need to be able to send patients back to primary surgical wards once they no longer need the special facilities of a neurosurgical unit. When more beds were available in Glasgow the number of head-injured patients in the neurosurgical unit did not greatly increase and they accounted for less than 20% of admissions; moreover, the mean duration of stay was shorter than before.

These Scottish studies suggest that a limited increase in neurosurgical facilities would probably be sufficient to enable optimal care by modern standards to be offered to most head-injured patients, provided that there was also a rethinking of the respective roles of primary surgeons and neurosurgeons in the light of local needs and facilities.

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Development of a cushion to prevent ischial pressure sores

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Summary and conclusions

A study was carried out jointly by nursing staff and technologists in an attempt to develop a cushion based on scientific principles and measurement that might prevent pressure sores. At each stage in the development clinical trials were carried out, and using the results of these together with the opinions of medical staff and patients who used the cushion the design was suitably modified. Over four years a seat was evolved that was simple to construct and fulfilled the clinical requirements for a wide range of patients while providing maximum relief of high-pressure points. The design was subsequently taken up commercially.

Introduction

The prevention and treatment of pressure sores have received considerable attention recently.¹⁻² Most research, however, has been concerned with bedfast²⁻⁵ rather than chairbound people.⁶⁻⁷ Some special cushions are available but have found only limited favour among users.⁸ Since 28% of all pressure sores occur in the ischial region⁹ and sores are consistently more

common in chairbound than bedfast patients with the same degree of helplessness,¹⁰ a cushion is needed that is effective in relieving high-pressure points by distributing body weight uniformly over a large area of the buttocks and thighs. We therefore set up this project jointly between technologists and nursing staff to develop a cushion based on both scientific analysis and the needs of the users that would have a wide potential field of application and be effective in eliminating areas of high pressure.

Theory

Pressure sores occur when the blood flow through the skin and underlying fat is interrupted by continuous pressure in excess of capillary blood pressure (30-40 mm Hg), so that the tissues are deprived of nutriment and become necrotic. These lesions may be prevented, therefore, either by reducing the applied pressure to less than 30 mm Hg or by limiting the time for which greater pressures act. In recumbent patients the area available for support is large, and by spreading the load the pressures can be reduced below capillary blood pressures.¹¹ Furthermore, these patients can be repositioned frequently, so that dangerously high pressures do not act for long. The scope for repositioning seated patients, however, is limited, while the minimum attainable pressure on a conventional padded seat (36-40 mm Hg) is still dangerously high. Thus the maximum practicable area of buttocks and thighs must be used for supporting the weight. Uniform distribution of body weight in the recumbent patient may be achieved by flotation using a water bed,¹² but this approach is impractical for the sitting patient, as a true flotation seat offers no stability and any slight movement of the patient causes flow of the fluid.

The problem is thus to design a support surface that is effectively both fluid (for uniform distribution of weight) and solid (for stability and acceptability in the wheelchair). These two apparently irreconcilable characteristics can, however, be combined by using a thixotropic substance. These materials are gels that in the unstressed state behave as solids. When pressure is applied the gel remains solid

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until the stress reaches a critical point (the yield value), when the gel flows like a liquid (fig 1). Thus when a person lowers his weight on to a cushion containing a thixotropic gel the contact area between patient and support is initially small and the local stresses high, so that the gel acts as a fluid and flows away from the areas of high pressure. This continuing flow causes the area of contact to increase progressively until the stress in the gel falls below the critical value, when flow stops and the cushion becomes solid. Hence the seat will have conformed to the profile and then "solidified" to form a firm and stable support once the patient has settled on it.

Fig 1—Characteristics of a solid, a fluid, and a thixotropic substance.

Methods and results

We carried out two separate studies. In the first, a laboratory investigation, we tested various thixotropic gels to determine which was the most suitable to form the cushion. In the second study we modified the cushion's design according to its acceptability under clinical conditions.

LABORATORY INVESTIGATIONS

A series of thixotropic gels was produced and their yield stresses estimated using an Instron 1195 testing machine. A 56 mm diameter flat-ended plunger was driven at a constant speed of 20 mm/min into a flat-topped "cylinder" of gel contained in a beaker. The load on the plunger was plotted against its depth of penetration into the gel, a change in the slope of the graph (see fig 1) indicating the yield stress as measured by this procedure.

The mean pressure under the buttocks of a sitting subject is of the order of 38 mm Hg, and therefore we chose four gels with measured yield stresses (τ) of about this value for further experimentation. These gels consisted of aqueous solutions containing: (1) 5% synthetic hectorite (a natural swelling clay that is a magnesium silicate having a layered structure): τ = 26 mm Hg; (2) 2.4% hydroxyethyl cellulose plus 2% of a zirconium organic complexing agent: τ = 32 mm Hg; (3) 2.0% hydroxyethyl cellulose: τ = 42 mm Hg; and (4) 20% bentonite clay (montmorillonite): τ = 53 mm Hg. Nine litres of each gel was sealed into large polyethylene bags, which were placed into the depressions in hollowed out blocks of polyurethane foam (fig 2). Each cushion was placed on a geriatric chair and

Fig 2—Section through initial experimental cushion.

the maximum pressure under the ischial tuberosities of eight healthy subjects measured using a 90 mm diameter pneumatic transducer similar to that described by Mooney *et al.*¹³ The subjects sat comfortably with arms folded in their laps, so that no weight was carried through the arm rests, with thighs horizontal and feet together squarely on an adjustable footrest.

For each subject at least six readings were obtained under each tuberosity and the maximum value taken as the peak pressure acting. The subject also reported whether he felt any tendency to slide off the cushion or for the cushion itself to roll off the chair.

Results—Table I summarises the results of this preliminary trial and shows that the cushions appreciably reduced peak pressures in the subjects, who had a wide range of body weights. Magnesium silicate and hydroxyethyl cellulose plus complexing agent both gave consistently low pressure readings and provided an acceptable degree of stability. We chose to use magnesium silicate in the clinical trial, since it was the only gel that did not support the growth of fungi and was in all other respects satisfactory.

TABLE I—Maximum pressures measured under ischial tuberosities of eight subjects using four experimental thixotropic cushions on a geriatric chair

	Case No							
	1	2	3	4	5	6	7	8
Weight (kg)	53.1	52.3	71.3	47.8	76.5	84.2	32.0	40.3
Maximum pressure (mm Hg):								
Base surface alone	>200	150	80	130	100	92	162	>200
2% hydroxyethyl cellulose	48	50	28	48	38	35	67	86
2.4% hydroxyethyl cellulose + 2% zirconium complexing agent	40	41	27	50	36	28	56	69
5% synthetic magnesium silicate	36	46	28	50	50	26	50	65
20% montmorillonite	80	62	36	92	89	48	128	134

CLINICAL TRIAL

We recorded each patient's age, weight, diagnosis, history of pressure sores and techniques of treatment, the condition of any existing or recent sores immediately before use of the cushion, the type of chair on which the cushion was used, the period of use each day, and the progress of existing sores or any tendency to tissue breakdown. We also noted opinions of medical and nursing staff and the users. Because of these opinions we made several changes in the cushion's design, which were primarily aimed at making the cushion easier to handle and considerably more durable, improving its appearance, and reducing its cost.

Finally, we compared our cushion with two others that appeared to be closest in design to it. These were the Reston pad (3M Co), which contains a liquid-filled microcell sponge, and the Flowform pad (Franklin and Sons), which consists of a thin layer of gel filled with polystyrene beads and overlaid by a layer of foam.

Results—Table II summarises the data on the patients and the results of the trial. Many patients used the cushion, but we report the results in only 15 suffering from stable chronic disabilities who were nursed on one ward and were followed up closely for several months. Table III compares the final version of the cushion with the Reston and Flowform pads when used on a rigid base. Identical experiments carried out with the cushions in a geriatric chair and a folding wheelchair showed that the nature of the base surface had little effect on the results obtained.

Discussion

We chose to measure the pressure with a pneumatic cell rather than a strain-gauge transducer for several reasons. Strain-gauge devices are rigid and have a minimum thickness of about 3 mm, so that their bulk modifies the normal pressure pattern. Additionally, a sensor of large diameter indicates the average pressure over its whole area, while with a small sensor precise positioning becomes difficult. The pneumatic sensor is extremely pliable, contours well round anatomical features, and indicates the peak pressure within a large area (6360 mm²). Shear stresses on the skin, which may contribute to tissue deformation,¹⁴ cannot be quantified with either instrument. The

TABLE II—Details of patients and results of clinical trial

Case No	Age (years)	Weight (kg)	Principal diagnosis	Recent history of sores and preventive or curative treatment	State of pressure areas immediately before use of cushion	Usage of cushion	Result
9	91	49.3	Dementia, glaucoma	Recurring areas of broken skin in sacral region: nursed prone and turned frequently	Small areas of broken skin in sacral region	9 hours/day in ward chair	All broken areas healed in 35 days; no recurrence within 1 year
10	52	58.7	Cerebrovascular accident	Deep, 30 mm diameter ischial sore, which healed in bed but recurred on sitting up	Healed in bed	12 hours/day in wheelchair	No further recurrence within 8 months
11	70	60.8	Multiple sclerosis, quadriplegia	Ischial sore, which healed in bed but repeatedly broke down sitting up	Small ischial sore	12 hours/day in wheelchair	Fully healed in 7 days; no recurrence within 7 months
12	67	90.8	Paraplegia	Long-standing superficial sores over both ischia	Superficial sores over both ischia	12 hours/day in wheelchair	Both sores fully healed in 21 days; no recurrence within 10 months
13	71	58.6	Pressure sore	None	Deep, 35 mm diameter sore over ischium	12 hours/day in ward chair	Sore reduced to 15 mm diameter in 21 days then closed surgically
14	88	42.3	Dementia, contractures at hips and knees	Ripple bed	Deep, 45 mm diameter sores over sacrum and right ischium	12 hours/day in ward chair	Ischial sore healed in 21 days and sacral sore in 38 days; no recurrence within 65 days (patient died)
15	47	124.2	Paraplegia	None	Tender, red areas over both ischia	15 hours/day in wheelchair	Clear in 7 days; no recurrence in 1 year
16	78	42.9	Cerebrovascular accident, fractured shaft of femur	None	Sacral sore resulting from plating of fracture	14 hours/day in wheelchair	Healed in 27 days
17	83	49.0	Rheumatoid and osteoarthritis	None	Small sacral sore	10 hours/day in ward chair	Healed in 8 days
18	60	59.3	Multiple sclerosis, epilepsy	Two broken areas between buttocks of 4 months' standing; nursed in bed	Two broken areas between buttocks	6 hours/day in ward chair	Both sores fully healed in 16 days
19	63	56.3	Cerebrovascular accident	Recurring sores over both ischia, which healed in bed but broke down within 2 days of sitting up	Sores over both ischia	4 hours/day in wheelchair	Both healed in 20 days; no recurrence within 8 months
20	92	92.7	Immobility associated with old age	None	Two 25 mm diameter superficial sores in sacral region	8 hours/day in ward chair or wheelchair	Both healed in 28 days
21	49	74.5	Multiple sclerosis	Ischial sore of 12 months' standing	Sore healed in bed	6 hours/day in wheelchair	No further tendency to breakdown within 15 months
22	74	48.3	Cerebrovascular accident, burns to back and arms, emaciated	Ripple bed	Deep infected sore to bone over right trochanter, superficial sore on left trochanter; severe redness on buttocks and sacral region	5 hours/day in ward chair	All redness cleared in 7 days; left trochanter healed in 30 days; right trochanter clean and static
23	45	51.8	Multiple sclerosis	Superficial sore between buttocks of over 12 months' standing; sitting up 3 hours/day in wheelchair	Superficial sore between buttocks	3 hours/day in wheelchair	Sores 50% healed in 28 days

TABLE III—Results of re-evaluation of thixotropic cushion and comparison with two other cushions, showing maximum pressures under ischial tuberosities

	Case No										Ranges
	24	25	26	27	28	29	30	31	32	33	
Weight (kg)	52.3	47.8	61.6	53.1	84.3	40.3	60.2	76.5	50.7	57.1	
Maximum pressures (mm Hg):											
Base surface alone	270	158	250	264	224	>300	224	186	142	238	142-300+
With Reston cushion	80	83	95	118	92	82	90	65	64	65	63-118
With Flowform cushion	67	61	78	110	86	78	78	63	61	65	61-110
With thixotropic cushion	52	50	60	68	63	57	60	50	48	51	48-68

method used enabled pressures to be read to ± 1 mm Hg, and calibration of the equipment showed its accuracy to be better than 2%.

One theoretical drawback of the pneumatic cell is that because it conforms so well to the profile of the patient it tends to reduce the measured peak pressure. This effect is minimal at low pressures because there is already close conformity between seat and user. The possibility of obtaining a low reading through poor positioning of the cell is eliminated by rejecting all but the highest values obtained, as it is impossible to generate a false high reading.

In the trial, errors arising from variations in the proportion of body weight carried by the buttocks and thighs on different cushions were avoided by ensuring that no weight was taken on the arms and that the thighs were horizontal. Theoretically, using a specially constructed seat to standardise posture would have reduced the number of variables, but the primary aim was to measure the pressures generated by the subjects in their

normal sitting positions. On this basis, the results showed that the thixotropic cushion distributed body weight uniformly over a large area of contact and was significantly better than the two other cushions tested ($P < 0.001$). All the volunteers gave low pressure readings and found the stability of the gel acceptable, indicating that a single design was suitable for a wide range of body weights.

Several difficulties are associated with testing clinically a device such as the thixotropic cushion. A control trial would be exceptionally difficult to carry out, and thus any placebo effect¹⁵ cannot be quantified. Furthermore, the presence of pressure trauma is always secondary to some other clinical condition, and the general health and lifestyle of patients using the cushion are variable. These effects were minimised, however, by reporting only on patients with stable disabilities who were nursed on one ward. By establishing whether any pressure areas were deteriorating, static, or improving before and after the cushion was used the contribution of the cushion itself

could be assessed. Our results thus indicated that the cushion had real value in preventing pressure sores and allowing existing sores to heal. This is particularly important, since ischial ulcers will not normally heal at all if the patient sits out of bed.

Figure 3 shows the current design of the cushion. It consists of a foam outer cushion measuring 400 × 400 × 100 mm fitted with a removable waterproof vinyl cover, and a polyvinyl chloride bag containing five litres of the thixotropic gel (a 6.6% dispersion of magnesium silicate powder in water). The complete cushion weighs 6.2 kg.

Fig 3—Thixotropic cushion in its present form.

The individual needs of patients who are suffering from or susceptible to pressure sores vary, and many different views are held on the effectiveness of the various special support surfaces that are available. No one single device can be expected to be ideal for all types of patients. Nevertheless, the basic require-

ments in all cases are that the pressure under the ischial tuberosities and sacrum should be minimised and that the cushion should be readily acceptable to both users and attendants. The evidence from our trials suggests that this cushion goes a long way towards achieving these objectives, since it is simple and inexpensive and appears to have a wide potential usage.

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ONE HUNDRED YEARS AGO From the report of Dr Holt, Sanitary Inspector of the fourth district of New Orleans, it appeared that, in 1878, out of a population of about 36 000 persons, there were upwards of 6000 cases of yellow fever. The sanitary condition of the district would appear to be bad, and to this Dr Holt attributes the fever, although the insanitary condition is constant, and yellow fever only occasional. "There are," he says, "precisely the same reasons for declaring yellow fever to be *ab initio* the product of human filth, as malaria to be the product of a marsh or swamp." Of several insanitary conditions existing at New Orleans, Dr Holt places first the "privy vault system." Thousands of these had been originally huge boxes, which, having become destroyed through time, permit saturation of the soil with human excrement to such an extent that water, taken from a depth of ninety-five feet, has yielded fifty-three grains per gallon of urea and organic matter. In the wet weather, these boxes (now pits) fill with water and overflow, "flooding yards and gutters with ordure," whilst in the day they are largely emptied by their fluid contents soaking into the ground, thus saturating the soil with human excrement. "In this respect," says Dr Holt, "it may be properly stated that the people have a huge privy in common, and that the inhabitants of New Orleans live upon a dung-heap." In many parts of Dr Holt's district, the gutters are below their outlets, and thus form stagnant pools, besides being otherwise badly constructed. Building on "low lots" and over-crowding is a third kind of insanitary condition in New Orleans; and a fourth, and probably the most important, is a deficient water-supply. Rarely a year passes, it appears, without two protracted droughts, and two weeks of dry weather suffice "to empty many of the cisterns," and three weeks produce a widespread water-famine, which becomes at times so severe as to compel the poor to have recourse "to the street-gutters to obtain the water which is to supply all of their wants to be used in cooking, drinking, washing, etc." The cause of this appears to be the selfishness of the landlords. "It is they," says Dr Holt, "who have built these hovels in the mud, the very construction of which makes grovelling wretches of the men and women whose necessities deliver them into the hands of men who are themselves dead to any instinct higher than the clutching of a penny." This condition of things it is

difficult to think of as actually existing in the free and enlightened republic of the United States. The description which he gives of the Locust Grove Cemetery, or Potter's Field, is deserving of consideration. This is one square of ground in which are buried the pauper dead of the entire city. Having been used for many years, the same graves were made to receive the bodies of many dead—as many as six occupying a single grave. Dr Holt witnessed the burial of a corpse. The grave was prepared by uncovering a coffin, opening it, raking the bones together and throwing them out, breaking up and prising out the old coffin, and depositing the new in the mould of the former. When laid in its resting-place, the lid of the box, like that of the one preceding, was two inches below the surface of the earth. To hide it, the earth formerly removed was piled upon the coffin in a mound about two feet high. In this covering he counted the skulls of three former occupants, besides observing other bones. So filled with bones was the earth as to make the use of the spade extremely difficult. Another coffin-lid, warped by the sun, displayed the body of a poor wretch who had died a few months before; the stench was disgusting. The whole surface of the ground was strewn with ribs and small bones, like pebbles upon the hills. Here and there, huge thigh-bones served as head and foot stones to the unknown dead. The citizens living in the vicinity presented a petition to the City Council, March 13th, 1877, wherein they set forth in the strongest terms the horrible facts relative to this graveyard. Requested by these people, and having made repeated inspections, Dr Holt appended to the petition his official report, declaring this graveyard an outrageous nuisance; first, as a sanitary violation of the most serious kind, not only prejudicial to the people of the immediate neighbourhood, but dangerous to the entire city, inasmuch as the bodies of those who had died of infectious diseases were brought from one end of the city to the other, through densely inhabited quarters, to be buried here; second, as a violation of the plainest laws of humanity and instinctive decency, in the infliction upon the helpless of such loathsome sights and disgusting smells; This petition, numerous signed, was presented at the City Hall, and was buried in a pigeon-hole; no special record nor account was kept of it. A square of ground, however, was at once selected, adjoining immediately the first. (*British Medical Journal*, 1879.)