COMPARISON OF PRESSURE DISTRIBUTION QUALITIES IN SEAT CUSHIONS

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INTRODUCTION

Support of living tissues by nondestructive external devices is essential in the fields of orthotics and prosthetics. In all areas of medical care for chronic illnesses, considerable effort is devoted to the creation of devices which are nondestructive to living tissue and yet accomplish their function of support when the neuromuscular skeletal system is inadequate because of disease or injury. From the blur of these generalities, sharp focus on a practical problem comes when we examine the design of seat cushions for wheelchairs.

The purpose of this paper is to discuss concepts in pressure distribution to living tissues, evaluate currently available seat cushions, and present specific data comparing various cushions. This discourse is not intended as an endorsement of any specific product or condemnation of another. Our goal has been to develop a rationale for the most appropriate design of seat cushions and to present specific facts to support this rationale.

CONCEPTS

The first point to be defined is whether a seat cushion which subjectively feels most comfortable to the healthy subject is an appropriate device for a disabled patient. The disabled patient cannot adjust to the most comfortable sitting position for he either has insufficient sensory feedback or too much physical disability to find a position of comfort. In fact, comfort is an extremely subjective point of evaluation. Airline companies and automobile manufacturers spend millions of dollars testing seats, cushions, positions, etc. Unfortunately, all this effort has produced no uniform standards by which to measure comfort. Various degrees of softness and yield are presented to the public in the multiple conveyances, which support the idea that the specific assessment of comfort is an inaccurate definition of seat cushion adequacy.

The most important function of cushions is not comfort, but rather pressure distribution. In clinical use, the most important contribution of design of seat cushions is to equalize and minimize pressure. Pressure *can* be quantitated, and most of this discussion will be devoted to the evaluation of pressure forces. Several other specifications also are important, such as heat and moisture exchange, material stability, cushion weight, and cost.

Heat and Moisture Exchange

Heat and moisture exchange are important elements in the subjective comfort of any sitting device. The seating element which is extremely efficient as a heat sink will be very chilling to sit upon (uncovered metal chairs). Prolonged sitting on such surfaces may have deleterious effects to the overlying skin by initiating a vasoconstrictor response evidenced by further decreasing a blood supply which is already embarrassed by excessive pressures.

Water vapor evaporation is also important in seat cushions used in a clinical setting. Clinical experience demonstrates the tendency of skin to macerate when it remains in environments of high humidity for long periods of time. Seat cushions used by disabled patients often are subjected to urinary incontinence and wound drainage. The ideal covering, therefore, must be easily cleaned and resistant to staining, while allowing some water vapor exchange and only slight heat absorption.

Material Stability

Stability of the disabled patient on the seat cushion material is extremely important. When applied to use in wheelchairs, a firm reaction point is necessary when patients with borderline trunk control and weakness attempt self-propelling their wheelchairs. Trying to stabilize a curved spastic torso on a floating pelvis is very demanding to a limited muscle control system. Propelling the wheelchair while floating on a fluid-filled cushion requires more energy than when the reaction force is dissipated by the slight yield of firm supporting structures.

Stability of the material in seat cushions also is important from the standpoint of maintenance and transfer. Unfortunately, fluids always have the potential to leak out of their encapsulating structure. It is common hospital experience to find the effective alternating air mattress rolled up in the utility closet because a leak in one of the air cells makes the entire system inoperative. Patching leaky cushions is one more problem for medical care of the chronically ill, which is already overburdened with a multitude of maintenance chores.

Cushion Weight

A fluid-filled cushion is more difficult to transfer to and from the chair than a rigid or firm material because its center of gravity is constantly shifting, which requires rapid compensation on the part of the person attempting to lift and carry it. This is a difficult task for a patient with weak or poorly controlled musculature. The problem of seat cushion transfer is especially significant in clinical settings. One of the elements which gives wheelchair users their greatest independence is the ability to transfer in and out of their wheelchairs, in and out of vehicles, etc. The ability to lift the wheelchair and/or its cushion may be the difference between independent or assisted transfers. Thus, weight of the cushion is a factor whose importance is directly proportionate to the degree of disability a patient suffers.

Cost

Most patients are willing to pay whatever amount is necessary to get a cushion which will eliminate or minimize pressure. It is incumbent upon the manufacturer to satisfy this need; however, it appears that this requirement is not the major consideration in the design and fabrication of wheelchair cushions. While cost is the least important element of the specifications, it is still significant in any competitive analysis of various devices.

Pressure Distribution

The most important characteristic of seat cushion design is pressure distribution. There is no argument that the chief factor creating skin ulcerations about areas of bony prominences is local tissue ischemia. Kosiak reviewed the literature and performed experiments to document the fact that there was a direct relationship between pressure and time in skin and muscle necrosis (1). He demonstrated from a theoretic mathematical standpoint that if the body weight of an average human were distributed ideally over the entire sitting area, skin pressure could be reduced to about 26 millimeters of mercury. Data from NASA, as illustrated in Figure 1, indicate this number may be somewhat higher for healthy adults.

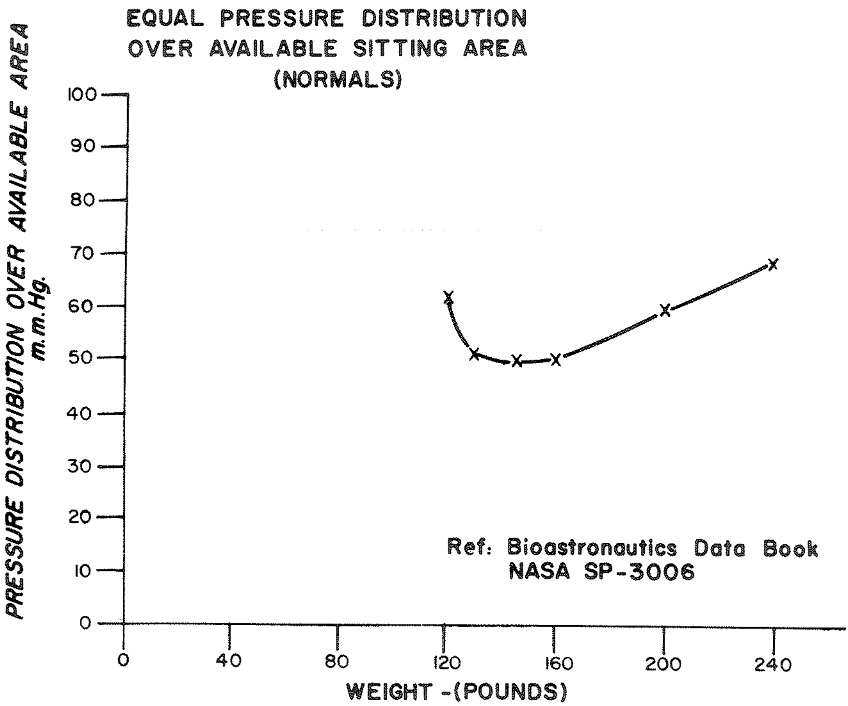


FIGURE 1.—Available pressure distribution on normal subjects.

In animal experiments (2), no tissue damage occurred when pressures were maintained below 35 millimeters of mercury for up to 7 hours. However, there was a direct relationship between increasing pressure and the time necessary for demonstrable tissue changes to occur. There are no precise data from human experimental work, but the critical pressures necessary to create permanent skin changes must have some relationship to capillary pressure and the maintenance of capillary circulation. In humans, capillary blood pressure has been measured at about 30 millimeters of mercury at the arterial limb (3). Sixty to 70 millimeters of mercury have been destructive to tissue when applied for over one hour (4). All authors agree that there is a time-pressure relationship in the creation of destructive tissue changes (5).

In another study, Houle (6) demonstrated that the range of pressure under the ischial tuberosity was between 140 millimeters of mercury for hard board to about 80 millimeters of mercury using a commercially available visco-elastic jell. By this standard, none of the devices presently available would theoretically be successful in preventing ischemic ulceration in the case of paraplegic patients. To meet the needs of these patients, Houle suggests the use of an automatic device which would alternately shift pressure from one area to another.

CLINICAL TEST METHOD

To test pressure distribution capabilities of various seat cushions, special test equipment had to be designed. To standardize test conditions, a special chair was constructed. This chair, with variable back angle, variable seat angle, and variable leg angle, could be adjusted to suit the anatomy of each subject tested. The tests were performed with both legs weighted equally, as tested by scales under each foot. The subject was tested with his hands resting on the thighs and the thighs parallel to the floor and the seat so that optimum distribution of weights was available (Fig. 2).

Pressure was measured by a pneumatic cell pressure sensor developed especially for this study. Clinical experience and previous studies on the problem of pressures and seat cushions both confirm that the greatest

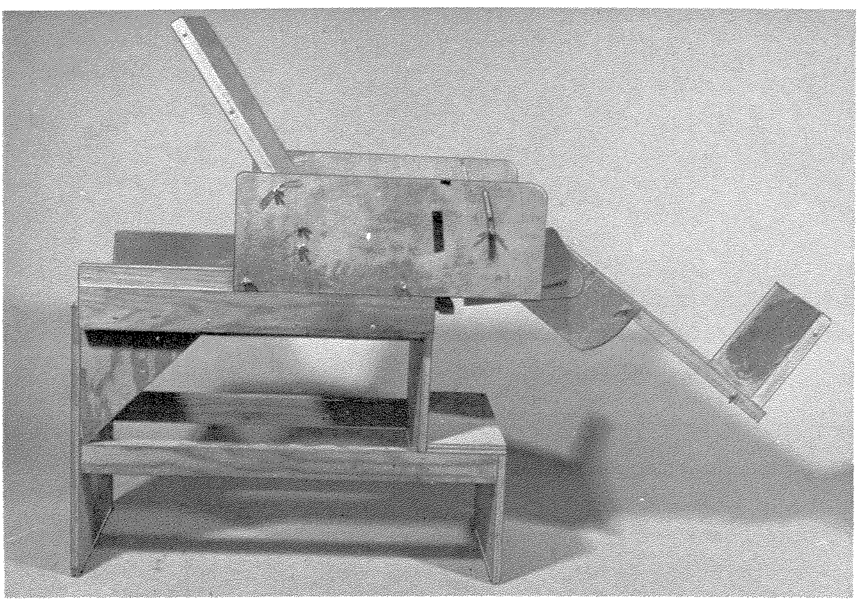


FIGURE 2.—Fitting chair.

pressures are under the ischial tuberosities (7–9). If destructive forces occur, they will be present at these sites. Measurement of pressure under the ischial tuberosities is clinically significant and effectively measures the seat cushion's capability to distribute these pressures. Distribution of these pressures may mean transfer of weight to the thigh area. This would appear acceptable if sharp pressure gradients did not occur between the ischial tuberosities and surrounding tissue. Other means of transferring pressure would be to recline and elevate the knees and legs accordingly so the weight is borne over a larger area. Other problems then arise as to practical limitations of the patient.

To measure pressures specifically at the ischial tuberosities, a special electropneumatic matrix of switches was designed. Without this, matrix tests indicated that peak pressures could be missed. This matrix device, contained within an inflatable plastic bladder, was made up of 25 switches, 1½ centimeters apart, covering a 7 centimeter square area. By inflating this plastic envelope until contact was broken, this pressure transducer measured the highest pressure at any location in the 7 centimeter square area (Fig. 3). The air pressure required to break all contact points and separate the two sides of the plastic envelope may be considered as the highest pressure on any point on the pressure transducer.

The pressure transducers contoured well around anatomic structures as the vinyl plastic was .001 in. thick and extremely pliable. Air pressure input was created by a sphygmomanometer bulb from a standard blood pressure cuff. Air pressure was read from the mercury manometer just as in the case of blood pressure readings. A small light placed on the

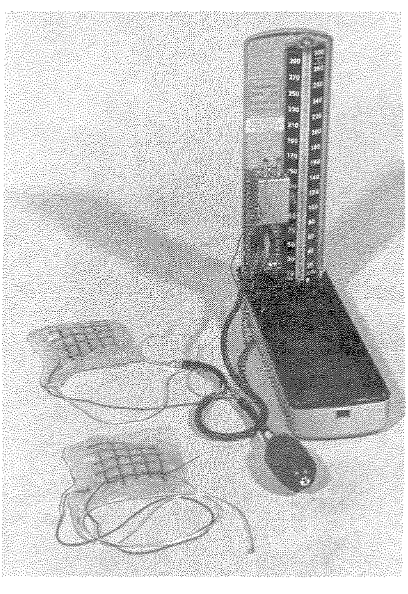


FIGURE 3.—Pressure transducers and readout manometer.

sphygmomanometer indicated when the contact points were broken (light off). Pressure readings were recorded using 10 different commercially available seat cushions. Measurements were taken from 12 normal subjects and six patients, five with spinal cord injury and one with bilateral above-the-knee amputations. The cushion characteristics are itemized in Table 1.

TABLE 1.—*Cushion Characteristics*

Cushion	Thickness in.	Weight lb.	Approx. cost	Characteristics
Decubitex	2	1	$35.00	Tiny plastic balls are displaced by concentrated weight.
Bye Bye Decubiti	4	2	20.00	Compartmentalized rubber envelope for air inflating. Depressions or buttons near ischial tuberosities.
Scimedics A	3	4	60.00	Non-flammable resin-filled polyurethane. Sifoam liners.
Scimedics B	3	3½	60.00	As in Scimedics I with an 8″ x 10″ x 1″ cutout.
Foam rubber	4	3	20.00	Cored foam with cotton cover.
Jobst	2	22	60.00	Open-pored synthetic foam filled with water and contained in a nylon cover.
Trenchard	2	17	20.00	Heavy vinyl cover encloses a gel-like material developed by adding water.
Orthopedic Equipment	2	15	150.00	Silicon fluid and foam are contained in a rubber envelope.
Stryker	2	14	350.00	Special gel is contained in a latex cover.
Lyn Bar	2	10	60.00	Water- and foam-filled vinyl envelope.
Ortho Industries	2	16	150.00	Special gel.
De Puy	2	10	150.00	Water and squared foam. Nylon covers.
Polyurethane foam	2 to 4	1	10.00	Convoluted surfaces.

FINDINGS

Figures 4 and 5 graphically show the pressure readings taken under the ischial tuberosities with the 12 normal subjects and the six patients. There was no correlation between the subject's weight and pressure distribution; this was especially true in the case of the patients. One patient (W. M.) weighed only 140 lb. but frequently had the highest pressure readings. This patient was 7 years post spinal cord injury, had a great deal of muscle atrophy, and had extremely prominent ischial tuberosities.

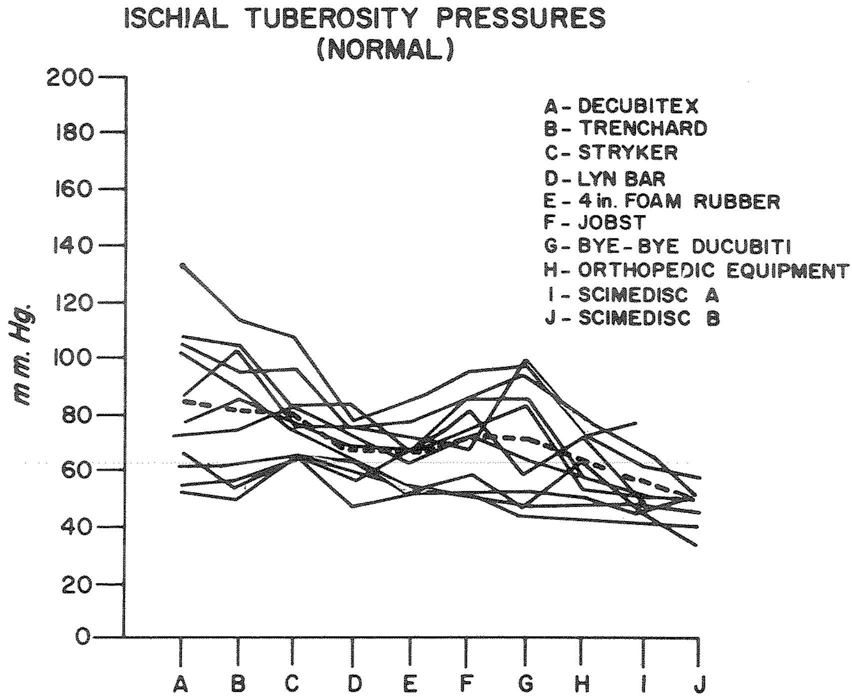


FIGURE 4.—Normal ischial tuberosity pressures versus cushions.

The mean weight of the patients was 136 lb. and the mean weight of the normal subjects was 128 lb. The mean pressure reading at the ischial tuberosities of the patients ranged from 152 millimeters of mercury to 83 millimeters of mercury, while the mean range was from 86 millimeters of mercury to 51 millimeters of mercury in the normal subjects.

Cushion Evaluation

The various cushions described below are pictured in Figure 6.

Decubitex: Normal subjects considered the cushion hard, but the patients had no adverse response on this point. It was easy to handle, quite stable, and there were no problems in patient positioning.

Byebye Decubiti: It felt comfortable to both normal subjects and patients, although it was slightly unstable when patients moved about on it. There was a severe problem in patient positioning. While it was easy for a normal subject to adjust his position so that the ischial tuberosities directly overlay the appropriate depressions in the cushions, disabled subjects could not adjust their position to attain the same position, and extremely high pressures resulted until the patients could be repositioned. The investigators were able to note high pressures and move patients. Because the cushion had to be filled by the patient, there was

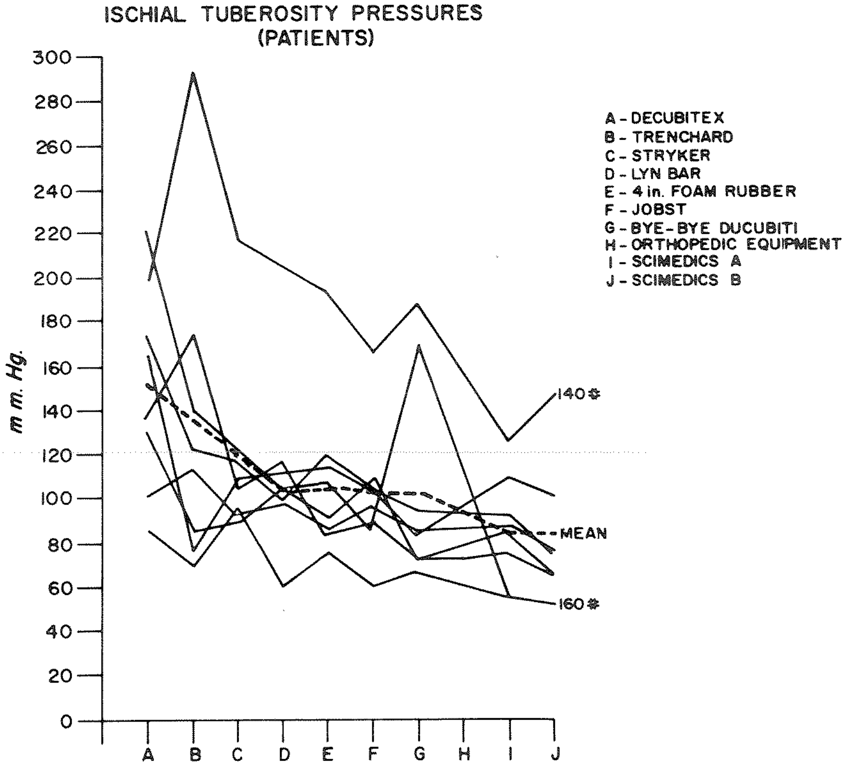


FIGURE 5.—Patient ischial tuberosity pressures versus cushions.

an opportunity to make the cushion excessively firm or deflated, and thus create an adverse effect on pressure distribution. Also, the patients had some problems with stability in that they tended to float on an unstable base while sitting on this cushion. Because the cushion was filled with air, there was the possibility of unobserved leakage. If the cushion leaked, its pressure distribution capabilities diminished.

Scimedics A: This cushion has a firm characteristic contrary to popular misconceptions of a cushion being soft for comfort. This was not an adverse point with the patients who had no sensation, and normal subjects were quite surprised at its comfort as the cushion conformed more appropriately to the pressure profile to relieve high pressure points.

Scimedics B: This cushion's response time was identical to "A" except that it had a cutout that gives a gradual transfer of pressure to the thighs. Neither cushion had problems with patient positioning, leakage, stability, handling, or filling. Shear forces tend to be transferred to pressure as the patient sinks into position.

Four-inch Foam Cushion: Both patients and normal subjects accepted

FIGURE 6.—Evaluated cushions.

this cushion as it had the greatest resemblance to standard seat cushions. Handling was reasonable, there was no leakage, it was not as unstable as the liquid or gel, and patient positioning was a problem only upon transfer.

Jobst Cushion: Great difficulty in handling was a major criticism of this cushion not only because it was heavy but also because the water tended to flow as it was lifted, making its transfer more complex. Without handles, this 22-lb. cushion would have been unmanageable and if the patient was not located accurately in the cutout area, excessively high pressures resulted.

Trenchard: This cushion also was difficult to handle because of its weight and flexibility; it has added problems relative to inexpert filling of the cushion. Because it was fluid-filled, it had the potential to leak and had some qualities of instability which gave patients a floating sensation.

Orthopedic Equipment Company: Handling was a severe problem with this cushion because of its weight and flow of the center of gravity. Although normal subjects had no adverse reactions (in fact, had a pleasing sensation in sitting on these cushions), patient reaction was quite negative due to severe instability while trying to propel a wheelchair or to hold themselves in a correct position. There was such inherent instability with this cushion that one patient fell out of the chair while using it. Reducing shear forces to a minimum results in complete lack of control in a horizontal direction. Leakage was a major problem and testing of this cushion had to be discontinued because of persistent leakage.

Stryker: This cushion also had severe handling problems because it was heavy and extremely unstable as a mass. Its instability was so bad that one patient fell out of the chair using it, and most patients thought it was too unstable to use while propelling their wheelchairs. Leakage did not occur while testing this cushion, although it had started at the end of the test project.

Lyn Bar: Although it was not as unstable as the previous two, because it was water-filled and heavy it did have some problems in handling ease. Leakage was a problem and the cushion had to be replaced because of persistent leakage. Leakage also has been reported from other institutions. Because it required the patient's skill to fill appropriately, the cushion was considered severely limited. The cushion, however, was stable and patient positioning was not a problem.

Cushions not included in the clinical pressure study but evaluated in a comparative sense, i.e., relative to comparable cushions, were Bioclinic, De Puy, Ortho Industries, and various configurations of plain polyurethane foam.

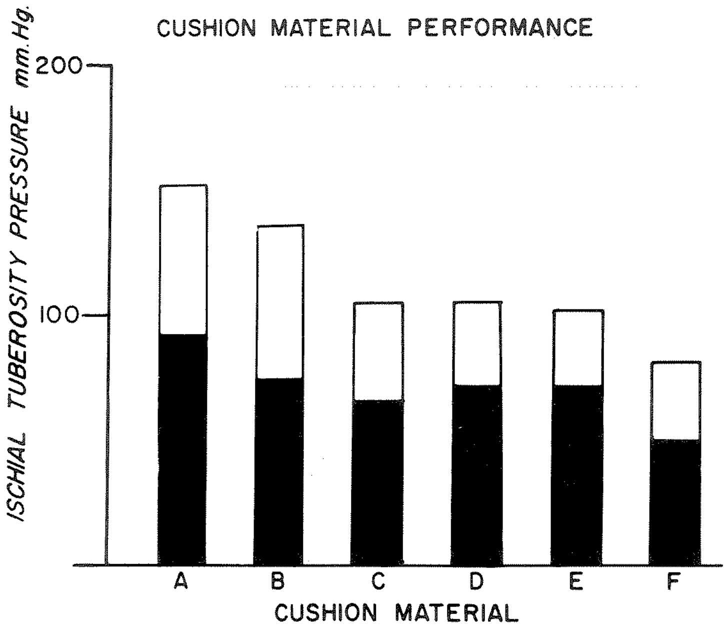
Bioclinic was comparable to Lyn Bar in performance and comments for liquid and foam-filled problems. De Puy was also a liquid-filled cushion with the internal foam segregated into squares and cut overall in somewhat of a wedge shape. The wedge shape helps to support the thighs, and overall foam spring constant is controlled by cutting foam into squares. Performance of the cushion, however, was similar to the Lyn Bar, Bioclinic, and foam rubber, also with the associated problems of filling, leakage, and difficulty in handling. The double nylon cover is durable, but the shear forces are reduced only minimally due to cover friction and travel. It should be noted that elimination of shear forces would make it impossible for patients to maintain equilibrium unless strapped into position.

Ortho Industries consists of a gel-type insert and initial results are comparable to other gel-like cushions.

Polyurethane foam cut in various ways, such as convoluted or peaks, increases the initial softness of the material and allows breathing of the skin. Pressure problems are similar to the standard foam rubber when compressibility limits are reached. It was found that anything less than 4 in. of foam rubber was inadequate and that if the polyurethane foam compressibility was comparable, it faced the same inherent problems.

DISCUSSION

Pressure distribution under the ischial tuberosities is the most important factor in the evaluation of clinically usable seat cushions. In this study no cushion presented was ideal or able to reduce pressure to the skin below arterial capillary level, as illustrated in Figure 7. The most successful cushion was the resin-filled, polyurethane foam (Simedics) which reduced mean pressures to 50 millimeters of mercury in normal subjects and to 83 millimeters of mercury in patients. The cutout in Scimedics B reduced ischial tuberosity pressure and increased thigh pressure.



CUSHION	MATERIAL
A	COTTON ENVELOPE & PARTICLE FILLED
B	"GEL" TYPE
C	FOAM RUBBER
D	WATER & PLASTER FOAM
E	AIR
F	RESIN-FILLED PLASTIC FOAM

FIGURE 7.—Patient and normal ischial tuberosity pressures versus type of cushion material.

The surprising finding of this study was the failure of fluid-filled cushions to achieve their hypothetical ideal of total, even pressure distribution. It seemed logical that if the supporting medium could flow, it would distribute pressure evenly throughout the entire supporting medium, according to the laws of fluid dynamics. The reason for this failure was the surface tension of the enveloping membrane. Even though the fluid contained can distribute pressure evenly, the container is limited by its physical qualities and elastic limits. This means that when sitting on a fluid-filled cushion, the body is not completely supported by the fluid but rather by the hammock effect of the container. Because the container is unyielding, high pressures result and ideal pressure distribution cannot be achieved. The composite material (resin-impregnated polyurethane foam) had minimal resistance to compression and thus gave way to high ischial tuberosity pressure, while the incompressibility of fluids limited the effectiveness of fluid-filled cushions. As in the case of foam rubber, the entire mass of the resin-impregnated cushion could be reduced considerably without increasing the surface tension. The viscosity of the resin prevented the cushion from "bottoming out" at the impact of seating. When the entire supporting surface area of living tissue was available, enough cushion surface was provided to give support in spite of the minimal resistance to compression in this material. However, this prolonged time constant for pressure distribution created an unyielding feel to the cushion which was interpreted as discomfort when first used by normal subjects.

The use of paralyzed patients as evaluators brought out points which might have been passed over as inconsequential by normal subjects. The instability of the cushion mass is a severe limitation in transfer to the cushion and stability of the patient as he sits upon the cushion trying to maintain stability against a floating reaction point. Also, all the cushions presented fairly acceptable figures for pressure distribution in normal subjects, but this was not the case when tested by the thinner and more atrophic patient population. Severity of patient disability was quite apparent when patients fell off the cushions twice. In normal subjects reflex reaction prevented this, although an initial adjustment still was necessary.

The problems of patient participation in maintenance of their equipment also became apparent. Devices which need to be filled by the patient have severe limitations in that large degrees of inconsistency result in the amount of filling accomplished by the patient. Frequently they fail to understand the ideal status of air or fluid filling and tend to either over- or under-shoot the mark. Leakage remains a potential problem. Some of the test cushions leaked and this is a persistent possibility with all fluid-filled equipment.

For severe problems of ischial tuberosity prominence, the use of a cutout gives an additional element of safety as long as it is properly designed to minimize high pressure gradients. Some type of material, such as that used in the Scimedics cushion, is needed to provide a graceful pressure gradient from the thighs to the ischial tuberosity area. Thus, if not properly designed and if a hard cutout board is used, a sharp gradient will exist even when padded with a foam that has spring-back or short-time constant.

SUMMARY

The provision of an effective wheelchair cushion is of paramount importance to prevent ischial pressure ulceration and to allow continued vocational productivity of a paralyzed patient. Ideally pressure should be distributed to prevent interference with capillary blood flow to skin over bony prominences. A search of the literature indicates no documentation of any material which accomplishes this goal.

This study of presently available cushions failed to demonstrate that any of the cushions tested were safe for prolonged sitting by paralyzed patients.

The secondary factors of size, weight, transportability, and cost are assessed and resulting limitations explored. The ideal cushion is one that has the most even pressure distribution over the largest skin area, that is the most stable for patient sitting, that is the lightest in weight; that requires least maintenance, that is the lowest in cost, and that has the most durable covering.

The experimental design of resin-impregnated polyurethane foam with a 1 in. x 8 in. x 10 in. cutout area (Scimedics B) under the ischial tuberosity appears to most closely approximate the clinical criteria for an acceptable wheelchair seat cushion for paralyzed patients.

REFERENCES

1. Kosiak, Michael: Etiology of Decubitus Ulcers, Arch. Phys. Med., 42:19–28, Jan. 1961.
2. Landis, D. M.: Microinjection Studies of Capillary Blood Flow in Human Skin, Heart, 15:209, May 1929.
3. McLennan, C. E., M. T. McLennan, and E. M. Landis: The Effect of External Pressure on the Vascular Volume of the Forearm and Its Relation to Capillary Blood Pressure and Venous Pressure, J. Clin. Invest., 21:319, May 1942.
4. Kosiak, Michael, et al.: Evaluation of Pressure as a Factor in the Production of Ischial Ulcers, Arch. Phys. Med., 39:623–629, Oct. 1958.
5. Lindan, Olgierd, R. M. Greenway, and J. M. Piazza: Pressure Distribution on the Surface of the Human Body: I. Evaluation in Lying and Sitting Positions Using a Bed of Springs and Nails, Arch. Phys. Med., 46:378–385, May 1965.
6. Houle, R. J.: Evaluation of Seat Devices Designed to Prevent Ischemic Ulcers in Paraplegic Patients, Arch. Phys. Med., 50:587–594, Oct. 1969.

7. Swearingen, J. J., C. D. Wheelwright, and J. D. Garner: An Analysis of Sitting Areas and Pressures of Man. Civil Aero Medical Research Institute, Federal Aviation Agency Aeronautical Center, Oklahoma City, Oklahoma, Jan. 1962.
8. Reichel, S. M.: Shearing Force as a Factor in Decubitus Ulcers in Paraplegics, J.A.M.A., 762–763, Feb. 15, 1958.
9. Newell, P. H., Jr., J. D. Thornburgh, and W. C. Fleming: The Management of Pressure and Other External Factors in the Prevention of Ischemic Ulcers. An ASME Publication, Paper No. 69–WA/SHF–1.