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Evaluation of cushions using dynamic pressure measurement

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Abstract
Reduction of pressures generated in the tissues overlying the ischial tuberosities is an important measure for predicting a cushion's effectiveness. In particular, the pressure-time relationship is significant in the prevention of pressure sores. In this study a dynamic pressure monitoring system was used to obtain pressure-time profiles for 25 spinal cord injured subjects. Each subject tested three types of cushion (Foam, Gel (Aberdeen) and Roho) for periods of two hours each during which routine activities were performed. Results obtained were broadly comparable with previous studies. Average pressures were: Foam 87.6mmHg (11.6kPa); Gel 68.6mmHg (9kPa) and Roho 54.6mmHg (6.7kPa). Pressure-time histograms are presented for three subjects for each cushion. These show inter-subject variability on the same cushion as well as intra-subject variability on different cushions. Therefore individual patient assessment is important in providing the most appropriate cushion. Dynamic pressure monitoring allows the pattern of pressure variation to be determined and hence the potential effectiveness of the cushion.

Introduction
When a person sits, the highest pressures are generated in the tissues overlying the ischial tuberosities (Fig. 1). This pressure is dependent on the bony configuration, the depth of the soft tissues and the support surface or cushion on which that individual sits. Numerous cushions (Fig. 2) are available which are made from different materials such as foams or gels, or may be filled with water or air (flotation). Some of these cushions have composite structures combining more than one of these basic materials. All of the cushions are designed to reduce pressure beneath the ischial tuberosities. The materials and geometry of a cushion are important variables that affect its ability to distribute pressure. Usually an estimate of this pressure is made by taking a single static reading with a pressure transducer placed between the tissues (overlying the bony prominence) and the support surface. This pressure reading is then used as a guideline to predict the effectiveness of the cushion for a given point.

Pressure alone cannot cause a sore and it has been known for many years that it is the pressure-

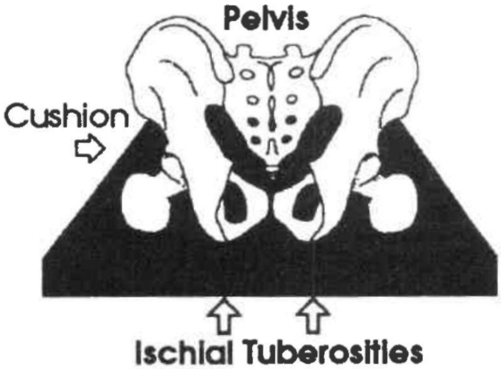

Fig. 1. Ischial tuberosities.

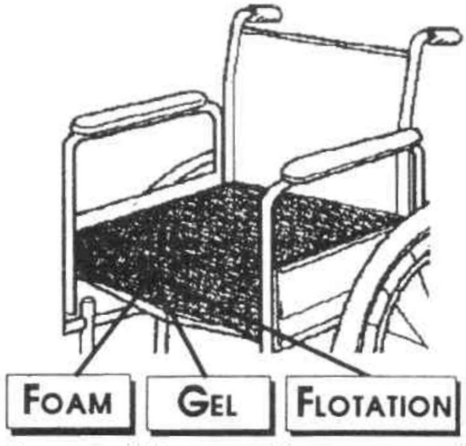

Fig. 2. The wheelchair cushion.

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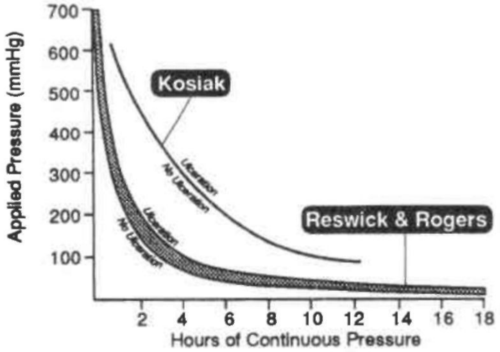

Fig. 3. Tissue tolerance guidelines (Reswick and Rogers, 1976; Kosiak, 1959).

time relationship that is of fundamental importance. Many studies have investigated the relationship between the level and duration of static pressure required to initiate pathological changes in animals (Brooks and Duncan, 1940; Groth 1942; Husain, 1953; Kosiak, 1959 and 1961; Lindan, 1961 and 1965; Dinsdale, 1973 and 1974; Daniel, 1981).

In the classic study of Kosiak (1959) an inverse relationship was shown to exist between the amount and duration of pressure required to render pathological changes in tissues. Reswick and Rogers (1976) have accumulated data from actual patient experience which confirms the shape of the curve produced by Kosiak but has a different gradient (Fig. 3). These experimental data have been useful in classifying the general form of the pressure-time relationship for a damage threshold (Fig. 4). However, the problem of using this relationship as a guideline for cushion prescription is that it ignores the variability of pressure that can occur over a period of time. Evidence for the presence of large numbers of movements in wheelchair-bound individuals has been reported in studies of the movement of the centre of gravity (Bardsley, 1977), wheelchair patient activity (Davies, 1978) and pressure relief patterns (Patterson and Fisher, 1980). This is particularly important when prescribing a cushion. The ability of a cushion to dampen movement and distribute the pressures generated can only be assessed accurately with dynamic measurement and the true effects of pressure beneath the ischial tuberosities can only be understood if the pressure-time distribution is investigated over a period sufficient to allow patterns of pressure variability to be established for a given support surface.

Method and materials

A portable battery operated dynamic monitoring system employing two electro-pneumatic type sensors (28mm in diameter) was developed for measuring simultaneously pressures beneath both ischial tuberosities (Bar, 1988). This system had a constant sampling rate of 10Hz for each channel. The dynamic pressure signal was analyzed on the basis of a cumulative frequency distribution represented graphically as a histogram (Fig. 4b). This enabled the large masses of pressure data collected to be described with little loss of significant information. The pressure-time curve (Fig. 4a) was divided into 6 class intervals of 30mmHg width based on the fact that 30mmHg (4kPa) represents capillary pressure (Landis, 1929), 60mmHg (8kPa) is a frequently used threshold for pressure ischaemia and 120/90mmHg (16/12kPa) represents systolic/diastolic pressures. The histogram was constructed by counting the number of times an observation fell or was distributed into each class (e.g. T1+T2+T3 . . . in the 30-60 interval) as illustrated in Fig. 4a.

Some 25 active Spinal Cord Injured subjects were selected for this study (17 paraplegics and 8 quadriplegics). Pressures were monitored simultaneously beneath both ischial tuberosities for a period of 2 hours. Subjects were free to wheel and move about in the test wheelchair during this period. No restriction was placed on pushup or other pressure relief behaviour.

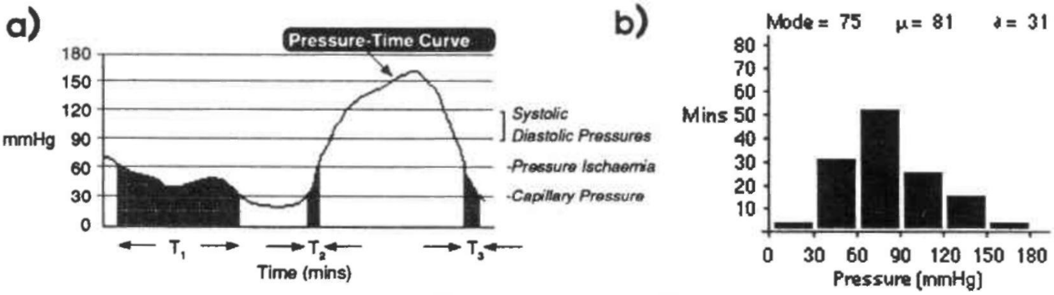

Fig. 4. The pressure histogram. For each pressure histogram the mode, the mean (μ) and the standard deviation (δ) were calculated. These parameters, together with the direction of skew, allow an estimation of the ability of the cushion to dampen movement, equalise and minimise pressures. Differences between left and right side histograms indicate posture.

Three cushions based on foam, gel and air-filled mediums were used in this study as follows:

Foam with vinyl cover

This cushion comprises a 100mm (4″) thick polyurethane foam inner with a vinyl cover. The density of the foam is $96 kg/m^3$ (6lb/cu.ft) (Fig. 5a).

Aberdeen Gel Cushion

A gel inner, enveloped in a vinyl cover, is contained within a foam border which is also covered in vinyl. The gel inner is 50mm (2″) thick and the foam surround is 25mm (1″) thick (Fig. 5b).

The Roho

Multiple inter-connected air-filled tufts form the basis of the Roho cushion. The inflation pressure is adjusted for each individual via an air inlet (Fig. 5c).

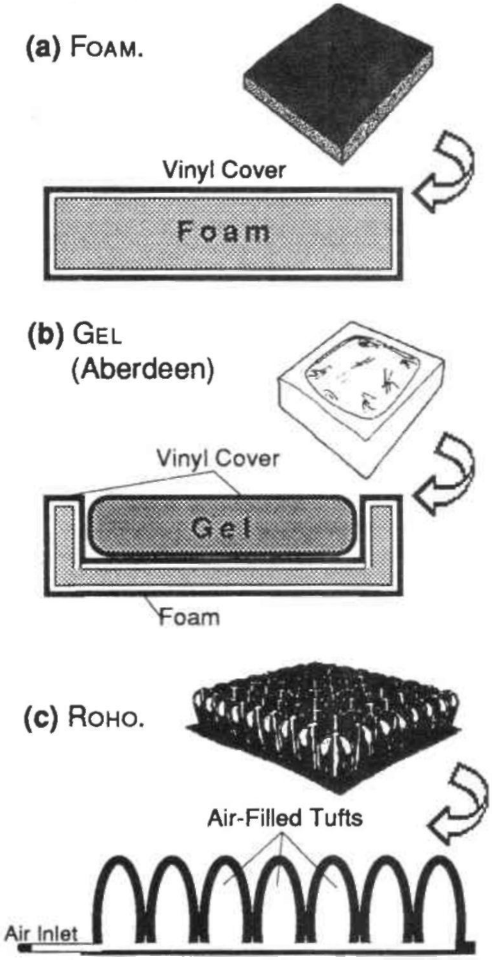

Fig. 5. Cross-sectional view of test cushions.

Fig. 6. Repositioning.

Results and discussion

Movement

Pressures generated at the interface were dependent on the complex interaction of three factors namely: bodily movements, the type of cushion and wheelchair motions. Common characteristics appeared in the pressure-time traces obtained from all the cushions tested and it was possible to isolate a number of features related to these three factors.

Postural changes or repositioning were characterized by significant changes in pressure lasting longer than a few minutes (macro-movements). In this study both tetraplegic subjects as well as paraplegic subjects were observed to adopt a number of different positions in the wheelchair such as hooking an arm behind the backrest handle of the wheelchair (Fig. 6).

Changes in pressure generally of a few seconds duration were frequently identified in the pressure-time records and were classed as micro-movements. These changes were probably a result of variations in trunk position. All pressure traces contained spikes of pressure of short duration i.e. ≤ 5 seconds (short transients). These spikes were of varying amplitude ranging from a few mmHg to changes approaching 200mmHg (26.6kPa) and were the result of upper limb movements, fast trunk movements and wheelchair motions. Frequencies up to 1Hz were recorded for the fastest bodily movements tested which included playing table-tennis, computer games (with a joy-stick on the lap) and propulsion of a wheelchair.

The effects of wheelchair motions were found to be relatively minor for a given cushion compared to the effects of bodily movements. Either micro-movements or short transients could be superimposed on macro-movements. In other words, a change of posture could occur, represented by a large shift in pressure distribution, followed by the presence of small pressure oscillations indicating further small trunk or limb movements or wheelchair movements.

Cushions

Pressures varying between 50 and 150mmHg (6.7kPa–20kPa) were recorded on the three types of cushions tested in this study which is consistent with the results of previous pressure studies on cushions when allowances are made for differences in measurement technique including the fact that all previous studies have measured pressure statically (Houle, 1969; Mooney *et al.*, 1971; Cochran, 1973; Souther, 1974; Palmieri, 1980; Garber *et al.*, 1978; Krouskop *et al.*, 1986). Unfortunately achieving interface pressures less than capillary pressures appears difficult from the practical point of view and, although there have been many attempts at cushion design, no cushion has been found to keep pressures below capillary pressures at all points.

In this study, the characteristics of the cushions were found to influence the interface pressures. Their effectiveness depended on their ability to distribute pressure and reduce peaks caused by movements so that average pressure over time was minimized. The differences between these cushions just reached statistical significance across the subject group ($p<0.1$). The mean pressures recorded for the subject group on each cushion were: Foam=87.6mmHg (11.6kPa); Gel=68.6mmHg (9kPa); Roho=50.6mmHg (6.7kPa).

The pressure distributions recorded for the individual subjects depended on the cushions on which they were obtained. Three examples are given (Figs. 7, 8 and 9) that illustrate the variability of pressure that can occur with time for a given subject as well as between subjects on different cushions.

Subject 1: A foam cushion could be potentially hazardous because this subject demonstrated a tendency to sit with high pressures under one buttock. Since foam is not a fluid material this pressure difference was not accommodated. This pressure difference improved on the Gel cushion, but still tended to be high (105mmHg or 14kPa) under the left buttock. On the Roho the pressures under the left and right buttocks were equalised and reduced to near capillary levels.

Subject 2: On all three cushions, pressure was distributed approximately equally between buttocks but tended to be high on foam. Both the Gel and Roho cushions produced acceptable pressures.

Subject 3: Acceptable pressures were obtained on all cushions for this subject with similar distributions of pressure for all cushions. For such a person, the need for a special cushion is not vital and a standard 100mm (4″) foam would be acceptable in terms of pressure. It is of interest to note that, at the time of testing, this subject had retained much of his muscle bulk and tone in the buttock and posterior thigh regions which provided a relatively well padded sitting area compared to many disabled persons.

For all subjects the pressure histograms for Foam and Gel tended to be broad and flat (Fig. 10). An explanation for these shapes may, in part, be obtained by reference to the nature of the damping effects of each type of cushion. Similar damping ratios for Foam and Gel type cushions have been demonstrated by Cochran and Palmieri (1980) using a flat indenter in "bench tests". This finding reinforces observations made in the present study. It was apparent from an inspection of the pressure-time traces that transient pressures of short duration occurred more frequently on the Foam and Gel cushions than on the Roho. Relatively small changes in position could produce large changes in pressure and possible "bottoming-out" on Foam. The same picture was not always true of Gel: the temperature of the Gel, the subject's anatomical shape and the rate of change of movement all appeared to affect the degree of damping afforded by the Gel. With regard to movement, rapid changes (short transients) tended to generate high pressure spikes but slower motions could be absorbed to some extend by the "flow" of the Gel. If the supporting Gel medium was allowed to flow freely it would, according to the laws of fluid dynamics, distribute pressure evenly throughout the entire supporting medium. However, the cover enveloping the Gel limits flow owing to its elastic limits i.e. surface tension. This means that ideal pressure distributions are in fact difficult to achieve on Gel type cushions and explains why dynamic pressures are not easily dampened resulting in broad frequency distributions for this type of cushion. It is of interest to note that high static pressure readings on Gel type cushions ranging from averages of 70 to 95mmHg (9.3–12.7kPa) have also been the surprising finding of several other authors (Mooney *et al.*, 1971; Souther *et al.*, 1974;

Palmieri *et al.*, 1980). These figures compare favourably to the mean pressures obtained for the Gel cushion in this study i.e. 69±18mmHg (9.2±2.4kPa).

The Roho was more efficient at permitting movement and distributing pressure than either the Foam or Gel cushions. The distribution of pressure on the Roho was approximately symmetrical for left and right sides for all subjects. In addition pressures were contained in the lower

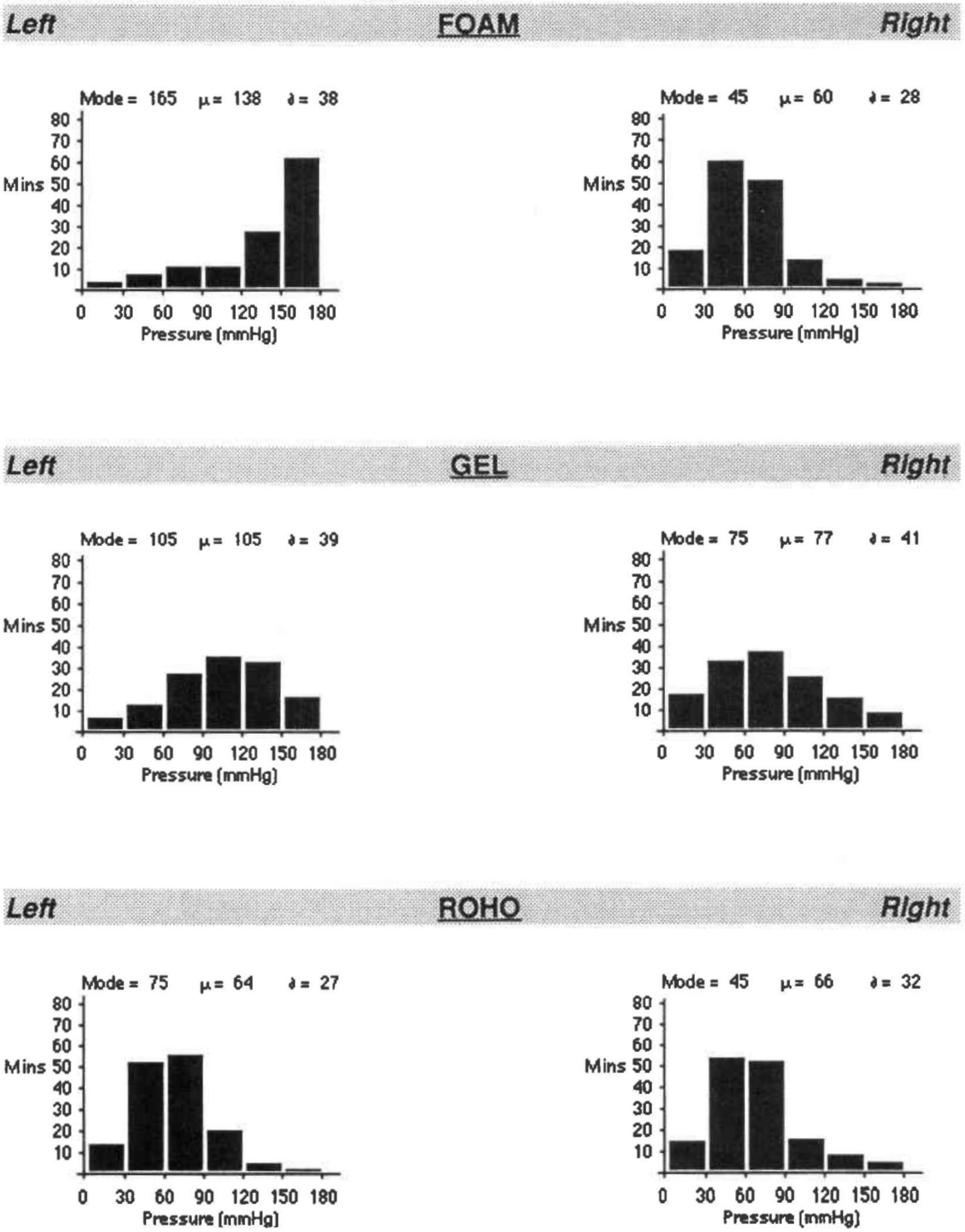

Fig. 7. Subject No. 1 — Tetraplegic (C2). Sex: Male — 36 years. History of sores: None. Push-ups: Yes.

class intervals of the pressure histograms with the result that narrower distributions were obtained for the Roho. Fisher and Kosiak (1979) have reported static pressures on the Roho when tested on twelve able-bodied individuals to be in the range of 53 to 55mmHg (7.0–7.3kPa) which agrees closely with the mean pressure of 51±10mmHg (6.8±1.3kPa) obtained in this study. However, these authors compared a 100mm (4″) Foam cushion to the Roho and could

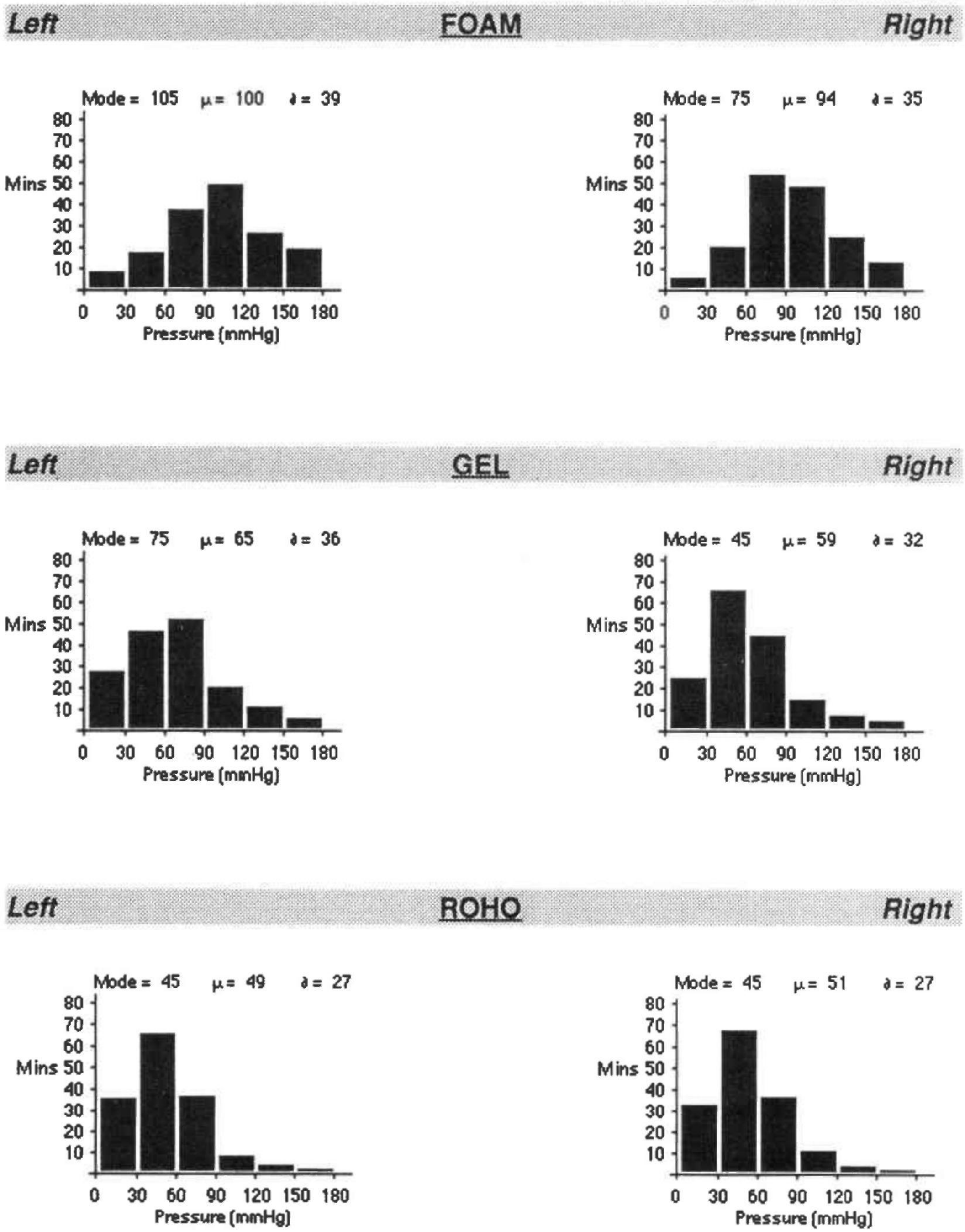

Fig. 8. Subject No. 2 – Tetraplegic (T3/T4). Sex: Male – 34 years. History of sores: None. Push-ups: Yes.

find no statistical difference between static pressure readings for the same subjects. There may be two reasons for this finding. Firstly static readings were made which, according to the results of this study, may not give an accurate assessment of the interface relationship for a wheelchair-bound person. Secondly, the authors used able-bodied subjects who may not provide realistic interface pressures owing to the muscle tone and bulk in the buttocks region. In this study

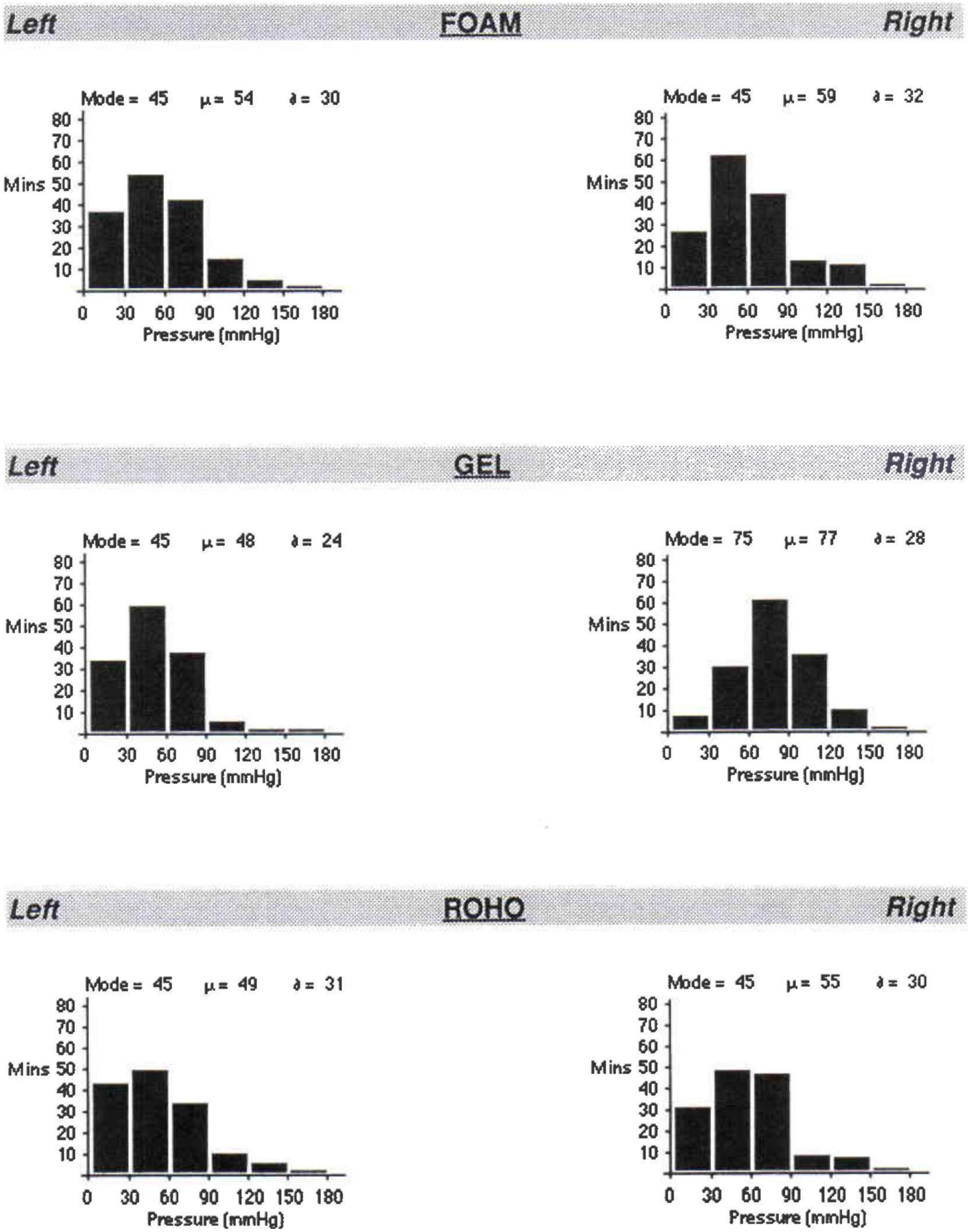

Fig. 9 Subject No. 3 — Paraplegic (L2). Sex: Male — 31 years. History of Sores: None. Pushups: Yes.

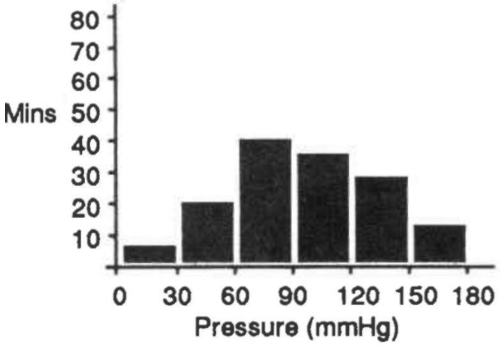

Fig 10. Broad pressure histograms for foam and gel.

all those subjects with significant muscle bulk in the lower limbs recorded low pressures on all cushions confirming the view that able-bodied subjects should not be used for the evaluation of supports designed for the disabled. The findings in this study demonstrate for a large number of disabled individuals the potential ability of the Roho to equalise and distribute dynamic pressures provided the inflation pressures are correctly established before sitting.

Conclusions

In general pressures beneath the bony prominences tend to be higher on foam than on other types of cushions. Gel cushions also tend to generate higher pressures because these are stiff materials which tend to deflect less beneath the patient with movement. The Roho, with its flotation properties, is able to distribute pressure in the sitting area more effectively than either of these other types of cushions provided the correct amount of air for optimal suspension is maintained in the cushion. The variability of pressure observed for these different cushions in this study confirms the view that the selection and fitting of cushions to patients must be done on an individual basis. It is common clinical practice to take single readings of pressure as part of the assessment process but this may not be sufficient for some patients especially young active wheelchair bound individuals. These patients require a more detailed assessment which should include dynamic pressure measurement to determine the extent of the pressure variation with time. Furthermore, clinical verification of the effectiveness of a cushion after a period of sitting is recommended since pressure alone may not account for all the factors causing a pressure sore.

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