

## EXPERIMENTAL EVALUATION OF WHEELCHAIR CUSHIONS: REPORT OF A PILOT STUDY<sup>a</sup>

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**Note:**—*The VA Prosthetics Center takes particular pleasure in acknowledging the publication of the following report by Dr. Cochran and Mr. Slater. As a large consumer of wheelchair cushions and pads, as well as bed mattresses, the Veterans Administration has had a deep interest in evaluating the merits in the relatively great number of such products. Several years ago the VAPC undertook a formal program to evaluate every known load-absorbing device of this type and to develop government standards and specifications governing their procurement. This was indeed a formidable task in an area in which we had little experience. Fortunately, the group at West Haverstraw under Dr. Cochran, had a wealth of experience in evaluation and design of cushions and mattress materials for spinal-cord-injured and similar-type patients. What they lacked we had—electronic transducers, recording apparatus, and other laboratory hardware to permit the objective testing and recording of results. A joint effort was subsequently organized in which VAPC provided equipment and the technical services of several staff members while Dr. Cochran and his group conducted their testing program in both laboratory and clinical settings.*

*The results as shown in the following report are highly commendable and to our knowledge represent the broadest systematic attack on the whole*

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<sup>a</sup> From the Biomechanics Laboratory, New York State Rehabilitation and Research Hospital, conducted in cooperation with the Veterans Administration Prosthetics Center, New York City, with instrumentation and technical assistance by the VAPC Bioengineering Research Service.

*problem of load-bearing materials to support the body. We believe that Dr. Cochran and his group have not only done an extensive job evaluating the relatively large number of devices but also have done so using creative and innovative methods.*

*The VAPC is not yet ready to prepare standards and specifications for cushions. However, we are quite certain that continuation of this work in the directions already taken and by the means already employed will have that result. Experience with additional patients and normal subjects, together with more experience in determining whether the rating system is completely free of bias, will surely put us in a position to promulgate government standards and specifications. . . Edward Peizer, Ph. D., Assistant Director, VA Prosthetics Center.*

## **INTRODUCTION**

The number of spinal-cord injury patients requiring rehabilitation has increased considerably in recent years. At the same time improved electromechanical devices are aiding mobility of both paraplegic and quadriplegic patients, enabling more of them to return to active, self-supporting lives, despite their handicap. Consequently, greater numbers of these patients are spending more hours each day in wheelchairs. Out on their own with less medical supervision and with more time being spent in a sitting position, these individuals are exposed to a higher risk of decubitus ulcers, particularly over the ischial tuberosity and sacral areas.

The consequences of "pressure sore" development are disastrous to the individual, both physically and economically. Therefore, more effective prevention of this complication is becoming essential. One active area of research has been improvement of wheelchair cushions; many new or modified types of cushions are now available, including rubber and synthetic foams, "gel types," "water pads," and impact absorbing types as well as other pads and cushions utilizing a composite of materials.

A problem has developed in the evaluation and selection of new cushions that are suitable for extended clinical trials. There are no adequate test procedures for determining which cushions are most promising or even safe. In the case of materials resembling foam rubber, ASTM standards exist, but there is no real index for relating these standards to use by spinal-cord-injury patients. Furthermore, there are few meaningful test standards by which the diverse new types of cushions can be compared to foam cushions, as finished products for clinical trials. Adequate specifications for manufacturing cushions also are nonexistent. Needed are testing procedures which can be utilized to compare all types of finished cushions, as

well as raw samples of foam, gel, and other complex materials, with regard to their potential clinical effectiveness and safety. This study was undertaken to provide such a program: to develop practical cushion evaluation techniques and standards for use by the Veterans Administration.

## **HISTORICAL REVIEW**

### **Etiology of Decubitus Ulcers**

An excellent review of the problem of decubitus ulcers in relation to wheelchair cushions has been published recently by Mooney et al. (1). The present concept of development of decubitus ulcers continues to be based on the classic papers of Landis (2), Nichol et al. (3), Lindan (4), Kosiak (5,6) and others. In the skin, capillary pressures are said to be approximately 30 mm. Hg. In experimental animals, ischemic skin ulcers are not produced when a low pressure (less than 35 mm. Hg.) is maintained for periods up to 12 hours or more. When this pressure level is exceeded, however, production of an ulcer is dependent on a time-pressure relationship, with higher pressure being tolerated for proportionally shorter amounts of time. Even pressures several times skin capillary pressure can be tolerated over longer time periods if applied intermittently.

The problem is most severe at the skin-cushion interface, where there is a sling effect, so that the applied pressure is concentrated at the skin, with only a fraction transmitted to the deep tissues (5). Theoretically, the problem of decubiti might be solved if pressures at the skin could be maintained below the 30 mm. Hg. capillary pressure. Unfortunately, this goal has not proved to be attainable in practice, although skin pressure theoretically could be reduced to 26 mm. Hg. if body weight were distributed perfectly over the entire buttock sitting area (1). Furthermore, factors *other* than the magnitude of direct compressive stress (pressure) also are important, particularly under clinical conditions.

Reichel (7) suggested the importance of shearing forces in production of decubitus ulcers in paraplegics. In patients lying in bed with the head portion raised, shearing forces are developed in deep layers of superficial fascia over the sacrum and act on the deeper blood vessels to further decrease circulation to skin and subcutaneous tissue.

Other factors thought to favor development of decubitus ulcers include loss of sensation with its attendant signals of discomfort (or perhaps neurotrophic effects), heat, moisture, irritating agents such

as urine and feces, poor nutrition, anemia, muscle wasting, and inflammation (1,4,6).

In short, many mechanical and physiological factors relating to the interaction between cushion and soft tissues are important. Decubiti can develop whenever the equilibrium of these factors with skin tolerance is disturbed.

### **Techniques for Measurement of Sitting Pressures**

Measurement of pressure and shear at the interface of skin and a supporting structure has defied investigators for years. Theoretically, this is almost an insoluble problem since the introduction of nearly any measurement device alters the system. Results then, inevitably are influenced by the measurement technique employed. Houle (8) and Kosiak et al. (9) employed rubber butterfly valves beneath the patient, the pressure necessary to force air through these valves being considered as the interface pressure. Many more elaborate devices have been developed to measure pressure beneath patients lying and sitting on supporting surfaces, as well as at the skin-socket interface of prosthetic devices. Clinical measurements of forces and pressures acting at body surfaces have been reviewed in detail by Cochran (10). The availability of ultra-thin electronic pressure transducers has permitted advances in this area. Also, a simple pneumatic cell matrix has been developed as an aid to mapping pressure isobars beneath a sitting patient (1). Unfortunately, it is difficult to compare raw pressure data obtained by different techniques and types of transducers. For example, transducer thickness or protrusion has been shown to be a significant factor in measurement of socket pressure (11). Nevertheless comparative studies using the same measurement system on different cushions can have considerable validity.

More recently, fresh attention has been paid to the mechanics of transference of load to flesh, and mathematical analyses of the problem have been published (12,13,14,15,16). Experimentally, elaborate test systems, such as a computerized array of miniature pressure transducers, being developed to map pressures at prosthesis-skin interfaces, could easily be adapted to the cushion problem (17). Hertzberg (18) also has reviewed the situation and discussed the use of "pressure-measuring blankets" and a modified "pediscope" to view sitting patterns. In another study, PVC plastisol is being employed in connection with prosthetic socket measurements (19); pressures are measured with miniature pressure transducers implanted within this substance after molding as a socket liner; this is another technique of possible use in cushion studies. Similarly,

very small "magnetostrictive transducers" described elsewhere by Cochran (20) might be implanted within cushion material or even subcutaneously for limited experimental studies designed to correlate external measurements with actual hydrostatic pressure in subcutaneous tissue.

Finally, the question of shear measurements remains. Although shear forces are thought to be important in production of decubiti (7,21), no attempts have been made to measure their magnitude at the skin-cushion interface. It is suggested that an electronic "tangential pressure" transducer developed for suction-socket studies could be applicable to this problem (22).

### **Wheelchair Cushion Requirements**

As is evident from the preceding discussion, a wheelchair cushion, particularly for spinal-cord-injury patients, must satisfy many requirements. Pressures beneath the ischial tuberosities and the sacrum are extremely high when sitting on a hard surface, higher still if the patient transfers all weight to one side. The basic function of a cushion, an adjunct to the buttock soft tissue, is to diffuse and distribute these pressures. Obviously, it must not "bottom out" or otherwise produce excessively high pressure during patient movement. The problem ultimately rests with the material forming the cushion, with its ability to distribute pressure and to reduce peaks caused by motion so that the average pressure is kept low.

A cushion must keep direct pressures and shear forces low, but at the same time must be comfortable and provide stability. An ideal cushion that could keep interface pressures below 30 mm. Hg. and shear forces zero would be highly unstable and unacceptable for sitting. Although many attempts have been made, no cushion ever has been developed that will maintain pressures below 50 mm. Hg. at all points, particularly in spinal-cord-injury patients. Aside from experimentation with different materials, as will be described later, researchers have tried intermittent or local relief of pressure by varying pneumatic inflation, or by "cut-outs." Unfortunately, these techniques tend to decrease pressure in one area, while increasing it elsewhere. Another approach has been the totally contoured "bucket seat" custom molded to the patient (23). Again difficulties are encountered if the subject cannot be precisely repositioned each time he sits down.

Aside from pressure equalizing properties, a cushion must protect against other conditions causing decubitus ulcers. Ideally, the surface should be absorbent and permit air circulation, as heat and moisture can be extremely detrimental to the skin. This problem requires an

appropriate replaceable cover, which also needs careful design. Cushion coverings can act as a "stressed skin" to radically alter the physical properties of the material within.

Finally, a suitable cushion should not be too heavy, too large, or too expensive. It should not require any adjustments. The cushion or its cover must be cleaned easily, preferably by the patient himself, and have a useful life of 6 months or more depending on its cost. No matter how efficient a cushion may be it will be useless unless used. The independently mobile paraplegic who finds his cushion too heavy to transfer from wheelchair to car by himself will discard it in favor of a lighter substitute. In like manner, a cushion requiring a specific filling of fluid or air for an individual will be useless and even dangerous if leaking or filled improperly, circumstances which seem to occur inevitably.

### **Current Cushion Specifications and Test Methods**

The Veterans Administration has published specifications for Decubital Pads (Specification X-1597) and Flotation Pads (Specification X-1595), which are stated in very general terms. These specifications are concerned only with size, weight, covering materials, and general qualities. Thus, the substance of a "Decubital Pad" might consist of chemical, air, foam, water, or any combination of these ingredients, while the "Flotation Pad" is required only to consist of a solid self-contained gel "similar" to human flesh. Further specifications as to the desirable mechanical properties and characteristics of these materials would be of value, but never have been defined precisely.

The ASTM sets forth certain standards for testing various types of synthetic materials. In the Annual Book of ASTM Standards, Vol. 28: D-1565 refers to "Standard Specifications for Flexible Foam" made from Polymers or Co-Polymers of Vinyl Chloride, while D-1564 refers to "Standard Methods of Testing Slab, Flexible Urethane Foam." Typically, the mechanical properties of these materials are described by variations of load-deflection characteristics as plotted on load-deflection curves, under specific test conditions. "Creep," or change in thickness under a constant load, is an important reaction of foam as well as other materials exhibiting visco-elastic behavior. The "elastic reaction" of a cushion refers to its ability to recover thickness after deformation and is indicated by the hysteresis loop of the load-deflection (indentation) curve. "Compressive resilience" is another related term indicating whether a foam is "live" or "dead," and is a measure of the rate at which thickness is recovered

following loading. Specifically, ASTM D-1564 includes "Indentation Load," "Compression Load," "Resilience" (percent ball rebound), and "Compression Set" (dead weight loading) as well as other tests. For example, "Indentation Load" requires that a 50-sq.-in. disk be used as a loading platen on a 15x15x4-in.-thick cushion. Under specified conditions, loads required to indent the cushion to 25 and 65 percent of its original thickness are determined, and 65/25 percent indentation ratio is determined. A cushion with a high ratio will be less likely to "bottom out." Similarly, the "Compression Loading" test specifies a uniform pressure applied over the entire surface of a smaller sample of material.

Although providing much background information, data of this type are difficult to apply in terms of clinical evaluation of fabricated foam cushions with different thicknesses, covering materials, and multi-layer construction. Furthermore, the standards do not seem to be applicable for nonfoam cushions and no universal test system exists. A clinically oriented laboratory test system by which all cushions could be compared would be of great value.

Up to the present, clinical cushion testing has been represented primarily by patient observation and/or pressure measurements beneath sitting subjects. As described earlier, the latter tests have been conducted by utilizing simple pneumatic butterfly valves (8,9), by arrays of miniature transducers (18) or by various types of pneumatic cells arranged to provide a pressure matrix or isobar readout of the buttock and sacral area (1,10).

Results of pressure studies on patients sitting on cushions have been reasonably consistent after allowances are made for differences in measurement techniques. On a hard surface, pressures of 300-600 mm. Hg. are present in the region of the ischial tuberosities, with even higher values reported in some instances, particularly in thin subjects. Pressures in the range of 50-150 mm. Hg. usually are recorded when sitting on cushions. Naturally patients or normal subjects with sparse buttock musculature and subcutaneous tissue tend to generate higher pressures. No cushion developed so far appears capable of maintaining pressures lower than capillary pressure or even less than 50 mm. Hg. (1 p.s.i.) beneath sitting patients (1,8,9,18).

As might be predicted, relatively higher pressures usually are recorded on gel-type cushions when used alone. These obviously stiffer cushions deflect less beneath the patient than soft foam and thus provide a smaller supporting surface area for the patient's weight. Nevertheless, these cushions have demonstrated their clinical effectiveness (21), again suggesting that simple magnitude of pressure is not the only factor to consider in cushion evaluation.

## EXPERIMENTAL TEST METHOD

In this study at the New York State Rehabilitation and Research Hospital, we developed a pilot test program applicable to all cushions to rate their suitability for clinical use. This protocol is composed of two phases: Laboratory (materials testing) and Clinical (patient testing, observation, and evaluation). The two phases include a total of seven tests which are scored and expressed on a "pressure profile" that summarizes the performance of each cushion. This profile provides a basis for the overall ratings.

### Laboratory Test Phase

For the laboratory testing, an attempt has been made to simulate *in part* the forces and pressures developed by patients sitting on the cushions, and to study the reactions of the cushions. In particular, the tests aim to determine which cushions best minimize and distribute pressures and shear forces at the cushion-patient interface.

#### Test Equipment

The basis of the laboratory test procedure is measurement of interface pressures beneath a test cushion deformed by a small circular loading or indenter disk. The apparatus consists of a heavy

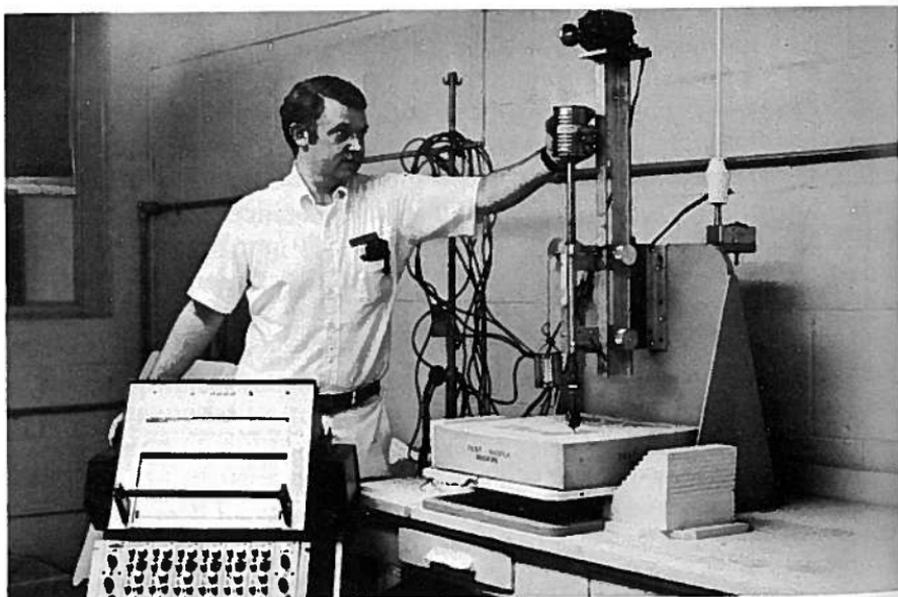


FIGURE 1.—Laboratory apparatus for cushion testing: recording equipment at left, test stand and plunger apparatus at right. A loading weight is being held by one of the authors (Mr. Slater).

wooden test stand firmly attached to a sturdy table, with mountings for aluminum supports which hold a vertical plunger apparatus. The top of this plunger has a platform for loading weights, while the lower end is fitted with an electronic strain gage load ring, attached in turn to the specially designed loading disk, which indents the

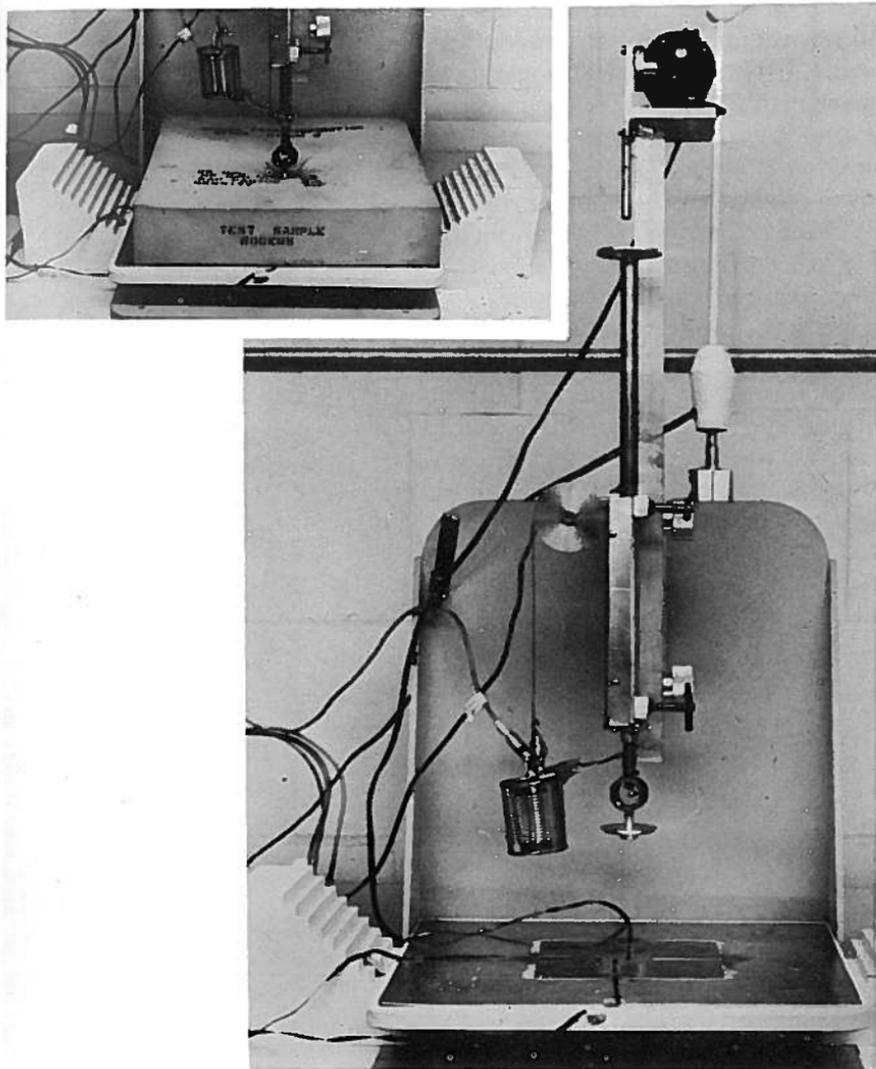


FIGURE 2.—Front view of test stand and plunger apparatus: motor employed for fatigue studies visible at top; in sequence below are weight, platform, plunger load ring, test disk, and cushion support plate. The counter balance and deflection apparatus is represented by the pulley and hanging weight. Top: Closeup of lower end of plunger apparatus showing load ring and test disk indenting cushion. Counterbalance weight at left.

cushion. The load cell measures actual forces applied to the test disk and the cushion, thus avoiding errors caused by plunger friction. The plunger is counter-balanced by a weight which may be adjusted to apply a preload. Plunger motion is recorded by a potentiometer linked to the counterbalance pulley (Fig. 1 and 2).

The loading disk consists of a circular aluminum plate  $2\frac{1}{2}$  in. in diameter ( $5 \text{ in.}^2$ ), with a beveled edge (Fig. 3). This size represents an approximation of the moderate high pressure area beneath each ischial tuberosity of a normal seated subject, as indicated by a "barograph" (Fig. 4). A higher pressure area, approximately  $\frac{3}{4}$  in. in diameter, also indicated by the "barograph" in thin patients is simulated by a "load concentrator" which can be attached to the lower surface of the loading disk (Fig. 3).

Three miniature, semi-conductor transducers (Sensotec LQL-125-25) are mounted in a grooved metal plate beneath the test cushion (Fig. 5). One transducer is located directly beneath the center of the loading disk, one at mid point, and a third at the edge, beneath the beveled portion. The surface of each transducer is slightly above the base plate and is covered with a 0.01 in. silastic sheet plus an additional  $\frac{1}{16}$ -in.-thick sheet of RTV silastic rubber. This configuration was found empirically to provide the most linear and reproducible pressure readings during calibration under actual test conditions.

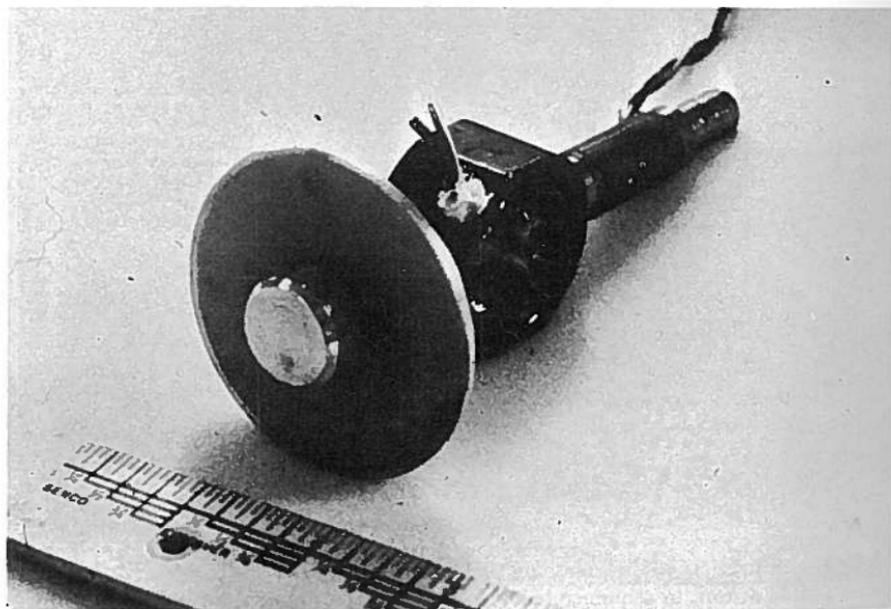


FIGURE 3.—Circular aluminum loading disk with stress concentrator in place. Strain gage load ring on upper surface of plate.

Furthermore, the RTV serves to facilitate reproducible measurements beneath foam material with large voids and bubbles, or beneath cloth cushion covers with irregular surfaces.

Transducer calibration is carried out with a 1-in. test disk under conditions simulating actual tests with both foam and gel materials. A sample of 2-in.-thick foam (or 1-in.-thick gel) 6 in. in diameter is placed over the transducer to be calibrated, then the disk is loaded sequentially with weights of 1,2,3 and 4 lb. Simultaneously, a concentric metal ring, with outer diameter three times the diameter of the calibration disk, is held down level with the test disk by means of a separate, manually applied force. This procedure provides an even pressure distribution beneath the 1-in.<sup>2</sup> test disk and negates edge effects.

#### *Test Procedure*

For all cushion tests, five parameters are recorded simultaneously on a Brush pen recorder utilizing Honeywell Accudata 113 Bridge Amplifiers: 1. total applied load (load cell); 2. deflection or indentation of cushion (potentiometer); 3. pressure at "C," beneath

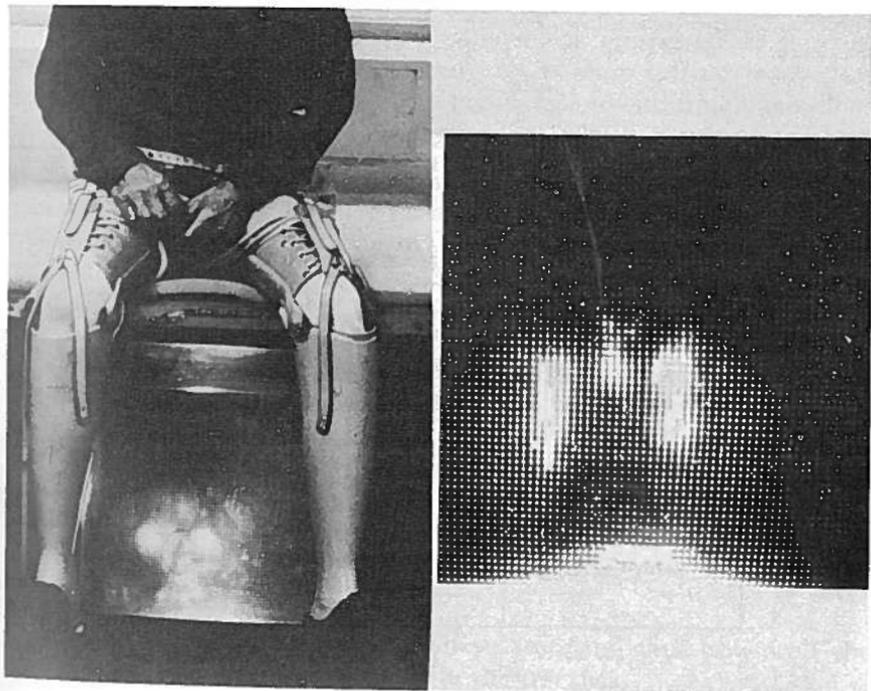


FIGURE 4.—Demonstration of VAPC "barograph" used to record pressure pattern of seated subject. Right: Closeup of pressure pattern, both ischial tuberosity and sacral high pressure areas are visible.

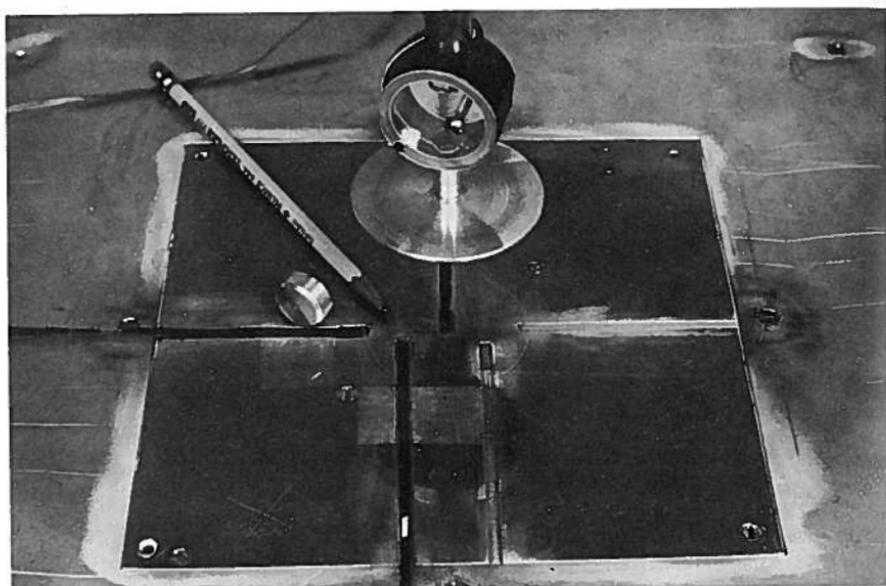


FIGURE 5.—View of load ring, test disk, and arrangement of miniature pressure transducers on plate beneath cushion. The stress concentrator (detached) is shown adjacent to the pencil.

Rapid Loading Classifications

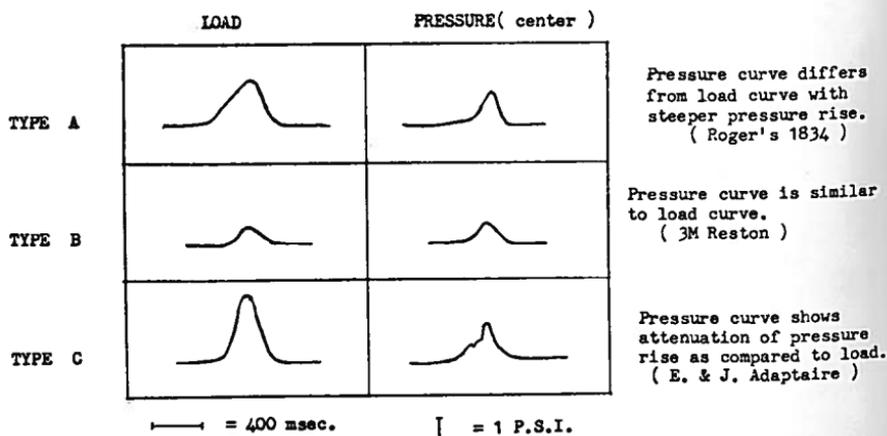


FIGURE 6.—Response of cushions to the rapid loading test. Three types of responses were found based on differences in configuration of increases in applied load as compared to pressure.

center of test disk (Sensotec pressure transducer); 4. pressure at mid-point; and 5. pressure at "E," beneath beveled edge of test disk. The test disk indents the top surface of each cushion, while the pressure transducers lay beneath the cushion.

A uniform sequence of tests is performed on each cushion at room conditions (70 deg., relative humidity 50 percent); a 0.5 lb. preload is standard for contact of the test disk and cushion. A reference baseline is determined by repeated test runs on a cushion arbitrarily selected as the "Reference Sample" (Rogers, Type 1834 foam, 4x18x18 in.). All results are normalized as percentages of performance for this reference sample, with the reference data being assigned the arbitrary value of 100. Equipment is restandardized against the reference sample at intervals.

The following standardized tests are performed in the same order for each cushion. For convenience, pressures are recorded in p.s.i. (1 p.s.i. = approximately 52 mm. Hg.).

1. *Creep-Recovery*: The test disk is loaded sufficiently to produce a pressure of 1 p.s.i. recorded at "C" (center pressure transducer). This load is maintained for 10 minutes, then removed; after an additional 10 minutes, the disk is lifted and the reaction observed 5 minutes longer. Creep-recovery behavior is expressed as a score reflecting any tendency for pressure to increase during loading as result of creep (increasing cushion compression with time), as well as any tendency to retain residual depression following unloading.

2. *Load Deflection Tests*: Beginning with 5 lb., the load on the plunger is increased in 5-lb. increments until recorded pressure at "C" exceeds 4 p.s.i. Following this test a 5-minute recovery period is permitted. Results are expressed on a load-deflection (indentation) plot. Points at which pressure of 1,2,3 and 4 p.s.i. are recorded at "C," beneath the center of the test disk, are marked on the curve.

- a. *Deflection Ratio*: The ratio of percent deflection (of original cushion thickness) at the 4 p.s.i. point, versus percent deflection at the 1 p.s.i. point, is calculated.
- b. *Applied Load Ratio*: The ratio of applied load at 4 p.s.i., versus load at 1 p.s.i. is computed in the same manner. Both of these ratios are indications of how well the cushion resists development of excessive pressures with varying loads during movement.

3. *Pressure Distribution Tests*: These tests indicate how well the cushion distributes pressure beneath the test disk.

- a. The plunger is loaded sufficiently to produce pressures of 1,2,3 and 4 p.s.i. on "C," the center transducer; these pressures are compared to those recorded by the transducer at "E," the edge

position, as a ratio of "E" to "C." The mid-position is used as a check on performance.

- b. The same edge/center ratio is computed again from data obtained with the stress concentrator in position on the lower surface of the test disk (Fig. 4).

4. *Rapid Loading:* The plunger is loaded sufficiently to produce a pressure of 1–2 p.s.i. on "C" with a loading (rise) time of 0.2 seconds. Rise time or profile of the recorded pressure curves are compared to those at the load cell. Performance is rated as shown in Figure 6.

*Fatigue Behavior 1–4:* Response of the cushion to fatigue is determined as follows: the test disk is loaded with a dead weight sufficient to maintain a pressure of 1–2 p.s.i. at "C." Then an additional deflection of the plunger is applied by means of a motorized cam apparatus. This additional deflection (0.5 Hz, 4 seconds duration) is adjusted to increase the pressure at "C" by 1 p.s.i. additional. This loading cycle is continued for 48 hours, at which time the load is removed and recovery observed, as for the creep test. Tests 1–4 then are repeated and results compared to the pre-fatigue behavior.

### **Clinical Test Phase**

For the clinical testing, patients on whom pressure measurements are made are evaluated first on the "barograph" to determine overall sitting pressure pattern. For the subjective tests, cooperative patients able to make good comparative judgments on cushions are selected.

5. *Patient Sitting Pressure:* A subject with normal sensation and relatively prominent ischial tuberosities is selected with the aid of the "barograph" pressure pattern. Two Sensotec pressure transducers are taped over the most prominent areas of the ischial tuberosities bilaterally. Beginning with the reference cushion, pressures generated by the subject sitting at rest with feet unsupported and arms folded are recorded sequentially on all cushions in the test series. Pressures also are observed with patient rocking from side to side and forward and back. To neutralize variables associated with transducer position, results are normalized with respect to the reference cushion, for each series of tests.

6. *Patient Skin Reaction:* A selected quadriplegic or paraplegic patient in a wheelchair is seated on each test cushion directly from bed in the morning. Following a 2-hour-test period, the skin over the buttock and sacral area are examined. Effects are rated and scored according to degree and persistence of erythema and edema.

7. *Patient Reaction:* Each cushion is evaluated by selected wheelchair patients with normal sensation. The patient sits on each

cushion for 2 hours and compares his sensations to those during similar periods on the reference cushion. Properties of the test cushion are scored on the  $\pm 1-4$  point schedule as compared to the reference. The properties evaluated are: a. stability and base of support; b. pressure sensation, frequency of movement to maintain comfort; c. skin moisture and temperature; d. ease of handling by patient himself; e. ease of cleaning and general maintenance; and f. general comfort.

*Expression of Test Results:* A key to the means of scoring and expressing all test results is shown in Table 1.

Following completion of the test sequence, a "pressure profile" of the cushion is prepared as a bar graph. Data for the reference sample are shown on this graph adjacent to the normalized cushion test results. In addition, an insert with the force-deflection (indentation) curve for the cushion is included. Points on this curve at which pressures of 1,2,3, and 4 p.s.i. were registered beneath the test disk are shown as the basis for the Deflection and Applied Load Ratios (2a and 2b).

Following examination of test results as displayed on the pressure profile, each cushion is assigned a laboratory, clinical, and overall rating based on its performance in comparison to the other cushions. The mean scores in the laboratory and clinical test phases are used as guidelines in these ratings: A (above average); B (average); and C (below average); further qualification may be indicated by (+) or (-).

TABLE 1.—Key to Test Scores

1. <i>Creep-Recovery</i>	
	200% No residual depression, no increase in pressure.
	150% No residual depression and/or increase in pressure less than 25 mm. Hg.
Ref. . .	100% Slight residual depression (<10%), or approx. 25 mm. Hg. increase in pressure.
	50% Marked residual depression and/or increase in pressure greater than 25 mm. Hg.
	10% Marked residual depression and/or increase in pressure greater than 50 mm. Hg.
2. <i>Load-Deflection Tests</i>	
a) Deflection Ratio	
	Percent deflection (indentation by test disk) of original cushion thickness: at 4 psi/deflection at 1 psi. Ratios for cushions tested expressed as % of ratio for reference cushion (1.13)
Ref. . .	100% = 1.13 (e.g. 200% indicates ratio 2.26)
b) Applied Load Ratio	
	Total applied load: at 4 psi/load at 1 psi. Ratios for cushions tested expressed as % of ratio for reference cushion (1.70)
Ref. . .	100% = 1.70 (e.g. 200% indicates ratio 3.46)

TABLE 1.—Key to Test Scores—Continued

3. *Pressure Distribution Tests*

- a) Plain disk: pressure at edge of disk vs. pressure at center.  
 Ref. . . . 100% = 0.56  
 b) Disk with stress concentrator, edge/center.  
 Ref. . . . 100% = 0.13

4. *Rapid Loading*

- 200% pressure rise attenuated as compared to load rise.  
 150% pressure rise equivalent to load rise.  
 Ref. . . . 100% pressure rise steeper than load rise.

5. *Patient Sitting Pressure*

- 200% = < 75 mm. Hg.      75% = 150–200 mm. Hg.    10% = > 300 mm. Hg.  
 150% = 75–100 mm. Hg.    50% = 200–250 mm. Hg.  
 Ref. . . . 100% = 100–150 mm. Hg.    25% = 250–300 mm. Hg.

6. *Patient Skin Reaction*

- 200% No erythema  
 150% +1 = slight redness, disappears after a few minutes.  
 Ref. . . . 100% +2 = mild erythema persists short period but blanches easily with digital depression.  
 50% +3 = skin very red, barely blanches with digital depression, slight edema.  
 10% +4 = severe erythema, non-blanching, edema.

7. *Patient Reaction*

- Each of the following items are rated on a  $\pm 4$  scale compared to the reference: stability, pressure, moisture-temperature, ease of handling, ease of cleaning, general comfort. Results are totaled, then scored on the present scale.
- |                                |                               |
|--------------------------------|-------------------------------|
| 200% = (+) 16–20 points, total | 75% = (–) 1– 5 points, total  |
| 175% = (+) 11–15 points, total | 50% = (–) 6–10 points, total  |
| 150% = (+) 6–10 points, total  | 25% = (–) 11–15 points, total |
| 125% = (+) 1– 5 points, total  | 10% = (–) 16–20 points, total |
| Ref. . . . 100% = 0 points     |                               |

Note: 1 psi. = 52 mm. Hg.

**RESULTS**

Results for selected cushions tested in this survey are presented in tabular form representing the average of results, pre- and post-fatigue testing.

Table 2 provides basic data on cushion type, measurements, and composition together with the laboratory, clinical, and overall ratings. In addition, relevant data from ASTM or manufacturers tests are included if available.

Table 3 provides details of laboratory test results normalized with respect to the reference cushion as given on the bar graphs. Mean raw data or scores from the reference cushion are given on the top line. Final scores from the clinical test phase are included in this table.

TABLE 2.—Characteristics and Ratings of Cushions Tested

Cushion type or combination tested	Material	Appearance	Size (in.)	Wgt. (oz.)	Cover	Manufacturers data	Rating		
							Lab.	Clin.	Over-all
<i>Reference sample</i>									
Type #1834 Foam (Rogers Corp.)	polyurethane foam	pale yellow foam, fine pores	18×18×4	23	none: foam sample only	"25% ILD—31 lb. 65% ILD—60.5 lb. Sag Factor—1.95 density—1.7"	Ref.	Ref.	Ref.
<i>Test cushion</i>									
1) ReOm <sub>3</sub> Foam (Rogers Corp.)	polyurethane foam	yellow foam, fine pores	18×18×4	32	none: foam sample only	"25% ILD—28 lb. 65% ILD—85 lb. Sag Factor—3.0 Density—2.5"	C	B	C
2) Koylon foam (Everest & Jennings)	latex "cored" type foam	vertical 3/16" holes spaced 1-1/4 in. apart	16×18×3	47	heavy gray cotton-removable	Uniroyal latex foam	A	B	A
3) 2" standard cushion (NYSR&RH)	solid foam latex	smooth, dense white foam	18×16×2	57	heavy, flexible, smooth, vinyl, permanent cover	B. F. Goodrich foam, covered by hospital	A	B	B

TABLE 2.—Characteristics and Ratings of Cushions Tested—Continued

Cushion type or combination tested	Material	Appearance	Size (in.)	Wgt. (oz.)	Cover	Manufacturers data	Rating		
							Lab.	Clin.	Over-all
4) 4" standard cushion (NYSR&RH)	3" latex "cored" type foam on 1" latex foam	3/16" holes spaced 3/4" apart.	18×16×4	76	heavy, flexible, smooth, vinyl, permanent cover.	F. B. Goodrich "pin-cor" foam-2 layer composite within hospital sewn cover	A (-)	A	A
5) Action Contoured Flotation Pad (Action product)	"elastomer gel"	plastic film covering brown homogeneous gel material	16×16×1 $\frac{5}{8}$	152	clear plastic film	cover (plastic film) "Tensile strength 5000 p.s.i., 700% elongation at break point"	A	A	A
6) Medcom Pad	polxvinyl-chloride gel	homogeneous gel covered by stockinet	16×16×1 $\frac{5}{8}$	124	thin latex cover with zipper plus outer cover of heavy cloth	outer cover for wheelchair use, and carrying case	A (-)	B	B
7) Reston Pad (3M) top layer	"liquid-filled microcell sponge"	thin plastic film covering a homogeneous gel-like material	16×16×1 $\frac{1}{2}$	180	thin white stretchable knit cover plus cloth carry sling	" psi. under simulated bony prominence: 2 lb. 5 psi. 6 lb. 1.0 psi. 10 lb. 1.0 psi."	A (-)	B	B
8) Aqua-mate pad	water, vinyl and polyurethane foam	foam pad within clear, vinyl, water filled cushion	15×15×1	89	none	outer envelope .20 ga. Union-Carbide with flexible vinyl, filling cap	C	B	C

9) Aqua-Rest (Aqua-Rest Corp)	water within vinyl envelope	water filled smooth white vinyl cushion	15×16×2	123	none	none available. Cushion is sealed	C	B	C
10) T-Foam (Alimed) with cover	impact absorbing, visco-elastic polyurethane foam (slow elastic resilience)	dense white foam with "memory" qualities.	18×16×2	26	red knit synthetic fabric	medium firm for subjects 175 lb., softens at body temperature and "breathes," retains impression temporarily	B	—	—
11) Adaptaire AC-60 VS no cutout (Everest & Jennings)	impact absorbing air rosin filled foam (slow elastic resilience)	black smooth vinyl covered cushion "memory" qualities	16×16×3	51	permanent cover washable surface	cushion retains impression temporarily	B	B+	B
12) "Frost" foam cushion (Everest & Jennings)	top layer-polyurethane; bottom layer—"frost" foam, with slow elastic resilience	two layer composite, within red stretchable cover, "memory" qualities	15×16×3	28	close fitting knit cover, removable	bottom layer of cushion retains impression temporarily	C	B	C

TABLE 3.—Results of Cushion Test Program (Score Relative to Reference Sample)

Cushion type	Creep-recovery	Deflection ratio 4:1 p.s.i.	Applied load ratio 4:1 p.s.i.	Pressure distrib. ratio (plain disk)	Pressure distrib. ratio (stress conc.)	Rapid loading	Lab. aver.	Clinical scores			Overall averages	
								Sitt. press.	Skin reaction	Pt. reaction		
1. Reference sample Roger's 1834	100	1.13	1.70	.56	.13	100	100	2.5	100	100	100	
Normalized values	100	100	100	100	100	100	100	100	100	100	100	
<i>Test sample or cushion</i>												
1. ReOms	100.	110.	110.	80.	170.	100	112.	100.	100.	175.	116.	
2. Koylon Foam	200.	140.	170.	190.	540.	150.	232.	50.	100.	175.	191.	
3. 2" N.Y.S.R.R.H.	200.	200.	230.	140.	330.	100.	200.	50.	100.	175.	169.	
4. 4" N.Y.S.R.R.H.	200.	150.	150.	150.	500.	100.	208.	75.	200.	175.	188.	
5. Action Pad	200.	220.	340.	110.	320.	150.	223.	75.	150.	200.	196.	
6. Medcom Pad	200.	240.	240.	110.	250.	150.	198.	50.	150.	100.	166.	
7. 3M Reston Pad	200.	150.	190.	160.	310.	150.	193.	75.	100.	175.	168.	
8. Aqua-matic Pad	50.	120.	120.	140.	0.	100.	88.	100.	100.	175.	101.	
9. Aqua-Rest	10.	100.	100.	70.	0.	100	63.	50.	100.	150.	91.	
10. T-Foam	100.	180.	180.	100.	180.	100	140.	—	—	—	140.	
11. Adaptaire AC-60-VS (no cut-out)	200.	120.	110.	100.	250.	200.	163.	50.	200.	150.	153.	
12. "Frost" foam cushion	50.	140.	140.	110.	150.	100.	115.	50.	100.	150.	110.	

Figures 7-18 are "pressure profiles" presenting data on individual cushions in bar graph form, based on data given in Table 2.

In addition to the findings detailed in the above tables, approximately 10 additional cushion materials and/or combinations were tested, but are not reported with the exception of the following results of general interest.

Covers: In testing cushions with and without covers it was found that addition of a cover would, in some instances, improve the test scores, as the cover improved the elastic reaction of the cushion; in other instances results were less favorable, as the cover tended to inhibit the cushion reactions.

Special Combinations: Several gel-type pads were tested with the addition of two different top layers of our own selection. The object was to improve moisture absorption and air circulation with an additional soft absorbent and porous layer. It was found that a layer of either 2-in. white "fiber coil" or 1-in. reticulated foam (Rogers) could be added without affecting laboratory mechanical test scores to a significant degree.

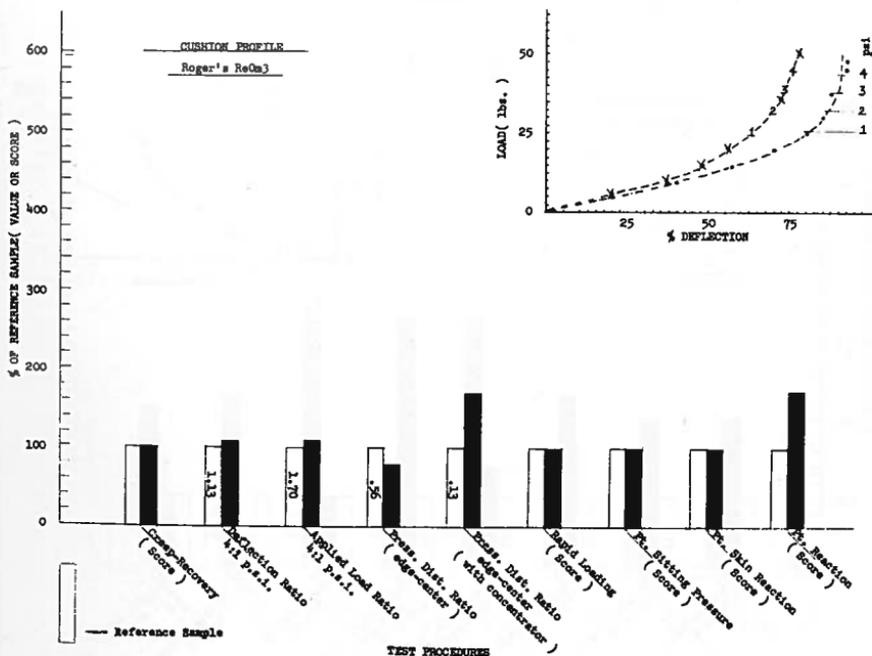


FIGURE 7

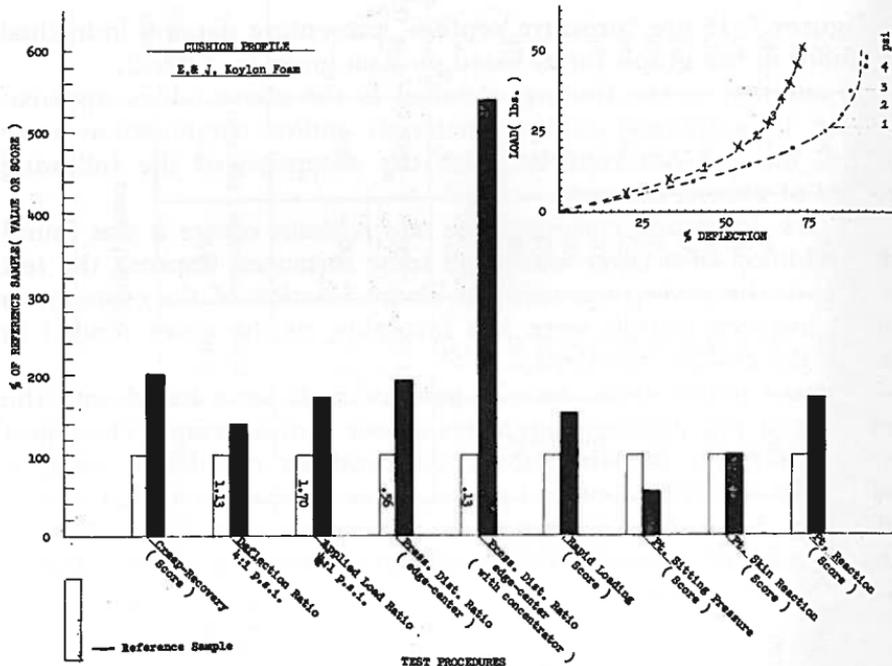


FIGURE 8

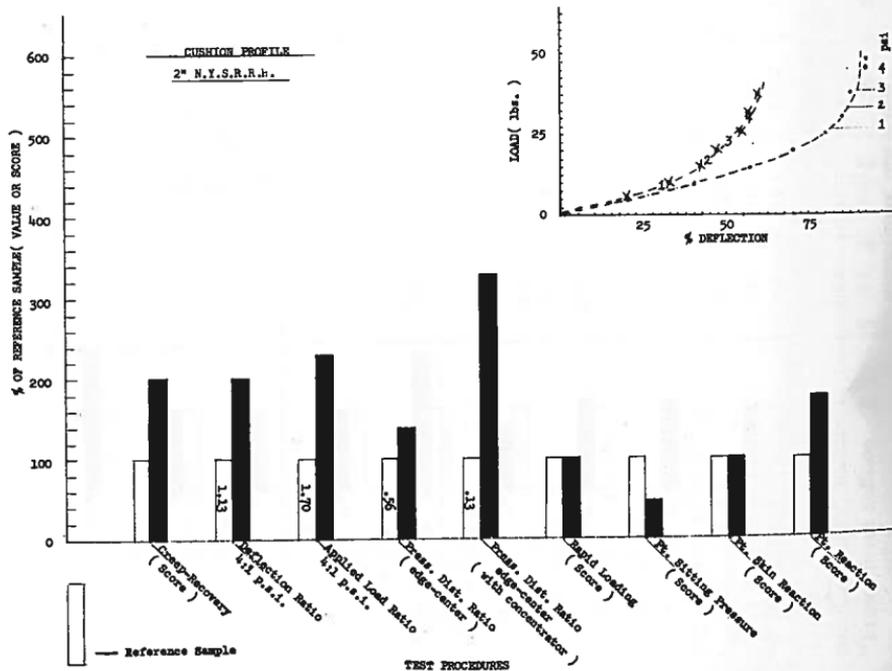


FIGURE 9

# Cochran and Slater: Eval. of Wheelchair Cushions

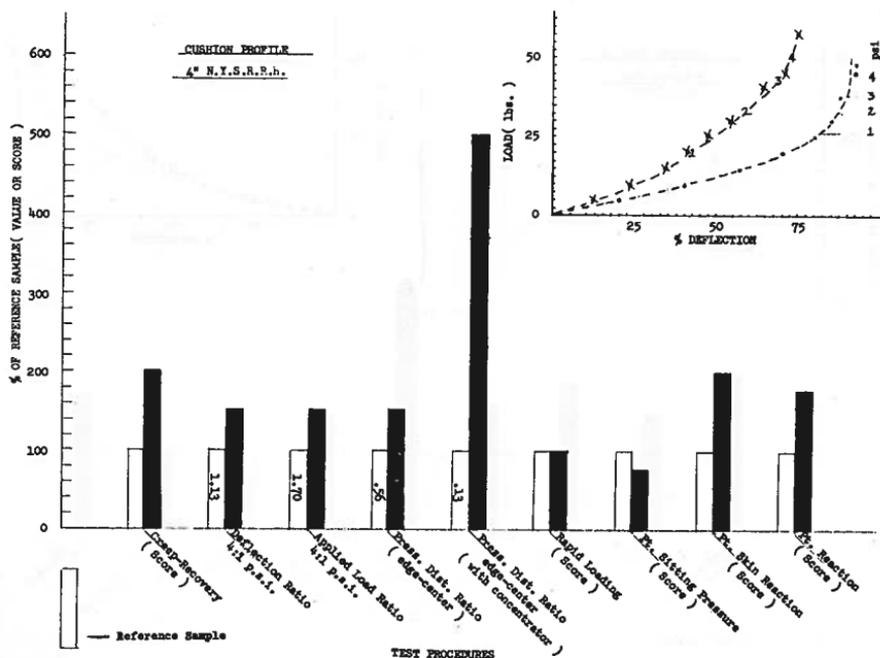


FIGURE 10

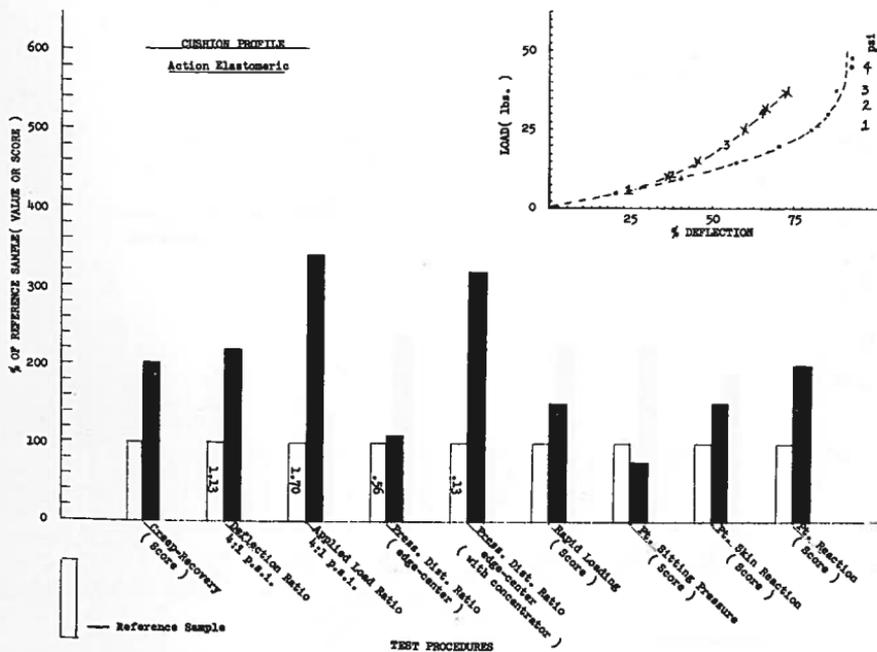


FIGURE 11

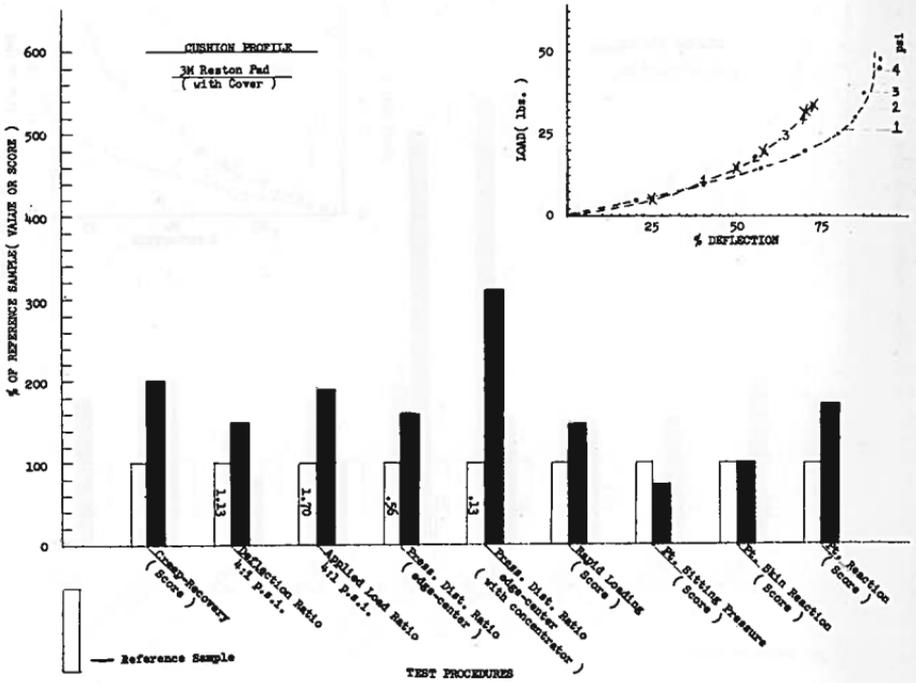


FIGURE 12

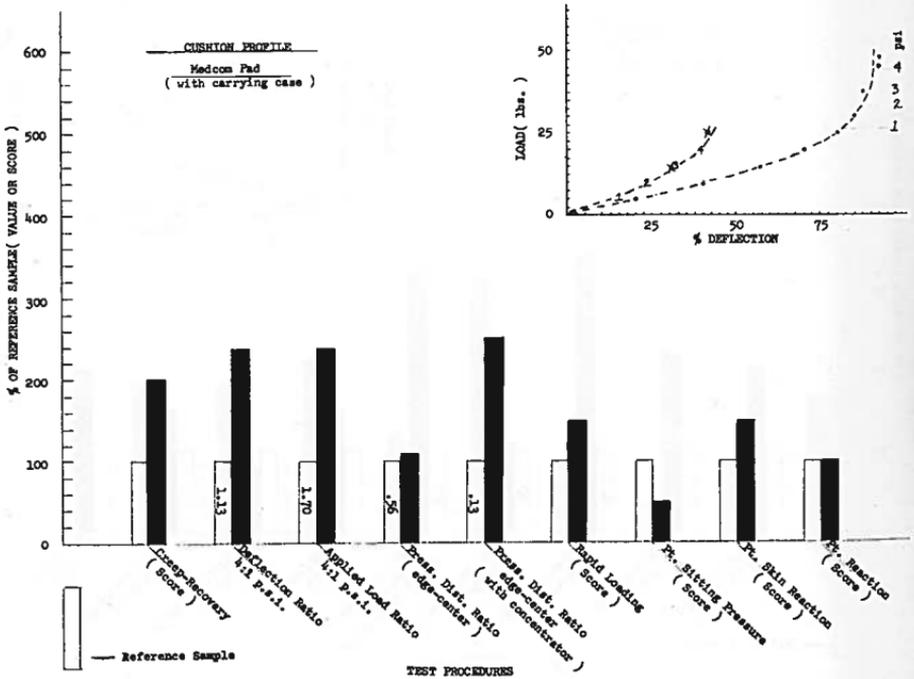


FIGURE 13

# Cochran and Slater: Eval. of Wheelchair Cushions

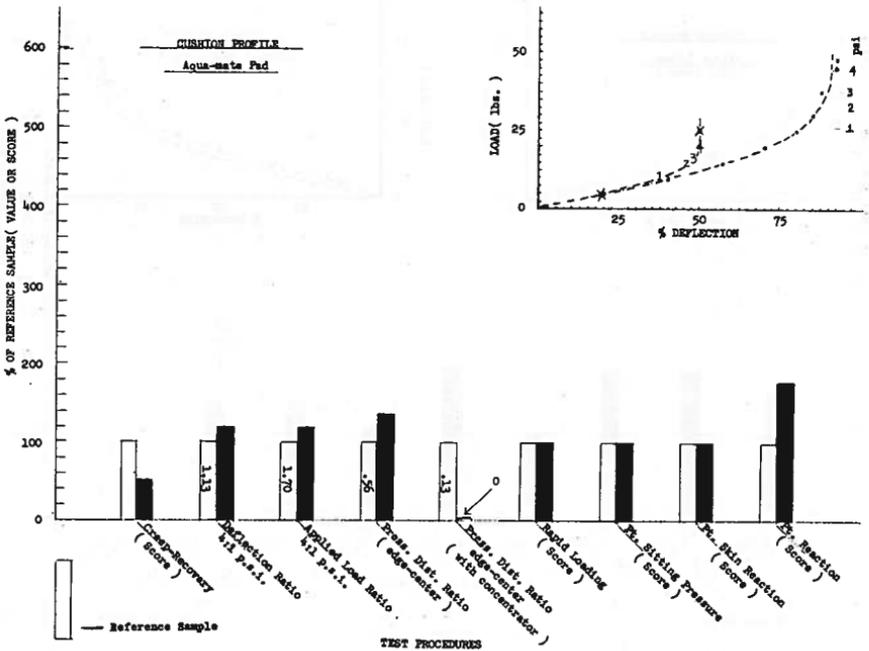


FIGURE 14

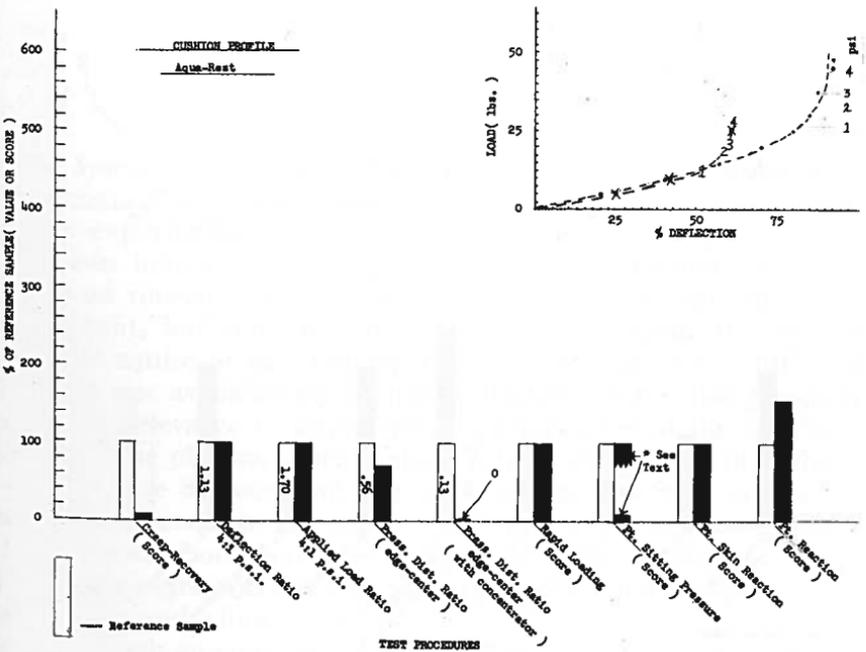


FIGURE 15

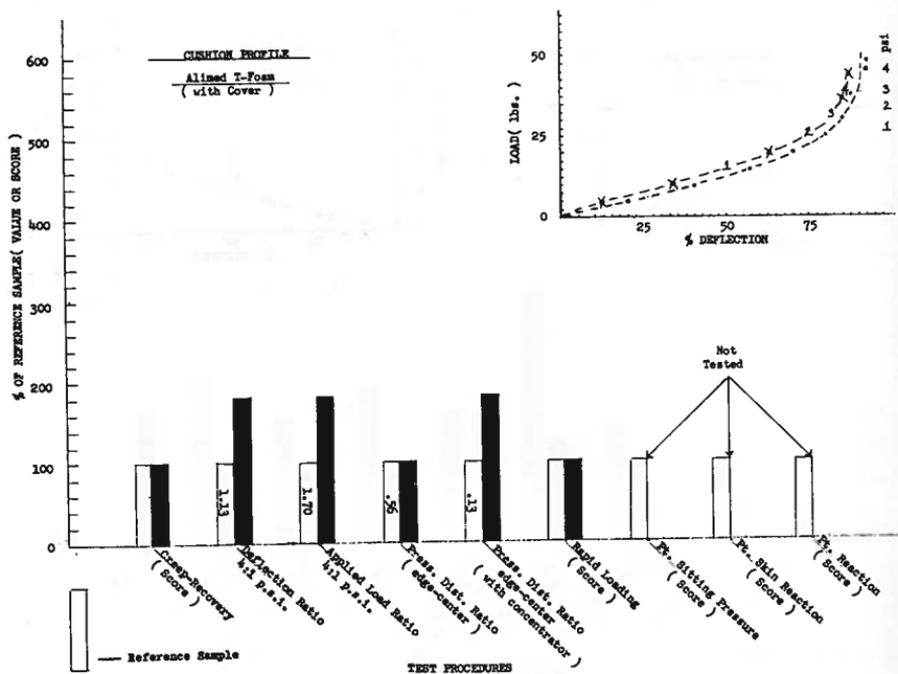


FIGURE 16

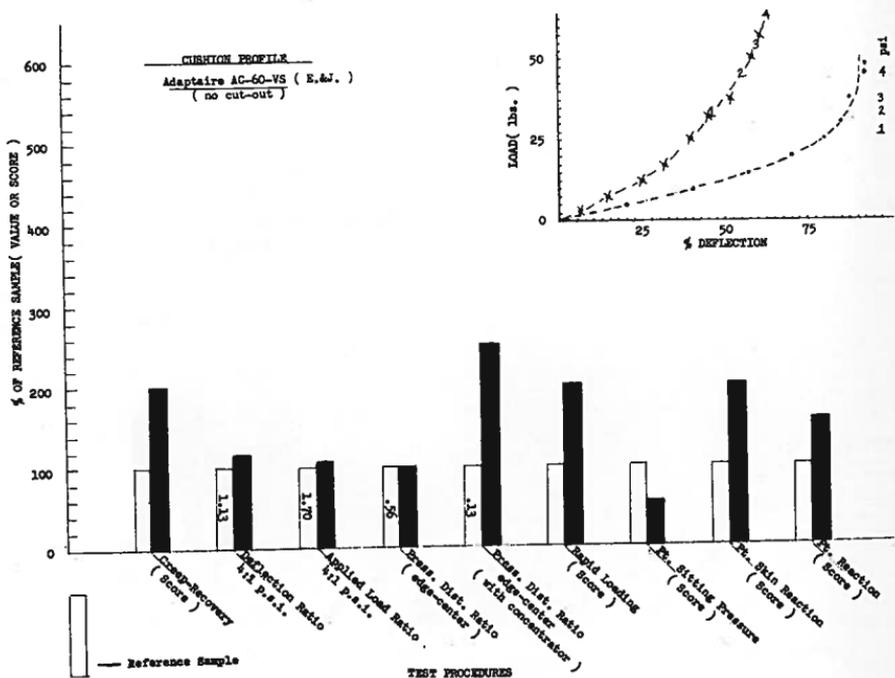


FIGURE 17

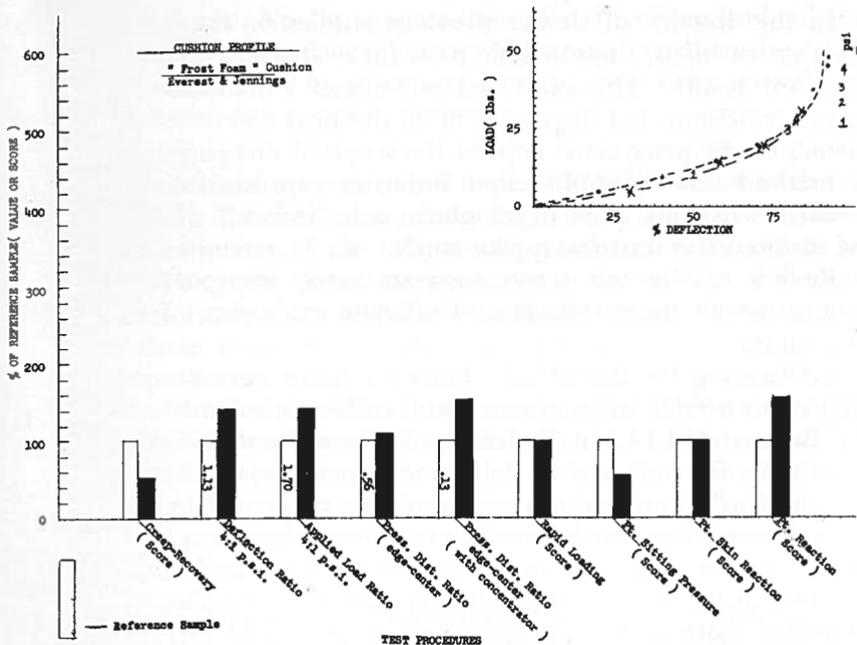


FIGURE 18

**DISCUSSION**

*Test Systems:* It is emphasized that the laboratory test apparatus, test program, and scoring system employed for this study were purely experimental: the result of empirical development with limitations imposed by the equipment available. In most instances results on repeated tests of the same cushion were reproducible  $\pm 10$  percent, but statistical analyses were not made due to the laborious nature of data reduction from recordings. Also, sufficient data are not available for formal evaluation of the test program regarding relevance to actual clinical performance of the cushions. Despite these obvious shortcomings, definite differences in cushion behavior were detected and this work represents a new, potentially valuable approach. In the past, cushion testing has been confined to clinical observations and measurements of actual sitting pressures. This study represents the first attempt to develop a comprehensive laboratory and clinical test program applicable to all types of cushions, with an emphasis on conditions encountered under clinical use.

In the absence of similar previous studies or long term clinical data on cushions, there is little basis for evaluation of the validity of our test results. The exact test techniques employed are open to many criticisms, but discussion of all the pros and cons of the many details of the program is beyond the scope of this paper. Essentially, a method was developed that indicates reproducible differences between cushions, then development was "frozen," while this series of cushions was tested as a pilot study.

Review of the test series suggests many improvements which would permit more reliable and efficient evaluation of cushions in the future.

Concerning the Laboratory Phase, a more rigorous engineering analysis is needed in accordance with cushion mechanics as described by Bennett (13,14,15). Redesign of the apparatus is indicated to eliminate friction and malalignment problems, while a special, instrumented indentation disk should be constructed incorporating flush-mounted pressure transducers in its surface. Due to fragility of leads, it was necessary to place the transducers *beneath* the test cushion in the present apparatus; placement in the disk itself would simulate more closely the pressures experienced on the buttocks during sitting, particularly if a thin layer of gel substance simulating skin could be bonded to the disk to cover the transducers. Also, a tangential force-measuring transducer (22) should be incorporated in the test head, possibly in association with the "stress concentrator." This transducer would indicate shearing forces at the interface, as opposed to the compressive forces monitored by the pressure transducers. Additional valuable data might be gained by placement of miniature magnetostrictive transducers (20) *within* the test cushion to monitor pressure distribution at various levels.

Regarding the Clinical Phase, an array of six miniature pressure transducers should be employed for measurement of actual sitting pressures to improve data from beneath the ischial tuberosities. These electronic transducers could be laminated in a fixed matrix according to the technique utilized in studies of below-knee prosthesis sockets (19). Miniature sensors for temperature and humidity also should be incorporated into this test matrix to monitor these factors, beneath the buttocks, for specified periods on each cushion. A pneumatic test matrix of the type developed at Rancho Los Amigos Hospital would be of value in positioning the electronic test array (1).

For the patient evaluation, a more extensive program is required. It is stressed that only *one* normal subject and *one* paraplegic subject were used in the foregoing study, the protocols for evaluation of patient skin reaction and general patient acceptance representing

only a limited trial. Now it appears that this type of test and scoring system is feasible, but it is recommended that each cushion should be evaluated following a 2-hour sitting period by *at least* five paraplegics and five patients with normal sensation.

The scoring system (Table 1) is another area requiring improvement, since the final average scores depend heavily on how each test is weighted. In the foregoing study the scoring system was based partially on estimates of the relative importance of each test, as an indication of *long term* clinical performance of the cushion. Although sufficient information to completely evaluate results of the present study on these grounds is unavailable, further testing under the improved programs described would be beneficial, particularly if correlated with clinical results from outside areas. The results from testing a new series of cushions would not only serve as a check on the validity of the present study, but could provide a possible basis for permanent ASTM or VA standards applicable to all wheelchair cushions and perhaps mattress materials, while serving also as an aid to development of new cushions.

*Test Results:* Despite the shortcomings of the test system, it is apparent that certain characteristics of cushions can be detected reliably. Furthermore, the ratings given to the cushions correlate reasonably well with general clinical observations on their effectiveness. In short, cushions with the highest reputations from past experience did tend to receive high ratings from this test program.

Although certain differences between individual brands of cushions were apparent, the most obvious trends in test results appeared between different types of cushions, summarized below.

1. *Foam Type:* The Reference Cushion and the denser ReOM<sub>3</sub> are representatives of commonly available polyurethane foams. Both specimens gave laboratory test scores near the lower end of the scale, and produced a force-indentation curve with a sharp rise spanning the clinical sitting pressures of 1-4 p.s.i. This implies that relatively small changes in applied load or indentation, generated by motion, could produce large changes in sitting pressure or possible "bottoming." However, the smooth, dense latex and latex "cored" type foams received above average scores. The density, excellent resilience, and possibly the cored construction apparently contributed to the excellent pressure distributing action of these materials despite relatively high sitting pressures. Clinically, all the foam cushions received favorable scores.

The results for this class of cushion then coincide with general past clinical experience. Polyurethane foams have not established a particularly good reputation in prevention of "pressure sores" as

indicated by the research concentrated on other materials, but they are popular, "comfortable," and generally accepted by the patients. The light weight and low cost of all foam cushions are a great positive factor in their use, so it is unfortunate that the polyurethane foams do not seem particularly effective in combating decubiti.

Latex "cored" foams are in widespread use with at least moderate success. In fact, it was discovered accidentally that "cored" foam was the basis of a rather successful 4 in. cushion made in the N.Y.S.R.R.H.'s sewing shop. This suggests that one avenue of research which could lead to an effective, inexpensive lightweight cushion is further development of a multilayer cushion based on "cored" latex foam. Additional layers probably could be selected to improve performance on the less satisfactory parts of the pressure profile (i.e., Load-Deflection curve, Rapid Loading, Patient Sitting Pressure) as well as moisture absorption and air circulation, without sacrificing the excellent pressure distributing properties (Fig. 8 and 10). An inner-layered cushion would best be enclosed in an easily replaceable outer cover.

2. *Gel Types*: These cushions are constructed of various gel-like materials basically intended to approximate mechanical behavior of human tissues; they received above-average scores on all counts with the exception of sitting pressures. The superior scoring of these cushions correlates with their past clinical reputation for good performance in decubitus prevention. It is of interest that this performance is evident despite the relatively high sitting pressures that are the consequence of their relatively stiff consistency. Since they do not deform very much with load, the supporting contact surface is relatively small and the pressures higher. This situation suggests that simple magnitude of interface pressures is only *one* factor affecting decubitus development.

Our tests highlighted the advantageous flat nature of the load-indentation curve for gel cushions; large changes were required to increase pressures beneath the cushion from 1-4 p.s.i. Also these cushions distribute pressure very well about a localized, concentrated load (Fig. 11, 12, and 13). Not evaluated was the effect of these cushions in minimizing shear forces on the skin surface, an effect which could account for the effectiveness despite the high direct pressures (21). Perhaps the large deformation of thick soft cushions unduly increases the tangential forces on the skin.

Severe disadvantages of the gels include weight and high cost, as well as poor aeration and moisture absorption. The covers on many gel cushions are inadequate for the latter purpose. Development of a multilayered cushion based on a gel material with a suitable cover is

another promising area for research. Our tests on the "Reston Pad" in combination with a porous top layer represent a step in this direction. Ideally, the top layer and outer cover should be inexpensive and disposable.

3. *Impact Absorbing (memory) Cushions:* These cushions consist of extremely visco-elastic materials which retain an impression for varying periods of time following deformation; "elastic resilience," is delayed. Hence, strain energy is absorbed during the "creep" phase of deformation in a different manner than in a very resilient cushion. Whether or not this is a desirable characteristic for a seat cushion is debatable. Nevertheless, this material does have the property of conforming and taking a temporary impression of the buttocks, which should aid in reducing localized sitting pressures. These cushions did not score particularly well on our tests, being intermediate between simple polyurethane foams and the gels. Sitting pressures actually tended to be high, giving a low score on this test (Fig. 16, 17, and 18). Furthermore, if loaded statically for periods of an hour or more, some of these cushions "bottomed out," with a sharp increase in pressure. Little clinical experience has been reported with these cushions for comparison. Despite the relatively poor test results a great variety of these materials is available, and some may have superior properties. It appears that these substances are worth exploring further, particularly concerning their use as one layer of a multicomponent cushion.

4. *Water Cushion:* The concept of the water pad is based on the theory that this medium could produce the ultimate in pressure distribution and reduction. In practice, however, the pads tested produced the lowest of all scores. Admittedly our testing methods place these cushions at a disadvantage, due to the small area of the indenter disk displacing water. Still, the water pad seems to have so many disadvantages that there would be more promise in development of other cushion types. Other investigators agree in this assessment (1), and clinical results, in general, have not been outstanding.

The basic principle of the water pad is good, but the practical difficulties are legion. Water necessarily must be confined in a strong envelope which then becomes the principal factor in determining cushion properties; only with a large surface, such as a bed, can this "skin effect" be minimized. Weight, leakage, instability, and variations in filling necessary to match a patient's weight all are problems. Even when properly filled, a water cushion of practical thickness has a tendency to "bottom out" if a patient with prominent tuberosities puts all his weight on one side.

## SUMMARY AND CONCLUSIONS

A comprehensive biomechanical test program for evaluation of wheelchair cushions has been described. Designed to be applicable to all types of cushions, this pilot program is intended to provide a means for estimating the potential of a cushion for prevention of decubitus ulcers, without the necessity for long-term clinical trials. In addition, this test program offers a possible basis for manufacturing standards for wheelchair cushions.

Twelve cushions representing various latex and polyurethane foams, gels, impact absorbing, and water types were subjected to the pilot test protocol, and results were reported. For each cushion type, the results correlated broadly with clinical behavior known from past experience. Further empirical and analytical development is recommended to improve the accuracy and relevance of the test apparatus, protocol, and scoring system, so that results can be used to predict long-term clinical behavior with maximum accuracy. Unfortunately, in the present system, cushions with widely divergent qualities may give similar overall test scores since high scores in some areas balance low scores in others. Establishment of standards for wheelchair cushions followed by a comprehensive testing of all available models is recommended once the necessary improvements in the test system have been accomplished.

The possibilities of utilizing this test system as an aid in developing new cushions and improving existing types also have been outlined. Since the tests highlight the good and bad points of each sample, attention can be directed toward improving the less favorable characteristics. Several combinations of cushion materials, suggested by this work, show promise as a basis for new cushions representing improvements over existing types. These combinations require further testing to determine an optimum design. Greater attention must be paid to covering materials which permit ease of cleaning while encouraging air circulation and heat dissipation.

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## REFERENCES

1. Mooney, V., M.J. Einbund, J.E. Rogers, and E.S. Stauffer: Comparison of Pressure Distribution Qualities in Seat Cushions. *Bull. Prosthetics Res.*, BPR 10-15:129-143, 1971.
2. Landis, E.M.: Micro-injection Studies of Capillary Blood Pressure in Human Skin. *Heart*, 15:209, 1930.
3. Nichol, J., F. Girling, W. Jerrard, E.B. Claxton, and A.C. Burton: Fundamental Instability of Small Blood Vessels and Critical Closing Pressures in Vascular Beds. *Am. J. Physiol.*, 64:330, 1951.
4. Lindan, O.: Etiology of Decubitus Ulcers: An Experimental Study. *Arch. Phys. Med. & Rehab.*, 42:774-783, 1961.
5. Kosiak, M.: Etiology and Pathology of Ischemic Ulcers. *Arch. Phys. Med. & Rehab.*, 40:62-69, 1959.
6. Kosiak, M.: Etiology of Decubitus Ulcers. *Arch. Phys. Med. & Rehab.*, 42:19-29, 1961.
7. Reichel, S.M.: Shearing Force as a Factor in Decubitus Ulcers in Paraplegics. *J.A.M.A.*, 166:762-763, 1958.
8. Houle, R.J.: Evaluation of Seat Devices Designed to Prevent Ischemic Ulcers in Paraplegic Patients. *Arch. Phys. Med. & Rehab.*, 50:587-594, 1969.
9. Kosiak, M., W.G. Kubicek, M. Olson, J.N. Danz, and F.J. Kottke: Evaluation of Pressure as a Factor in the Production of Ischial Ulcers. *Arch. Phys. Med. & Rehab.*, 39:623-629, 1958.
10. Cochran, G.V.B.: The Clinical Measurement and Control of Corrective and Supportive Forces. *Clin. Orthop.*, 75:209-234, 1971.
11. Appoldt, F.A., L. Bennett, and R. Contini: Socket Pressures as a Function of Pressure Transducer Protrusion. *Bull. Prosthetics Res.*, BPR 10-11:236-249, 1969.
12. Murphy, E.F.: Transferring Load to Flesh, Part I. Concepts. *Bull. Prosthetics Res.*, BPR 10-16:38-44, 1971.
13. Bennett, L.: Transferring Load to Flesh, Part II. Analysis of Compressive Stress. *Bull. Prosthetics Res.*, BPR 10-16:45-63, 1971.
14. Bennett, L.: Transferring Load to Flesh, Part III. Analysis of Shear Stress. *Bull. Prosthetics Res.*, BPR 10-17:38-51, 1972.
15. Bennett, L.: Transferring Load to Flesh, Part IV. Flesh Reaction to Contact Curvature. *Bull. Prosthetics Res.*, BPR 10-18:60-67, 1972.
16. Veronda, D.R. and R.A. Westman: Mechanical Characterization of Skin-Finite Deformations. *J. Biomechanics*, 3:111-124, 1970.
17. Rae, J.W. and J.L. Cockrell: Interface Pressure and Stress Distribution in Prosthetic Fitting. *Bull. Prosthetics Res.*, BPR 10-16:64-111, 1971.
18. Hertzberg, H.T.E.: The Human Buttocks in Sitting: Pressures, Patterns, and Palliatives. *Soc. Automotive Eng.*, Pub. No. 720005, 12 pp., 1972.
19. Sarmiento, A., J. Infante, and W.F. Sinclair: Development of Refined Fitting Procedures for Lower-Extremity Prostheses. *Bull. Prosthetics Res.*, BPR 10-16:112-129, 1971.
20. Cochran, G.V.B.: Use of Magnetostrictive Transducers for Stress Measurements within Methylmethacrylate "Bone Cement." *J. Biomed. Mater. Res.*, 6:283-285, 1972.
21. Spence, W.R., R.D. Burk, and J.W. Rae: Gel Support for Prevention of Decubitus Ulcers. *Arch. Phys. Med. & Rehab.*, 48:283-288, 1967.
22. Appoldt, F.A., L. Bennett, and R. Contini: Tangential Pressure Measurements in Above-Knee Suction Sockets. *Bull. Prosthetics Res.*, BPR 10-13:70-86, 1970.
23. Hassard, G.H., J. Conry, and W. Rice: Bucket Seat for Control of Decubitus Ulcers. *Arch. Phys. Med. & Rehab.*, 52:481-484, 1971.