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REVIEW

Abdominal binder use in people with spinal cord injuries: a systematic review and meta-analysis

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Study design: Systematic review and meta-analysis.
Objectives: To review the evidence for the use of an abdominal binder on breathing, speech and cardiovascular function in people who have suffered a spinal cord injury (SCI).
Setting: Brisbane, Australia.
Methods: A search of multiple databases (Medline, Cinahl, Cochrane, Embase, PEDro) was undertaken accompanied by the reference list evaluation of each relevant publication identified. Methodological quality of studies identified was assessed using the PEDro scale. The size of effect of an abdominal binder on outcomes was also calculated where sufficient data were reported. Further descriptive analysis was performed.
Results: Eleven studies met the review inclusion criteria and employed either crossover or within subject designs. Comparison of studies involving elastic and non-elastic binders was performed. A PEDro mean score of 4.3 out of 8 (range: 3–6) was found. Meta-analysis indicated that the use of abdominal binders improved vital capacity (VC) by (weighted mean difference (95% confidence interval (CI)) 0.32 (0.09, 0.55) litres, decreased functional residual capacity (FRC) by 0.41 (0.14, 0.67) litres, but did not significantly influence total lung capacity (TLC).
Conclusions: This review found some evidence that the use of an abdominal binder improves VC, but decreases FRC when assuming the sitting or tilted position in people who have suffered SCI. Overall, the quality of the studies was poor. Available evidence is not yet sufficient to either support or discourage the use of an abdominal binder in this patient population. Further studies utilizing more methodologically rigorous designs are required.
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Keywords: spinal cord injury; abdominal binder; pulmonary function; review

Introduction

Complications arising from compromised respiratory function are the major cause of morbidity and mortality in people after cervical spinal cord injury (SCI).[1] Compromised respiratory function is caused by denervation of intercostal muscles, which limits inspiratory and expiratory ability, and loss of abdominal muscle function, which prevents an effective cough. These impairments lead to decreased pulmonary capacity, greater retention of secretions and increased atelectasis.[2]

Abdominal binders (ABs) have been used to aid respiratory function in people who have suffered SCI.[3–13] Several studies have reported that vital capacity (VC) in tetraplegic SCI is decreased to 50–80% of predicted values.[14,15] The mechanism of action of ABs is thought to be related to improving respiratory mechanics.[16] In the upright position, the abdominal contents are unsupported and migrate in an anterior and downward direction because of both gravity and increased abdominal compliance on account of denervation of the abdominal muscles.[6] Because of the diaphragm's connection with the viscera, this results in a decrease in diaphragmatic curvature as the diaphragm is drawn inferiorly. In the uninjured person, as the diaphragm moves caudally during inspiration, it presses on the abdominal contents, which act as a fulcrum and transmit 'appositional' forces laterally to expand the lower rib cage.[17] In a patient with SCI, binding of the abdomen is hypothesized to improve respiratory mechanics by mimicking the non-functioning abdominal muscles, compressing the

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abdominal contents to increase intra-abdominal pressure, and thus elevating the diaphragm into a more optimal position for breathing.[4] This is thought to allow an increase in lung volume, particularly VC, and a more forceful expiration when required, which may provide increased breath support for speech. The increase in intra-abdominal pressure provided by the AB is also believed to aid in venous return and thus cardiac output when upright.[18]

A number of studies have investigated the effect of AB use on lung volumes, respiratory mechanics, cardiovascular parameters and speech parameters among people with SCI; however, this evidence is yet to be systematically reviewed so that the clinical recommendations based on the best available evidence can be formed. The aim of this systematic review is to compile and evaluate available research investigating the effects of AB use on pulmonary, cardiovascular and speech function among people who have suffered SCI.

Materials and methods

Search strategy
Study identification commenced by electronic searching from the earliest available time until March 2008 using the following databases: Medline, Cinahl, Cochrane, PEDro and Embase. The search terms used were (1) spinal cord injur* OR tetrapleg*, OR quadripleg*; combined with (2) abdominal bind* OR corset OR abdominal strap* OR abdominal support. These terms were combined to produce a list of articles. Reference lists of all articles obtained were reviewed, and additional potentially relevant studies retrieved. Studies investigating the effects of abdominal binding in persons with SCI were selected based on the abstract.

Inclusion criteria
Inclusion and exclusion criteria are detailed in Table 1. It was decided a priori to include trials employing crossover and within-subject designs because of the low numbers of available studies in this area, and the amenability of research to be conducted in this field using these designs.

Assessment of methodological quality
The PEDro scale[19] was used to describe the methodological quality of trials included in this review. This scale consists of 11 criteria being (1) study eligibility criteria specified, (2) random allocation of subjects, (3) concealed allocation, (4) measure of similarity between groups at baseline, (5) subject blinding, (6) therapist blinding, (7) assessor blinding, (8) less than 15% dropouts, (9) intention to treat analysis, (10) between group statistical comparisons and (11) point measures and variability data. Criteria 2–11 are used to calculate the PEDro score. Criterion 4 was scored according to the statistical analysis for an order effect as all studies were either crossover studies or within-subject studies. Each criterion was scored as either 1 or 0 according to whether the criteria was met or not, respectively.

Table 1 Inclusion/exclusion criteria

Inclusion criteria	*Exclusion criteria*
SCI of acute or chronic nature	Studies with two or less subjects
Respiratory outcome measurements reported	Used an abdominal binder and lower limb pressure garment in the same variable
Cardiovascular outcomes reported	Language other than English
Speech outcomes reported	Animal subjects
Randomized controlled trial	Single patient studies
Randomized crossover trials	Case studies
Within patient studies	Didactic articles
Systematic reviews	

Procedure
The title and abstract of identified articles were assessed by two independent reviewers. Full articles were obtained where inclusion criteria could not be determined from title and abstract. Each reviewer completed the assessment of eligibility and any differences were resolved by direct discussion between reviewers until consensus was reached. If consensus were unable to be reached, a third reviewer would arbitrate. Studies meeting the eligibility criteria were assessed by both reviewers for methodological quality. Once each reviewer had completed the assessment, discrepancies were discussed and resolved by consensus.

Analysis
Meta-analysis to calculate the size of the effect of an AB had on outcomes reported was pursued for outcome measures that were present in at least three studies. Heterogeneity between individual studies in the reported results for each of these outcomes was analysed using Cochrane's Q statistic (which tests whether estimated effect sizes differ only by sampling error) and the I^2 statistic (which represents the percentage of the total variability in a set of effect sizes because of between-studies variability). Pooled weighted mean differences (95% confidence interval (CI)) for each outcome along with Cochrane's Q and I^2 statistics were calculated using Revman version 5.0.[20]

Further descriptive analysis was undertaken for outcomes not subjected to meta-analysis. Articles were separated for analysis according to the type of AB used; either elastic or non-elastic. Authors were contacted where it was not clear what type of AB was used.

Results

The search methods identified 39 articles. Sixteen were excluded as duplicates (Figure 1). Detailed assessment of the remaining articles resulted in the exclusion of a further 12 articles. The final library comprised 11 empiric studies.[3–13]

Study quality and design
Study design details are reported in Table 2. There were no reviews (narrative or systematic) or parallel group (between-subjects) randomized controlled trials found in the search (Table 2).

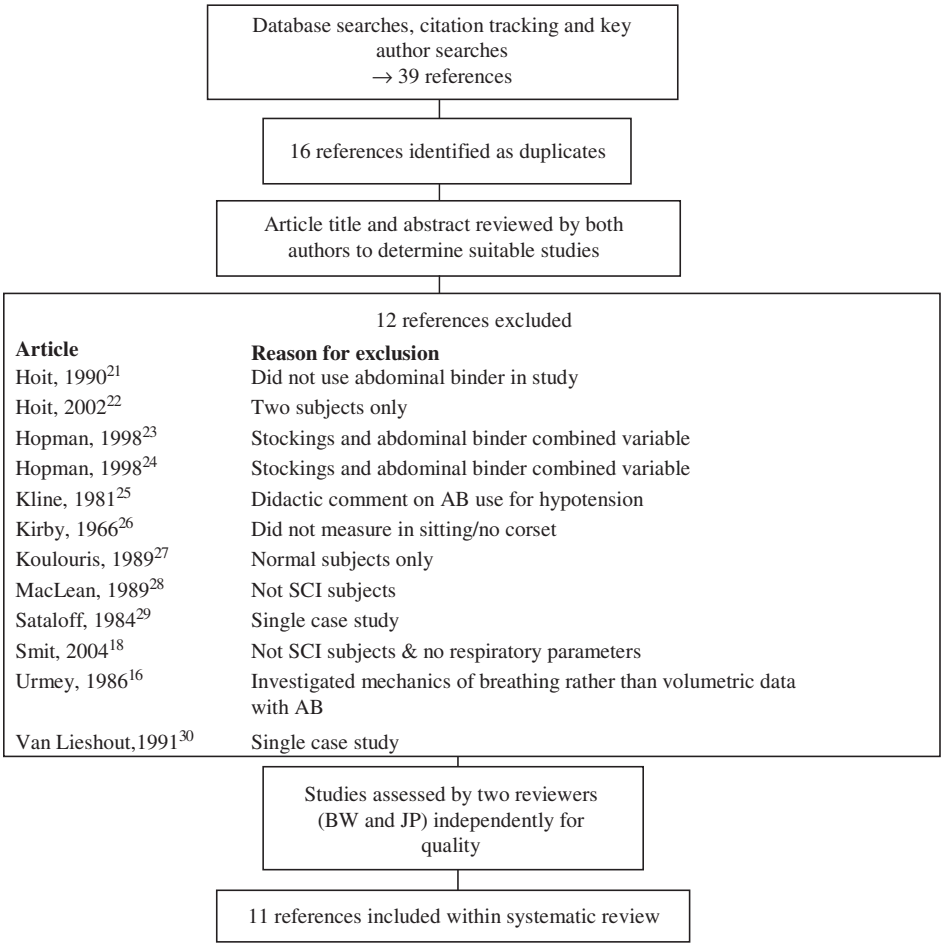

Figure 1 Outline of search strategy and review process.

As it was impossible to blind the patient or therapist, these items were dropped from the calculation of the total PEDro score for each study. A mean score of 4.3 out of 8 (range: 3–7) on the PEDro scale was found across the articles reviewed (Table 3). Most studies reported anthropomorphic data on subjects; however, only two studies reported ASIA (American Spinal Injuries Association) classification[31] impairment grades of subjects.[4,7] Several studies reported subjects to have complete injuries, which implies ASIA A grading.[3,6,8–10] Different postures, such as supine, sitting and tilt, were a second independent variable.

Blinding and randomization

In several studies, the order of testing procedure was randomized.[3,4,6,7,10] Seven studies incorporated a rest period between measurements on the same subjects to minimize fatigue.[3–5,7–10] No studies included statistical analysis for an order effect or stated that a washout period was enforced between interventions. No studies were able to blind the subjects as the intervention required AB application. Most subjects had likely worn an AB at the time of their initial rehabilitation, and thus had some understanding of the reason for applying an AB. One study blinded the investigator to whether the AB was on/off.[3] In the study investigating speech outcome data, this was analysed by an external assessor, and therefore the assessor was unaware of the presence of an AB.[13]

As 10 of the 11 studies looked at the immediate effect of an AB (effect of an AB on and then off), there were no dropouts from these studies. The study by Boaventura *et al*.[3] looked at AB effect in four separate testing sessions over a 12-week time frame and reported no dropouts. The choice of whether to perform an intention-to-treat or per-protocol analysis was therefore not an issue in these studies.

Statistical analysis

Data were presented for between group comparisons in all studies where appropriate. Simple univariate analysis procedures were used in most studies. However, there was no adjustment for potential confounding factors, such as time since injury, level of injury or prior history of AB use.

Sample size and clinical presentation

The median sample size of included studies was 13 (range: 3–27). The age range of subjects was 16–69 (mean 42). Eighty-five percentage of the subjects across all studies were males ($N = 102$), although gender was not reported in one

Table 2 Summary of studies with subject details

Study	*Design*	*Subjects*	*Number of subjects*	*Time since injury range*	*Age (yrs)*	*Gender*
Boaventura *et al.*[3]	Crossover randomized	Complete C4–C7 ASIA not stated	10	>1 yr	16–49	M:F, 9:1
Bodin *et al.*[4]	Crossover pseudorandomized	Complete C5–C8 ASIA A	20	Mean 13 yrs SD 9 yrs	39(±9)	M:F, 17:3
Estenne *et al.*[5]	Within patient study	C5–C8 ASIA not stated	8	6 mths–16 yrs 8 mths	21–52	M:F, 8:0
Goldman *et al.*[6]	Crossover randomized	Complete C5–C7 ASIA not stated	7	4 mths–22 yrs	24–44 Mean 33	M:F, 7:0
Hart *et al.*[7]	Crossover randomized	C5–T6 ASIA A	10	3 mths–2 yrs 3 mths	18–56 Mean 35.8	M:F, 6:4
Huang *et al.*[8]	Within patient	Complete C6–C7 motor	13	19–92 days	17–55	M:F, 11:2
	Comparison of two groups, although no significant difference between the groups for posture or device therefore combined.	Complete C4–C5 motor ASIA not stated	14	17–72 days Mean 47 days SD 22 days	19–69 Mean 32±13	M:F, 12:2
Kerk *et al.*[9]	Crossover randomized	Complete T3–T6 ASIA not stated Experienced athletes	6	Mean 3 yrs 8 mths SE 5 mths	21.8±1.8 (20–25)	M:F, 2:4
Lin *et al.*[10]	Crossover randomized	Complete C4–C8 (TP)	24, two groups of 12	TP, Mean 9 yrs 10 mths, SE 1 yr 7 mths	TP 36.2±1.9	Not stated
		Complete T2–T12, -(PP) ASIA not stated		PP, Mean 9 yrs 5 mths, SE 1 yr 8 mths	PP 36.0±1.5	
Maloney[11]	Crossover[a]	C4–T1 ASIA not stated	15	1–18 yrs	19–36	M:F, 14:1
McCool *et al.*[12]	Within patient study	C5–C7 and normals, ASIA not stated	13 SCI	1 mth–38 yrs	SCI 29.05±13.2	SCI M:F, 13:0
			9 normals		Normals 28.2±8.25	Normals Not stated
Watson *et al.*[13]	Within patient study—single subject A–B–A withdrawal design	Complete C5–C6 ASIA not stated	3	7–18 yrs	24–41	M: 3

Abbreviations: ASIA, American Spinal Injuries Association; PP, paraplegic; TP, tetraplegic.
[a]Language used to describe study randomization is ambiguous and the authors are not contactable.

study.[10] Methodology used to assess neurologic level and completeness of injury was not described in the majority of studies. Most studies involved subjects with tetraplegia. One study looked at paraplegic level subjects only, whereas another considered both tetraplegia and paraplegia (C5-T6) level injuries within the same small group ($n=10$).[7,9] The study by Lin *et al.*[10] compared AB effect on peak expiratory flow rate for two groups–paraplegia and tetraplegia.

There was a wide variation in time post-injury of the subjects tested. The range was from 17 days to 38 years (Table 2). Only one study looked specifically at subjects within the first 100 days of postinjury.[8]

No studies reported whether a patient usually wore an AB daily outside of the study. Hart *et al.*[7] spoke of subjects wearing a girdle according to the practice in their hospital; however, the exact details of 'hospital practice' was unclear. Ten of the eleven studies reviewed investigated the immediate effect of an AB on outcomes in different postures. One study looked at the effect of the AB on outcomes over four testing sessions over a 12-week period.[3] The subject group was made-up of subjects 12 months or more post injury, and they found that time had no influence during the study period.

Cigarette smoking, a major determinant of pulmonary function in able-bodied populations, was not reported in adequate detail by many of the studies.[32] Only two studies[3,4] stated that they excluded smokers, whereas Estenne *et al.*[5] reported that one subject was an active smoker. Although several studies[6,10,12,13] reported that the subjects had no lung disease, eight studies made no comment with regard to whether subjects were active or past smokers.[6–13]

Type of abdominal binder

The method used to bind the abdomen is detailed in Table 4. Binding of the abdomen that involved the use of a corset, girdle, straps or a mechanical device to truss the abdomen were classed as non-elastic binders. Binding of the abdomen that used stretchable fabric around the girth of the abdomen or used a low-pressure pneumatic binder was considered to be an elastic binder. One study reported the use of a 'girdle' with stretchable lateral portions and rigid anterior/posterior components in an attempt to provide truncal and abdominal support.[7]

Four studies reported on how binding the abdomen was standardized across subjects.[4,6,9,10] In terms of compression

Table 3 PEDro scoring

PEDro score	*Boaventura* et al.[3]	*Bodin* et al.[4]	*Estenne* et al.[5]	*Goldman* et al.[6]	*Hart* et al.[7]	*Huang* et al.[8]	*Kerk* et al.[9]	*Lin* et al.[10]	*Maloney*[11]	*McCool* et al.[12]	*Watson and Hixton*[13]
1. Study eligibility criteria specified	1	1	1	1	1	1	1	1	0	1	1
2. Random allocation of subjects	1	1	0	0	1	0	0	1	0	0	0
3. Concealed allocation	0	0	0	0	0	0	0	0	0	0	0
4. Measure of similarity between groups at baseline	0	0	0	0	0	0	0	0	0	0	0
5. Subject blinding	0	0	0	0	0	0	0	0	0	0	0
6. Therapist blinding	0	0	0	0	0	0	0	0	0	0	0
7. Assessor blinding	1	0	0	0	0	0	0	0	0	0	1
8. Less than 15% dropouts	1	1	1	1	1	1	1	1	1	1	1
9. Intention to treat analysis	1	1	1	1	1	1	1	1	1	1	1
10. Between group statistical comparisons	1	1	1	0	0	1	1	1	1	1	0
11. Point measures and variability data	1	1	1	1	1	1	1	1	1	1	1
Total score out of 8	6	5	4	3	4	4	4	5	4	4	4

Shading denotes that these items are not used to calculate the final PEDro score.
0—not met, 1—reported in study

applied, Kerk *et al.*[9] and Goldman *et al.*[6] reported on decreasing abdominal girth by 4–5 cm, whereas Lin *et al.*[10] reported a decrease in girth of 10% with the application of the AB. Bodin *et al.*[4] utilized a non-elastic AB, but were still able to report on the standardized level of compression using a pressure bladder between the AB and the abdomen. Only one study reported on the position in which the AB was applied, being supine in that study.[6] The height of the AB was reported in some studies.[3,4,6,9]

Outcome measures

Table 5 provides information on study outcomes. A variety of outcome measures were reported including respiratory (for example, VC, functional residual capacity (FRC)), cardiovascular (blood pressure) and speech (for example, sustained phonation).

Respiratory outcomes with an abdominal binder

Technical aspects of performing spirometry were reported in only two of the eleven studies.[3,7] No studies reviewed acknowledged modifying spirometry testing to cater for their study participants with SCI. Table 5 shows that one study reported only peak expiratory flow rate,[10] whereas two studies reported on multiple respiratory outcomes.[7,11] Because of the large number of variables collected as outcome measures, it was difficult to compare results. All studies reported an overall increase in VC when seated with the AB in place, though this was statistically significant in only six studies. Of these studies, three used an elastic AB,[3,6,12] and the other three used a non-elastic AB.[4,5,7] Subjects in the studies by Boaventura *et al.*[3] and Bodin *et al.*[4] could be considered chronic SCI, as all were over 12-month postinjury, however, all other studies included subjects from 1 month to 38 years postinjury with 13 or less subjects in total. Meta-analysis for the VC outcome is presented in Figure 2, and demonstrates that when a subject wears an AB, there is an improvement (weighted mean difference (95% CI)) in their VC of 0.32 (0.09, 0.55) litres. This represents a significant effect from an AB on VC. There was also a decrease (weighted mean difference (95% CI)) in FRC by 0.41 (0.14, 0.67) litres when a subject wears an AB (Figure 3), and a decrease (weighted mean difference (95% CI)) in total lung capacity (TLC) by 0.33 (−0.15, 0.81) litres, when the subjects wears an AB (Figure 4), although this latter reduction was not statistically significant.

In the majority of studies, FRC, RV and ERV all decreased with the application of the AB when not supine. Of the three studies, which measured TLC,[4,7,12] the study by McCool *et al.*[12] was the only study to report an increase in TLC with AB use when seated (however, no raw data was provided to allow the pooling of data for effect–size calculations for this study).

Studies, which measured maximum inspiratory pressure (MIP) reported no significant difference with the use of an AB.[3,6,9] Of the two studies, which measured maximum expiratory pressure (MEP), only Boaventura *et al.*[3] found it to be significantly greater for the seated position with the AB.[3,7] The study by Hart *et al.*[7] was the only study to investigate dynamic abdominal compliance. This study demonstrated a decrease in compliance of the abdomen with the AB in place when seated.

The exertion, as reported by subjects, was measured in the study by Hart *et al.*[7] using the Borg scale.[33] A further study by Boaventura *et al.*[3] questioned subjects about their ease of breathing and coughing when wearing the AB. Both of these studies reported less exertion and increased ease of breathing/coughing with the AB in place.

Speech outcomes with an abdominal binder

Only one study in this review has investigated the effect of an AB on respiratory support for speech and voice as measured by listener preference, sound pressure levels, utterance duration, syllables per utterance, pause duration and pause location.[13] Binding the abdomen through a mechanical device (non-elastic) in sitting resulted in increased syllables per utterance (or breath) in all subjects, and increased utterance duration in two of the three subjects. Overall, there was a listener preference for speech with the

Table 4 Abdominal binder type and application

Study	*AB type*	*Application*	*Conclusion*
Boaventura *et al.*[3]	Elastic binder—composed of three different lengths but same width, 20 cm	Costal margin and pelvis position	AB ↑ MEP and FVC when used with tetraplegics in sitting
Goldman *et al.*[6]	Elastic binder—70% viscose, 20% cotton and 10% elastidiene; 20 cm width; three different lengths Thermoplastic—tailor made for each subject, fit beneath lower costal margin and above ASIS	Standardized abdominal compression in all postures; ↓ in the girth of 4.5 cm supine and 7.5 cm seated	Both AB ↑ VC in seated ($P<0.01$) and 70° tilt. No difference in the type of AB overall
Huang *et al.*[8]	Pneumatic binder	Appeared to encroach on lower rib cage; 35 mm Hg compression	No difference in the two groups of different level of tetraplegics. AB, most effective for maintaining CVS, no impact on respiration (measured by TV and RR)
Kerk *et al.*[9]	Elastic—S, M and L and 30 cm width	AB applied to ↓ abdominal girth by 10% or 4–5 cm	No significant effects of AB on any outcomes for highly trained athletes
Lin *et al.*[10]	Elastic—several different models	AB applied to ↓ abdominal girth by 10%. Fitted xiphoid process to pubis	AB alone did not sig. ↑ PEFR. AB combined with elect stimulation significance ↑ PEFR in both groups.
McCool *et al.*[12]	Elastic–nylon	Anteriorly secured with Velcro, costal margin to pubis; folded under costal margin to allow rib cage expansion	Inspiratory effect of AB on augmenting rib cage volume is greater than the effect of impeding diaphragm descent; therefore AB produces a net ↑in TLC
Bodin *et al.*[4]	Non-elastic $44 \times 13\,cm^2$	Standardized compression by inflatable cuff to ensure 40 mm Hg pressure applied	VC ↑with AB; TLC, RV and FRC are less with an AB
Estenne *et al.*[5]	Non-elastic—two or three straps; no picture or further description	Tight abdominal support	Strapping produced only small and inconsistent changes in maximum Vexp and Pes; small effect on forced expiration and unlikely to improve cough ↑ VC <0.002 ↓ FRC, RV 0.001
Hart *et al.*[7]	Non-elastic anterior/posterior, elastic laterally; girdle—50% cotton and 50% polyester galvanized steel stays and stretchable synthetic fabric	No comment	AB resulted in lower Borg score, ↓FRC/ERV/RV/TLC, ↑IC/FVC and ↓abdominal compliance
Maloney[11]	Non-elastic	Tight abdominal support—pubis to xiphoid	In sitting, no true AB effect confirmed. No significant changes in volume and flow with AB in sitting compared with no AB
Watson and Hixton[13]	Custom built rigid plate; mechanical device for trussing (50% inward)	Plate positioned halfway between resting position of abdominal wall and maximum inward position	Abdominal trussing may be useful in improving speech in SCI; only three subjects at not all consistent outcomes

Abbreviations: AB, abdominal binders; CVS, cardiovascular system; ERV, expiratory reserve volume; FRC, functional residual capacity; FVC, forced vital capacity; IC, inspiratory capacity; MEP, maximum expiratory pressure; PEFR, peak expiratory flow rate; Pes, oesophageal pressure; RR, respiratory rate; RV, residual volume; TLC, total lung capacity; TV, tidal volume; Vexp, expiratory flow.

abdomen bound. At the end of each experimental condition, subjects reported less effort to speak in the trussed condition as opposed to the untrussed condition.

Haemodynamic outcomes with an abdominal binder

Only one study measured haemodynamic effects of an AB, and it reported that the AB was significantly more effective than pneumatic leg splints in maintaining systolic blood pressure at pretilt levels and 45° head-up tilt.[8] Seated posture was not measured in this study.

Discussion

Abdominal binders are frequently used among patients with SCI; however, this is the first systematic review investigating the effect of an AB on respiratory, cardiovascular and speech outcomes. Overall, the findings of this systematic review highlight the paucity of information surrounding the use of an aid recommended as standard management by many texts on SCI management.[34–37] Only 11 studies were included in this review, which were mostly low-to-medium quality. All of these studies examined the short-term response of measures that relate mainly to respiratory

Table 5 Study outcome measurements

Study	*Outcome measures*	*Intervention*	*Statistics*	*Results*
Boaventura *et al.*[3]	MIP, MEP and FVC	Seated in their own wheel chair and supine AB versus no AB Weeks 0, 4, 8 and 12	ANOVA and *t*-test	NSD between weeks 0–12 Supine > seated no AB: FVC ($P<0.05$), MIP, MEP and NSD Supine > seated no AB FVC Supine AB versus no AB FVC, MIP, MEP and NSD Seated AB versus no AB FVC, MEP $P<0.05$
Bodin *et al.*[4]	TLC, VC, RV and FRC	Standard chair AB versus no AB DB, PEP 10 cmH_2O, IR-PEP—5 H_2O 10 cmH_2O	Fisher's non-parametric permutations	AB—↓ $P<0.001$ (FRC), ↓ $P<0.01$ (TLC, RV) AB—VC $P<0.01$
Estenne *et al.*[5]	FRC, VC, TLC, RV, Peak Vexp Peak Pes, Flow plateau IVPF curve	Seated in their own wheel chair AB versus no AB	Paired *t*-tests	AB—VC < 0.002, A—FRC, RV ↓ 0.001 AB—peak Vexp NSD, AB—peak Pes NSD
Goldman *et al.*[6]	Sniff Pdi VC Pi_{max}	AB versus no AB versus new binder Supine Seated 70° tilt	Paired *t*-tests	Conventional AB ↑ SniffPdi@70 tilt $P<0.05$, supine/sit sniff Pdi NSD ↑ VC in sitting $P<0.01$ New binder ↑ SniffPdi@70 tilt $P<0.02$, supine/sit sniff Pdi NSD ↑ VC in sitting $P<0.01$ NSD between AB for VC. Pimax NSD by posture or AB
Hart *et al.*[7]	IVC, FVC, IC, FRC, ERV, RV, TLC, FEV1, PEF, PE_{max}, Borg score, TI V_T/T_1, RC-VT, $PtcCO_2$, V_T, f_R, V_E C_{ABdyn}, C_{Ldyn}, Pes_{swing}, Pdi_{swing}, Pdi_{swing} PTP_{di}, Pdi_{max}, TwPdi	Seated in their own wheel chair AB versus no AB	Paired *t*-tests	Pulmonary fx results AB—IVC ($P=0.02$), FVC ($P=0.02$), FEV_1 ($P=0.02$), PEF ($P=0.03$), PE_{max} ($P=0.18$) AB—↓ FRC ($P=0.006$), ERV ($P=0.95$), RV ($P=0.01$), TLC ($P=0.26$) Respiratory mechanics AB—↓C_{ABdyn} ($P=0.001$) Borg scale: ↓ in score ($P=0.02$ 4.3 ± 1.8 to 2.3 ± 1.8)
Huang *et al.*[8]	V_T, RR, REE, Sap, DAP, HR Energy expend, VO_2, BP	Supine versus 20° HU versus, 45° HU versus 20° HD AB versus no AB Leg splints versus no splints	No primary method of analysis stated. *Post hoc* Neumann–Keuls	NSD effect ($P>0.05$) of compressive device with V_T, NSD effect ($P>0.05$) of compressive device with RR, energy expend and VO_2 with devices ($P<0.01$), assistive devices had NSD on SAP except at 20° HU and 45° HU ($P<0.01$), ↓ HR with devices in HU postures ($P<0.01$)
Kerk *et al.*[9]	MIP, FVC During X—HR, VO_2 VCO_2, V_I and R Trunk range of motion and duration of the stroke phase	During exercise tests maximal and submaximal AB versus no AB	Two-way repeated measures ANOVA Paired *t*-tests *Post hoc* Neumann–Keuls	NSD on FVC with AB (5/6 FVC $31\pm15\%$, 1/6 18% ↓ FVC). MIP NSD with AB. NSD with AB for HR, VCO_2, V_I and R
Lin *et al.*[10]	PEFR	Seated Coughing with AB, no AB, AB+FES	MANOVA (multivariate analysis of variance)	Paras-AB—NSD in PP, AB +FES PEFR (*P*, 0.01) compared with NB but not B. Quads-AB—NSD, AB+FES over control ($P<0.01$)

Table 5 Continued

Study	*Outcome measures*	*Intervention*	*Statistics*	*Results*
McCool *et al.*[11]	FRC, TLC, IC,	Supine versus tilted to 37° versus seated, AB versus no AB	Two-way ANOVA Two sample Unpaired *t*-tests	AB ↓ FRC, IC in all positions ($P<0.01$) AB TLC in tilted and sitting only ($P<0.05$)
Maloney[12]	VC, IC, ERV, FEV1, FEV1%, MBC, PEFR, FEF25–75%, V_{max} 50% VC, V_T, PeO_2, $PeCO_2$	Sitting versus supine AB versus no AB	ANOVA	VC corset effect = 0.974 VC position effect = 0.001 VC interaction effect = 0.025 FEV1 corset effect = 0.159 FEV1 position effect = 0.122 FEV1 interaction effect = 0.405 ERV corset effect = 0.568 ERV position effect = 0.163 ERV interaction effect = 0.886
Watson and Hixton[13]	IC, VC, ERV, Utt D, dB SPL, syll Utt, pause, BND LOC, list pref	Sitting with abdominal truss and without	*t*-test	Atruss—IC ($P<0.001$, $P=0.016$, $P=0.022$), VC ($P=0.001$, $P=0.003$, $P=0.001$), NSD for ERV dB SPL—NSD Utt D—two subjects had ($P=0.015$,$P=0.011$) Syll Utt—($P=0.001$, $P=0.049$, $P=0.005$) Pause—NSD

Abbreviations: Atruss, abdominal trussing device; BND LOC, boundary locations; C_{ABdyn}, dynamic abdominal compliance; DAP, diastolic arterial blood pressure; dB SPL, average sound pressure level; FEF25–75%, forced expiratory volume over 25–75% of VC; V_{max} 50%VC, flow at 50% maximum VC; FES, functional electrical stimulation; FEV1, forced expiratory volume in 1 s; F_R, breaths/minute; HD, head down; HR peak, peak heart rate; HR, heart rate; HU, head up; IR-PEP, inspiratory resistance positive expiratory pressure; IVC, inspiratory vital capacity; list pref, listener preference; MBC, maximum breathing capacity; MIP, maximal inspiratory pressure; NSD, no significant difference; Peak Pes, peak oesophageal pressure; Peak Vexp, peak expired volume; $PeCO_2$, end tidal expired CO_2; PEF, peak expiratory flow; PE_{max}, maximal expiratory mouth pressure; PeO_2, end tidal expired oxygen; PEP, positive expiratory pressure; PO, peak power output peak; R, respiratory exchange ratio; SAP, systolic arterial blood pressure; SBP_{max}, maximal systolic blood pressure; Sniff Pdi, transdiaphragmatic pressure during maximal sniff; syll Utt, syllables per utterance; Utt D, utterance duration; V_I, ventilation; VO_2, oxygen uptake; VO_2peak, peak oxygen uptake; V_T, tidal volume.

function. The outcomes recorded varied across all studies making it difficult to compare data. In analysing the methodological quality, it was evident that a number of variables were not well controlled, for example, the type of AB used and the time since injury of the subjects.

Although many studies included subjects across a broad range of time points since injury, it is unclear whether subjects with time since injury of less than 1 year responded differently to those that were several years postinjury. The abdominal wall of patients with SCI, with no innervation of the abdominal muscles, has been found to be twice as compliant of those of healthy people.[38] Therefore, the abdomen is able to be bound with relative ease. With increasing time since SCI, patients may have adaptive migration of the abdominal contents and decreased anterior/posterior chest wall dimensions with the presentation of a 'quad belly'. This increased compliance in the abdominal wall is offset by stiffening of the rib cage.[39,40] The impact of putting on an AB momentarily may enhance VC, but the impact of wearing an AB daily in a group of acute and a group of patients with chronic SCI needs to be investigated.

It is reasonable to assume that for an AB to be effective, it must provide compression. However, the degree of compression/tightness of the AB was not well controlled across studies. Goldman *et al.*[6] compared girth measurement without the AB for normals and tetraplegic subjects, and found that the girth was 6% greater from supine to sitting in the tetraplegic group above that of the normal group. Fitting the AB in the supine position allows for the soft tissue of the abdomen to be compressed more easily than attempting application once in the sitting position (especially for larger subjects). Inadequate or inconsistent levels of compression may result in lack of standardization of compression.[3,5,7,11,12] This may alter any physiological effects of an AB and thus study outcomes.

The type of material making up the AB differed between studies. The elastic material used in some of the ABs could be considered to mimic the 'elastic' nature of the abdominal muscles, which allow the abdomen to expand and recoil with breathing. If a rigid support is applied to the abdomen, it has the potential to completely restrict the abdominal expansion with inspiration. The study by Goldman *et al.*[6] evaluated the use of a standard elastic AB against a custom thermoplastic rigid AB for the same subject, and found that both AB enhanced respiratory volume outcomes to the same extent. However, binding the abdomen with a rigid support may be expected to alter the pattern of breathing such that the upper chest moves, and expansion of the lower ribs and decent of the diaphragm are inhibited. This could be thought of as a less efficient breathing pattern utilizing

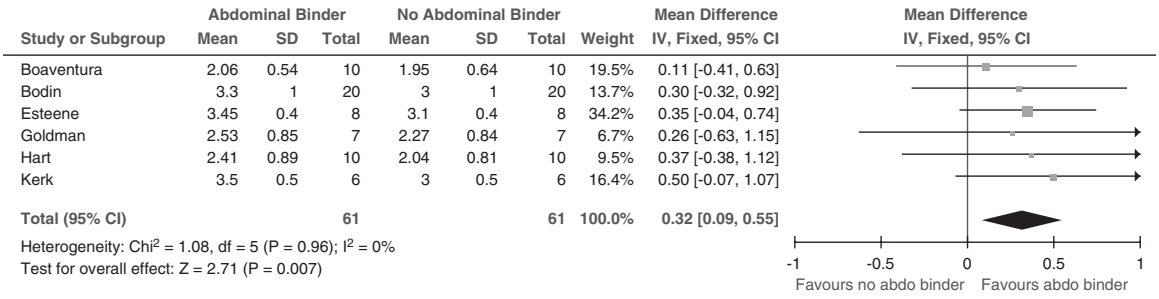

Figure 2 Abdominal binder versus no abdominal binder for vital capacity (VC).

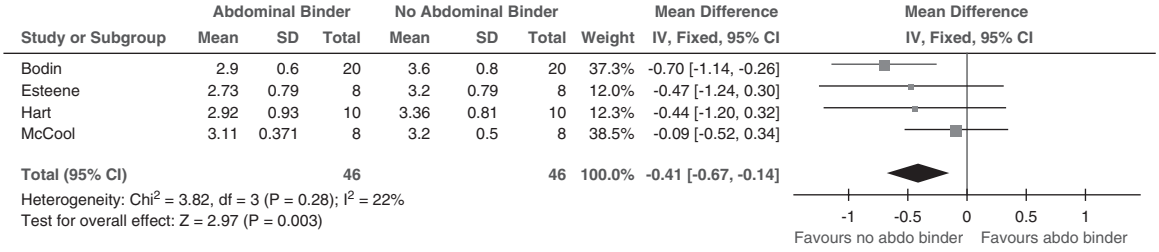

Figure 3 Abdominal binder versus no abdominal binder for functional residual capacity (FRC).

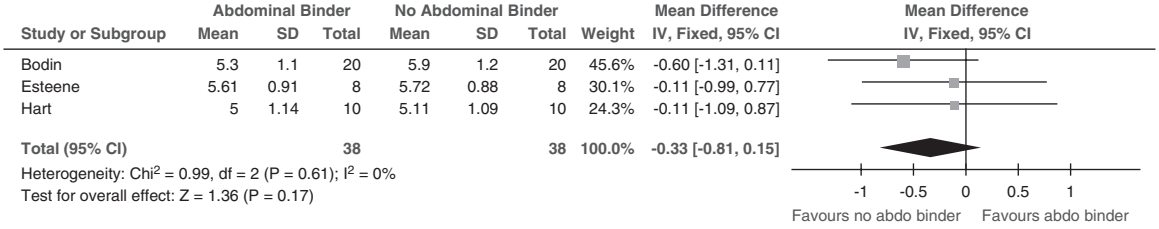

Figure 4 Abdominal binder versus no abdominal binder for total lung capacity (TLC).

more effort to breath at rest. However, the effect of the type of AB on breathing pattern has yet to be investigated.

The upright position adopted by subjects varied across the studies. Most studies utilized sitting in the subjects' own wheelchair to be a test position, although Bodin *et al*.[4] utilized a 'standardized chair with armrests,' which was assumed to be not the subjects' own wheelchair. Although seemingly a logical step to enhance the standardization in a study design, it does introduce potential confounding from patient discomfort during testing. A great amount of effort is required to ensure comfortable seating for people with SCI. Additionally, testing in the patient's usual chair is more likely to reflect the changes in respiratory, speech and cardiovascular function that the patient would expect to see in real life, making it arguably a superior choice for seating position during testing. Huang *et al*.[8] utilized tilt tabling to 45° as an upright position; however, they found that the pneumatic abdominal corset had no significant effect as measured by respiratory rate and tidal volume. Potentially, this is because of the decreased angle of upright used.

No studies performed statistical analysis for an order effect. This meant that it was unclear whether there was any persisting effect of the intervention, that is, application of an AB or change in position, applied first or second in the order of testing. A rest period between the outcome measures is also important to minimize fatigue, and in seven studies, this period was greater than 1 min, which is the minimum rest period recommended by the American Thoracic Society/ European Respiratory Society guidelines.[41] A study by Kelley *et al*.[42] in 2003 proposed modified acceptability standards for the American Thoracic Society spirometry guidelines for use in SCI. However, no studies reported the inclusion of this guideline.

It is a common practice within the group of patients with tetraplegic and high paraplegic SCI to wear an AB on commencement of sitting out of bed in a wheelchair. It has been reported that orthostatic hypotension persists during the first month post-SCI in 74% of cervical motor complete patients.[43] Despite this figure, there has been only one study, which has investigated the effect of AB itself on orthostatic hypotension.[8] Although they found the AB to be effective at maintaining systolic blood pressure at pretilt levels when tilted to 45°, they failed to assess the AB effect when sitting upright. A recent review by Gillis *et al*.[44] found inconclusive evidence for the use of compression/pressure garments to aid

orthostatic hypotension. However, in clinical practice, ABs are commonly used for only the first 6–8 weeks of being upright in a wheelchair after the initial injury. At this point, patients are often weaned from an AB as patients accommodate to postural hypotension and rely less on an AB to assist with minimizing dizziness, nausea and even syncope. The effect of an AB on breathing ability when initially mobilizing in a wheelchair seems to be a secondary consideration. Patients have often reported that their main concern when first sitting in a wheelchair is the fear of fainting. Once this is no longer a real threat, then the ability to talk becomes a concern in high-level SCIs.

Results from the present meta-analysis showed that VC is significantly improved in patients with tetraplegic SCI when wearing an AB in the seated position. However, these studies were not homogenous, and had many variables, minimal subject numbers and investigated the immediate effect of the AB only. Although VC has been shown to improve when wearing an AB in sitting, an AB decreases FRC.[4,5,7,12] Bodin *et al*.[4] have previously hypothesized that ABs cause a decrease in FRC because the diaphragm is pushed in the cranial direction. This causes the inspiratory VC manoeuvre to start from a lower lung volume when using an AB. Four studies measured TLC.[4,5,7,12] Three of these studies used a non-elastic AB and found that VC increased significantly in sitting with an AB. but FRC, RV and TLC decreased. Whether an increase in VC can compensate for the decrease in RV, TLC and FRC should be considered.[4] This decrease in the amount of air that stays in the lungs during normal breathing (FRC) may potentially cause atelectasis leading to retained secretions and pneumonia. However, as all studies to date have looked at AB effect on short-term respiratory function, there have been no studies, which consider whether those patients that continue wearing an AB have more or less respiratory complications.

An important complication of SCI is impaired speech with evidence that patients present with reduced volume, breathiness, roughness of voice and slower speaking rate.[45] Improved respiration by means of a greater VC with an AB is thought to improve the ability to talk by providing more breathe support for speech.[13,22] In complete cervical SCIs, a decrease in inspiratory pressures and resultant decrease in VC may lead to short breath groups (fewer words per breath). This means that a persons' speech has more frequent breaths and is more interrupted when speaking in sentences. A decrease in expiratory pressure may result in a decrease in loudness of speech.[13] Despite this, there have been very few studies investigating the relationship between breathing and speech in the population with SCI. Studies that have investigated the effect of an AB on speech are case studies only (three subjects or less).[13,22,29] Watson *et al*.[13] used a rigid force plate to 'truss' the abdomen of tetraplegic level subjects. Their results suggest that binding the abdomen in this way may improve speech; however, this method is not practical to use within the rehabilitation and community environment. Improving VC in these subjects resulted in speech that contained longer utterance duration for oral reading. Perceptually, two out of three speech pathologists subsequently indicated a preference for the reading samples where subjects are 'trussed'. These outcomes are important as patients who can speak with more volume and do not have to pause for long between words are more likely to fit in with their peers and have confidence to speak in noisy environments. Further investigation needs to be done in this area.

Only one adverse effect was reported when using an AB, and this was discomfort in female subjects because of the AB impinging on the breast line.[9] This may have limited the physiological benefit because of the noxious stimulus. The height of the AB in this study was 30 cm, which in most female subjects would impinge in this area. The height of an AB needs to be considered on an individual basis as trunk height varies in adults. Of the studies using elastic AB, Boaventura *et al*.[3] and Goldman *et al*.[6] used 20 cm (8″), Kerk *et al*.[9] used 30 cm (12″), Huang *et al*.[8] used a pneumatic AB that appeared to be greater than 20 cm and McCool *et al*.[12] and Boaventura *et al*.[3] used an AB that ranged from the pubis to the costal margin, but was either positioned or folded down at the top to ensure that it did not interfere with the lower rib cage. As the diaphragm moves caudally during inspiration, it presses on the abdominal contents, which act as a fulcrum and transmit 'appositional' forces laterally to expand the lower rib cage.[46] It is likely that an AB that interferes with the rib cage will limit the expanding ability of the AB by way of preventing appositional forces.[6]

Future studies

The results of this review highlight the need for more appropriate control of variables for future studies. A homogenous subject group with respect to ASIA classification and time since injury would be recommended. Future research should consider the impact of AB use over time, standardize AB specifications and application procedures, employ random ordering of testing, blinding of investigators, measure respiratory, speech and haemodynamic variables concurrently, test patients in the sitting position in their own wheelchair and investigate abdominal wall compliance and the effect of AB use over time with this.

The effect that decreasing FRC with an AB may have on the ventilation/perfusion of this already respiratory compromised group of individuals, needs to be considered. Feedback from subjects on compliance of wear with longer-term use and the effect of an AB on endurance, fatigue and activities of daily living would be worthy of consideration. Because of the concept that an AB helps restore the abdominal pressures in SCI, the effect on digestion and elimination may also be an interesting question to raise. The effect of an AB on medium term outcomes, such as pneumonia or atelectasis also needs to be considered.

Conclusion

This review found some evidence that an AB improves VC in people who have suffered SCI, and has highlighted the need for greater methodological rigour in trial designs. Available evidence is not yet sufficient to either support or discourage

the use of an AB in this patient population. Further investigation is required.

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