VA RESEARCH & DEVELOPMENT

JRRD
Journal of Rehabilitation Research & Development
Vol. 35 No. 4, October 1998
Pages 396 — 404

Retention of supportive properties by eggcrate and foam wheelchair cushions

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Abstract--This study investigated the reported lack of ability of the eggcrate cushion (EC) to provide wheelchair users with adequate support necessary for comfort and tolerably low-peak sitting pressures over time. The primary parameter used to quantify the ability of the cushion to distribute load was the indention force deflection (IFD) metric. The EC was compared to a high-density planar foam cushion (HD). The IFD was measured for both cushions after successive periods of compression to simulate use. Study results failed to support the common perception that the soft EC would lose its supportive properties more rapidly than the much firmer HD cushion. Although the initial IFD of the EC was much lower than that of the HD, a smaller percentage of its IFD was lost after compression. This difference between the two cushions likely was due to differences in packaging. The EC was rolled into a cylinder, compressing it to 60% of its original thickness; the HD was packaged without compression.

Key words: *cushions, foam, indention force deflection, nursing home, sitting pressure, wheelchair.*

INTRODUCTION

Previous research, comparing the cushions of 21 nursing-home wheelchair users (1), suggested that an inexpensive eggcrate cushion (EC) performed better than a high-density foam cushion

(HD) with respect to comfort and peak pressure. The EC received 56 positive comments, compared to 36 for the HD. At the end of the study, subjects were given the chance to chose one of the test cushions for use on their wheelchair. Ten chose an EC; one an HD. The average peak sitting pressure recorded for the EC, 11.6 kPa (86.6 mmHg), was significantly less ($p<0.05$) than that of the HD, 14.1 kPa (105.6 mmHg).

These findings are at odds with the conventional wisdom of most seating specialists, researchers, and designers of contract furniture, who believe that a high-density is superior to a low-density cushion such as the EC (2,3). This perception has contributed to a decline in EC use in nursing homes. The present study investigated the reported lack of endurance for the EC. It is commonly believed that its low-density cell structure would not retain adequate cushioning capabilities nearly as long as a higher density foam (4).

This study was designed to provide information regarding the relative retention of supportive properties of the EC and HD cushions after use. The indention force deflection (IFD) metric was used to quantify the ability of the cushions to distribute load. Formerly known as the indention load deflection (ILD), the IFD procedure indicates how much force is required to compress a cushion to specified percentages of its original thickness; it is an indication of how firm the cushion is. Cushions that have low IFD values are soft and may "bottom out" under bony prominences, especially if the IFD values decrease with use (5). Cushions with high IFD values are firmer and are thought to retain sufficiently high IFD values longer than softer cushions (4). The 65 percent measure (65% IFD), recorded after a circular flat plate indentor is driven into the cushion to a depth of 65 percent its original thickness, is a good measure of the support region of the stress-strain curve. The 25 percent measure (25% IFD) quantifies initial firmness upon compression (6).

METHOD

The study consisted of measuring the IFD of three EC and three HD cushions before and after several hours of static compression. Static compression has been shown to approximate the effects of long-term cushion use (4). The IFD was also measured after the cushions were given time to recover.

Investigations were also conducted in an attempt to explore the clinical relevance of the IFD and its testing procedures. In order to help determine whether static compression was an acceptable surrogate for actual cushion use, IFD measurements of EC cushions that had been used by eight nursing-home wheelchair users were also taken.

Test Cushions

The same types of EC and HD cushions (Sunrise Medical, Torrance, CA) used in the cushion comparison study (1) were selected for the present study. We used the Bioclinic #70007 10×43.2×43.2 cm EC cushion, an inexpensive ($6.50), commonly used nursing home seat pad, that consists of convoluted foam (**Figure 1**). The HD cushion (#700722, 5.1×40.6×45.7 cm, with an estimated price of $90.00) consisting of a flat block of high-density foam in a waterproof nylon slip cover, was chosen because it is similar to many of the simple slab cushions offered as accessories by wheelchair manufacturers. It also approximates the guidelines for seat cushion design for the nondisabled market, which recommend 38 mm-thick firm padding (2). Others have found planar foam to have good pressure-relieving capabilities, relative to many of the cushions we found commonly used in nursing homes (7,8).

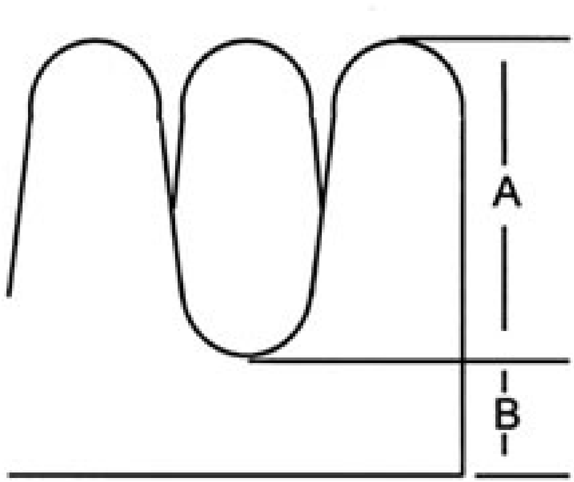


Figure 1.
Elevation of an EC cushion showing the convolutions or peaks (A) and the uncut foam of the base (B).

Both cushions were fabricated from polyurethane foam. The structure of the foam consists of gas-filled polyhedral cells comprised of struts connected to membranes. Compressing the foam buckles the struts and membranes, driving air through the cell structures. Removing the compressive load allows elastic recovery of the struts and membranes. The severity and duration of compression determines the degree of recovery.

The foam used for both cushions was cut from a large "bun" or slab of foam. The densities of standard urethane foam produced in this manner vary widely (16-24 kg/m^3). The measured density of the low-density, combustion-modified EC foam is 17.0 kg/m^3. The density of the HD cushion is 38.6 kg/m^3, a density normally associated with foams molded into the desired shape. In addition to being more than twice as dense as the EC foam, its urethane was a medium-to-firm grade high-resilience (HR) foam. HR foams are chemically altered to provide a more linear compression stress-strain curve (9).

The EC is not provided with a cover. The HD was provided and tested with a nonstretch nylon cover, the hammocking effects of which increased the apparent stiffness of the cushion.

Cushion Compression and Recovery Cycle Testing

Both cushions were subjected to a compression / noncompression recovery regimen and their IFDs measured periodically (**Table 1**).

Table 1.
Outline of cushion compression and recovery cycle testing.

Time	Action
Baseline	IFD measured prior to 1st compression period.
1st compression: 1 hr	Cushions placed in hydraulic press; IFD measurement taken.
2nd compression: 1 hr	Cushions placed in hydraulic press; IFD measurement taken.
3rd compression: 3 hr	Cushions placed in hydraulic press; IFD measurement taken.
1st recovery: 16 hr	IFD measured 16 hr after previous measurement.
4th compression: 6 hr	Cushions placed in hydraulic press; IFD measurement taken.
2nd recovery: 38 hr	IFD measured 16 hr after previous measurement.

Used Eggcrate Cushion Testing

The IFD was measured for eight EC cushions that had been used by nursing home residents 5 to 12 hrs per day for 1 to 4 mo. A local nursing home was identified as using the EC cushion we were studying, and 8 of 30 residents who had received new cushions in March 1995 were identified as still using them and agreeable to exchanging them for new ones. A modest honorarium was offered to the residents and to the nursing home.

The cushions had been used an average of 2.3 mo at an average of 7.4 hrs per day. User weight averaged 57.1 kg (range 29.9-96.6 kg), and most were incontinent. All except one used a standard sling-seat wheelchair.

In order to establish a baseline, a new EC cushion from the nursing home stock was tested. The eight used cushions also were tested in the same manner.

Test Protocol for Indention Force Deflection

The American Society for Testing and Materials (ASTM) Standard Test Methods for Flexible Cellular Materials IFD Test (**Table 2**) was used to assess the relative supportive properties of the EC and HD cushions (6).

Table 2.
IFD testing procedure

Verification of Instron and load cell:
Zero and balance Instron.
Verify load cell calibration and full scale with 22.7 kg test weight.
Place cushion on aluminum plate.

Zero out cushion weight.
Determine cushion thickness:
Bring indentor foot in contact with cushion until 4.5 N is recorded for the eggcrate foam and until 22.5 N is recorded for the foam cushion.
Zero Instron crosshead measurement indicator.
Pre-flex cushion:
Lower indentor into cushion to a total deflection of 77% of original thickness at a rate of 200 mm/min; raise indentor to its original position.
Repeat.
Allow cushion 6±1 min to recover.
25% IFD measurement:
Lower indentor into cushion to a total deflection of 25% of original thickness at a rate of 50 mm/min.
Record load cell force after 60±3 s.
65% IFD measurement:
Continue compression by lowering the indentor into cushion to a total deflection of 65% of original thickness at a rate of 50 mm/min.
Record load cell force after 60±3 seconds.
Return indentor to the original position.

The following minor modifications were made to the test procedure:

1. Because both cushion surfaces were planar, the indentor foot was held parallel to the cushion surface; no swivel joint was used.
2. The plate upon which the cushions rested was not perforated to allow air flow. In the case of the EC, the open cell foam provided adequate ventilation. The HD was encased in a non-permeable cover with vents that were not obscured by the plate.
3. The contact load for the indentor foot was increased from 4.5 N to 22.5 N in order to properly seat the indentor for the HD.

The simulated use cushion compression cycle was performed using the general techniques described in the ASTM standards (6) and by McFayden and Stoner (4). Cushions were placed in a chamber capable of compressing them to 10 percent of their original thickness (**Figure 2**). The duration of compression was based on the McFayden and Stoner results that showed significant loss of IFD within the first 3 hrs. The IFD was measured after 1, 2, 5, and 6 hrs of compression (**Table 1**), and also after 16- and 38-hr recovery periods, to assess the ability of the cushions to recover their supportive qualities overnight and after a night and a full day. This later recovery time would be possible if residents were provided two cushions.

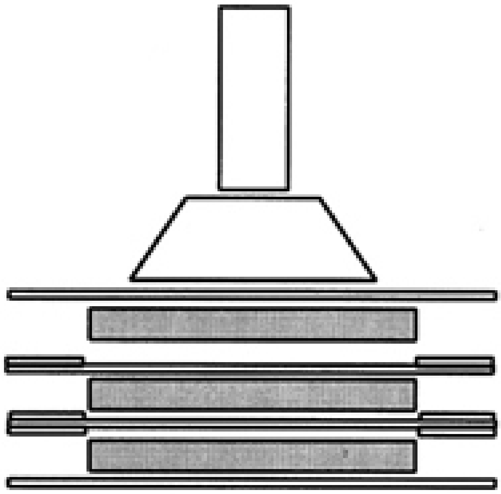


Figure 2.
Compression method. A hydraulic press was modified with partitions to accommodate three cushions. The thickness of the spacers on the perimeter of the partitions controlled the extent of the compression. Rigid top and bottom plates ensured equal pressure across the entire cushion surface. 35.9 kPa was required to compress the HD cushions.

Testing Apparatus

The IFD tests were conducted on an Instron Universal Testing Instrument (Model 1123, Instron Corporation, Canton, MA, see **Figure 3**). The compression mode was used to drive into the cushions the indentor foot, a 323 cm^2 flat circular steel plate, at a compression speed manually selected in accordance with ASTM D 3574. The cushions rested on a 356×365 mm aluminum plate atop a proving ring load cell, constructed with four peizoresistive strain gauges in a Wheatstone Bridge configuration (full bridge). Within the range used to determine IFD, 0-667 N, the load cell was accurate within ±1 percent.

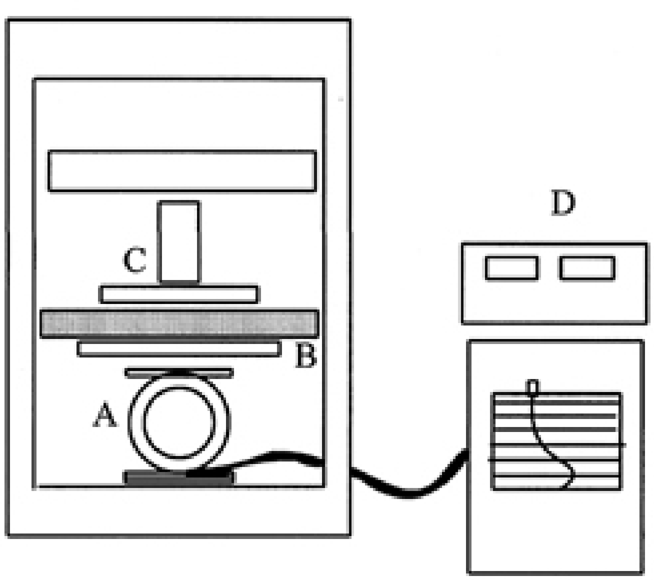


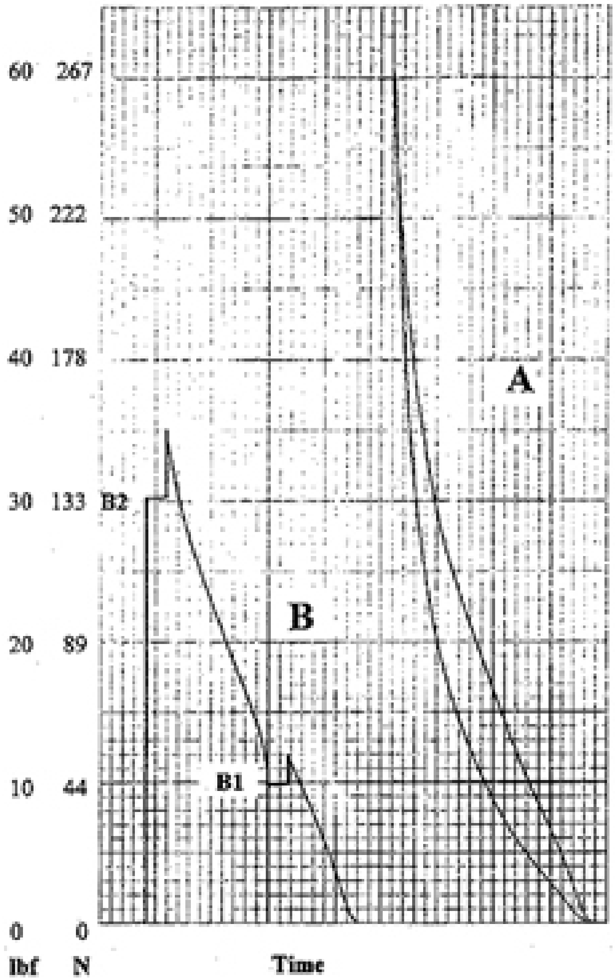
Figure 3.

IFD testing hardware. A=load cell; B=cushion; C=indentor; D=Instron controller and chart recorder.

RESULTS

Figure 4 illustrates the IFD test procedure and resulting compression curves. **Tables 3** and **4** outline the test results for the compression/recovery cycles. The baseline IFD measurements were taken twice, in order to verify the repeatability of the load cell and overall test procedure. There was good agreement between the measurements. The second series of measurements was consistently slightly lower (2-10 percent) than the first. The average IFD loss, over the three cushions and two measurements, for the HD was 6.3 percent and for the EC, 3.7 percent. Although measurement error may have been a contributing factor, it is likely that the observed reduction was due to the effects of compressing the cushions in the course of the initial IFD measurement.

Figure 4. Instron chart recorder output for IFD test of a new EC cushion. Curve A=cushion compression required prior to IFD measurement (**Table 1**). Curve B=IFD test procedure. From right to left: indentor is driven into the cushion to a deflection of 25 percent of original thickness,



and compressive force rises. The force exerted by the indentor is recorded by the load cell after 60 s (point B1). During the delay before B1, the load decreases due to relaxation effects. The indentor is then lowered to a deflection of 65 percent of original thickness and the load recorded after 60 s (B2).

Table 3.
Eggcrate cushion results.

Condition	Cushion A				Cushion B				Cushion C			
	25% IFD		65% IFD		25% IFD		65% IFD		25% IFD		65% IFD	
	N	lbf	N	lbf	N	lbf	N	lbf	N	lbf	N	lbf
Baseline												
Run 1	45	10	128	28.8	49	11.0	132	29.7	46	10.3	132	29.7
Run 2	43	9.7	124	27.9	46	10.3	129	29.0	44	9.8	129	28.9

Average	44	9.9	126	28.4	47	10.7	131	29.4	45	10.1	130	29.3
1 hr	40	9	114	25.7	48	10.8	128	28.8	45	10.2	127	28.5
1 hr	39	8.8	113	25.5	45	10.2	125	28.0	42	9.4	119	26.7
3 hr	37	8.3	105	23.5	36	8.2	106	23.9	36	8.0	108	24.2
16 hr (recovery)	40	9	115	25.9	44	9.8	120	27.0	42	9.5	121	27.2
6 hr	39	8.8	117	26.2	40	9.0	115	25.9	38	8.5	112	25.2
38 hr (recovery)	37	8.4	111	24.9	41	9.2	117	26.2	39	8.7	113	25.5

Table 4.
Foam cushion results.

Condition	**Cushion A**				**Cushion B**				**Cushion C**			
	25% IFD N	**lbf**	**65% IFD N**	**lbf**	**25% IFD N**	**lbf**	**65% IFD N**	**lbf**	**25% IFD N**	**lbf**	**65% IFD N**	**lbf**
Baseline												
Run 1	313	70.4	663	149	328	73.6	683	153.4	328	73.6	676	152
Run 2	294	66	639	143.6	302	67.8	656	147.4	296	66.6	647	145.4
Average	303	68.2	651	146.3	315	70.7	669	150.4	312	70.1	662	148.7
1 hr	263	59.2	552	124	276	62	575	129.2	276	62	580	130.4
1 hr	257	57.8	536	120.4	265	59.6	558	125.4	255	57.4	540	121.4
3 hr	255	57.2	530	119.2	247	55.6	523	117.6	254	57	534	120
16 hr (recovery)	261	58.6	534	120	265	59.6	546	122.6	265	59.6	545	122.4
6 hr	232	52.2	498	111.8	247	55.4	522	117.4	248	55.8	528	118.6
38 hr (recovery)	260	58.4	530	119.2	266	59.8	545	122.4	263	59	541	121.6

Table 5 summarizes the data from the measurements of the used cushions. Inspection of the reportedly identical cushions revealed meaningful differences in thickness and convolution height "peaks" (**Figure 1**). Cushions A, B, C, and D were similar in dimension and proportion to both the new cushion tested for baseline data as well the cushions tested in the compression/recovery cycles. Cushions E, F, G, and H averaged 8 mm thicker and were convoluted so that their peaks were higher. The ratio of peak height to the thickness of the uncut foam base was 60 percent higher for these cushions. Cushion H had been modified by cutting out a section to relieve sacral pressure.

Table 5.
Results of used cushion testing.

Cushion	25% N	IFD lbf	65% N	IFD lbf	Height mm	Comments
New	42	9.5	125	28.2	89	New cushion from nursing home stock.
Group 1						
A	49	11.0	133	30.0	96	Dimensionally similar to New cushion.
B	46	10.4	125	28.0	94	Dimensionally similar to New cushion.
C	41	9.3	114	25.7	90	Dimensionally similar to New cushion.
D	45	10.1	124	27.8	99	Dimensionally similar to New cushion.
Group 2						
E	34	7.7	100	22.5	109	Peaks higher and bent over. Evidence of incontinence.
F	24	5.3	77	17.2	93	Peaks higher and bent over.
G	32	7.2	89	20.1	106	Peaks higher and bent over. Longer and wider than others.
H	31	7.0	85	19.0	99	Peaks higher and bent over. Cut-out section in sacral area.

Data Analysis

Analysis of Compression/Recovery Test Results

The HD was predictably much firmer than the EC cushion. The 25% IFD is a measure of perceived firmness (4): the baseline 25% IFD for the HDFC was 6.8 times that of the EC (**Tables**

3 and **4**). After the test was completed, the HD 25% IFD remained high at 6.7 times that of the EC and also demonstrated a much higher 65% IFD, a measure of a cushion's ability to resist bottoming out under load. The baseline 65% IFD for the HD was 5.3 times that of the EC. After the test was completed, the HD 65% IFD remained 4.7 times that of the EC.

The compression/recovery cycling had a significant effect on the 65% IFD of the cushions (single factor ANOVA, $F=2.62$, $df=5,30$, $p=0.044$). The overall IFD response to the compression/recovery cycle was significantly different (two factor ANOVA, $F=150.9$, $df=1$, $p<0.001$) for the two cushions (**Figure 5**). IFD responses for individual compression/recovery conditions were also significantly different (two factor ANOVA, $F=14.06$, $df=5$, $p=0.008$). After each compression or recovery period, the EC retained a greater percentage of baseline 65% IFD, 90 percent on average, while the HD retained 82 percent.

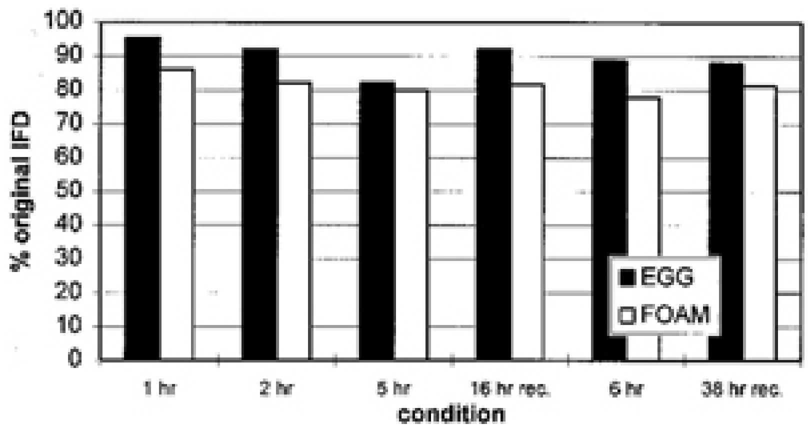


Figure 5.
Comparison of EC and HD cushions based on the percent of retained 65% IFD recorded after the compression/recovery cycle stages.

Generally, there were small IFD differences between individual cushions of the same type for the baseline and the various compression/recovery conditions. These results suggest that the cushions are manufactured with reasonably close tolerances in terms of general supportive qualities.

A comparison was made between the set of IFD values recorded after the third and fourth compression periods and the set of values recorded after the first and second recovery periods. Although there was a significant difference between two sets of data (two factor ANOVA, $F=7.9$, $df=1,12$, $p=0.016$), the average postrecovery IFD was only 3 percent greater than that recorded after the preceding compression period. The IFD recovery after a `rest' period of noncompression was inconsistent for the EC; it recovered 10 percent of its baseline value after the 16-hr (overnight) recovery, but lost 1 percent after the 38-hr period. The HD cushion IFD recovered only 2 and 3.5 percent of its baseline value after the 16- and 38-hr periods, respectively.

Analysis of Used Cushions Test Results

Because of the dimensional differences among the used cushions, they were grouped for analysis. Group 1 cushions were similar to the new cushions tested, and Group 2 cushions had the higher convolutions or peaks. Cushion H was not included because it had been modified.

New and Group 1 cushions were compared after the 38-hr recovery period to assess the relative effects of compression/recovery cycling versus actual use. The Group 1 cushions, having been subjected to many daily compression (sitting) and recovery cycles, had last been used by residents approximately 35 hrs prior to the beginning of the testing.

The 65% IFD was significantly higher for the Group 1 than for the new cushions (two-sample t-test, df=4, t=2.42, p=0.036, t critical one-tail = 2.13, see **Figure 6**). The strength of the relationship, as indexed by eta squared, was 0.59. Visual inspection of the data (**Tables 3** and **4, Figure 6**) suggests minor differences between the new (prior to compression/recovery cycling) and the used cushions. The apparent differences may be due to measurement error, estimated to be approximately ±4 percent. A two-sample t-test failed to reveal significant differences between the two groups of cushions (df=4, t=-1.20, p=0.30, t critical two-tail=2.78).

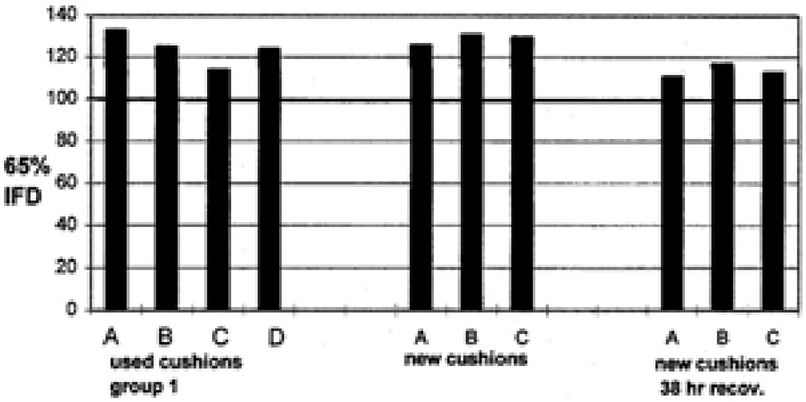


Figure 6.
Comparison of 65% IFD.

DISCUSSION

Both the foam used and the convolution of the sitting surface contributed to the relative softness of the EC cushion. The 25% IFD of the EC foam prior to convolution (manufacturer's data) was half that of the HD cushion (147 N vs 310 N): the convolution process decreased the original value by 70 percent.

The IFD testing was at odds with conventional wisdom that would predict a greater loss of IFD for the cheaper, softer EC cushion. I believe that the explanation for this result lies not with the inherent foam properties, but with the method of handling prior to the test. The EC arrived rolled into a cylinder and compressed approximately 60 percent of its original thickness, while the HD cushions were packaged without compression. It is likely that the IFD of the EC was markedly reduced by long-term storage in a compressed state. Because most of the original IFD was lost within the first 3 hrs of compression (4), further periods of compression resulted in less IFD loss. After the first hour of compression, the EC IFD lost 5 percent while that of the HD lost 14 percent.

Although limited in its scope, the investigation of Group 1 cushions found them to be unaffected by up to 5 mo of daily use (as determined by IFD values). At the nursing home, the soiling of cushions by incontinence, and not the degradation of their pressure-relieving qualities, was the primary reason for discarding them.

The finding that the average 65% IFD values for the Group 1 cushions were slightly greater than those for new cushions that have undergone compression/recovery cycles suggests that the cycling may be more damaging to the cushions than actual use for 1 to 5 mo. This supports prior research that recommends severe compression as a surrogate for worst-case use of heavy people for an extended period of time (4). It should be noted however, that the recorded IFD differences, although significant, may not be clinically meaningful.

Evidence from former studies suggests that the differences must be much greater before an effect is recorded in peak pressure values. **Table 6** summarizes selected (baseline) peak sitting pressure and 65% IFD values for two previous cushion comparison studies (1,10) In the study of 21 nursing home residents, the peak pressure of the HD cushion was 22 percent greater than that of the EC; a statistically significant difference. The IFD of the HD was 515 percent greater than that of the EC.

Table 6.
Peak pressure/IFD comparison for unused cushions or cushions prior to compression.

Type:	**Eggcrate**	**Foam**	**Foam**	**Viscoelastic Foam**	**Laminated Foam**
Thickness:	**100**	**50**	**76**	**76***	**76***
kPa	11.6**	14.1**	9.3*	9.7*	12.2*
(mmHg)	(86.6)	(105.6)	(70)	(73)	(91)
65% IFD	13	67	75	45	215

Thicknesses in mm. *Chung (10) used the Texas Institute of Rehabilitation Research (TIRR) pressure measurement system that was found to give higher readings than the Oxford Pressure Monitor in laboratory tests. For this reason and due to differences in pressure measurement test procedures, comparison of the absolute pressure values between the tests would be misleading. **Data from the cushion comparison study in which IFD was not measured.

An examination of Chung's cushion comparison data shows no relationship between IFD and peak sitting pressure for the 76 mm HD foam and the viscoelastic foam cushions; peak pressure is virtually the same despite the foam cushion's 67 percent greater IFD. However, the Chung data do indicate a possible relationship for cushion types that record very high IFDs. One cushion type, a laminated dual-density polyurethane foam cushion, recorded a 65% IFD of 215 kg which was 287 percent greater than that of the HD and 478 percent greater than that of the viscoelastic cushion.

The reported peak sitting pressure for the laminated foam cushion was approximately 30 percent greater than that of the polyurethane foam and viscoelastic foam cushions. The results of both studies suggest a possible inverse relationship between peak pressure and IFD for cases in which the difference in IFD is very large.

The study results do not support McFayden and Stoner's recommendation that cushions should used on alternating days, thereby allowing them a day and night to recover their supportive qualities (4). There were only minor postrecovery increases in IFD. However, their suggestion of preloading cushions before clinical use was supported by the IFD results. Denne also suggests this strategy to minimize IFD loss with use (11). Preloading by compressing the cushion to 10 percent of its original thickness for 5 hrs cumulatively or 6 hrs continuously appeared to permanently reduce the IFD from its original level.

Study Limitations and Recommendations for Further Investigation

Additional work is needed to further explore the relationship of peak sitting pressure to IFD. It would be useful in terms of cushion selection for clinical use to have an upper limit for the 65% IFD value in terms of peak pressure reduction (i.e., a "too firm" threshold). The IFD measurement also may be useful in helping to quantify firmness in terms of comfort. In the seat cushion comparison study (1), several subjects complained that the foam cushion was "too firm", while a few found it to be comfortable. A consumer-oriented cushion firmness rating scale, derived from the IFD value, would help in the selection of comfortable cushions.

Due to the small sample of used cushions, analyses and conclusions regarding used cushion test results should be considered preliminary. A more representative sampling of cushions used by a variety of residents over different time periods is required to confirm identified trends and to explore the effects on the cushions of user weight, hours of use per day, and soiling.

CONCLUSIONS

Study results failed to support the common perception that the soft EC would lose its supportive properties more rapidly than a much firmer HD cushion. The IFD metric was used to compare how well the EC and HD cushions retained their supportive properties after use (as simulated by periods of compression). Although the initial IFD of the EC was much lower than that of the HD, a smaller percentage of the EC IFD was lost after compression. This difference between the two cushions likely was due to differences in packaging.

Additionally, the IFD was also measured after recovery periods, during which the cushions were not in the compression chamber or being tested. Although there were significant postrecovery increases in IFD for both cushions, these were too small to be meaningful. Small IFD differences between individual cushions of the same type suggested reasonably close manufacturing tolerances as measured by this parameter. An investigation of the IFD of used cushions suggests that the compression/recovery cycling used to approximate cushion use has a greater effect on IFD loss than an average of 2.3 mo of actual use. However, the magnitude of the differences produced by the two conditions may be too small to be reflected in clinical performance. Evidence from previous work suggests that clinically meaningful increases in peak pressure come only with very large increases in IFD.

Further investigation is needed to explore the relationship of peak pressure and sitting comfort to the IFD metric. The resulting information could be used to quantify cushion firmness and thereby aid in the cushion selection process.

ACKNOWLEDGMENTS

I thank the staff and residents of Eldercare Gardens, the source of the used cushions for the study, and Professor John Thacker, who generously provided assistance with the cushion testing.

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Contents

Back to Top