pressure and Temperature Patterns under the Ischial Tuberosities[a]

ROBERT P. PATTERSON, Ph.D.
University of Minnesota Hospitals[b]
Minneapolis, Minnesota 55455

STEVEN V. FISHER, M.D.
St. Paul Ramsey Medical Center
St. Paul, Minnesota 55101

ABSTRACT

A study was conducted to investigate the pressure relief patterns under the ischial tuberosities in a group of 12 paraplegic subjects. A small electrical pressure transducer was taped over each ischial tuberosity, and each subject had a thermistor taped near one tuberosity.

The subjects were instrumented in the morning and allowed to go about their normal activities for the day sitting on a 4-inch foam cushion. The subjects sat at pressures > 150, > 90, and > 30 mmHg for 17.6 percent, 53.5 percent, and 91.8 percent of the time, respectively. The subjects sat on the average for 10.1 min without doing a pushup with a duration > 1 sec and sat on the average for 29.6 min without doing a pushup with a duration > 5 sec. Two of the subjects sat for periods > 60 min for > 75 percent of the time (ignoring pushups < 5 sec) and > 65 percent of the time ignoring pushups < 1 sec. The average time between pushups[c] was within the generally accepted limits to prevent ulcers—10–30 minutes. A few of the subjects had occasional long periods of uninterrupted pressure greater than what is thought to be required to produce ulcers—and did not develop them.

INTRODUCTION

Many studies have investigated the pressure-time relationship that causes decubitus ulcer development in animals (1-4). Kosiak (3) has shown that tissue pressures of 70 mmHg for 2 hours will cause pathological changes in the muscle tissue of rats, and an applied pressure of 60 mmHg for 1 hour will cause microscopic changes in the tissue of dogs. On the other hand, he also showed that pressures of 35 mmHg for up to 4 hours did not cause any problems in rats.

A study by Mooney et al. (5) of the pressures under the ischial tuberosities of individuals sitting on various seat cushions found pressures that ranged between 51 and 86 mmHg for normals, and from 83 to 152 mmHg for patients with spinal cord injuries. Souther et al. (6) in a similar study in normals showed the sitting pressure with various cushions to range between 41.7 and 69.1 mmHg.

The above physiological studies suggest the need to periodically relieve the tissue pressures that would remain for extended times above 35 mmHg. Kosiak (2) has stated that paraplegic patients can remain ulcer-free by relieving the pressure under the ischial tuberosities several times per hour. Griffith (7) suggests that sitting paraplegic patients should relieve their pressure under the ischial tuberosities every half-hour, and every 2 hours they should lie down for 15 minutes. (In our institution, we suggest pressure relief of approximately 5 seconds every 15 minutes.)

[a]This study was supported in part by Grant No. 16-P-56810/5-19, Office of Human Development, Department of Health, Education, and Welfare, Washington, D.C., for the University of Minnesota Medical Rehabilitation Research and Training Center.

[b]Mailing Address: Inquiries concerning this paper may be addressed to Robert Patterson, Ph. D., University Hospitals, Box 279 Mayo, 420 Delaware Street S.E., Minneapolis, MN 55455. (Dr. Fisher is at the St. Paul Ramsey Medical Center, St. Paul, Minnesota 55101.)

[c]A "pushup" is defined here as a "pressure relief producing readings below 30 mmHg".

The purpose of this study was to investigate the pressure relief patterns in a group of paraplegic subjects who had not exhibited any significant problems with ulcers as they went about their normal daily activities. The type of experiment that involves applying controlled pressures for various time periods, as described above, cannot be performed on human subjects; however, this investigation allowed information to be obtained about the pressure-time patterns measured for one day that did not produce ulcers.

The temperature was also recorded because of the many studies that suggest the importance of tissue temperature, both as a causative factor in the generation of ulcers and as a response of the tissue to injury (8,9).

METHODS

Twelve paraplegic subjects, including males and females, were studied. Their physical characteristics, date of injury, level of injury, and spasticity state are shown in Table 1. All subjects had strong triceps and could do pushups for at least 5 seconds. No subject used a device and none of them had any special methods to remind themselves to do a pushup.

Four of the 12 subjects had in the past developed a decubitus ulcer, but no subject had had more than one.

The pressure was determined by taping a small (1 mm thick by 5 mm in diameter) Entran Model ESP–200 pressure transducer under each ischial tuberosity. The transducers were calibrated in a small pressure chamber with a mercury manometer for reference. The zero pressure reference point (no external force on skin) was determined as the average of the pressure observed during a pushup at the start and at the end of the experiment.

A Yellow Springs Model 427 thermistor was placed near the pressure transducer on each patient's right buttock.

During the application of the pressure transducers, the subjects were lying on their sides with their hips and knees flexed (similar to a sitting position). Each subject's transducers were connected to a small four-channel Medilog Model 4–24 tape recorder[d] capable of recording for 24 hours. The transducers, applied in the morning and removed in the late afternoon or evening, left the subjects free to go about their normal daily activities. The average recording time was 7 hours. All subjects used a 4-inch foam cushion during the study.

The data were played back at 60 times real time using a Medilog high-speed playback unit with the internal output low-pass filter in the .5-Hz position. As a result, the measured time response in original experimental time units (real time) showed a time constant of .45 seconds. This implies, for example, that a sudden drop in actual pressure from 50 mmHg to zero would show a recorded pressure value dropping to about 18.5 mmHg in .45 sec and to .5 mmHg in .9 sec.

The output from the playback unit was converted to digital form and analyzed using a DEC LSI–11 digital computer.

The data were analyzed by developing histograms of the uninterrupted time periods during which the pressure remained above various pressure levels. This was done so that the distribution of pushups during the recording time could be determined—if all the pushups occurred at one time of the day, their effect

[d]This tape recorder is made for ambulatory recording and can be belt-worn. The two pressure transducers and one thermistor utilized three of the recorder's four channels.

TABLE 1

Subjects	Age (years)	Ht. (cm)	Wt. (kg)	Date of injury	History of Ischial Ulcer	Vertebral level of injury	Time since injury (mo)	Spastic (S) Flaccid (F)
M.V.	50	178	64	1/78	–	T_{12}	16	F
J.S.	34	175	84	5/63	+	T_5	180	S
J.L.	42	196	84	6/78	–	T_4	12	S
M.L.	20	185	75	7/75	–	T_{11}	45	S
E.K.	20	170	54	7/76	+	L_1	36	F
B.K.	21	175	61	5/76	–	C_7	35	S
S.H.	27	168	68	12/76	–	T_{12}	30	S
L.H.	25	160	64	11/76	+	T_4	31	S
G.K.	27	175	77	8/75	–	T_4	33	S
R.B.	29	183	68	7/77	–	T_4	23	S
D.M.	25	183	73	8/78	–	T_4	12	S
S.H.	28	170	67	7/77	+	T_7[a]	25	F

[a]Anterior spinal artery syndrome

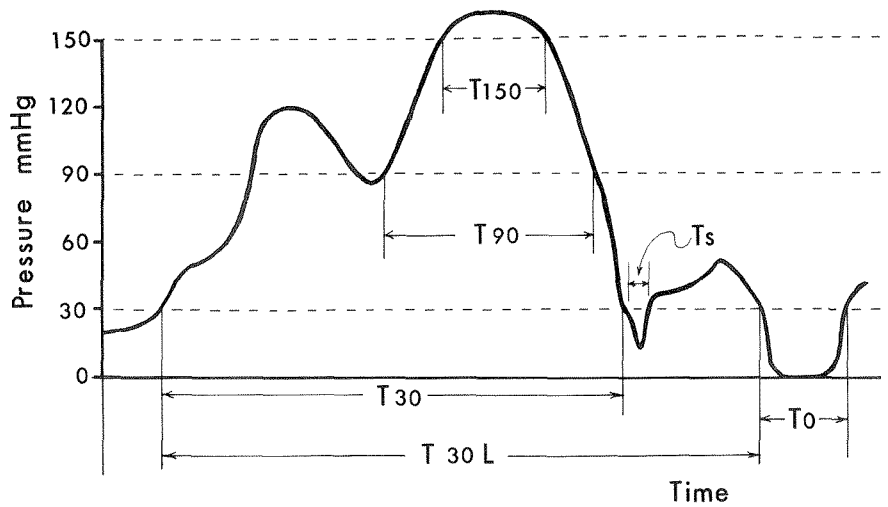

FIGURE 1.
A sample pressure record indicating the pressure levels chosen to generate the pressure-time histograms. T150, T90, and T30 indicate the time periods in which the pressure is above 150 mmHg, 90 mmHg, and 30 mmHg, respectively. T_0 is the time period in which the pressure is below 30 mmHg. T30L is the time period in which the pressure is above 30 mmHg (neglecting the short-duration fall in pressure below 30 mmHg of < 1 sec or < 5 sec, as indicated by time T_s).

would not be the same as if the same number were distributed evenly throughout the day.

Figure 1 shows an example of a pressure record which indicates the points used in analyzing the data. The labels T150, T90 and T30 represent the time periods in which the pressure remains > 150 mmHg, > 90 mmHg, and > 30 mmHg, respectively. An array of time period values was obtained for each of the pressure levels by the computer. The label T_0 represents the time the pressure is below 30 mmHg, i.e., the duration of a pushup. (A hysteresis of 5 mmHg was built into the computer program to prevent the data from oscillating in and out of a pressure region if it was near reference level.) A pushup was defined as a pressure relief below 30 mmHg. Pushups were counted for each of three different time periods: any time duration, > 1 second, or > 5 seconds. If the pushup time was less than the selected duration, as indicated by T_s in Figure 1, a relief of the pressure was not recorded and the sitting-time period continued to increase in duration. This is indicated in Figure 1 by the time interval T30L, which is longer than T30 because the short drop in pressure (shown as T_s) below 30 mmHg is ignored.

Pressure channel 1 was over the right ischial tuberosity and channel 2 over the left.

RESULTS

Figure 2 shows a typical pressure and temperature record of one subject. When the equipment is initially put on in the morning, the temperature recorded is low. The temperature channel shows a climb, to near body temperature (Fig. 2) after approximately 2 hours. The temperature frequently falls as a result of a pushup or transfer and then regains its former level or rate of rise.

The time and temperature scales were expanded in Figure 3 to show the changes resulting from a pushup: the record indicates that the fall in temperature resulting from a pushup occurs after the subject sits down. This was frequently seen in most subjects. A possible explanation is offered in the "Discussion."

The pressure records show many oscillations which appear as noise in the slow time scale and are apparently due to body movement. An example of one of the most noisy pressure records is shown in Figure 4; but

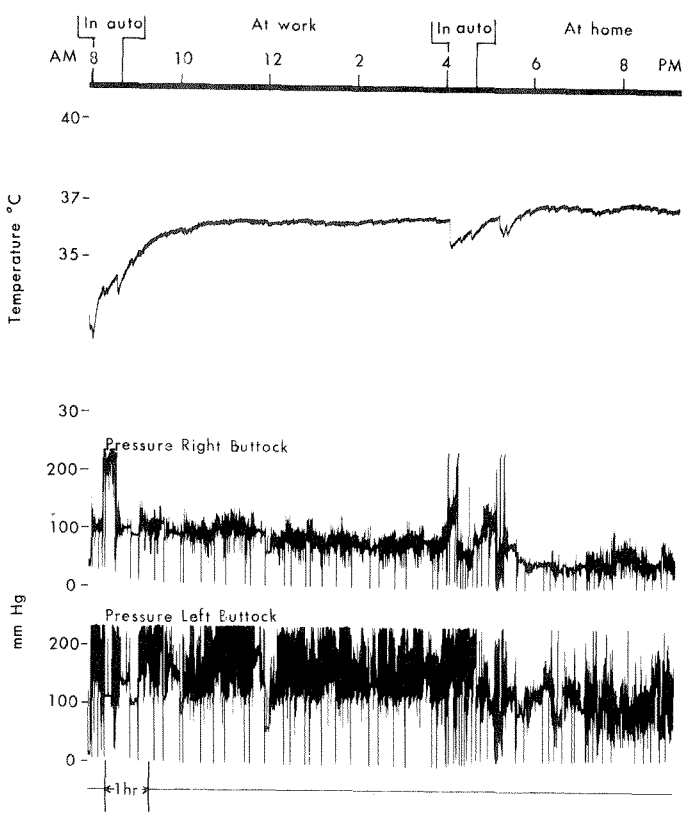

FIGURE 2.
A typical pressure and temperature record from one subject recorded for 12 hours. (Subject S.H., Exp. date 8/1/79).

even in this case, if the time scale is expanded as shown in Figure 5, it is clear that a pushup which is indicated by a flat zero pressure region can be distinguished from short oscillations due to body movement.

Table 2 shows the average percent time the subjects sat with pressures > 30 mmHg, > 90 mmHg, and > 150 mmHg. The average periods between pushups of various durations are shown in Table 3. A histogram of the average percent of the total experimental time spent sitting for various time periods without a pushup is shown in Figure 6. The data are shown ignoring pushups < 1 sec and < 5 sec.

There were some individuals whose sitting time was considerably longer than the mean time between pushups. One subject with a negative ulcer history sat for periods > 60 min for 99.8 percent of the time (if we ignore pushups of duration < 5 sec), and 65.4 percent of the time (ignoring pushups of duration < 1 sec). Another subject, who has been paraplegic for 15 years and who had one ulcer 5 years ago, sat for periods > 60 min for 78.1 percent of the time (ignoring pushups of duration < 5 sec), and 67.1 percent of the time (ignoring pushups of duration < 1 sec). A comparison of the histograms showing pressure relief for the > 30 mm and > 90 mm pressure level is shown in Figure 7. Two of the subjects sat for periods of between 10 and 30 min for > 50 percent of the total experimental time with readings above the 90 mmHg pressure level. Table 4 shows the percent time subjects spent with sitting periods > 30 min (ignoring pushups of duration < 1 sec and < 5 sec).

TABLE 2

The average percent time subjects sat with pressures > 150, > 90, > 30 mmHg

Pressure mmHg	%Time ± S.D.
> 150	17.6 ± 19.0
> 90	53.5 ± 34.8
> 30	91.8 ± 10.7

TABLE 3

Average time between pushups of various durations

Duration of pushups (Sec)	Period between pushups ± S.D. (Min)
Any	7.1 ± 4.3
> 1	10.1 ± 6.4
> 5	29.6 ± 27.5

TABLE 4

% time spent with sitting periods > 30 minutes

Ignoring pushup with a duration of	% Time
< 1 sec.	26.3 ± 27
< 5 sec.	49.9 ± 33

DISCUSSION

On the average, these subjects sat for periods longer than recommended by the medical personnel in our institution, which is a pushup of approximately 5 seconds every 15 minutes. The average time interval was approximately 30 minutes, which is the value Griffith (7) says should not be exceeded without a shift in position or lying down. It should be remembered, therefore, that for half of the time the subjects sat, with pressure unrelieved according to the data, for periods longer than the time Griffith recommends. None of the subjects had developed an ulcer 6 months after the experiment. It is interesting to note that if a 5-sec

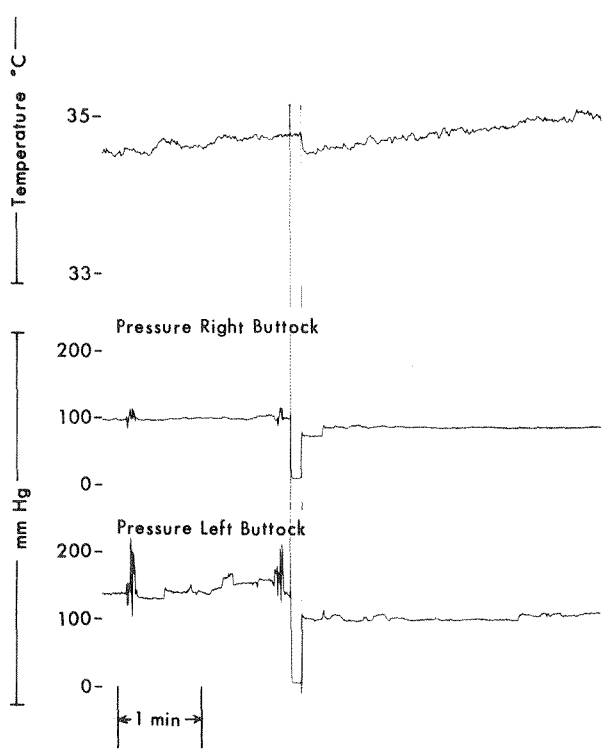

FIGURE 3.
An expanded time and temperature scale is used here to show a portion of the same record shown in Figure 2, so that the temporal relationship of the temperature change to the pressure change can be seen. (The short spikes at the start of the temperature record are calibration signals.)

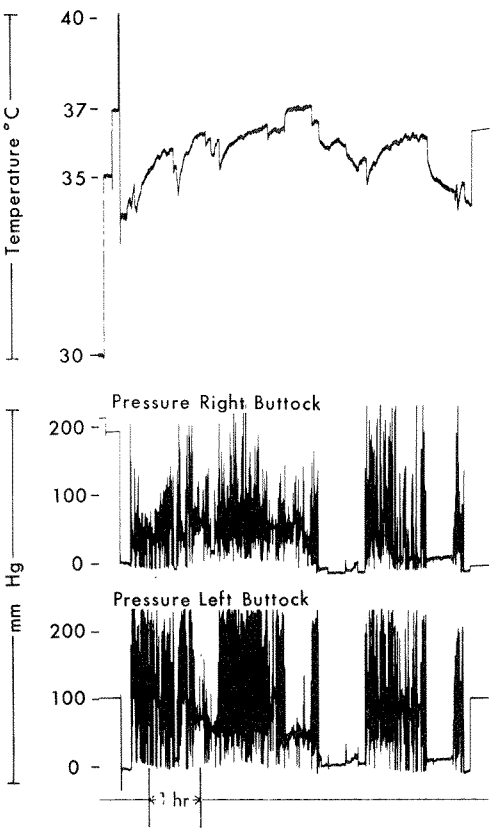

FIGURE 4.

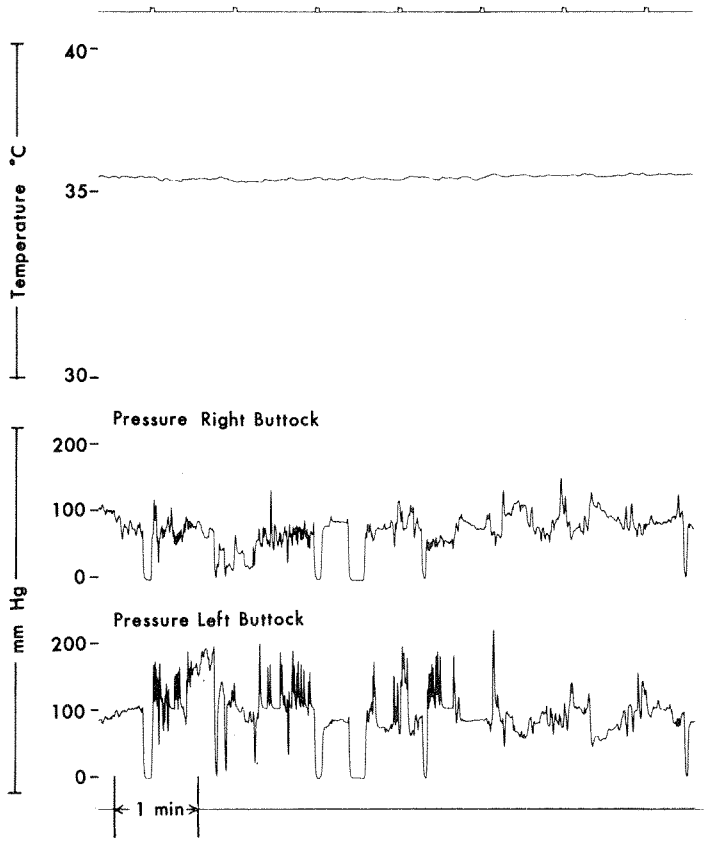

FIGURE 5.

Figure 4 is an example of one of the most "noisy" records of the pressure and temperature obtained. In Figure 5, a section of the same "noisy" record is shown using an expanded time scale. In Figure 5 a pushup can be identified by the presence of a flat bottom near zero and by the duration of the pressure relief: these indications separate the record of the pushup from the pressure oscillation due to movement.

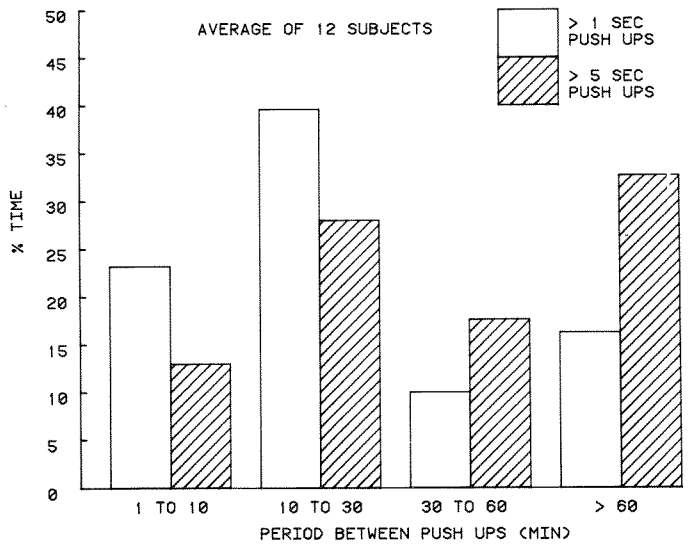

FIGURE 6.
A histogram of the percent of the total experimental time spent with various periods at pressures > 30 mmHg (ignoring pushups of duration < 1 sec and < 5 sec).

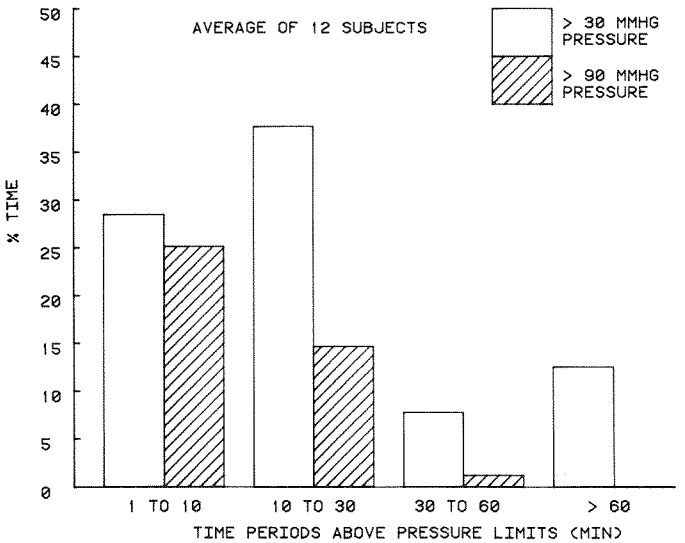

FIGURE 7.
A histogram of the percent time spent with various periods at pressures > 30 mmHg and >90 mmHg (ignoring pushups < 1 sec).

pushup is considered necessary in order to allow blood flow to supply oxygen and to remove the metabolites, then on the average during 32 percent of the total experimental time subjects sat "unrelieved" for periods > 60 min.

There appeared to be no significant difference in pushup behavior between subjects who had positive and those who had negative ulcer histories. One subject with negative ulcer history sat for essentially the entire recording period of over 7 hours without doing a pushup of a 5-sec duration—and did not develop an ulcer. However, three of the four subjects with positive ulcer history had a less-than-average time between pushups with > 5 sec duration. Also, two of these four subjects were below the mean in time spent with pressures > 90 mmHg.

The average values obtained in this study are of general interest because this information has not been available before. The results, however, should not be extended to the general paraplegic population because only 12 subjects were studied, and only 1 day for each subject. Of more scientific interest are the individual subjects who had long uninterrupted sitting periods, because we need to compare their results with the results obtained from animal experiments (1–4).

A very consistent pattern in the temperature data is the slow rise of temperature after the subject starts the experiment. A fast drop in temperature associated with a pushup was frequently observed as shown in Figure 3. The temperature fall occurs after the pushup, when the subject returns to the sitting position. Evaporative cooling of the moist clothing, which falls away from the skin during the actual pushup, is the most likely cause of the drop in temperature.

Although a rise in temperature was observed with some transfers to an apparently hot surface, such as a car seat which was exposed to the sun during the summer, no significant temperature rise associated with a pushup was observed with any of the patients. Brand (9) and others have reported a rise of temperature to be related to potential skin problems. Although no temperature rise was seen in our subjects, the duration of a pushup was in terms of seconds, whereas other researchers have documented the maximum temperature rise to occur in 2–4 min (12,13). Also, most studies (12,13,14) that have applied controlled pressures on the skin and observed temperature changes have used higher pressures and/or a longer duration of application than observed in this study. The results of those studies generally showed an initial temperature rise.

The investigation by Mahanty and Roemer (12) showed a temperature fall below the initial value after approximately 5 min when using a low pressure (100 mmHg) or short time period (11 min). Goller et al. (13) observed in some cases an initial fall in the temperature. In that study, the seat cushion insulated a large region of the buttock which resulted in the skin temperature approaching body temperature. This fact would minimize the observation of a temperature rise because it would not be expected for the skin temperature to go above body temperature.

The meaning of short oscillations

The fast, less-than-one-second oscillations seen in our pressure records may be artifacts caused in part by shearing forces and the uneven loading of the diaphragm of the pressure transducer, or they may be due to quick pressure reliefs. Since the physical meanings of the recorded short pressure oscillations are not known, and also because no study has shown that quick pressure reliefs are of benefit in preventing ulcer development, this analysis concentrated on pressure reliefs longer than 1 sec, where we had most confidence in the data.

The absolute value of the pressure measurements are in error due to the difficulty in placing the transducer on the skin exactly over the ischial tuberosities and because of the error inherent in the use of these (or most other) transducers for soft-tissue pressure measurements. With changes in hip angle and in the stresses on the tissue due to sitting forces, the exact skin region which is over the tuberosities changes—which causes the transducers to move off the center. An example of this problem may be seen in Figure 2, where the left buttock pressure is higher (this, however, could have also been due to the subject leaning to the left). From data obtained in a previous study over the pressure range of interest, the estimated error is believed to be about 15 percent, but a given measurement could have more error (11). Even though there is error in determining the maximum pressure under ischial tuberosities, a pushup to near zero pressure could be reliably determined in this study.

These data raised the following questions:

1. What is different about the physiology of some of these subjects that allows them to sit for such long periods of time without getting ulcers?
2. Have the subjects conditioned their tissues to withstand the long sitting periods?
3. Are many repeated daily bouts of long-uninterrupted pressure needed to produce an ulcer?
4. Are the wrong parameters being measured? (Friction (2) and shear (10) have been implicated as factors in the generation of ulcers.)

This study did not investigate the role shear forces play in the generation of ulcers. Bennett et al. (10) and Dinsdale (2) have both suggested that shear plays an important role in the generation of ulcers. The short oscillations in the pressure record which were ignored in this analysis may represent movement-induced shearing of the tissue. Visual observations of pressure records indicate that there was considerable differences between subjects in regard to such oscillations. An investigation correlating these oscillations with known shear forces is needed.

This data-recording and analysis method could eventually be used to study patients with ulcer problems, to determine their actual pressure-relief pattern and to counsel accordingly. Repeated daily measurements should first be made, though, on patients who have no problems, to compare them with patients who repeatedly develop ulcers.

If it is assumed that the pressure-time patterns observed in this study represent the typical behavior of these paraplegic subjects, more studies will be needed to explain how these subjects remain ulcer-free. It may be that the pressure-time curve presented by Kosiak (1) should be thought of as a probability curve, with individuals varying considerably depending on the physiological state or conditioning of their tissues.

REFERENCES

1. Kosiak M: Etiology of Decubitus Ulcers. Arch Phys Med Rehabil 42:19–29, 1961.
2. Dinsdale SM: Decubitus Ulcers: Role of Pressure and Friction in Causation. Arch Phys Med Rehabil 55:147–152, 1974.
3. Kosiak M: Etiology and Pathology of Ischemic Ulcers. Arch Phys Med Rehabil 40:62–69, 1959.
4. Husain T: Experimental Study of Some Pressure Effects on Tissues, with Reference to the Bed-sore Problem. J. Path and Bact. 66:347–358, 1953.
5. Mooney V, Einbund MJ, Rogers JE, Stauffer ES: Comparison of Pressure Qualities in Seat Cushions. Bull Pros Res BPR 10–15:129–143, Spring 1971.
6. Souther SG, Carr SD, Vistnes L: Wheelchair Cushions to Reduce Pressure Under Bony Prominences. Arch Phys Med Rehabil 55:460–464, Oct. 1974.
7. Griffith BH: Advances in the Treatment of Decubitus Ulcers. Surg Clin North America 43:245–260, 1963.
8. Romanus EM: Microcirculatory Reactions to Controlled Tissue Ischaemia and Temperature: a Vital Microscopic Study on the Hamster's Cheek Pouch. Bedsore Biomechanics (Ed. RM Kenedi, JM Cowden & JT Scales) University Park Press, Baltimore, pp. 79–82, 1976.
9. Brand PW: Patient Monitoring. Bedsore Biomechanics (Ed. RM Kenedi, JM Cowden & JT Scales) University Park Press, Baltimore, pp. 183–184, 1976.
10. Bennett L, Karner D, Lee BK, Trainor FA: Shear vs. Pressure as Causative Factors in Skin Blood Flow Occlusion. Arch Phys Med Rehabil 60:309–314, 1979.
11. Patterson RP, Fisher SV: The Accuracy of Electrical Transducers for the Measurement of Pressure Applied to the Skin. IEEE Transactions on Bio Med Eng BME-26:450–456, 1979.
12. Mahanty SM, Roemer R: Thermal Response of Skin to Application of Localized Pressure. Arch Phys Med Rehabil 60:584–590, 1979.
13. Goller H, Lewis D, McLaughlin R: Thermographic Studies of Human Skin Subjected to Localized Pressure. Am J of Roent Ther & Nuclear Med 113:749–754, 1971.
14. Goller H, Lewis D, McLaughlin R, Verhonick P: The Effect of External Pressure on Skin Temperature Distribution by Thermography. Med Res Eng 12:6–8, 1976.