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Abstract

We studied the seated buttock pressure distribution in six paraplegic patients by means of computerized pressure mapping. They were all male and their age ranged from 18 to 48 years old. Their level of paralysis varied from Th5 to L1. Five kinds of wheelchair cushions were studied: an air cushion, a contour cushion, a polyurethane foam cushion, a Cubicushion (which is made of polyurethane foams) and a silicone gel cushion. A tactile sensor consisting of 2064 matrices was used for measuring the buttock pressure distribution and the data was analyzed on a personal computer. Peak pressures measured for each cushion were as follows (in descending order): the Cubicushion, the polyurethane foam cushion, the contour cushion, the silicone gel cushion, and the air cushion. The areas of total contact measured for each cushion were as follows (in descending order): the air cushion, the silicone gel cushion, the polyurethane foam cushion, the contour cushion and the Cubicushion. Based on these findings, we conclude that the most advantageous cushion is the air cushion or the silicone gel cushion. Likewise, we conclude that the Cubicushion is not practical for pressure sore prevention.

KEYWORDS: Paraplegia, wheelchair cushion, pressure distribution

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Evaluation of Wheelchair Cushions by Means of Pressure Distribution Mapping

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We studied the seated buttock pressure distribution in six paraplegic patients by means of computerized pressure mapping. They were all male and their age ranged from 18 to 48 years old. Their level of paralysis varied from Th5 to L1. Five kinds of wheelchair cushions were studied: an air cushion, a contour cushion, a polyurethane foam cushion, a Cubicushion (which is made of polyurethane foams) and a silicone gel cushion. A tactile sensor consisting of 2064 matrices was used for measuring the buttock pressure distribution and the data was analyzed on a personal computer. Peak pressures measured for each cushion were as follows (in descending order): the Cubicushion, the polyurethane foam cushion, the contour cushion, the silicone gel cushion, and the air cushion. The areas of total contact measured for each cushion were as follows (in descending order): the air cushion, the silicone gel cushion, the polyurethane foam cushion, the contour cushion and the Cubicushion. Based on these findings, we conclude that the most advantageous cushion is the air cushion or the silicone gel cushion. Likewise, we conclude that the Cubicushion is not practical for pressure sore prevention.

Key words: paraplegia, wheelchair cushion, pressure distribution

Wheelchair cushions play an important role in preventing buttock sores in wheelchair-bound paraplegic patients (1-3). We used buttock pressure mapping to evaluate various wheelchair cushions. However, the system we used differs from previous measuring devices which were only able to measure buttock pressure at a single point, such as the ischial tuberosity, the greater trochanter or the coccygeum (4-8). Thus, with these devices one could not measure overall buttock pressure distribution precisely.

The purpose of this paper was to evaluate wheelchair cushions currently used in Japan, measuring the buttock pressure distribution by means of a computerized sensor seat.

Materials and Methods

Six paraplegic patients were involved in this study and their relevant data is shown in Table 1. All six could propel their wheelchairs independently and sit on wheelchair cushions. The five types of wheelchair cushions examined are shown in Table 2 and Fig. 1. The air

Table 1 Subjects

Case	Sex	Age (years)	Body weight (kg)	Level of paralysis	Complete/ Incomplete
1	M	18	47.9	Th5	Complete
2	M	19	38.8	Th12	Complete
3	M	30	46.5	Th12	Complete
4	M	28	66.0	Th12	Complete
5	M	48	61.1	L1	Complete
6	M	37	47.9	L1	Complete

M: Male; Th: Thoracic spine; L: Lumbar spine.

Table 2 Thickness of the five types of wheelchair cushion

Wheelchair cushion	Thickness (cm)
Air cushion	10
Contour cushion	10
Polyurethane foam cushion	10
Cubicushion	8
Silicone gel cushion	4

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cushion is made of rubber and manufactured by ROHO Co., USA. (Fig. 1a). The contour cushion is custom built for each paraplegic patient's physical status and was developed by the Royal Perth Rehabilitation Hospital, Australia. The cushion has two layers; the upper layer is polyurethane foam and the lower layer is chip molded polyurethane. The part contacting the ischial tuberosities is cut out, alleviating pressure on the ischial tuberosities (Fig. 1b) (1). The polyurethane form cushion is made of solid elastic urethane foam (Fig. 1c). The Cubicushion (Cape Trading Limited, Japan) is made of polyurethane foams and consists of 49 cubes of polyurethane foam arranged in seven rows and seven columns mounted on a polyurethane sheet measuring 37.5 × 37.5 × 1.5 cm (Fig. 1d). The silicone gel cushion contains an inner gel portion, enclosed in a vinyl cover (Fig. 1e).

In order to measure buttock pressure, the subject sat on a standard wheelchair with a cushion on which a tactile sensor sheet was placed. The tactile sensor sheet (Big-Mat type 2000, Nitta Corporation, Japan) consisted of 2064 (43 × 48) matrices. Each matrix measures the pressure exerted on a square centimeter area. Maximum sampling frequency is 50 Hz. The sensor sheet was connected to a personal computer (NEC 9821NE, Tokyo, Japan) through an interface board. In order to confirm the error precisely, the error was measured prior to each trial. In this study, the error ranged from − 6.5 to + 5.8 %. The personal computer produced a visual display of the area of buttock contacting the upper surface of the cushion and a pressure distribution map of the area (Fig. 2).

Results

Air cushion. All subjects showed almost the same pattern of pressure distribution. A graphic computer printout is shown in Fig. 3. The areas of buttock contacting the air cushion and the peak pressures observed at both ischial tuberosities are shown in Table 3. The total area of contact varied from 1067 to 823 cm^2. The point of highest buttock pressure was detected at the ischial tuberosities and the peak value varied from 257 to 87 g/cm^2.

Contour cushion. In the area cut out of the contour cushion, the pressure was less than 30.0 g/cm^2. The highest buttock pressure was observed at the lateral aspect of the ischial tuberosities (Fig. 4). The total areas of contact and the peak pressures are shown in Table 4. The total area of contact varied from 860 to 672 cm^2. The peak value of the buttock pressure varied from 319 to 134 g/cm^2.

Polyurethane foam cushion. All subjects showed almost the same pattern of pressure distribution (Fig. 5). The total areas of contact and the peak pressures are shown in Table 5. The total area of contact varied from 905 to 663 cm^2. The highest buttock pressure was observed at the ischial tuberosities and it varied from 386 to 123 g/cm^2.

Cubicushion. All subjects show almost the same pattern of pressure distribution (Fig. 6). The total areas of contact and the peak pressures are shown in Table 6. The total area of contact varied from 829 to 431 cm^2 and the point of highest buttock pressure was measured at the ischial tuberosities and the peak value varied from 401 to 174 g/cm^2.

Silicone gel cushion. All subjects showed almost the same pattern of pressure distribution (Fig. 7). The total areas of contact and the peak pressures are shown in Table 7. The total area of contact varied from 941 to 696 cm^2. The highest buttock pressure site was measured at the ischial tuberosities and the peak value varied from 292 to 129 g/cm^2.

Discussion

Pressure sores are one of the most common complications in paraplegic patients and often occur at the bony prominences of the buttocks while the patient is seated in a wheelchair. A pressure sore is defined as a region of cellular necrosis of the skin and subcutaneous tissue induced by external compression forces. Malnutrition, anemia, poor skin care, skin infection and skin trauma promote pressure sores in paraplegic patients, however, the most important causal factor is pressure exerted on the buttocks.

In 1959, Kosiak reported a pressure-time relationship in the development of pressure sores using dogs. He observed that there is a time/intensity relationship at work in the production of pressure sores, meaning, that pressure sores can be produced both by a low pressure exerted over a long time and a high pressure exerted over a short time (2).

In 1976, Reswick and Rogers also mentioned a pressure-time relationship. Furthermore, they noted that pressure sores are seldom produced in the greater trochanter region by a pressure of less than 80 mmHg (108.8

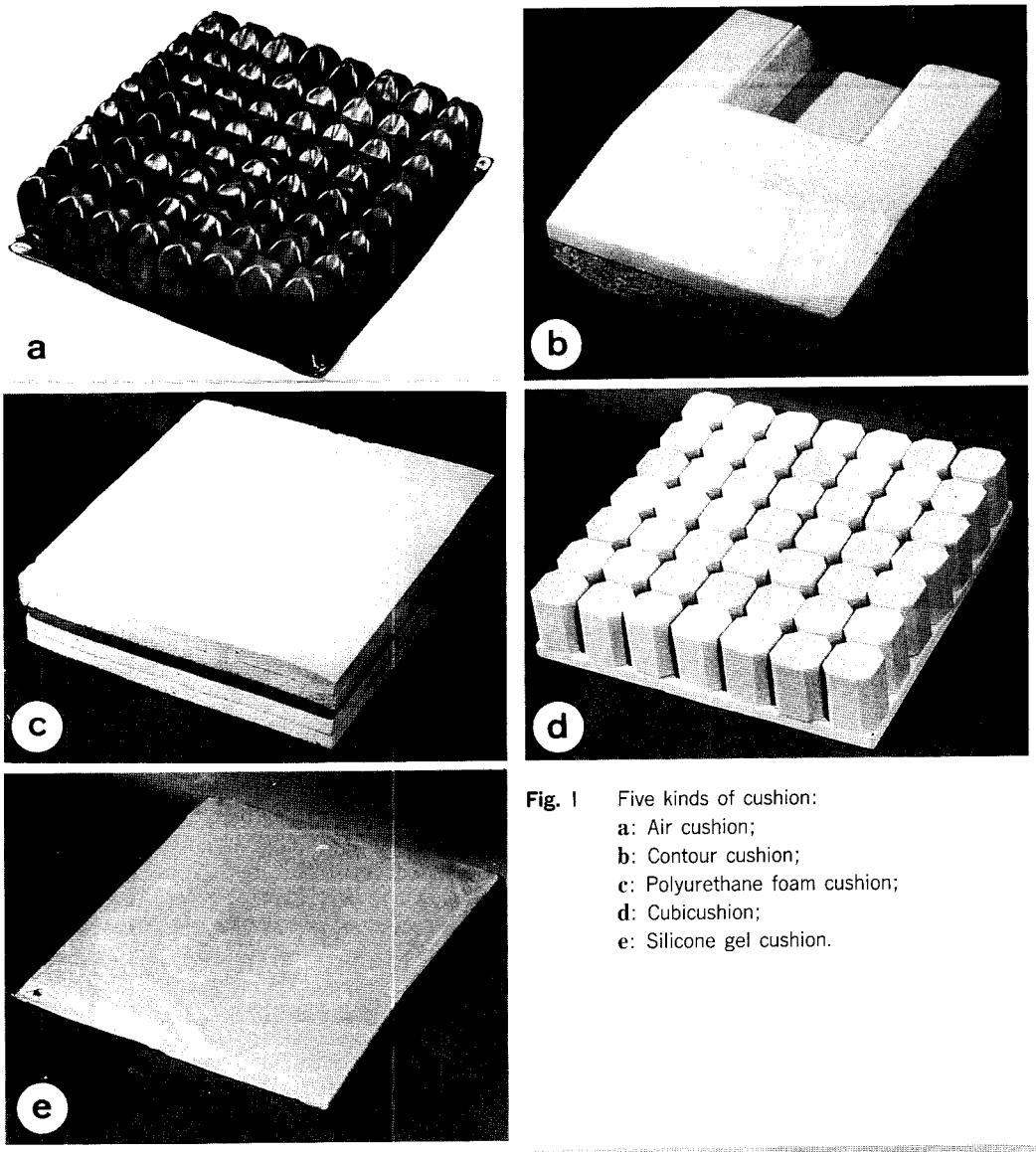

Fig. 1 Five kinds of cushion:
a: Air cushion;
b: Contour cushion;
c: Polyurethane foam cushion;
d: Cubicushion;
e: Silicone gel cushion.

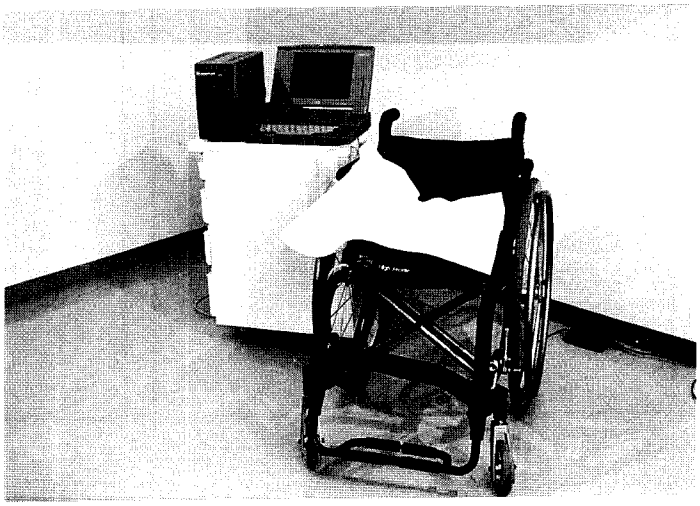

Fig. 2 Pressure distribution measurement system.

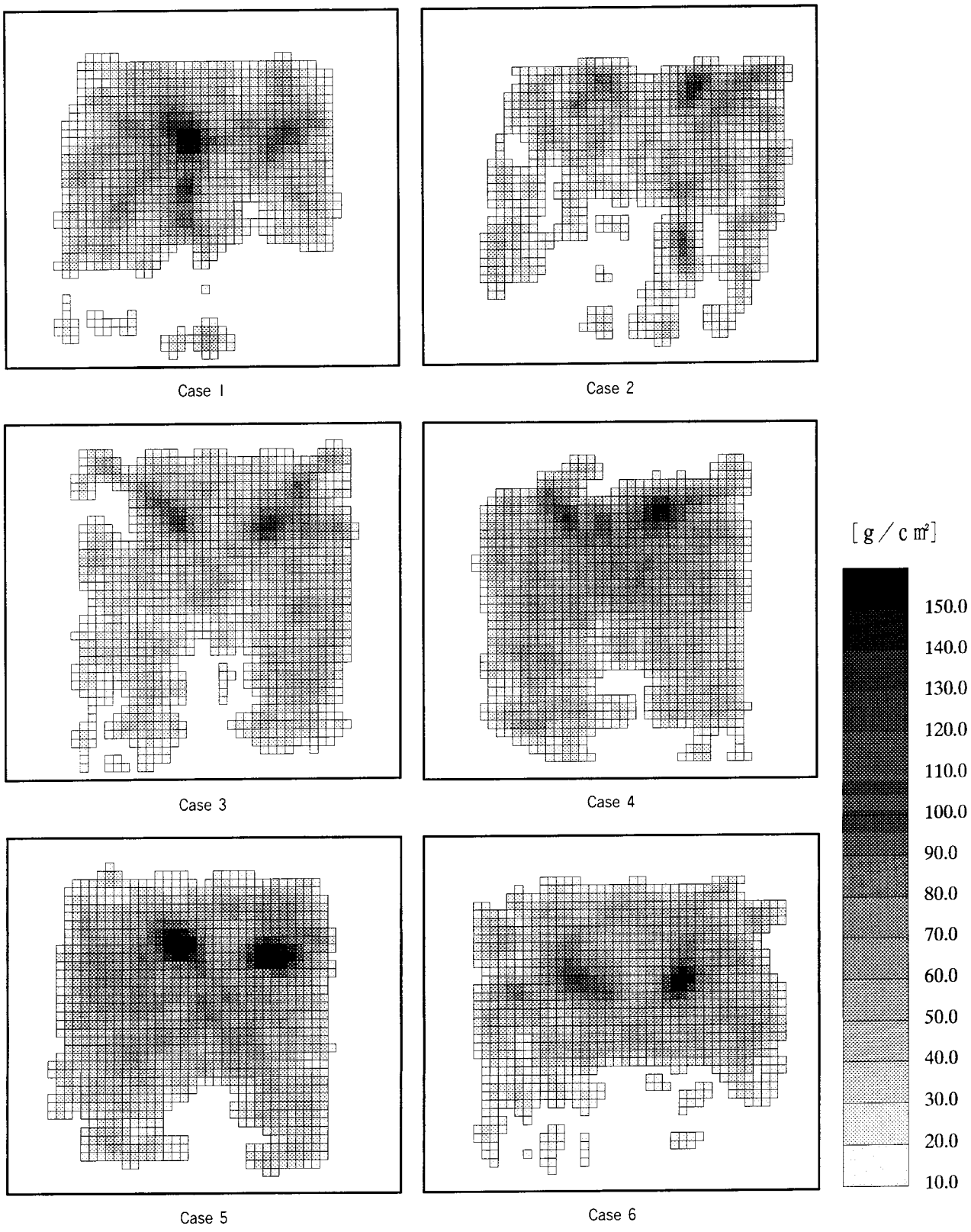

Fig. 3 Pressure distribution of the air cushion.

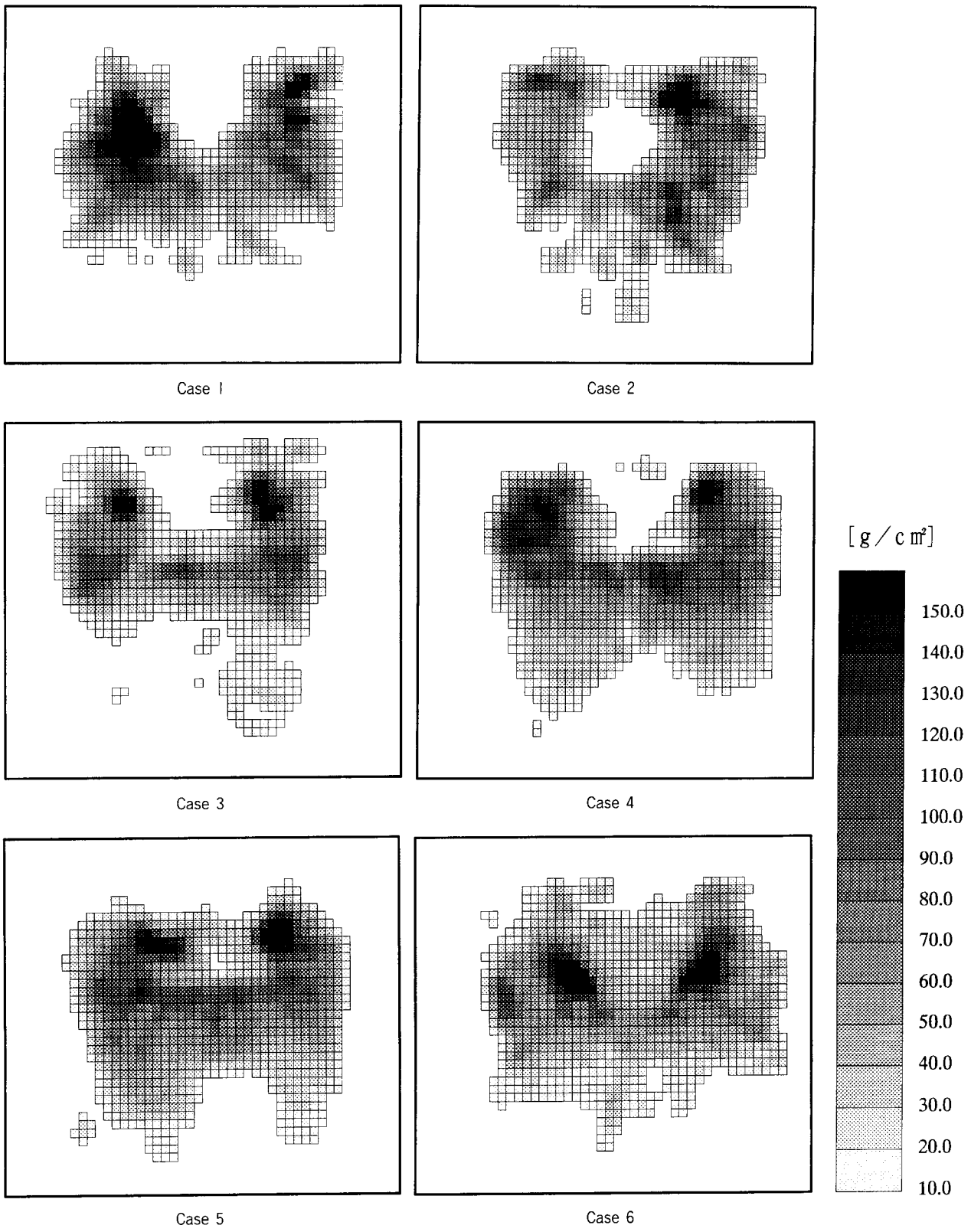

Fig. 4 Pressure distribution of the contour cushion.

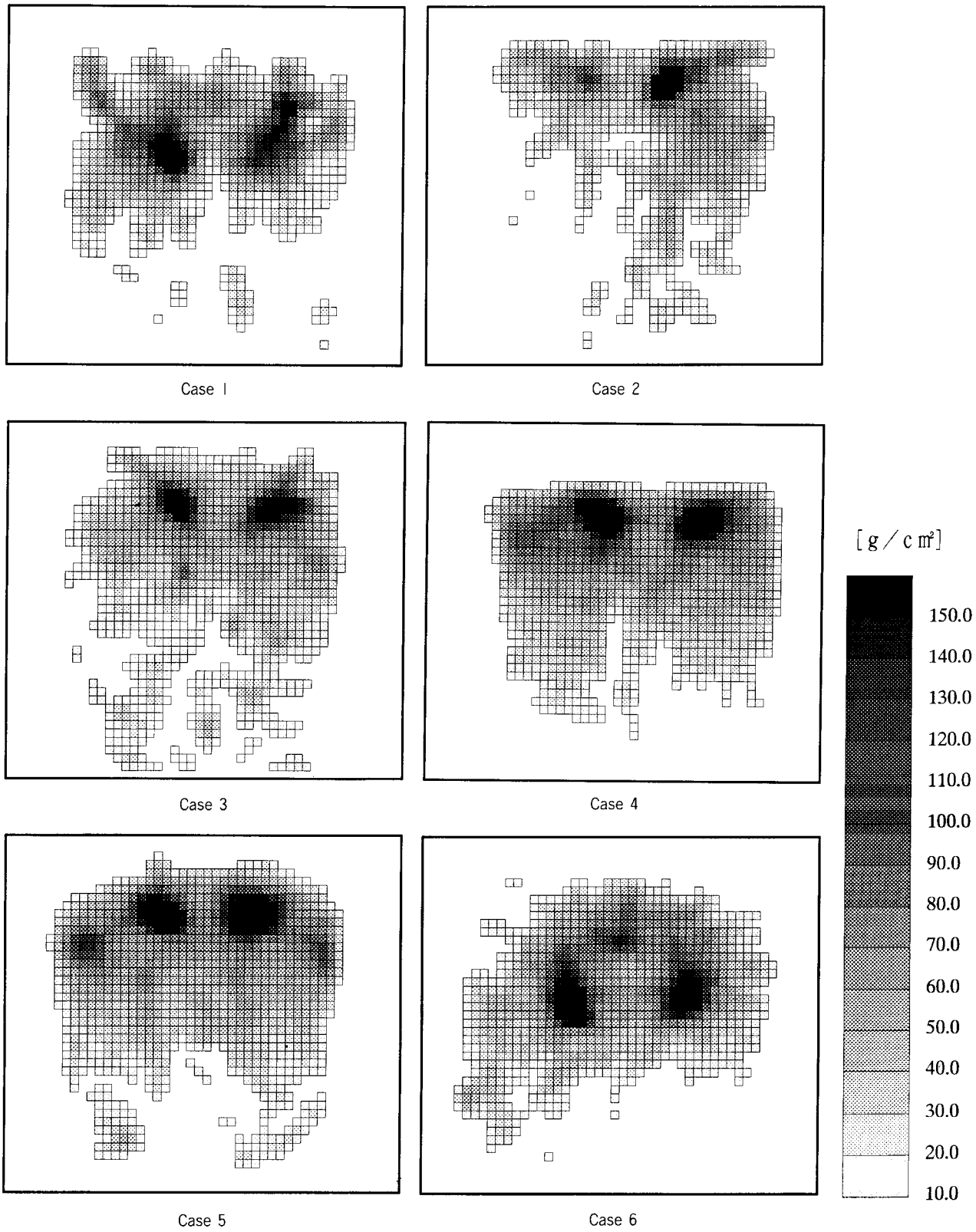

Fig. 5 Pressure distribution of the polyurethane foam cushion.

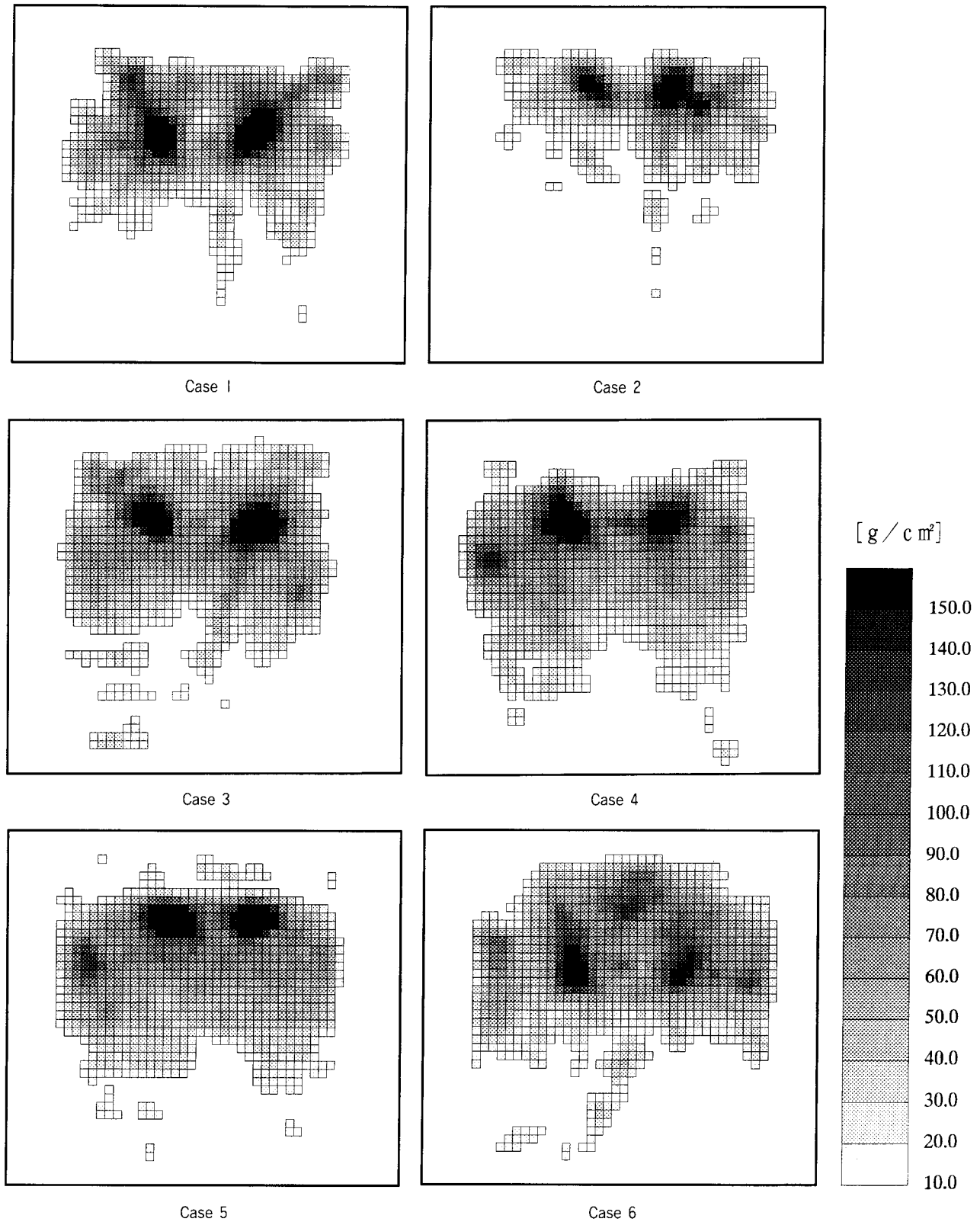

Fig. 6 Pressure distribution of Cubicushion.

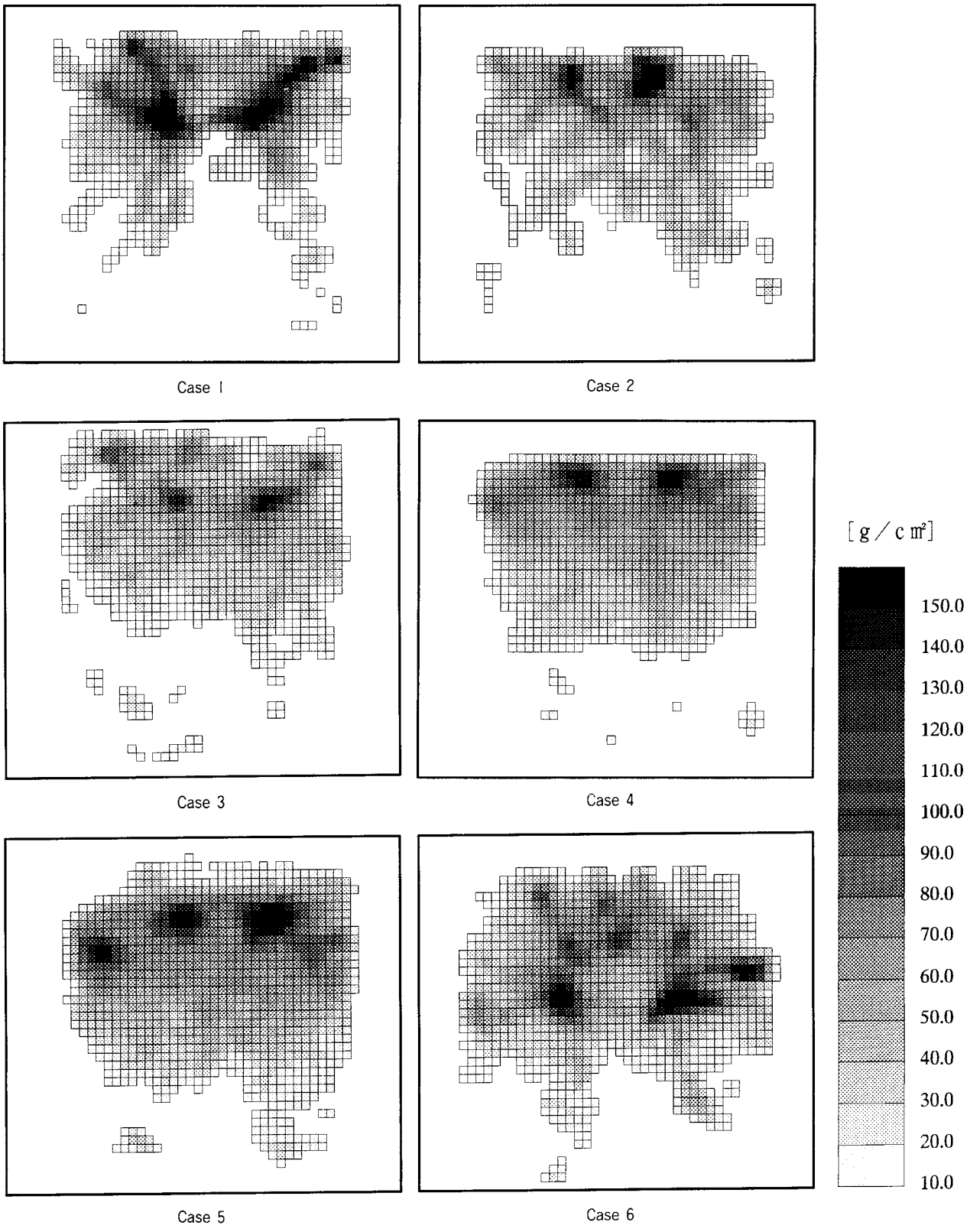

Fig. 7 Pressure distribution of the silicone gel cushion.

Table 3 The areas of buttock contacting the air cushion and the peak pressures observed at both ischial tuberosities

Case	Total area (cm^2)	Peak pressure (g/cm^2)	
		Right	Left
1	824	215	113
2	869	87	134
3	1067	115	136
4	1009	133	171
5	1056	249	257
6	963	123	188

Table 4 The areas of buttock contacting the contour cushion and the peak pressures observed at the lateral aspect of both ischial tuberosities

Case	Total area (cm^2)	Peak pressure (g/cm^2)	
		Right	Left
1	855	319	209
2	672	134	211
3	703	185	173
4	804	158	210
5	809	181	267
6	860	254	196

Table 5 The areas of buttock contacting the polyurethane foam cushion and the peak pressures observed at both ischial tuberosities

Case	Total area (cm^2)	Peak pressure (g/cm^2)	
		Right	Left
1	689	295	218
2	663	123	337
3	884	243	214
4	816	372	338
5	905	366	386
6	823	335	253

Table 6 The areas of buttock contacting the Cubicushion and the peak pressures observed at both ischial tuberosities

Case	Total area (cm^2)	Peak pressure (g/cm^2)	
		Right	Left
1	637	295	326
2	431	184	323
3	769	279	295
4	823	401	296
5	769	340	332
6	829	228	174

Table 7 The areas of buttock contacting the silicone gel cushion and the peak pressures observed at both ischial tuberosities

Case	Total area (cm^2)	Peak pressure (g/cm^2)	
		Right	Left
1	696	232	204
2	739	176	292
3	813	129	148
4	779	169	172
5	941	192	232
6	938	188	206

Table 8 The areas exerting pressure over $80\,g/cm^2$

Wheelchair cushion	Area over $80\,g/cm^2$ (cm^2)
Air cushion	68～ 23
Contour cushion	253～108
Polyurethane foam cushion	157～ 47
Cubicushion	124～ 60
Silicone gel cushion	140～ 34

g/cm^2) and in the ischial tuberosity region by a pressure of less than 60 mmHg ($81.6\,g/cm^2$) in paraplegic patients (3). In the years following these reports, many studies on seated pressure distribution have been carried out.

Pressure sores develop mostly in the tissue overlaying bony prominences such as the ischial tuberosities, the greater trochanter and the coccygeum in paraplegic patients. To prevent pressure sores produced while seated in wheelchairs, paraplegic patients use wheelchair cushions. The function of wheelchair cushions is to relieve the pressure concentration on the tissue overlaying bony prominences. Cushioning materials are chosen with this in mind. Therefore, measurement of buttock pressure distribution is a reliable method for evaluating the performance of wheelchair cushions.

Although several measuring devices for buttock pressure have been used, most of them measure pressure only at a single site, namely, the above mentioned bony prominences. Moreover, with these measuring devices, real time information on buttock pressure is unobtainable (4-8). Recent advances in electronics have led to the development of computerized pressure measuring sensors. In 1993, Ferguson-Pell and Cardi compared three representative mapping systems: the Tekscan system, the FSA system and the Talley TP3. They concluded that the Tekscan system was clinically preferable because of its reliability and usefulness (9). The Tekscan system is available as the Big-Mat 2000, produced by the Nitta

Corporation of Japan.

In 1996, Koo *et al.* carried out a comparative study of an air cushion and a polyurethane foam cushion using a sensor seat and they emphasized its reliability and usefulness. However, their sensor seat consisted of only 12 matrices so they could only measure the pressure exerted at both ischial tuberosities (10).

The cushions we examined are used by practically all paraplegic patients in Japan. The contour cushion and Cubicushion are distinctive in shape. The air cushion, the polyurethane foam cushion and the silicone gel cushion are distinctive in materials.

Peak pressures measured for each cushion were as follows (in descending order): the Cubicushion, the polyurethane foam cushion, the contour cushion, the silicone gel cushion, and the air cushion. The areas of total contact measured for each cushion were as follows (in descending order): the air cushion, the silicone gel cushion, the polyurethane foam cushion, the contour cushion and the Cubicushion.

Based on these observations, we conclude that the larger the total area of contact, the lower the peak pressure. In other words, if the buttock pressure is distributed over a large area, the pressure is dispersed, thereby reducing peak pressure. Accordingly, we conclude that the most advantageous cushions are the air cushion and the silicone gel cushion. The Cubicushion does not provide adequate pressure relief and, consequently is inadequate for pressure sore prevention.

The polyurethane foam cushion and the contour cushion have quite similar characteristics of pressure distribution, however, the contour cushion decreases buttock pressure exerted at the skin covering the ischial tuberosities.

In 1994, Henderson *et al.* reported that in humans, the threshold pressure for the production of pressure sores is 60 mmHg (81.6 g/cm^2) exerted for one hour. Above this threshold, tissue ischemia begins (11). Their conclusion is the same as that reached by Reswick and Rogers in 1976. Based on their reports, we measured the areas exerting pressure above 80 g/cm^2 of pressure (Table 8).

Among the five kinds of cushion, the air cushion showed the smallest area above 80 g/cm^2 of pressure. The polyurethane foam cushion, Cubicushion and the silicone gel cushion showed almost the same area above 80 g/cm^2 of pressure. Of the five cushions measured, the contour cushion had the largest area above 80 g/cm^2 of pressure.

Based on these findings, we conclude that by removing part of the contour cushion at the location of the ischial tuberosities, the pressure which would normally be exerted at these points is shifted laterally to less sensitive areas.

Generally speaking, wheelchair cushions containing gas or fluid (air cushions or silicone gel cushions) support buttock pressure uniformly over a wider area based on Pascal's law. Solid elastic wheelchair cushions (polyurethane foam cushions) support buttock pressure over a narrower area than cushions containing gas or fluid. However, to avoid buttock pressure exerted at the ischial tuberosities, one can modify the shape of solid elastic cushions (the contour cushion and Cubicushion).

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