ORIGINAL RESEARCH

Performance Parameters of Support Surfaces: Setting Measuring and Presentation Standards

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Abstract: Different support surfaces are used for the prevention of pressure ulcers. Data on the physical performance of these surfaces are not always available, and if it is, it is not generated in a standardized way. Presentation of the data in different graphic formats is also not standardized, which leads to difficulties for health care providers when comparing the performance characteristics of different support surfaces and choosing which one to use. This article proposes a standard set of performance data and a standardized way to present these data. To illustrate different ways of presentation, a set of tests was executed using polyurethane support surfaces with a wide range of physical properties.

Key words: support surfaces, data presentation, standardization

Pressure ulcers are a serious health and economic concern, having a negative effect on the overall cost of patient care,[1] length of hospital stay,[2] and mortality and morbidity rates,[3] thus reducing quality of life.[4]

A number of internal and external factors contribute to pressure ulcer development.[5] This article focuses on the measurement and presentation of the results of the external physical factors (ie, pressure, friction, shear, temperature, and moisture) that may lead to the development of pressure ulcers, and on how the performance of support surfaces, which are designed to reduce the effect of external physical factors, can, and should, be measured and presented.

Some of the external contributing factors of pressure ulcer development are not commonly quantified, and data on these factors for the different types of support surfaces is scarce, if available at all. Consequently, performance of these support surfaces is difficult to evaluate and compare. Data on pressure management and redistribution are more commonly available for different surfaces. However, the graphical presentation of these data is not standardized, which makes it difficult to compare data sets for different surfaces.

While guidelines are available with regard to what category of surface should be used for which type of patient and which anatomical location,[6-11] making a data-based decision on the type of surface to use within a specifically recommended group (ie, polyurethane foam, low air loss, etc) is virtually impossible for the reasons noted.

The Support Surface Standards Initiative (S3I) was founded in 2001 to fill the need for performance and reporting standards.[12] The S3I is designated by the Rehabilitation Engineering and Assistive Technology Society of North America's Assistive Technology Standards Board as the designated standards committee responsible for producing standard test methodologies for support surfaces in the United States. In 2007, S3I published a document of terms and definitions related to support surfaces, which now are generally accepted by the industry.[13] The S3I is currently working on standardization of performance testing and reporting.

The authors recommend that, in line with the S3I effort, a standard series of data should be generated for each category of support surface and published in a standardized way; this will make it significantly easier for the health care provider to compare the performance of different support surfaces and to make an informed choice about which surfaces to use for which type of patient.

To demonstrate how graphics may be used to assist in making a data-based informed choice, a series of comparative tests[14-16] were executed. They compare the performance of a series of polyurethane foam surfaces (standard) with the performance of a polyurethane foam surface made through a different manufacturing process (test surface). These comparisons were chosen since the different manufacturing processes generate surfaces with a wide range of physical properties, thus making the differences in the illustrations more distinct. Brand names were left of the graphic representations used for comparison.

Material and Methods

A commercially available pressure mapping system was used (XSENSOR Technology Corp, Calgary, Alberta, Canada) to analyze the performance of each support surface. The system is positioned between the body and the support surface, has a mapping rate of 600 frames per minute, and presents the average of its measurements. Measurements were performed during 3-minute test intervals for each subject and each type of surface. Subsequently, data for each measurement for each surface were averaged. Calculations were made using Microsoft Excel 2010 or Access 2010 software (Microsoft Corporation, Redmond, WA).

Since healthy volunteers were used, no International Review Board approval was required. Both female and male volunteers were recruited in order to test different body shapes. The support surfaces used for the tests were all passive, polyurethane-based mattresses, but with a wide range of different physical properties such as foam density, indentation force deflection, the level of reticulation, and other parameters.

Pressure. Pressure is the exertion of force upon a surface by an object and, scientifically, should be expressed using the Système Internationale (SI) designation, Pascal (Pa). However, since Pascal is rarely used in the medical world, the more common entity, mmHg per surface unit (in^2 or cm^2) is used throughout this article.

If and when pressure remains below a certain threshold for a specific anatomical location, the chances of the development of a pressure ulcer diminish, essentially because the circulation at the locale remains sufficient. Bogie et al[17,18] suggested a threshold value of $TcPO_2$ of 30 mmHg and a value of $TcPCO_2$ of 44 mmHg. The risk for tissue damage is significantly higher when pressure falls below or above these threshold values. Bogie and colleagues' studies were done in patients with spinal cord injuries, and pressure was measured at the sacral area. Other anatomical areas or different types of diseases may lead to different values; the pressure-duration threshold for the occurrence of pressure ulcers is lowered dramatically when physiological changes in soft tissue occur, as is the case in paraplegia, infection, or repeated trauma.[19] Threshold values also change when other forces, such as shear, are simultaneously at work.[20,21]

In addition to the influence of pressure on the perfusion threshold, recent models also have demonstrated the role of ischemia and reperfusion in the development of pressure ulcers.[22,23] Normal, healthy tissue has been shown to be far more resistant to pressure-induced ischemia than previously considered.[24] Still, the previously mentioned reference values give a good indication of risk to perfusion in general, although it is acknowledged that, because of the other factors contributing to pressure ulcer development, no absolute quantification of the predictive or prognostic value of interface pressure can be given.[25] Although not linear, there is also a relationship between the amount of pressure and the duration of pressure exposure.[26,27]

Pressure mapping is used as a way of demonstrating the pressure distribution over part of the body, and a colored graphic representation is used to demonstrate differences of pressure on the body's surface. Different types of transducers, each with unique advantages and disadvantages, may be used; but with all systems, a thin surface containing a number of transducers is inserted between the patient and the support surface. A series of measurements is performed, and a computer compiles the data and presents them as a graph, usually a multicolored chart where different colors represent various levels of pressure.

Very few data are available on reproducibility, consistent accuracy, and stability of data generation within 1 system of data collection, and few tests comparing different systems have been published. One article describes 3 pressure mapping systems tested with patients with spinal cord injuries who are dependent upon wheel chairs, with a contoured loader gauge. The study concluded that, among the systems tested, there were substantially different levels of hysteresis, accuracy, and stability.[28] Similar conclusions were drawn in a second, similar test.[29] In contrast, another article describing the testing of 3 pressure mapping systems with healthy volunteers found that a frequency analysis approach enables more adequate and precise ways to perform such studies, with a higher level of consistency between the systems.[30]

Figure 1. Heel pressure on 9 adjacent locations on the heel of a male on a polyurethane support surface.

	1	2	3
A	0 Δ1=B2-A1	16.68 mmHg Δ2=B2-A2	0 Δ3=B2-A3
B	20.76 mmHg HgΔ4=B2=B1	56.62 mmHg	9.68 mmHg Δ5=B2-B3
C	0 Δ6=B2-C1	11.48 mmHg Δ7=B2=C2	0 Δ8=B2-C3

Δ: Difference between maximum pressure point and surrounding areas.
Highest pressure value: B2
Largest pressure difference: Δ = B2-A1
Average pressure difference: $\text{Avg. } \Delta = \frac{\Delta 1+\Delta 2+\Delta 3+\Delta 4+\Delta 5+\Delta 6+\Delta 7+\Delta 8}{8}$

Commonly in pressure mapping, only average pressure readings are presented when commercially available surfaces are compared, as a way to show low-pressure values and efficient pressure redistribution. However, peak pressures are the more important measurements for indicating a potential risk for pressure ulcer development. When just 1 of 10 measurement areas show 60 mmHg/cm^2, and the other 9 show, for example, 25 mmHg/cm^2, the average pressure is 28.5 mmHg/cm^2 ([9*25+60]/10); but the chances for the development of a pressure ulcer are high, specifically in the 60 mmHg area.

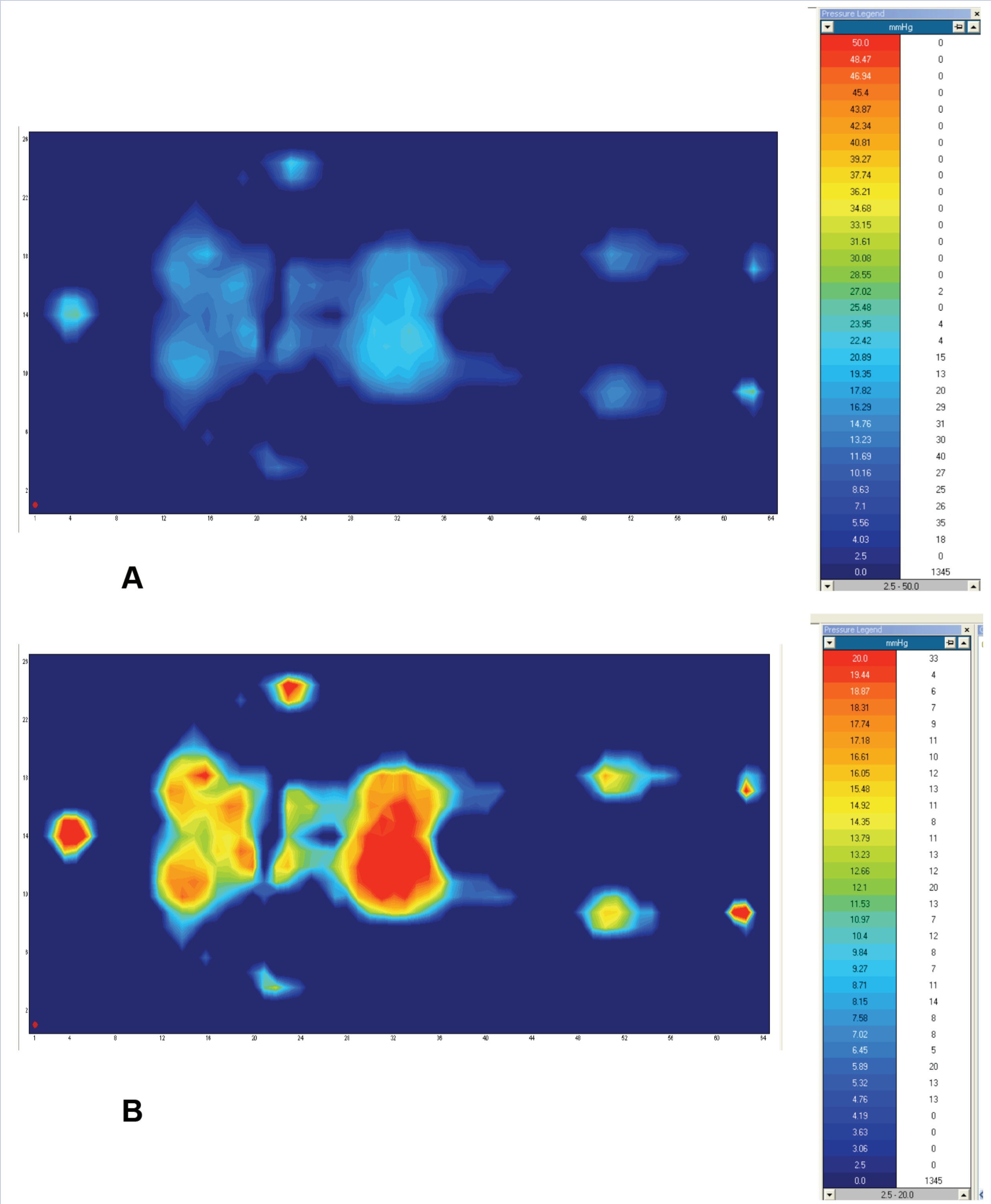
Envelopment. The level of envelopment depends on the ability of a support surface to conform and mold around the body, preferably without substantial increases in local (ie, small area) pressure. A high level of envelopment allows for a larger contact surface over which the entire weight of a given body is distributed and is expressed as cm^2 or in^2. The larger the surface over which weight is distributed, the lower the average pressure on individual anatomical areas, and the higher the level of comfort. At the same time, a high level of envelopment *per se,* does not necessarily guarantee avoiding high areas of peak pressures.

Friction and shear. Friction is a force on objects or substances in contact with each other that resists motion of the objects or substances relative to each other. The friction coefficient is symbolized by the SI by the letter μ, a dimensionless value describing the ratio of the force of friction between 2 bodies and the force pressing them together. When surfaces in contact move relative to each other, the friction between the 2 surfaces converts kinetic energy into heat.

Shear is the deformation of a body in which a plane in the body is displaced parallel to itself relative to parallel planes in the body. Friction is still considered by many as a force that contributes to pressure ulcer development by itself. However, if a body or body part is not moving, it is the static friction that prevents it from moving: only pressure, combined with temperature and moisture, may lead to pressure ulcer formation. Once moving occurs it is unlikely that the entire moving surface (ie, skin, subcutaneous fat, muscle) moves in exactly the same direction and/or at the same time, and/or with the same force. Consequently, the shear forces, rather than friction *per se*, are responsible for the development of pressure ulcers. Shear results in capillary destruction, and tissue death follows the same pathway as with pressure alone. However, in contrast to pure pressure, the influence of shear is not related to time.[20,31]

Shear forces are greater when the pressure on one area is significantly larger than the pressure on the adjacent areas, as is the case in convex anatomical regions such as the occiput and the heels. To determine the shear forces on such areas, the maximum pressure point is measured and its difference with the surrounding areas is calculated and expressed as Δ (Figure 1)(H.E. Hermans, MD, unpublished data, 2012).[14] A high Δ value indicates a high shear force.

Bulk modulus and sliding resistance are other ways of measuring shear forces. To take the measurement, a standard weight with a standard contact surface is pulled over a pressure redistribution surface. The amount of



Figures 2a and 2b. Illustration of the importance of a standardized graphical data presentation. A single set of pressure mapping data was used. However, for the figures, different scaling of the color legend (right) was used, resulting in seemingly different performance of pressure distribution (measurements in mmHg/inch^2).

force necessary to start the weight moving and the amount of force, once the surface moves, to continue its movement, is measured against the amount of displacement. Lower values indicate lower forces and better performance. Peak forces can be measured and the total amount of force (expressed in Newton according to SI, and by pound force in the United States) can be calculated using specific equations.

Temperature. Elevated skin temperature, formally expressed as degrees Kelvin (K) according to the SI, contributes to the development of pressure ulcers.[32,33] Body heat becomes trapped when a patient is in a supine position. An increase in skin temperature increases metabolism and, in tissue under pressure, the perfusion may fail relative to the demand, which increases the possibility of skin breakdown.

Conversely, mild skin cooling appears to result in some protection, and a lower skin temperature by itself indicates a reduced chance of pressure ulcer development.[34] A literature review, expanded with additional research, indicated that a 5°C reduction in skin temperature would have an effect similar to that of the differences in sacral interface pressure measured between some of the least expensive and most expensive support surfaces available.[35] In patients with spinal cord injuries it was shown that the reactive hyperemic response (ie, a physiological reaction after a period of ischemia) was significantly lower with cooling, indicating lower temperatures have a protective effect.[36] Results of a different experiment in volunteers demonstrated the link between pressure, temperature, and ischemia.[37]

Heat flux (expressed in units of W/m^2) is a precise, high-resolution metric for characterizing the dry and wet heat loss mechanisms for any support surface. Heat flux can be used to predict the effective skin cooling expected for a given support surface as well as the moisture removal rate (expressed in g/m^2/hr).[38] The effectiveness and predictive capabilities of heat flux measurements are firmly grounded in the laws of thermodynamics and have been used successfully for physiological predictions for more than 50 years. Generally, the higher the heat flux, the cooler and more permeable a support surface is to

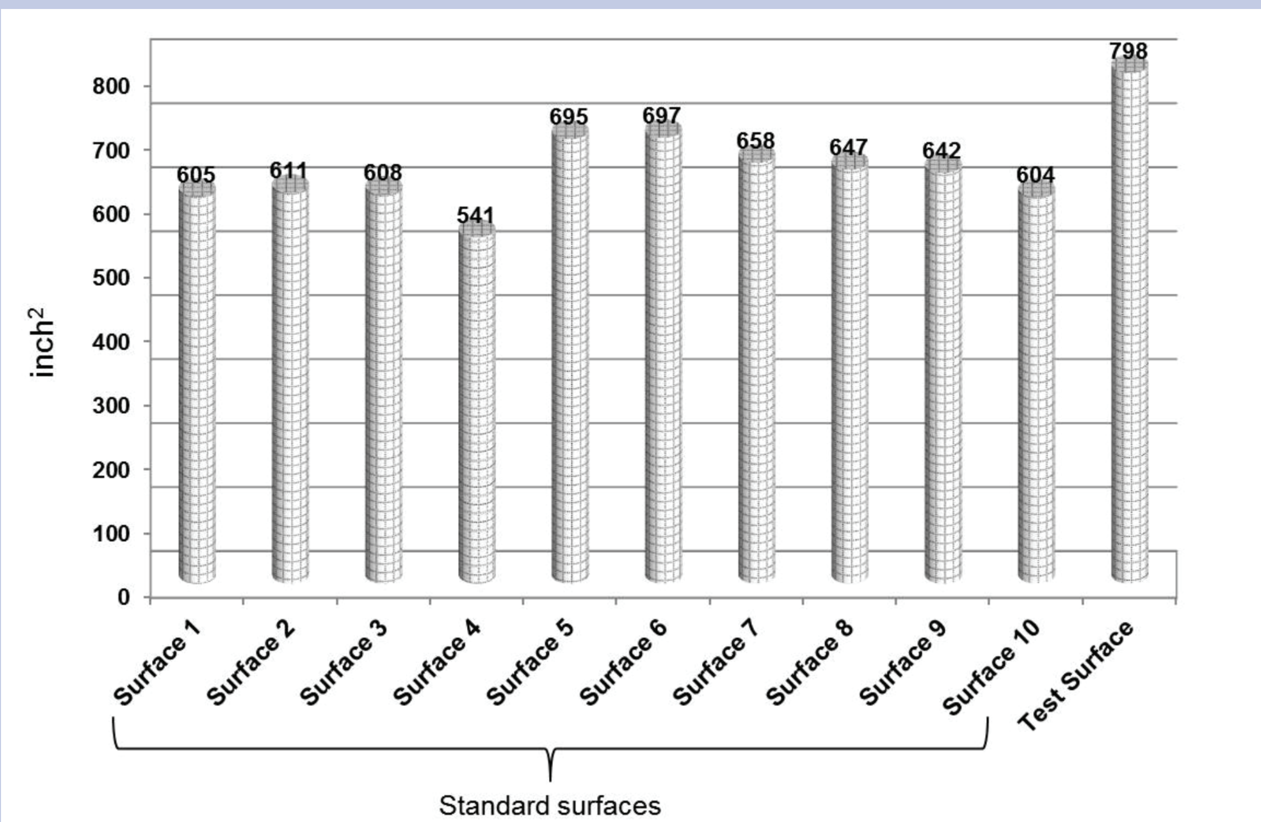


Figure 3. Envelopment differences. Illustration of how some data is best presented in a bar chart.

moisture. Given the well-established role of temperature and moisture, data on this metric should be generated and published.

Results

Data itself, as well as the way it is presented, can be manipulated to suggest optimal results. One of the ways to present data clearly is by using a standard set of parameters and, on the presenting charts, showing the parameters and measured values on all axes. Pressure mapping results are a good way to illustrate how data presentation can be used to create different impressions. Figures 2A and 2B show the results of a single set of pressure mapping data. However, different scaling of the color legend was used, resulting in seemingly different performances: the blue/yellow colors in Figure 2A suggest lower pressures than the yellow/red colors in Figure 2B. Only when the axis values and scaling are taken into account does it become clear that both representations in fact show the same pressure results.

As noted in other findings (H. E. Hermans, MD, unpublished data, 2012), average and peak pressure,[16] as well as envelopment data (Figure 3),[15] are best presented as bar charts: the height of the individual bars allows for a quick and easy comparison of performance data. Differences in shear force data, expressed as Δ (Figure 1), are also well-presented in a bar chart. The authors believe data representation is easier to interpret in a bar chart (Figure 4) than in a grid (Figure 1).

Different types of data can also be combined into 1 chart, giving a better impression of overall performance. The radar, or star chart, consists of a sequence of equi-angular spokes, where each spoke represents 1 variable. The length of an individual spoke is proportional to the magnitude of the variable for the data point relative to the maximum magnitude of the variable across all data points. A line connects data values for each spoke. It is a useful way to display multivariate observations, relative overall performance (total surface of the plot), as well as outliers as illustrated in Figure 5 (Δ values [shear forces] of a standard surface vs a test surface on 3 different anatomical locations).

Different data sets can also be combined in other kinds of graphs, allowing for a more comprehensive,

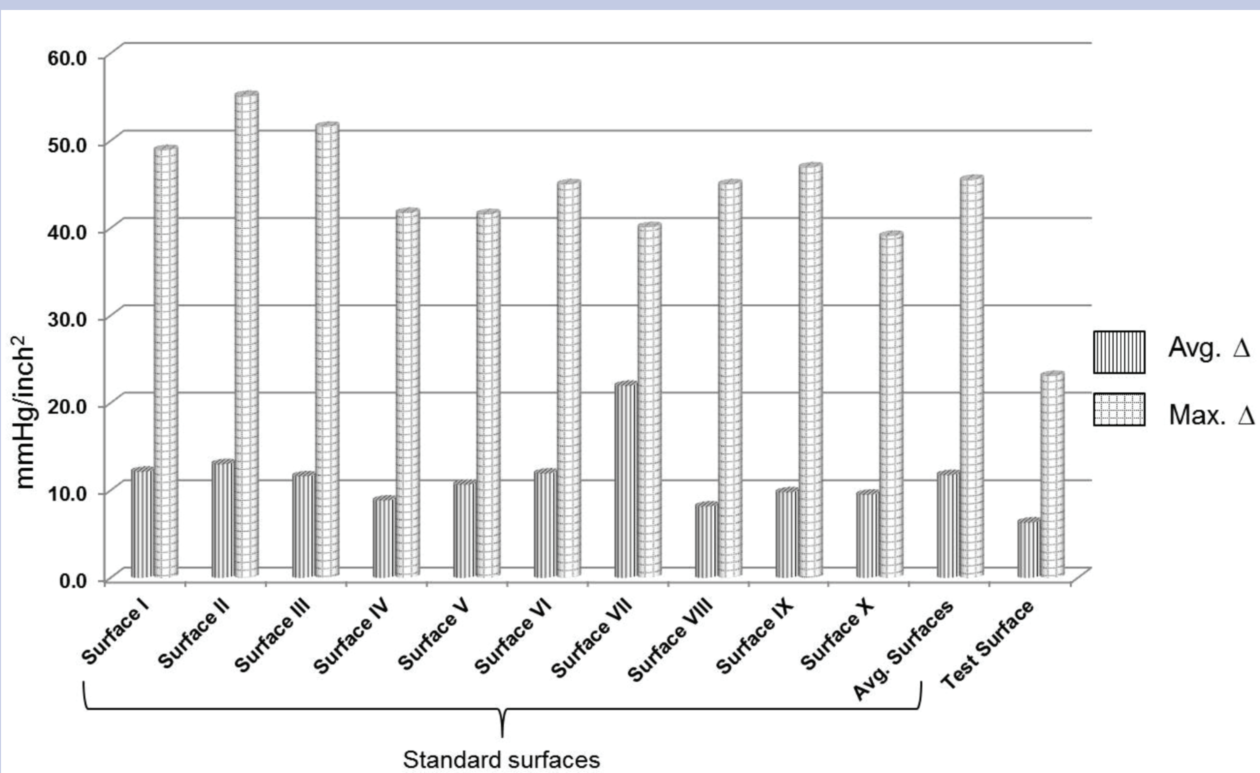


Figure 4. Average and maximum Δ, heels. Illustration of how presentation of data as a bar chart can be easier to interpret than as a grid (Figure 1).

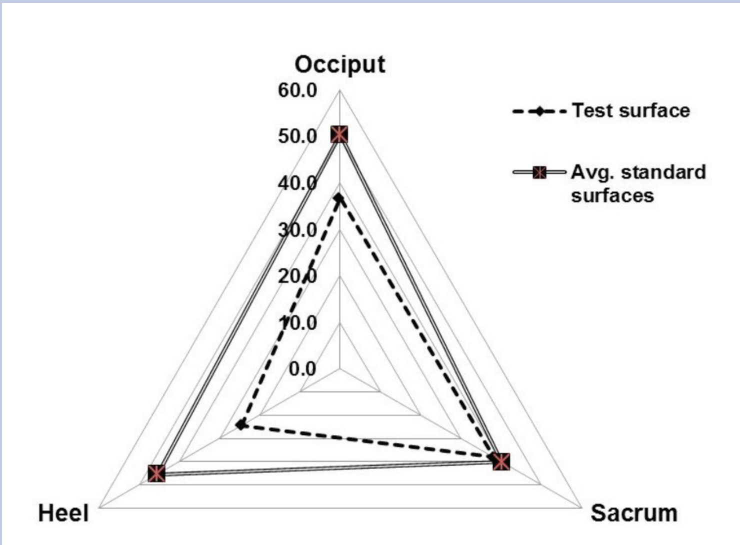


Figure 5. Radar chart. Indicates maximum Δ value (mmHg/inch^2) for 3 different anatomical locations.

but still easily understood, performance comparison. Given the importance of shear, pressure *per se*, and envelopment, a new way of analyzing these 3 components, the Pressure Redistribution Quotient, is proposed: data for all 3 elements are plotted in 1 graph, where the x-axis represents the peak pressure, the y-axis the level of envelopment, and the size of a plotted dot the shear pressure (Figure 6). The coordinates on the graph immediately indicate the different properties of a surface (closer to the left and higher is superior) and this type of performance presentation allows for a better comparison of different types of support surfaces and, consequently, for a scientific, data-based decision on the choice of a support surface.

Discussion

Several guidelines exist to analyze the chances for the development of pressure ulcers on patients. Based on risk factors, the guidelines then recommend a specific category of support surface be used. The choice of surfaces (eg, polyurethane foam or low air loss) is extensive and performance differences may vary widely among surfaces that may appear similar. It is, therefore, crucial for health care providers to make an informed choice; but this has proved difficult, given information on performance parameters is sometimes confusing or incomplete.

In the opinion of the authors, a standard series of parameters should be made available for all support surfaces. This series should include pressure-mapping data for both average as well as maximum pressure. Metrics on envelopment, another determinant of pressure redistribution, should also be made available, as should data on shear, using the previously mentioned Δ calculations.

In addition, data on bulk modulus, sliding resistance, moisture management, and heat flux ought to be measured and made available. This information should be generated in a standardized and validated way.

It is also necessary to develop systems that allow for objective comparison of different measurement techniques for the different performance parameters. Thus, sensitivity, specificity, and reproducibility of the different systems have to be analyzed, and for each type of measurement system, a standard has to be developed against which support surface properties are tested.

All data should be presented in an easily understood way, with standardized and identifiable scaling—particularly important for pressure mapping—and with clearly indicated x-axis and y-axis values. The combination of different types of performance data allows for a comparison on a broader scale: for that purpose, presentation techniques such as a radar chart (Figure 5) or a bubble chart (Figure 6) are very useful.

Conclusion

Generation of relevant data and presenting those data in easily comparable charts will enable the health care provider to make a better-informed choice of superior support surfaces which, in the end, will help reduce the number of pressure ulcers.

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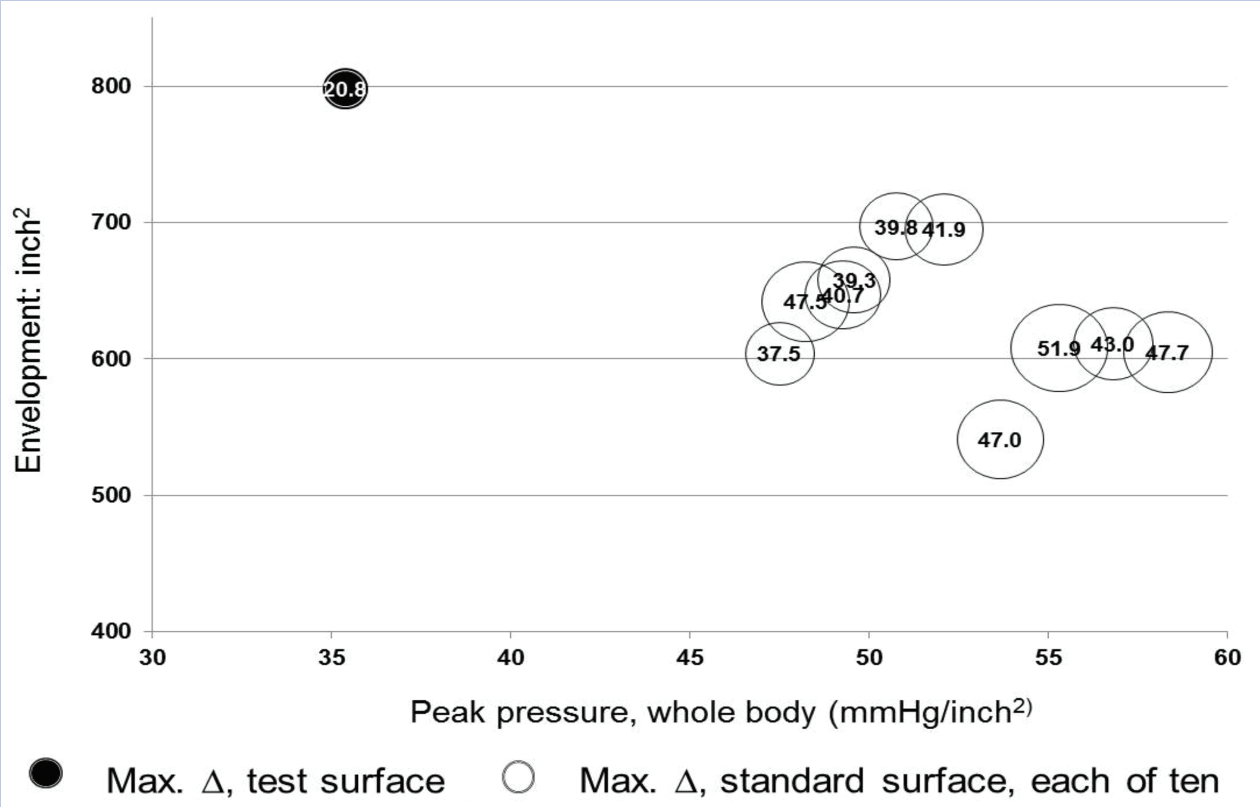

Figure 6. Bubble chart. Pressure redistribution quotient: envelopment vs maximum pressure vs maximum Δ.

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