Effect of abdominal binders on breathing in tetraplegic patients

J M GOLDMAN, L S ROSE, S J WILLIAMS, J R SILVER, D M DENISON

From the Lung Function Unit, Brompton Hospital, London, and the National Spinal Injuries Centre, Stoke Mandeville Hospital, Aylesbury, Bucks

ABSTRACT We studied the effect on breathing of a conventional and a newly designed abdominal binder in seven patients with complete tetraplegia. The indices of respiratory ability used were the transdiaphragmatic pressure on maximal sniff (sniff Pdi), the maximum static inspiratory mouth pressure (P_{imax}), and the vital capacity (VC). These were measured in patients with and without binders, in the supine position, raised up to 70° on a tilt table, and seated upright. When patients were raised from the supine to the 70° tilt and to the seated posture, sniff Pdi and VC decreased. Both binders improved VC in the seated position and at 70° tilt, and sniff Pdi at 70° tilt. The new binder was as effective as but no better than the conventional binder. P_{imax} was too variable to be a valuable index of inspiratory power. These findings support the view that abdominal binders assist breathing in tetraplegic patients who are seated or raised to near vertical positions.

When the diaphragm contracts abdominal pressure rises, to an extent determined by the distensibility of the abdominal wall.¹ If the wall is stiff the pressure rise is substantial, pushing the lower rib cage outwards² and opposing the descent of the diaphragm, which is obliged to lift the rib cage instead.³ If the wall is compliant it displaces easily, with slight pressure rise, and little elevation or expansion of the rib cage. Recently we found that the abdominal wall in tetraplegic patients is twice as compliant as in normal subjects.⁴ In erect postures the abdominal contents fall forwards unopposed and the diaphragm flattens, thus impairing the rib cage expanding mechanism of the only major respiratory muscle available in tetraplegia. Abdominal binders decrease the compliance of the abdominal wall. They have been used in patients with high spinal injuries for many years, for postural hypotension, and for respiratory problems. The binder in present use has the disadvantage of binding the lower rib cage as well as the abdomen (fig 1a). It therefore increases intra-abdominal pressure, but opposes its own rib cage expanding effect. The aim of this study was to compare the effects on respiration of a conventional binder and of one that did not encroach on the rib cage (fig 1b) in a group of patients with complete tetraplegia.

Methods

Seven male patients with tetraplegia due to trauma were examined. All were judged to have suffered from complete transection of the cervical spinal cord, in

Fig 1 (a) Conventional elastic abdominal binder used in tetraplegic patients; note that the binder encroaches on the lower rib cage. (b) Newly designed abdominal binder made of low temperature thermoplastic, tailor made for each patient, to fit beneath the lower costal margin.

Address for reprint requests: Dr JM Goldman, Brompton Hospital, London SW3 6HP.

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Table 1 Clinical and anthropometric details of patients

Patient No	Age (y)	Ht (cm)	Wt (kg)	Level of lesion	Time since injury	Predicted VC (l) seated	Actual VC (l) seated
1	43	184	73	C5	22 y	5.03	3.10
2	24	178	76	C6	4 y	5.11	2.32
3	27	193	76	C5	6 m	5.84	1.68
4	34	183	64	C5/6	7 m	5.16	1.13
5	29	168	64	C5/6	11 m	4.48	2.66
6	44	178	73	C6/7	4 m	4.68	3.43
7	31	180	73	C5	7 m	5.03	1.68

VC—vital capacity.

that on clinical examination there was no detectable motor or sensory function below the cervical level indicated in table 1. Other clinical and anthropometric data are included in table 1. All of the patients had been injured at least three months before the study, and none was suffering from any respiratory complication at the time of examination. There was a control group of 20 normal men of similar age and stature. The mean age of both groups was 33 years; the mean height of the patients was 180.5 cm and of the controls 178 cm, and the mean weights were 71 and 70 kg.

Each subject was studied in three different positions: sitting in their wheelchairs, lying horizontal and supine on a tilt table, and resting at 70° to the horizontal on the same tilt table. Subject 3 could only tolerate 50° of tilt because of postural hypotension. Subjects were held to the table with straps at the knees and at the pelvis below the binder. Their legs were braced with their feet on a foot plate, and a safety strap was placed loosely around the chest, but did not encroach on rib cage motion unless the patient tipped forward.

Abdominal girth was measured at the mid point between xiphisternum and pubis, at resting end expiration, in each patient in all postures. Changes in this measurement with posture were taken as an index of abdominal wall compliance. Similar measurements were made on the group of normal subjects.

THE BINDERS

Each patient was provided with a conventional abdominal binder appropriate to his size. This binder (fig 1a) was made of 70% viscose, 20% cotton, and 10% elastidene (Credelast). It was 20 cm in width and came in three different lengths. It fastened at the front with Velcro. The newly designed binder (fig 1b) was tailor made for each subject, and was fitted in the supine posture. The front plate was made of low temperature thermoplastic (Orthoplast) cut to fit beneath the lower costal margin and above the bony margins of the pelvis. The binder was held in place by cotton webbing riveted to the front plate, wound around the body and fastened in front by Velcro.

To standardise the degree of abdominal compression provided by each binder, girth was reduced by a similar amount by both binders in each posture. This varied between patients; the mean abdominal compression provided by the binders represented a decrease in girth of 4.5 cm supine, 7.5 cm seated, and 6.5 cm at 70° tilt.

Three indices of respiratory ability were measured: (1) Transdiaphragmatic pressure during maximal sniff (sniff Pdi); (2) maximum static inspiratory mouth pressure (P_{imax}); (3) vital capacity (VC). Each index was measured in all three positions with no abdominal binder, with the conventional binder, and with the new binder. In each posture the order in which the three states were assessed was randomised.

TRANSDIAPHRAGMATIC PRESSURE DURING MAXIMAL SNIFF

Sniff Pdi was measured with gastric and oesophageal balloons, according to the method of Miller *et al.*⁵ The balloons were introduced via the nose, while the patients sat in their wheelchairs. One was positioned 45 cm from the nares to measure oesophageal pressure⁶ and the second 65 cm from the nares to measure gastric pressure.⁷ The oesophageal balloon contained 0.5 ml of air and the gastric balloon 1.5 ml of air. They were connected to a matched pair of Elema Schonander EMT 35 pressure transducers linear to 200 ± 0.5 cm H₂O, and linked after amplification to a Gould 4400 thermal pen recorder. Calibrations were made before and after each study against a water manometer. The positions of the balloons above and below the diaphragm were confirmed by obtaining a negative deflection from the oesophageal pressure trace, and a positive deflection from the gastric pressure trace on inspiration. Pdi was obtained by electrical subtraction of oesophageal pressure from gastric pressure. Pdi at resting end expiration was used as a reference zero.

Each subject was asked to perform a single short, sharp sniff from functional residual capacity (FRC), followed by three quiet breaths. The manoeuvre was repeated 10 times, and the best sniff used for analysis. Each subject underwent a training period of two sets

of 10 sniffs, during which they could see the recordings and were encouraged to make maximal efforts. In the formal study they were not allowed to see their results. Subjects were initially studied in their wheelchairs and then after transfer to the tilt table—supine and at 70° tilt in a random order. An occlusion manoeuvre was performed according to the technique of Baydur *et al*⁸ after each change of posture. Appropriate adjustments were made in the position of the oesophageal balloon to ensure that it provided accurate recordings of pleural pressure. When satisfactory measurements of sniff Pdi had been made in each posture with each binder, the balloons were removed.

MAXIMUM STATIC INSPIRATORY MOUTH PRESSURE

P_{imax} was measured as an indication of total inspiratory muscle strength.⁹ Each subject wore a nose clip, breathed through a mouthpiece, and made maximum inspiratory efforts from FRC against a closed shutter that incorporated a standardised 2 mm leak to keep the glottis open. Each effort was sustained for 1–2 seconds. Pressure at the mouth was measured with a SE labs SEM 425 pressure transducer, which was linear to 100 ± 0.4 cm H₂O. This was connected after amplification to a Gould 4400 thermal pen recorder. The transducer was calibrated before and after each study against a water filled manometer. Subjects performed a training period of two sets of three maximal inspiratory efforts while observing their recordings, and were encouraged to make maximal efforts. Subsequently they performed sets of three maximal inspirations blind, and the best result was used for analysis. P_{imax} was measured initially with the patients supine or at 70° tilt according to the randomisation. Measurements were made without a binder, with the conventional binder, and with the new binder in random order. The subjects were then transferred to their wheelchairs and the measurements repeated.

VITAL CAPACITY

VC was measured after each set of P_{imax} measurements, with a Vitalograph single breath wedge spirometer accurate to ± 2% at ATPS. Sets of three forced expirations were performed and the best reading was used for analysis. This protocol was designed so that the patient would be lifted on and off the tilt table only once.

STATISTICAL ANALYSIS

For statistical analysis of the data Student's paired test was used. The Kolmogorov-Smirnoff test showed there was no significant difference between the data and a normal distribution.

Results

When tetraplegic patients were raised from the supine to the seated posture and then to 70° tilt, their abdominal girth increased more than that of normal subjects in the same positions. We believe that this is because their abdominal walls are more compliant than normal. When they moved from the supine to the erect position, girth increased by 4.65% ± 1.53% (SEM 0.34%) in the normal subjects and by 6.27% ± 1.60% (SEM 0.60%) in the tetraplegic patients. In the seated posture girth was 6.77% ± 1.69% (SEM 0.38%) greater than in the supine posture in the normal subjects, and 12.09% ± 1.53% (SEM 0.60%) greater than in the supine posture in the tetraplegic patients. There is a significant difference between the two groups in both positions ($p < 0.01$).

Table 2 shows the mean data for sniff Pdi, P_{imax} and VC. In subject 7 we failed to make accurate measurements of sniff Pdi, as the patient could not tolerate the oesophageal and gastric balloons. P_{imax} and VC were measured in the normal way and the data included in analysis.

Table 2 Mean (SD) peak transdiaphragmatic pressure on maximal sniffing (sniff Pdi), vital capacity (VC), and maximum static inspiratory mouth pressure (P_{imax}) in seven patients with tetraplegia when supine, seated, and tilted at 70°

	No binder	Conventional binder	New binder
Supine			
Sniff Pdi*	70.5 (13.0)	68.5 (13.0)	74.0 (10.5)
VC†	2.91 (0.49)	2.96 (0.53)	2.92 (0.44)
P _{imax} ‡	54.5 (15.5)	51.5 (17.0)	50.0 (17.0)
Seated			
Sniff Pdi*	59.5 (14.0)	62.5 (15.0)	63.0 (14.5)
VC†	2.27 (0.84)	2.53 (0.85)	2.46 (0.78)
P _{imax} ‡	49.0 (17.0)	54.0 (17.0)	53.0 (18.0)
70° tilt			
Sniff Pdi*	52.0 (14.5)	61.5 (17.5)	65.0 (13.0)
VC†	1.95 (0.57)	2.24 (0.57)	2.42 (0.71)
P _{imax} ‡	47.0 (11.5)	48.0 (15.0)	48.0 (13.5)

*Measured as cm H₂O (n = 6); †measured as litres (n = 7); ‡measured as cm H₂O (n = 7).

SNIFF Pdi

There was a significant difference between sniff Pdi in the three different postures without a binder (fig 2). Sniff Pdi was greater in the supine than the seated posture ($p < 0.05$) by 18.5% (11.0 cm H₂O, SED 3.5 cm H₂O), greater in the supine posture than at 70° tilt ($p < 0.01$) by 36.5% (19.0 cm H₂O, SED 3.5 cm H₂O), and greater in the sitting position than at 70° tilt ($p < 0.02$) by 15% (8 cm H₂O, SED 2 cm H₂O). At 70° tilt both binders improved sniff Pdi (fig 2)—the conventional binder ($p < 0.05$) by 19.5% (10 cm H₂O, SED 3 cm H₂O) and the new binder ($p < 0.02$) by 26% (13 cm H₂O, SED 3.4 cm H₂O). The binders had no significant effect on sniff Pdi in the sitting or supine postures, and there was no significant

difference between the effect of the two binders in any posture.

VITAL CAPACITY

There was also a significant difference between VC in the three postures (fig 2). VC without binders was greater in the supine than the sitting position ($p < 0.05$) by 28% (640 ml, SED 210 ml) and in the supine position than at 70° tilt ($p < 0.02$) by 49% (960 ml, SED 160 ml). When patients were seated, both binders improved VC ($p < 0.01$), the conventional binder by 11.5% (260 ml, SED 50 ml) and the new binder by 8% (180 ml, SED 40 ml). At 70° tilt both binders improved VC, the conventional binder ($p < 0.01$) by 15% (290 ml, SED 70 ml) and the new binder ($p < 0.01$) by 24% (470 ml, SED 70 ml). Binders did not alter VC in the supine posture. There was no statistical difference between the effect of the two binders.

MAXIMUM STATIC INSPIRATORY MOUTH PRESSURE

P_{max} was not significantly altered by change in posture, and was little affected by binding the abdomen (table 2). In the supine posture patients had a greater P_{max} without a binder than with the conventional binder ($p < 0.05$) by 5% (3 cm H₂O, SED 1.1 cm H₂O), but in practice this is probably unimportant. P_{max} was measured on 10 occasions in one seated subject; the mean measurement was 60.3 cm H₂O with 95% confidence limits of ± 7 cm H₂O.

GASTRIC PRESSURE

Mean gastric pressures (P_g) are shown in table 3. There was no significant difference between pressures in different postures without a binder, though they were lower in the supine posture. In the sitting position the conventional binder increased resting P_g, end tidal inspiratory P_g ($p < 0.05$) and maximal sniff P_g ($p < 0.05$). The new binder increased end tidal inspiratory P_g ($p < 0.05$), but did not significantly increase resting or maximal sniff P_g. The conventional binder increased resting P_g in the sitting position ($p < 0.05$) by an average of 1.5 cm H₂O more than did the new binder. With patients in the supine posture and at 70° tilt, both binders increased resting, end tidal inspiratory, and maximal sniff P_g.

Discussion

This study yielded data on changes in abdominal girth, transdiaphragmatic pressure, vital capacity, and maximum inspiratory pressure at the mouth, with posture and with the application of binders, in a group of patients with stable tetraplegia. The values of sniff Pdi, VC, and P_{max} obtained in the absence

Sniff Pdi (cm H₂O) **VC (l)**

Fig 2 Effect of change in posture and binding the abdomen on transdiaphragmatic pressure during maximal sniff (sniff Pdi) in six tetraplegic patients, and on vital capacity (VC) in seven tetraplegic patients. Patients were studied in the supine, sitting, and 70° tilt postures, wearing no binder and wearing a conventional binder and a newly designed binder. The p values quoted for wearing no binder refer to comparisons with the supine posture; p values quoted for wearing a binder refer to comparisons with wearing no binder.

Table 3 Mean (SD) gastric pressures (cm H₂O)

	No binder (n = 6)	Conventional binder (n = 6)	New binder (n = 6)
Supine			
Resting	2.5 (1.0)	5.5 (1.5)	4.0 (1.5)
Inspiratory	6.5 (2.5)	11.0 (3.5)	10.0 (4.5)
Sniff	11.5 (4.5)	14.0 (4.5)	16.5 (7.5)
Seated			
Resting	5.0 (3.0)	7.0 (4.5)	5.5 (4.0)
Inspiratory	10.5 (4.5)	13.0 (5.5)	12.0 (4.5)
Sniff	13.5 (3.5)	18.5 (7.0)	16.5 (6.0)
70° tilt			
Resting	4.5 (3.0)	7.5 (3.0)	7.0 (3.0)
Inspiratory	10.0 (3.5)	14.5 (3.5)	16.5 (4.0)
Sniff	16.0 (7.5)	24.0 (13.5)	28.0 (15.0)

of binders are typical of those seen in tetraplegic patients,¹⁰⁻²¹ suggesting that the observations below may apply to such a group generally.

Abdominal girth increased when patients were tilted up from the supine position and increased more when they sat in a chair. These increases were significantly greater in the patients with tetraplegia than in a group of healthy men of the same age and stature. We presume that the abdominal wall falls outwards because of the weight of the enclosed viscera on being tilted to upright postures, and because of the combination of this and of flexion of the lumbar spine in the sitting posture. On the basis of the arguments of Duomarco and Rimini,²² the changes in abdominal girth with tilting will be determined in part by abdominal wall compliance and may be used as an index of it. The differences between patients and healthy subjects agree with our previous findings of increased abdominal wall compliance in tetraplegia.⁴

When normal subjects lie down, VC decreases by 7.5%.²³ When tetraplegic patients who have been tilted head up lie down VC increases by about 45%.¹⁶ If they lie down from the sitting position when the abdomen is splinted, VC rises by 28%.¹⁶ In the present study the rises in VC when they lay down after the 70° tilt and after sitting were 49% and 28% respectively. The differences between normal subjects and tetraplegic patients may be attributed to differences in abdominal tone. When healthy people stand up abdominal tone increases,²⁴⁻²⁶ preventing the abdominal wall from falling outwards and so maintaining a high arched diaphragm. When tetraplegic patients are tilted up, the abdominal wall falls outwards and the diaphragm must descend to a lower and flatter end expiratory position, diminishing inspiratory capacity. In the seated posture the abdominal wall is splinted, the spine may be flexed and the costal margin is in closer proximity to the pelvis than in the 70° tilt position. As a result the abdominal contents tend to be pushed forward rather than dropping into the pelvis. The abdominal wall becomes stretched and less compliant, opposing the descent of the

diaphragm to a lower and flatter position. Sniff Pdi and VC in the seated posture are thus greater than at 70° tilt. Pimax failed to alter significantly in this study with change in posture or binders, though there was a trend in line with the sniff Pdi data. Patients found the maximum static inspiratory efforts difficult to perform, especially in the 70° tilt posture, as they tended to tip over. We had hoped that measurements of Pimax could be used for within patient comparisons but they were apparently not sufficiently reproducible.

When our patients with abnormally compliant abdominal walls were tilted up, binding the abdomen improved the VC and Pdi. This has been shown previously in occasional atypical cases.²⁷⁻²⁹ In 1979 Maloney³⁰ described the effects of a corset on pulmonary function in 15 tetraplegic patients in the supine and seated postures. He found that VC increased from 51% of predicted during sitting to 62% of predicted in the supine posture. This represents an improvement in VC of 21%, which is comparable to our figure of a 28% increase. Our data also agree with his finding that a corset had no effect on lung volumes in the supine posture, while in the seated posture there was a trend towards improvement. In this study we have shown a significant increase in VC in the sitting position, and in sniff Pdi and VC at 70° tilt when binders were applied. Binders act by increasing intra-abdominal pressure, pushing the diaphragm into a position of greater mechanical advantage. They also decrease abdominal wall compliance, so that excessive shortening of the diaphragm on inspiration is opposed. This generates more intra-abdominal pressure and promotes rib cage expansion. In this study the conventional abdominal binder increased resting, end tidal inspiratory, and sniff gastric pressures in all postures. This was not the case with the new binder, which failed to significantly increase resting and sniff gastric pressure in the seated posture. The explanation for this is inherent in the design of the new binder. The front plate was made of inelastic material

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moulded to the shape of the patient's abdomen in the supine posture. In the seated position it did not fit the altered configuration of the abdominal wall, and when it was applied resting gastric pressure did not rise significantly (table 3). Descent of the diaphragm to a lower and flatter position was therefore unopposed and, though the lower rib cage was free to expand, the new binder showed no advantage over the conventional binder.

These findings suggest that abdominal binders are valuable aids to breathing when patients with tetraplegia are mobilised, and that the conventional binder should continue to be used until a better one is designed.

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