

## Factors affecting the pressure-distributing properties of foam mattress overlays

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**Abstract**—A universal concern of those in nursing care is the occurrence of decubitus ulcers. To minimize this problem foam overlays are routinely used on hospital beds throughout the country. This study was undertaken to develop laboratory testing procedures which will reliably predict the support characteristics of mattress overlays in clinical service. Initially, test methods based on constant load and constant deformation boundary conditions were developed. These methods were applied to measure the pressure-distributing properties of 10 polyurethane foams fabricated in a wide range of pliances and densities. Based on these laboratory data, a single index was developed to express the effectiveness of each overlay in distributing interface pressures. This index was found to be influenced by the stiffness (ILD), density, and thickness of each device. These data were then compared with measurements of interface pressure obtained from volunteer subjects who were supported on mattress overlays fabricated from each of the original foams. Correlation of these data with the laboratory results demonstrated that the effectiveness index was an accurate predictor of mattress overlay performance under end-use conditions.

### INTRODUCTION

Historically, the development of aids and devices for prevention of pressure sores has concentrated on designing specialized beds and support surfaces for bedfast individuals and improved cushions for the wheelchair user (1,3,4,6-8,11,13-17). Through these efforts, methods for characterizing the performance of these devices has been studied by investigating the pressures developed between the skin and supporting surfaces (2,5,9,12). In most studies it has been assumed that interface pressures are a good indicator of the potential risk of skin ulceration,

an assumption which has been supported by several clinical studies (10, 14).

Recently, attention in our program has broadened from the specific needs of disabled individuals with a high risk of skin ulceration to a more generalized challenge of decubitus prevention in various nursing situations, ranging from the acute intensive care unit to the long-term nursing home facility. Although pressure management is a vital consideration in each of these settings, little attention has been devoted to the appropriateness of available aids and devices. Although in nursing care most risks of skin ulceration are associated with confinement to bed, under most circumstances, the expensive solutions provided by fluidized beds or air-flotation systems are neither practical nor cost-effective. For this reason, use of foam overlays, commonly with a convoluted surface, has become a universal, convenient method of attempting to reduce the risk of pressure sores while increasing patient comfort. Used over a conventional hospital mattress, disposable foam overlays have also proved hygienic. Foam overlays also minimize the incidence of skin maceration. This problem has been associated with impermeable plastic mattress covers, which, for reasons of hygiene and durability, have become mandatory in the construction of modern hospital mattresses.

Despite the efficacy of foam overlays, our previous studies have demonstrated that the interface pressures developed using these devices are extremely variable and depend on the geometry, thickness, and material of fabrication of the overlay itself. Consequently, a study was undertaken to develop methods which would allow the ultimate performance of plain foam overlays to be pre-

dicted in the laboratory. This would obviate the need for repeated testing of alternate designs of mattress overlays in the ward setting.

## EXPERIMENTAL METHODS

Systematic development of mattress overlays which are both effective and economical relies on a thorough understanding of how the stiffness and density of polymeric materials are related to the development of interfacial pressures. Mattresses support the human body through the development of a mechanical equilibrium between a body of given total weight and a mattress whose resistance to deformation increases with the depth of penetration by the supported body. Although the weight of the body deforming a mattress or overlay is constant, the applied pressure at the body/mattress interface changes with increasing area of contact. For this reason, minimum average pressure is achieved with maximum envelopment of the body by the mattress.

To evaluate the performance of different foams in supporting the body, a range of test procedures was considered to meaningfully reflect the complex loading patterns to which an overlay is subjected during use. From this range, two extreme loading configurations were selected. In the first test procedure, a force was applied through a spherically shaped indenter to evaluate the load-bearing capacity of the sample. The maximum interface pressure that developed was measured in response to applied loads comparable to those generated in the clinical setting (typically 20–40 mmHg). Use of this loading pattern to simulate service conditions assumed that the supporting surface was of sufficient thickness to envelop the indenter to a degree which simulated the contours of the body without bottoming out. In the second test procedure, the support medium was subjected to a fixed deformation which simulated the anatomic contours imposed by the variations between the waist and trochanter in side-lying and the sacrum and lumbar lordosis in supine support. Use of this procedure assumed that the support medium was capable of generating reaction forces sufficiently large to support the human body.

To develop the testing process, samples of polyurethane foam were selected according to the characteristics most commonly encountered in commercial products. The properties of the samples are summarized in **Table 1**. Each test piece measured 15 × 15 inches (standard indentation specimens).

Before testing, each sample was repetitively loaded

with a standard ILD indenter (50 sq. inches) for a total of 50 cycles at a rate of 1 cycle/second. Each cycle caused 90 percent deformation on the test piece. After this loading regime, the test piece was left to stand unloaded for at least 2 minutes before measurements were taken. The indentation load deflection (ILD) at 25 percent indentation was measured for each test piece after the initial conditioning. The density of each of the test pieces was calculated from direct measurements of the weight and volume.

**Table 1**

Mechanical properties of foams selected for testing.

Density, lbs/ft <sup>3</sup>	Nominal Hardness, (25 % ILD, lbs)						
	27/31	32/38	39/49	50/59	60/69	70/79	80/100
1.2–1.3	X	X	X				
1.4–1.6	X	X	X	X	X		
1.8–2.0	X	X	X	X			
2.1–2.3				X			
2.5–2.7		X		X	X		
3.0–3.5			X			X	
3.6–4.0							X

ILD = indentation load deflection

To facilitate reproducible testing of each foam specimen, the spherical indenting head was mounted in a rigid frame instrumented to allow measurement of its depth of penetration into the supporting surface (**Figure 1a**). Pneumatic-type pressure sensors were also mounted on the indenter to allow measurement of interface pressures (**Figure 1b**). Two sensors were situated over the bottom point of the indenter, two others were located 1/4 inch vertically above the bottom and 1 inch vertically above the bottom. The geometry of the spherical section was designed to be dimensionally similar to the trochanter, and the depth used to deform the foam was equal to the average dimensional difference between the trochanter and waist measurements in a sample of volunteer subjects at The Institute for Rehabilitation & Research (TIRR).

In the load-bearing capacity test, a load sufficient to generate a uniform pressure over the surface of the indenter was placed on the loading device. The indenter was then allowed to descend freely into the test specimen, at which point the depth of indentation and maximum interface pressure were measured. The applied load was increased to a level equivalent to 40 mmHg and the measurements of indentation depth and maximum pressure were repeated. For each specimen the loading regime and

pressure measurements were repeated at least five times.

In the fixed deformation test, the indenter was initially placed in contact with the surface of the test piece and the corresponding sample height measurement was recorded. The indenter was then loaded until a maximum depth of penetration of 1 1/2 inches was attained. The pressure at each of the six sensor points was then recorded and the process was repeated to assure reproducibility of the data.

To relate the results of the laboratory testing procedure to the clinical setting, 30 foam overlays were fabricated from foams of identical mechanical properties as those tested in the laboratory phase of this study. These samples were evaluated with 32 subjects selected from volunteers at TIRR. In this evaluation, each subject lay on each of the overlays in the supine and lateral positions. Interface pressures were measured under the scapulae, sacrum, and the greater trochanter. All of the subjects were clothed in loose-fitting clothing that presented no measurable load concentration points, e.g., double seams or wrinkles.

A pressure sensor pad for the Texas Interface Pressure Evaluator (TIPE) was placed between the overlay and the area of the subjects' body being monitored. The TIPE is a large-area (41 × 41 cm) pressure transducer capable

of monitoring pressures at the body/support interface while the subject is sitting or lying. The transducer pad consists of 144 pneumatically controlled contact switches which activate a matrix of lights on the display unit. The prominence was palpated to locate it on the TIPE readout and the peak pressures in each area were then measured. To improve the reproducibility and the accuracy of the pressure reading, each measurement was repeated a minimum of three times and the average recorded for use in the data reduction.

## RESULTS

The test procedures adopted in this study result in a large volume of data documenting the performance of each of the foams tested. For this reason, methods were explored to characterize the overall performance of each foam sample by a single effectiveness index. Separate

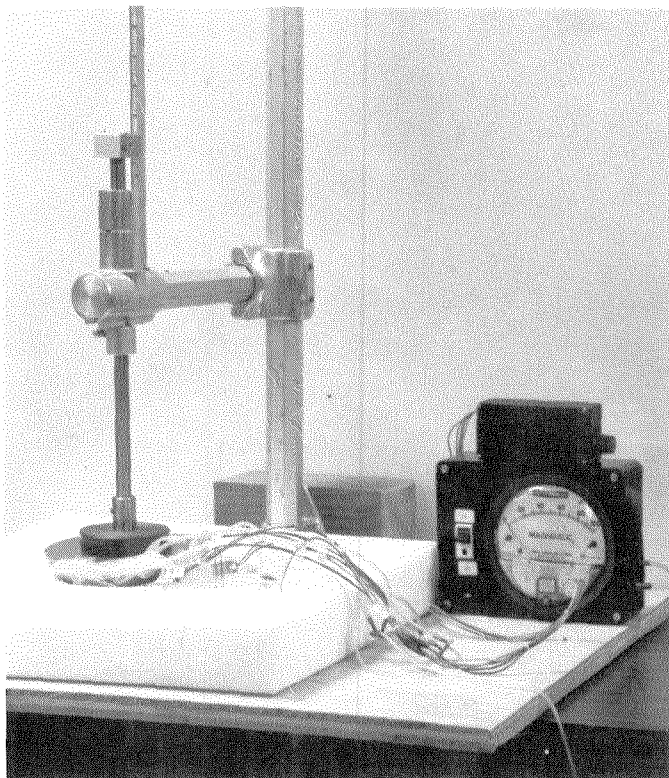


Figure 1a.

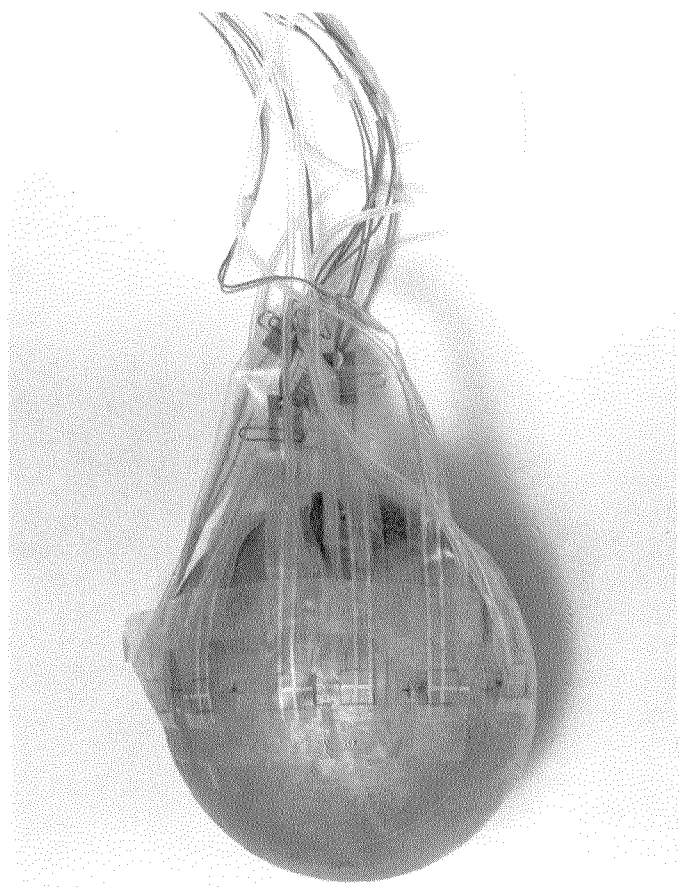


Figure 1b.

indices were initially derived to represent the effectiveness of each sample under fixed load and deformation conditions.

For the fixed load-bearing case, the pressures developed beneath the indenter were compared with the average applied pressure to allow the uniformity of support of the applied load to be assessed. An effectiveness index  $E$  was then derived

$$E(P) = \frac{100 \cdot W}{A^* P_{max}}$$

where  $E$  = effectiveness of support at nominal pressure  $P$ ,  $A$  = available area of indenter,  $P_{max}$  = maximum contact pressure measured at interface, and  $W$  = the load required to develop the nominal pressure  $P$ . Effectiveness indices were calculated at nominal pressures of 20 and 40 mmHg. These values were then averaged to yield a net index which was considered representative of conditions developed in the use of mattress overlays. With this expression, a uniform, fluid-like pressure distribution would be awarded an effectiveness of 100. Indices for the foams tested in this study actually ranged from 15 to 60.

For the fixed deformation test, an expression for effectiveness was derived by considering the combined effects of the maximum pressure beneath the indenter and the average pressure gradient over its surface. As average contract pressures were generally around 30 mm Hg, maximum pressure values were normalized through the expression

$$P^* = \frac{30(\text{mmHg})}{P_{max}(\text{mmHg})}$$

The pressure gradient ( $G$ ) typically ranged from 50–100 mmHg/in and were calculated through the expression

$$G = \frac{0.75 P_1 + 0.25 P_2}{0.1875}$$

where  $P_1$  is the difference in pressure between pressure sensor located on the bottom of the loading head and the pressure sensor located 1/4 inch vertically from the bottom;  $P_2$  is the pressure difference between the intermediate sensor and the sensor located 1 inch above the bottom of the loading head. All pressures were expressed in millimeters of mercury.

The pressure-gradient data were then normalized, based on a typical value of 100 mmHg/in, using the expression

$$\text{GRAD} = \frac{1}{1 + G/100}$$

With these expressions, the effectiveness  $E^*$  was calculated

$$E^* = 100 \text{ GRAD } P^*$$

In the fixed load-bearing tests the 4 inch thick specimens demonstrated a wide range of effectiveness in pressure distribution, with only the softest specimen showing evidence of "bottoming out" under the 40 mmHg load (**Figure 2**). In the same tests performed on 2-inch specimens, virtually identical effectiveness indices were obtained for specimens of high ILD and density, the same relations between the three variables being observed until the ILD values dropped below 49 lb, where upon bottoming-out effects were experienced at applied pressure of 40 mmHg. Bottoming out was not observed under the 20 mmHg constant load test for any of the specimens examined in this study (**Figure 3**).

For the specimens of identical ILD and density, the effect of varying specimen thickness of effectiveness was complex and could not be simply expressed, given the available range of specimen properties and the scatter of the data. This complexity arose because foam thickness only significantly influenced the support characteristics when bottoming out occurred. (**Figure 4**). Thus the contribution of thickness was variable and interrelated with the ILD and density of each specimen.

The data collected during the fixed deformation tests were used to calculate an effectiveness number for each foam sample. The effectiveness numbers were then used as dependent variables in a multiple regression analysis that explored the relationship between the density, ( $D$ ), thickness and (ILD) of the foam sample and combinations of these variables. The results of this analysis are summarized in **Figure 5**, where  $\sqrt{D \cdot \text{ILD}}$  and thickness were found to be the best performance predictors. Without adjustment, the predictive value of the parameters used as independent variables to predict the effectiveness number was 0.8644, which is quite high. When several abnormally deviant observations were deleted from the sample, the predictive value of the variables increased to 0.9436. These data were used to formulate the nomograph which can be used to predict the effectiveness of a given foam overlay system (**Figure 5**).

When the effectiveness indices calculated from the fixed load and deformation tests were compared with the clinical performance of foam mattress overlays, there was

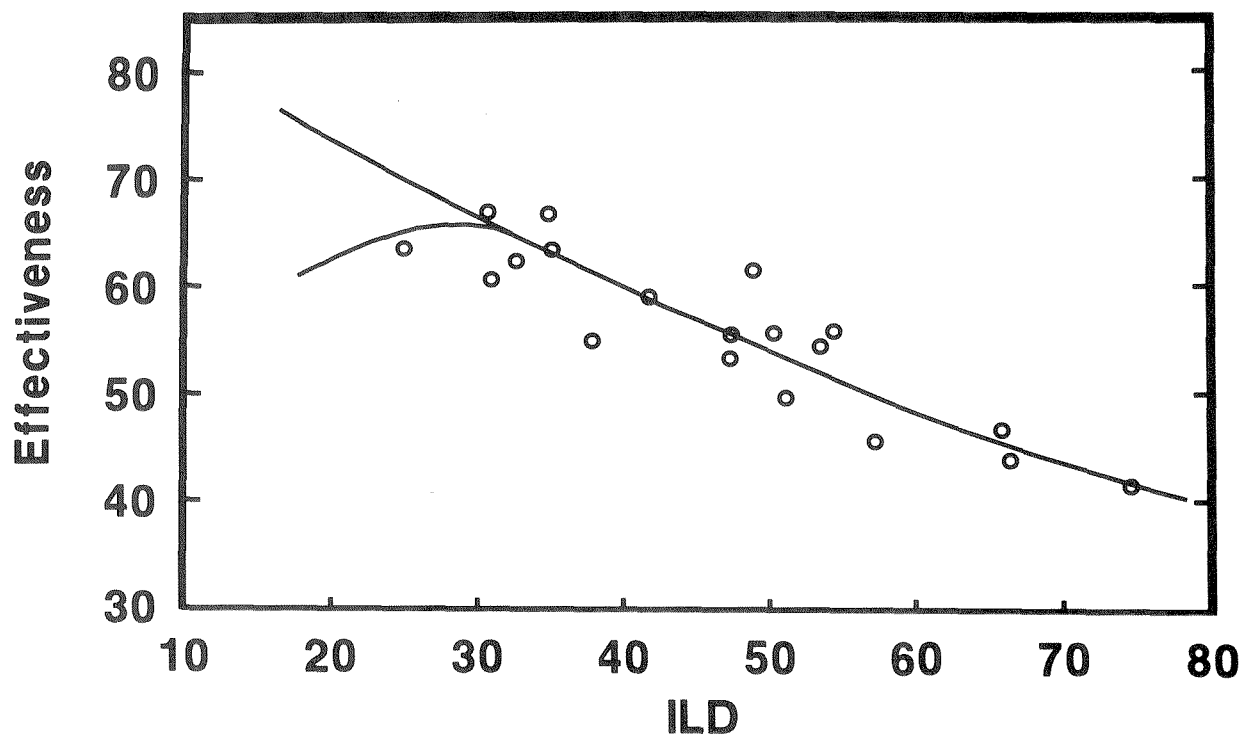


Figure 2.

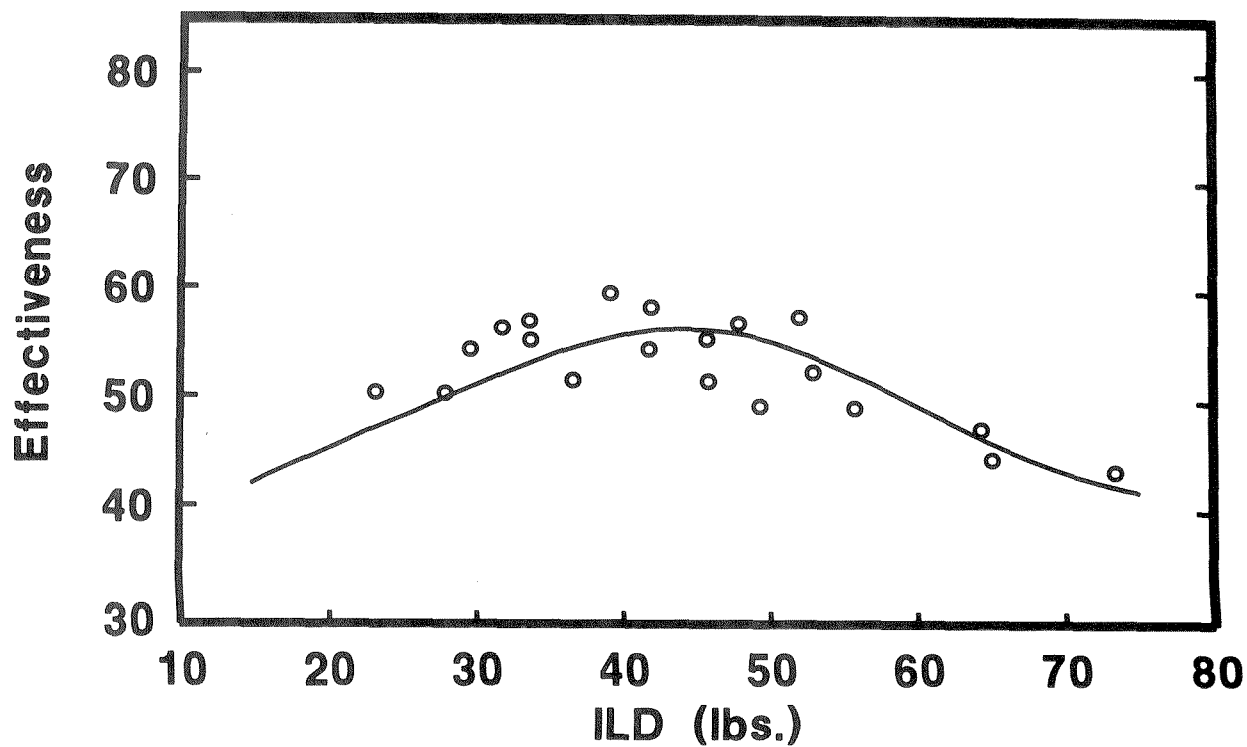


Figure 3.

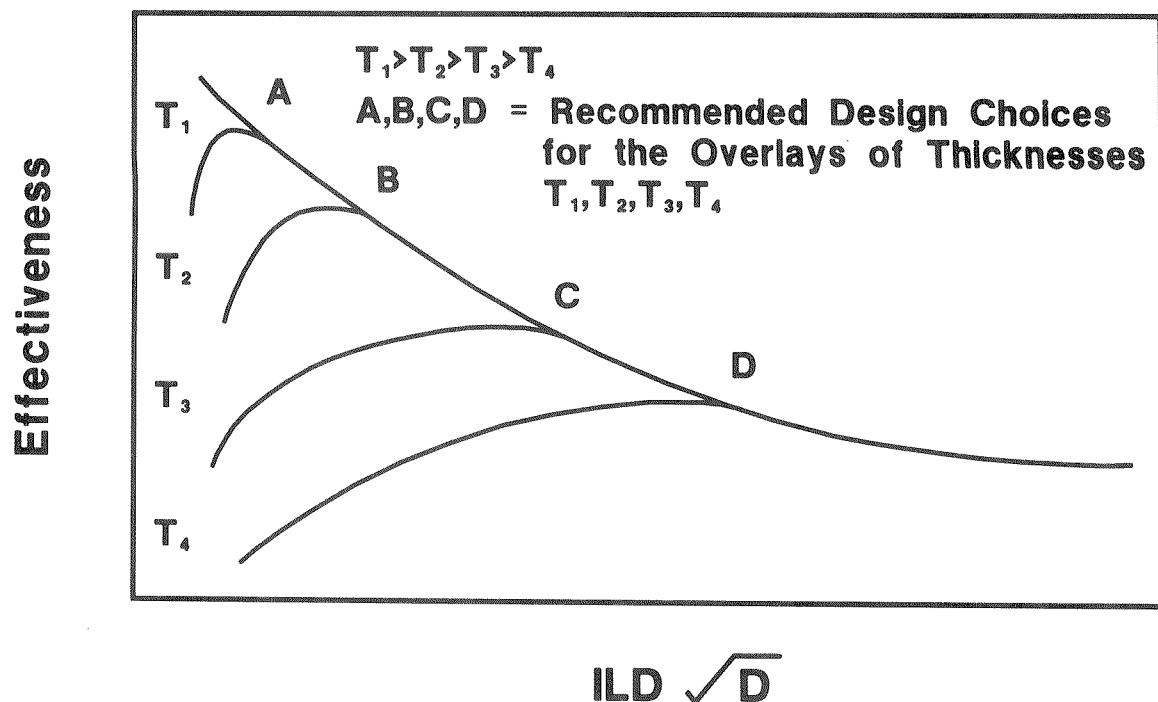


Figure 4.

good agreement for overlays in the middle range of ILD and density. For softer foams, predictions based on the fixed deformation test became unreliable; while at the higher end of the scale, the fixed load test gave a poor correlation with clinical performance. In contrast, a composite effectiveness index, derived as the simple average of the fixed load and formation indices proved to have a very high predictive value when assessing clinical performance. This correlation is illustrated in **Figure 6** where the composite effectiveness and the interface pressures under the greater trochanter are plotted as a function of foam overlay. When the interface pressures from the other sites, (scapula, heels, and sacrum) were plotted, a similar fit was observed.

## CONCLUSIONS

1. A simple, two-step bench testing procedure can accurately predict the performance of foam mattress overlays as interface pressure relief devices.
2. Strong correlations were observed between the hardness (ILD), density and thickness of a mattress overlay and its ultimate performance as a pressure-relief device.
3. Irrespective of the foam used to fabricate 2-inch mattress overlays, the devices are only effective for use with patients restricted to supine and/or prone positions.

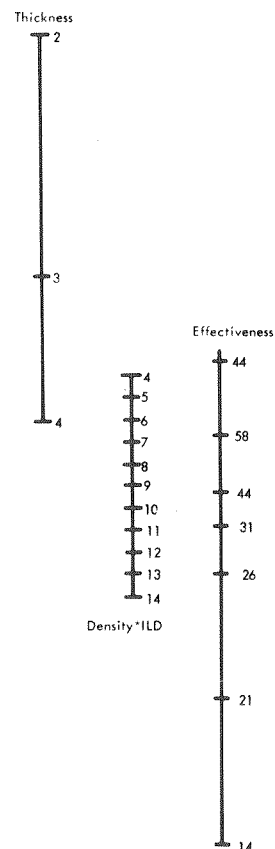


Figure 5.

Nomograph for predicting effectiveness on the basis of the fixed deformation tests.

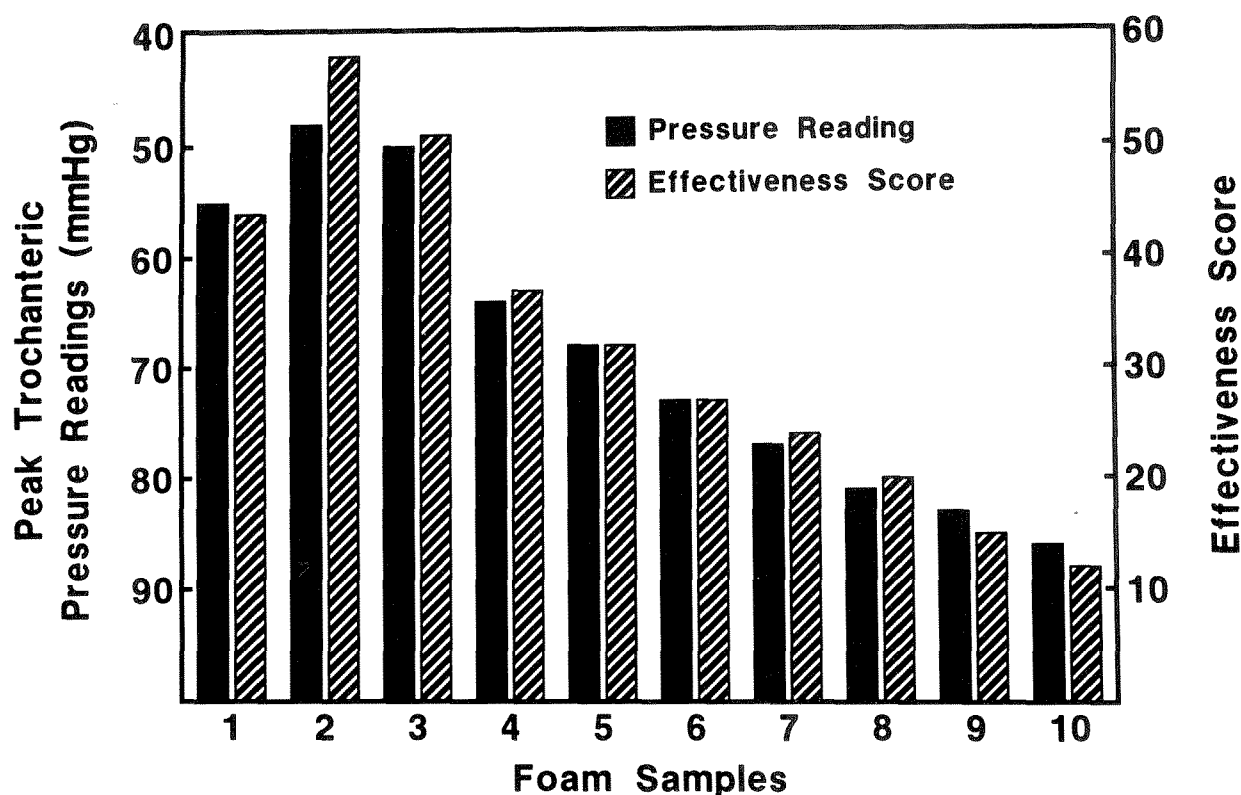


Figure 6.

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