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Technical note

ISO 16840-2:2007 load deflection and hysteresis measurements for a sample of wheelchair seating cushions

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ABSTRACT

Load deflection and hysteresis measurements were made on 37 wheelchair seating cushions according to ISO 16840-2:2007. Load deflection plots for all 37 cushions are reported and fundamental aspects of graph interpretation discussed. ISO hysteresis data are also reported and interpretation discussed.
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1. Introduction

Wheelchair seating cushions must fulfil a variety of requirements to meet an individual's specific rehabilitation aims, including managing comfort, tissue integrity, postural control, postural alignment and functional enablement. Clinical selection of the best seating support surface however continues to be based principally on custom and practice, the individual clinician's experience, seating theory, user trial and, if available, interface pressure mapping. The reason for this must be, in part at least, the lack of evidence available to guide prescription [1].

The evidence required to facilitate more objective prescription of cushions includes detailed information about the intended user's diagnosis, associated physical and cognitive complications, other aspects of their health, postural presentation, ability, lifestyle, environment, and rehabilitation goals. There is also however a need for objective information about the performance of the available cushions.

Several measures have already been defined and some are in use. Kuncir et al. [2] for example describe compliance factor and compressibility factor. Other measures are from the furniture industry, such as indentation force deflection [3]. Some manufacturers of wheelchair seating cushions also provide information on specific products. Qbitus Products (Halifax, UK) for example, publish Linear Load Limit. Invacare (Elyria, OH), by contrast, publish Loaded Contour Depth, Overload Deflection and Impact Damping data [4], which are defined in the ISO 16840-2:2007 standard [5], for cushions in the Flo-tech range. Other manufacturers however do not provide any objective measures at all. The paucity and inconsistency of data therefore makes rigorous comparison of cushions difficult or impossible.

ISO 16840-2:2007: Wheelchair seating—Part 2: Determination of physical and mechanical characteristics of devices intended to manage tissue integrity—Seat cushions, was published in 2007. Standards are important as they can facilitate the production of transparent data that can be globally understood, allowing objective comparisons of products. This can increase the safety, quality

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and reliability of design and hence provision, and means manufacturers cannot make unsubstantiated claims. ISO 16840-2:2007 is the first version of this standard and was current at the time of testing. A revision however is in preparation at the time of writing.

ISO 16840-2:2007 details a set of measures which describe static and dynamic/elastic characteristics of wheelchair seating cushions which are relevant to tissue integrity. Tests are accompanied by rationale linking each test to clinically relevant features of cushions such as pressure redistribution and shock absorption. In its introduction the standard also states, "The link to clinical efficacy, although implied, has not been validated," and goes on to express the intention that, "this part of ISO 16840 will evolve when the evidence of clinical relevance is confirmed." The emergence of this evidence however is unlikely unless the standard and its resulting data are familiar to and better understood by clinicians. Although the standard was not developed for clinicians to apply directly in clinical decision making, it is hoped that this Technical note will begin the process of developing better understanding amongst clinicians, and hence may lead to theories of clinical effectiveness which draw upon their valuable experiential knowledge.

The aim of this study therefore is to begin this process by examining the results from one of the tests for a selection of wheelchair seating cushions with a view to identifying aspects of the data most salient to differentiating the cushions according to clinical potential. The test examined in this study is the load deflection and hysteresis test described in section 9 of the standard, and which considers the compression characteristics of the cushion as it is loaded and unloaded.

2. Method

Load deflection and hysteresis measurements were made on 37 wheelchair seating cushions according to section 9 of ISO 16840-2:2007 [5]. For full details of test procedures please refer to section 9.2 of this standard.

The cushions tested are listed in Table 1. The cushions represented a variety of manufacturers' designs in current clinical use and also a range of foam types used in custom-made wheelchair seating systems. Cushions were 410 mm wide by 460 mm long where available, which was the size judged to be most appropriate to fit the experimental apparatus, i.e. the rigid cushion loading indenter (RCLI) specified in Annex A of the standard. Where this size was not available, the closest available size was used.

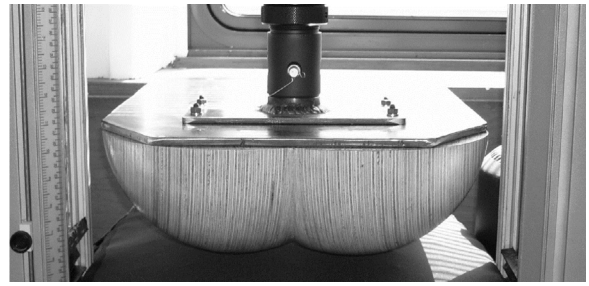

Fig. 1. Rigid cushion loading indenter (RCLI).

The load deflection and hysteresis test requires that each cushion is loaded with an RCLI, which is a rigid representation of human buttocks and thighs (Fig. 1). The thickness of the cushion is measured as the difference between the height of the RCLI top surface with and without the cushion on the test surface. Thickness measures are made when the RCLI is loaded onto the cushion at 8 N, 250 N, 500 N and 750 N as the load is increased and 500 N, 250 N and 8 N as the load is decreased. The cushion is allowed to equilibrate at each load for 120 s $\pm$ 10 s before each measurement is taken. The test is repeated three times for each cushion. An Instron 5567 mechanical testing machine (Instron, High Wycombe, United Kingdom) was used to apply these controlled loads and data were collected with Instron Merlin software. Reported values are the means of the three measurements as required by section 9.3 of ISO 16840-2:2007 [5].

ISO 16840-2:2007 does not distinguish between different designs of cushion. This means that the same method was used

Table 1
Cushions.

Cushion	Construction	Cushion	Construction
Roho single valve[a]	Single compartment, cellular air filled	Propad[c]	Planar foam, single layer
Roho Quadtro[a]	Multi-compartment, cellular air filled	50 mm V33 polyether[f]	Planar foam, single layer
Jay J2[b]	Contoured foam, single layer with viscous fluid overlay	75 mm V33 polyether[f]	Planar foam, single layer
J2 Deep Contour[b]	Contoured foam, single layer with viscous fluid overlay	50 mm CM60	Planar foam, single layer
Jay 3 with Roho[b]	Contoured foam, single layer with cellular air filled insert	75 mm CM60	Planar foam, single layer
Jay Gel[b]	Contoured, gel and foam dual layer	50 mm CM35	Planar foam, single layer
Flo-tech Contour[c]	Contoured foam, single layer	75 mm CM35	Planar foam, single layer
Flo-tech Contour Visco[c]	Contoured visco-foam, single layer	50 mm RX39	Planar foam, single layer
Flo-tech Plus[c]	Contoured foam, single layer with viscous fluid insert	75 mm RX39	Planar foam, single layer
Flo-tech Solution[c]	Viscous fluid sacks overlaid on contoured foam	50 mm Pink viscose	Planar foam, single layer
Flo-tech Lite[c]	Contoured foam, single layer	75 mm Pink viscose	Planar foam, single layer
Flo-tech Lite Visco[c]	Contoured visco-foam, single layer	50 mm Sunmate[g] soft	Planar foam, single layer
Varilite Evolution[e]	Triple foam construction, contoured by air evacuation	75 mm Sunmate[g] soft	Planar foam, single layer
Qbitus Mercury 100[h]	Contoured foam, dual layered	50 mm 3lb chip	Planar foam, single layer
Qbitus Mercury 200[h]	Contoured foam, dual layered	50 mm 6lb chip	Planar foam, single layer
Qbitus Mercury 300[h]	Contoured foam, dual layered, with gel-foam insert	75 mm 6lb chip	Planar foam, single layer
Qbitus Qbi-gel	Planar, gel and foam dual layer	25 mm Pink viscose on 50 mm 3lb chip	Planar foam, dual layered
Vicair Adjuster 6[d]	Air sacs in multi-compartmental cover	25 mm Sunmate[g] soft on 25 mm CM35 on 25 mm CM60	Planar foam, triple layered
Vicair Adjuster 10[d]	Air sacs in multi-compartmental cover		

[a] The Roho Group, Belleville, IL.
[b] Sunrise Medical, Boulder, CO.
[c] Invacare, Elyria, OH.
[d] Vicair, Wormer, The Netherlands.
[e] Varilite, Seattle, WA.
[f] Vitafoam, Manchester, United Kingdom.
[g] Dynamic Systems Inc., Leicester, NC.
[h] Qbitus, Halifax, United Kingdom.

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irrespective of cushion material or whether the cushion was flat, contoured, homogeneous, inhomogeneous or multicompartment. Cushions were preconditioned before testing as required by section 7 of the standard. This involves setting the cushion according to manufacturer's instructions and then applying two cycles of loading with the RCLI at 830 N ± 10 N. Prior to performing a test the standard then requires that, if manufacturers indicate, cushions should be adjusted to accommodate the load applied, and those containing displaceable materials should be reset by flattening them. Where a cushion should be adjusted to a user the cushion should be adjusted to the indenter. The temperature of the test environment conformed to the requirements of section 6 of the standard (23 °C ± 2 °C). However it was not possible to guarantee the humidity requirements of section 6 which requires a relative humidity of 50 ± 5%.

Hysteresis at 250 N (h_{250}) and 500 N (h_{500}) was computed for each cushion according to the following equations which are given in the standard.

$$h_{250} = 1 - \frac{\bar{h}_{250u}}{\bar{h}_{250c}} \quad (1)$$

$$h_{500} = 1 - \frac{\bar{h}_{500u}}{\bar{h}_{500c}} \quad (2)$$

where $\bar{h}_{250c}$ is the average of the three cushion thickness measures at 250 N during the loading phase, $\bar{h}_{250u}$ is the average at 250 N during the unloading phase; and $\bar{h}_{500c}$ and $\bar{h}_{500u}$ are the corresponding averages at 500 N.

Graphs of average compressive and unloading thicknesses were also plotted for each cushion as specified by ISO 16840-2:2007.

3. Results

For full details of test report requirements please refer to section 9.3 and 9.4 of ISO 16840-2:2007 [5]. Sample load deflection plots from selected cushions are shown in Figs. 2 and 4. Plots for all 37 cushions are given in Figs. 6 and 7 online. Hysteresis for the full set of 37 cushions at 250 N ranged between 0.041 and 0.371 with a mean value of 0.142 and a mode of 0.099. At 500 N they ranged from 0.023 to 0.223 with a mean of 0.090 and a mode of 0.069. The full set of hysteresis values is given in Table 2.

Standard deviations are also presented in Table 3 to allow examination of test and test lab repeatability. The standard deviation for the three repeated thickness measures ranged from 0 for 75 mm Sunmate at 750 N to 8.59 for the Vicair Adjuster 6 at 8 N in the compression phase.

Table 2
Hysteresis at 250 N and 500 N. Values are the means of three measurements as required by 16840-2:2007.

Cushion	h_{250}	h_{500}
Roho single valve	0.096	0.043
Roho Quadtro	0.090	0.045
Jay J2	0.071	0.047
J2 Deep Contour	0.042	0.023
Jay 3 with Roho	0.086	0.035
Jay Gel	0.084	0.055
Flo-tech Contour	0.090	0.098
Flo-tech Contour Visco	0.180	0.142
Flo-tech Plus	0.050	0.060
Flo-tech Solution	0.058	0.056
Flo-tech Lite	0.096	0.092
Flo-tech Lite Visco	0.216	0.155
Propad	0.287	0.142
Qbitus Mercury 100	0.095	0.066
Qbitus Mercury 200	0.108	0.078
Qbitus Mercury 300	0.099	0.063
Qbitus Qbi-gel	0.068	0.036
Vicair Adjuster 6	0.161	0.082
Vicair Adjuster 10	0.121	0.059
Varilite Evolution	0.274	0.223
50 mm V33 polyether	0.371	0.168
75 mm V33 polyether	0.253	0.121
50 mm CM60	0.091	0.087
75 mm CM60	0.051	0.064
50 mm CM35	0.267	0.121
75 mm CM35	0.215	0.115
50 mm RX39	0.292	0.138
75 mm RX39	0.240	0.142
50 mm Pink viscose	0.282	0.140
75 mm Pink viscose	0.307	0.196
50 mm Sunmate soft	0.078	0.068
75 mm Sunmate soft	0.066	0.058
50 mm 3lb chip	0.099	0.069
50 mm 6lb chip	0.074	0.063
75 mm 6lb chip	0.041	0.027
25 mm Pink viscose+ on 50 mm 3lb chip	0.114	0.066
25 mm Sunmate soft on 25 mm CM35 on 25 mm CM60	0.087	0.088

4. Discussion

ISO 16840-2:2007 states that all the tests it describes are "intended to differentiate performance characteristics between cushions and are not appropriate for ranking or scoring cushions or for directly matching these characteristics with the requirements of individual users". However it is desirable that, if possible, this information be interpretable to inform clinical decision making. The standard does not provide explicit guidance on clinical interpretation, but it does provide a rationale for each test which relates to clinically important properties. The rationale for load deflection and hysteresis suggests that stability, pressure management and shock absorption are areas in which clinical decision making may be assisted by consideration of these data. However the standard also states that, "The link to clinical efficacy, although implied, has not been confirmed". Therefore, the objective of this study is to explore the clinical interpretation of the load deflection and hysteresis test by careful examination of the curves and measurements obtained.

4.1. Load deflection graphs

Visual inspection of the load deflection graphs discloses various forms. Two aspects of the graphs should be considered when reviewing the plots: loading–unloading curve proximity and curve gradient.

4.1.1. Loading–unloading curve proximity

The area between the loading and unloading curves is equal to the average energy absorbed by the cushion during one loading–unloading cycle. A cushion for which the loading and unloading curves approximate will therefore absorb less energy than one for which the loading and unloading curves are far apart. The proximity of the loading and unloading curves is therefore potentially an indication of a clinically interesting property. An example of a cushion exhibiting close proximity is the cushion made from 75 mm thick Sunmate soft (a viscoelastic polyurethane open-cell foam) (Fig. 2a).

The ISO rationale states that this is an indication of a cushion's resilience which "describes how much the cushion tries to return to its undeformed shape" and gives the example, "in the case when a user leans to the side to perform a task, a resilient cushion will facilitate this person in returning to an erect posture". The 75 mm Sunmate cushion therefore shows high resilience and should be expected to be more effective than equivalent but less resilient cushions in returning a user to an erect position after a perturbation. However it should be remembered that this can

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Table 3
Standard deviations of repeated thickness measures (mm) for each cushion under each loading condition. c denotes loading (compression) phase of test, u denotes unloading phase.

Cushion	8 N c	250 N c	500 N c	750 N	500 N u	250 N u	8 N u
Roho single valve	2.29	0.95	0.44	0.29	0.32	0.21	1.49
Roho Quadtro	0.88	0.68	0.31	0.09	0.09	0.09	0.40
Jay J2	2.77	2.04	0.95	0.46	0.40	0.40	0.17
J2 Deep Contour	1.53	0.61	0.31	0.09	0.09	0.12	0.18
Jay 3 with Roho	1.23	0.40	0.17	0.01	0.04	0.09	0.70
Jay Gel	0.44	0.40	0.25	0.06	0.10	0.20	0.25
Flo-tech Contour	0.25	0.36	0.25	0.06	0.15	0.25	0.23
Flo-tech Contour Visco	0.63	0.58	0.32	0.03	0.06	0.39	0.40
Flo-tech Plus	0.74	0.29	0.21	0.03	0.11	0.25	0.40
Flo-tech Solution	0.90	0.31	0.30	0.15	0.20	0.25	0.70
Flo-tech Lite	0.20	0.40	0.25	0.06	0.10	0.20	0.20
Flo-tech Lite Visco	0.42	0.73	0.38	0.14	0.12	0.24	0.22
Propad	0.29	0.70	0.25	0.06	0.06	0.42	0.51
Qbitus Mercury 100	0.32	0.43	0.25	0.01	0.09	0.21	0.13
Qbitus Mercury 200	1.89	0.73	0.45	0.20	0.21	0.17	0.31
Qbitus Mercury 300	0.84	2.63	0.59	0.22	0.29	0.41	0.47
Qbitus Qbi-gel	0.28	0.19	0.05	0.03	0.04	0.07	0.09
Vicair Adjuster 6	8.59	1.68	0.74	0.37	0.39	0.46	2.30
Vicair Adjuster 10	2.25	0.79	0.44	0.29	0.32	0.32	1.63
Varilite Evolution	2.87	2.76	2.45	1.76	1.35	1.31	0.85
50 mm V33 polyether	0.38	0.81	0.28	0.05	0.05	0.12	0.28
75 mm V33 polyether	0.56	1.14	0.60	0.08	0.14	0.44	0.21
50 mm CM60	0.10	0.35	0.15	0.06	0.06	0.20	0.10
75 mm CM60	0.20	0.35	0.40	0.10	0.20	0.35	0.20
50 mm CM35	0.42	0.70	0.11	0.03	0.05	0.16	0.21
75 mm CM35	0.39	0.79	0.17	0.03	0.08	0.35	0.23
50 mm RX39	0.33	0.83	0.21	0.02	0.06	0.17	0.18
75 mm RX39	0.49	1.17	0.89	0.10	0.14	0.44	0.21
50 mm Pink viscose	0.33	0.77	0.35	0.05	0.05	1.01	0.14
75 mm Pink viscose	0.78	1.84	0.97	0.36	0.46	0.66	0.36
50 mm Sunmate soft	0.03	0.08	0.01	0.03	0.06	0.01	0.02
75 mm Sunmate soft	0.17	0.31	0.15	0.00	0.06	0.06	0.06
50 mm 3lb chip	1.01	1.03	0.43	0.11	0.14	1.19	0.53
50 mm 6lb chip	0.58	0.30	0.45	0.18	0.96	0.38	0.66
75 mm 6lb chip	0.58	0.36	0.20	0.10	0.14	0.20	0.22
25 mm Pink viscose on 50 mm 3lb chip	0.25	0.66	0.15	0.15	0.15	0.25	0.21
25 mm Sunmate soft on 25 mm CM35 on 25 mm CM60	0.26	0.46	0.51	0.15	0.20	0.25	0.15

only be confidently stated for homogeneous cushion construction. This is because some cushions are constructed such that the lateral borders have different properties from the central areas and these borders may assist recovery from functional lean. The load deflection test cannot reflect this design feature and so the lateral lean stability properties of a cushion cannot be predicted from this test in all cases. Temperature may also be a factor in the behaviour of cushion materials, for example some viscoelastic foams and viscous fluids. This may mean that behaviour under the conditions required by ISO 16840-2:2007 does not reflect the behaviour under all clinical temperature conditions. Additionally, contoured cushions may react differently because the lateral borders are higher and hence may support postural recovery by providing an additional medially directed force.

It can be seen that, amongst those cushions in the sample which show larger areas between the loading and unloading curves, i.e. marked energy absorption, further differentiation is possible by considering the proximity of the initial thickness value to the final thickness value. Contrasting examples are the Propad (castellated foam) with a near closed hysteresis loop (Fig. 2b), and the Vicair Adjuster 10 (comprising free-moving, individual, air-filled cells contained in compartments) with an open loop (Fig. 2c). The closed loop indicates an absorption of energy but with an ultimate return to full thickness, i.e. the cushion has less ability to react to the compressive force when unloading at certain loads, but the original thickness is ultimately recovered. It would seem reasonable that a cushion with this type of behaviour might offer better repeated absorption of shock energy.

On the other hand, the open loop indicates that, in the time scale of the test, the cushion does not fully recover its shape. This may be because the cushion has remodelled to achieve improved envelopment of the pelvis or indenter, which is clinically significant. The test however does not explicitly measure this envelopment and the same result may also be obtained from a cushion which compresses without showing envelopment. It is acknowledged that this test was not designed to measure envelopment and so it is important that users of the standard do not interpret results in this way.

Caution is required when interpreting these open loop curves however, because the 2007 version of the standard requires that they are plotted from the averages of three cycles, but does not explicitly require resetting of the cushion between tests. This means that cushions which require manual redistribution of materials for continued effectiveness may have given different results on the first cycle compared to subsequent cycles. The Jay J2 cushion (a composite cushion comprising contoured foam with viscous fluid sacks under the pelvis) demonstrates this and Fig. 3 shows each cycle individually plotted. It can be seen that a greater degree of permanent deformation was observed over the first cycle, and means that the averaged plot does not represent the true resilience of the cushion under any defined condition, and hence is not an accurate representation of its behaviour. The authors however understand that the revision of ISO 16840-2 in preparation will address this issue and require cushions to be reset between test repetitions.

It is important to note that for analysis of these graphs it is necessary to assume that the test provides enough time under each loading condition for the cushion to have fully reached its equilibrium state. If this is not the case then time dependent effects may introduce further uncertainty and obstruct meaningful comparison of cushions. The amount of time required for a cushion to achieve

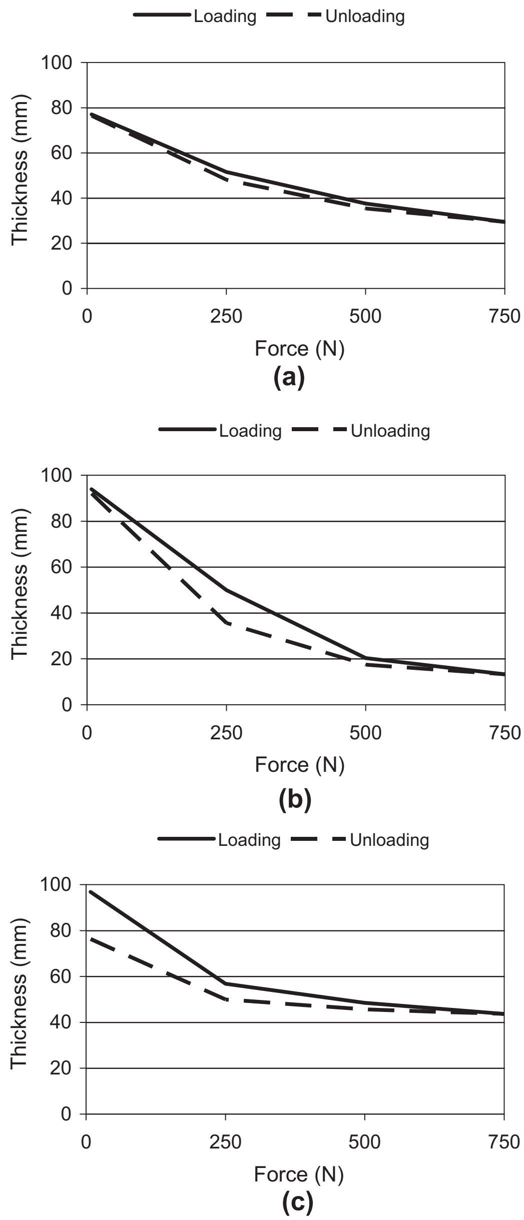

Fig. 2. Load deflection plots (a) 75 mm thick Sunmate soft cushion, (b) Propad, (c) Vicair Adjuster 10. Values are averages of three cycles as required by ISO 16840-2:2007.

its equilibrium state after compression is, of course, dependent on its design and materials of construction.

4.1.2. Curve gradient

The stiffness of a cushion is the force required for compression by a given amount. This means the gradient of the load deflection curve gives an indication of the cushion stiffness. A shallow gradient denotes a stiffer cushion whereas a steeper curve denotes a more compliant one.

This measure can give us some insight into a cushion's ability to contour around the pelvis, i.e. its ability to envelop, because a very stiff cushion will not envelop. This is clinically important because envelopment increases the potential for pressure redistribution by increasing the load bearing area. However this test does not aim to provide a measure of envelopment and it must be remembered that the load deflection curves cannot be interpreted to tell this without additional knowledge about the cushions ability to conform. To illustrate this, consider a set-up constructed from a piece of rigid

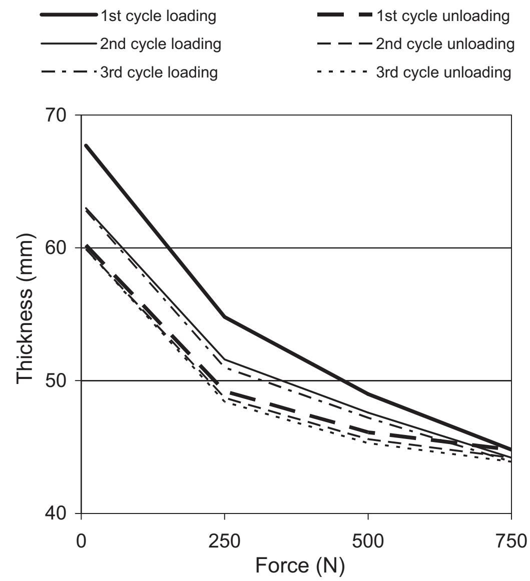

Fig. 3. Individually plotted load deflection cycles for Jay J2 cushion.

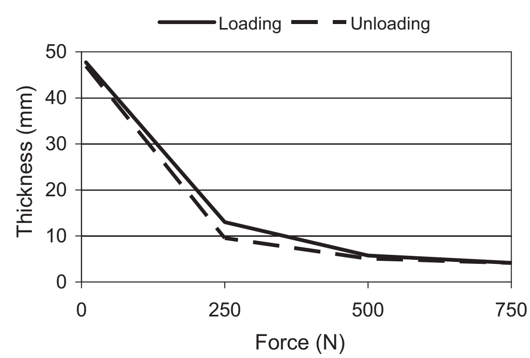

Fig. 4. Load deflection plot for 50 mm thick CM35 foam cushion. Values are averages of three cycles as required by ISO 16840-2:2007.

board on a thick layer of soft foam. This would produce a steep load deflection curve but without any envelopment.

The load deflection gradient does however have the potential to indicate that a cushion is approaching the limit of its compressive range. For example, the gradient of the plot for the 50 mm thick CM35 foam cushion (low density open cell polyurethane foam) diminishes to a very low value at higher loading suggesting that the foam is approaching its maximum compression (Fig. 4). All of the cushions tested exhibit decreasing gradient with increasing load indicating that all cushions reach a maximum compression when loading is sufficiently high. "Bottoming out" is a term used clinically when the load distribution under the pelvis is undesirable, and occurs either at, or prior to the point of maximum compression. It is not however possible to use the graphs to identify a single point at which a cushion will bottom out clinically because it is also dependent on the user–cushion interaction. It is however important to ensure that cushions do not bottom out in use, because this leads to localised areas of high pressure, usually under bony prominences which are vulnerable to pressure ulcers. A cushion such as the 50 mm thick CM35 foam therefore may not be safe to use if loads of around 500 N or more were expected.

4.2. Hysteresis

ISO 16840-2:2007 advises that, "Hysteresis is a measure of the energy lost to the cushion during a cycle of loading and

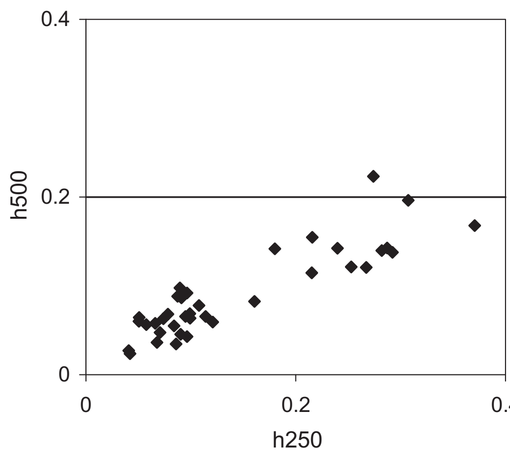

Fig. 5. Plot of h_{250} vs. h_{500} for all cushions.

unloading," and defines it at the two specified loads of 250 N and 500 N using Eqs. (1) and (2). These equations yield a dimensionless number ranging from 0 to 1 and express the difference between the compressive and unloading thicknesses, divided by the compressive thickness at the given load. However, the proximity of the loading–unloading plots is also an indication of the energy absorbed by the cushion. The standard states performance characteristics may be better defined when the test is "performed in a continuous loading and unloading manner". This would indeed be the case because the hysteresis of a cushion could then be calculated by measuring the difference in area below the loading and unloading curves hence giving a true energy value measured in Joules, rather than a hysteresis value at a single load.

Generally we can see hysteresis values are lower at the higher load when the cushions are more compressed. We can also see that all cushions have values within the first 37% of the maximum range at 250 N and 22% at 500 N compression (Fig. 5). It should be remembered however that these hysteresis values only represent the behaviour of the cushion at four instances during the loading/unloading cycle, and the values will be affected by the original thickness of the cushion and whether it is close to its compression limit at the given load. It may be advisable therefore to interpret these values in conjunction with the load deflection graphs so that this additional information can be considered.

ISO 16840-2:2007 states that, "Cushions with larger hysteresis values will tend to absorb energy when used on rough surfaces or when dropping down steps, rather than transfer the impact energy to the user's tissues". A comparison with impact damping tests defined in part 11 of the standard will help inform this statement, and this is a matter for further study. It is however hypothesised that the correlation between this hysteresis test and impact damping will vary depending on the time dependency of the cushion. This is because cushions with a slower recovery time may recover in the hysteresis testing because 120 s is required between measurements; whereas recovery time in impact damping tests is dependent on the rebound reaction after impact.

It is also important to note that some cushions are intended to be adjusted. The Vicair Adjuster, for example, is designed such that cells can be removed or added to the compartments to optimise performance for the user. This process however is likely to change the cushion's thickness and hence the ISO hysteresis values. Variation of test values with cushion set-up is therefore a further factor to be considered before interpreting test results.

A final observation is that ISO 16840-2:2007 does not require testing of multiple samples of the same cushion design. ISO 16840-2:2007 however can be used to investigate variability amongst different samples of the same cushion because it provides a repeatable test method which is evident from the very low standard deviations for some cushions. This is potentially important since variability and inconsistency in manufacturing methods could result in clinically significant differences.

5. Conclusion

This study has acquired data which confirms that the ISO 16840-2:2007 load deflection and hysteresis test achieves its objective of differentiating wheelchair cushion performance. The ISO's rationale for this test however also links it with stability, pressure management, and shock absorption. This study has therefore also examined the potential for the load deflection and hysteresis measures to inform on these clinically relevant features, and has highlighted the following factors pertinent to the interpretation of results.

- The temperature range specified for the test protocol does not represent all of the temperature range expected in clinical use.
- The test does not examine all aspects of cushion design which may affect stability.
- The test does not examine all aspects of cushion design which may affect envelopment.
- The graphs specified for reporting of results are averaged and this may obscure true material behaviour.
- The time scale specified for the test may not be relevant to some aspects of clinical use.
- The mechanical limit of compression inferred from the graphs may not correspond to clinical 'bottoming out'.
- The test results do not represent outcomes for all users or variations in cushions which are intended to be adjusted to the user.
- Variability of cushions may be determined using the standard but is not explicitly required by it.

It must be acknowledged that this test does not set out to examine all of the aspects of cushion behaviour which are relevant to stability, pressure management, and shock absorption, and so it would not be reasonable to expect it to do so. It is also important to remember that the load deflection and hysteresis test is just one of a number of tests described in ISO 16840-2:2007, all of which should be included when evaluating objective cushion data. Nonetheless, it is still important to be aware of the above factors when attempting to interpret these data.

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Ethical approval

Not required.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.medengphy.2013.10.010.

Conflict of interest

None declared.

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