Which Body Position Is the Best for Chest Wall Motion in Healthy Adults? A Meta-Analysis

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BACKGROUND: Chest wall motion is a vital component of the respiratory system. Body position changes disturb joint orientation around the chest wall and results in performance modifications of respiratory muscles and movement surrounding the rib cage and the abdomen. Body position is a priority treatment for preserving and promoting chest wall motion. The objective of the study was to conduct a meta-analysis to provide insight into which body position most effectively improves chest wall motion. METHODS: Medical literature databases were systemically searched up to January 31, 2018. Methodological quality was evaluated by using a checklist for measuring quality. A meta-analysis was performed to evaluate the effects of body positions on chest wall motion. The quality of evidence was judged by using the GRADE (Grades of Recommendation, Assessment, Development and Evaluation) approach. RESULTS: Six studies (5 high- and 1 low-quality) were identified. Our results showed that the sitting position provided greater improvement in chest-wall diameter changes and volume related to rib-cage function versus other body positions (very low to moderate evidence). The supine position demonstrated greater enhancement of chest-wall–diameter changes and volume in the part of the abdomen than the other body positions with very low to moderate evidence. CONCLUSIONS: The results of this review indicated that the sitting position improved the rib-cage compartment of the chest wall, whereas the supine position resulted in the superior enhancement in the part of the abdomen relative to other body positions. These changes in the body position could have some effect on the movements of the rib cage and abdomen and the variations in lung volumes, which need to be interpreted with caution when considering implementation in the clinical setting. *Key words: body position; chest wall motion; antero-posterior diameter change; medio-lateral diameter change; volume variation*; *meta-analysis*. [Respir Care 2018;63(11):1439–1451. © 2018 Daedalus Enterprises]

Introduction

Patients with cardiopulmonary problems often have difficulty breathing and impairments in chest wall motion and lung function.[1-3] A common intervention for addressing these problems is the use of body position changes to make it easier for patients to breathe comfortably and to enhance chest wall motion and lung function.[3-5] Knowledge regarding the specific body positions associated with improvements in breathing, as represented by displacements and volume variations of the chest wall and its compartments,[6,7] is critical for helping patients with cardiopulmonary problems.

Chest wall compartments are classified into 2 parts, the rib cage and the abdomen, that can be differentially influenced by different body positions.[8,9] Good rib cage function for breathing is directly related to intercostal and accessory muscle recruitment and to pressure changes in the lung and pleural cavity. Abdominal function involves contraction of diaphragmatic muscles and pressure changes in

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the intra-abdominal region. Limitations in the rib cage or abdomen compartment directly interfere with the activity of respiratory muscles and lung function, and are associated with an increased risk of respiratory problems and medical complications.[1-3] reduced rib cage expansion and the recruitment of intercostal and diaphragmatic muscles, which then decrease tidal volume, FVC, and FEV_1.[10,11]

Several factors are known to influence chest wall motion, including age, sex, body mass index, and body positions.[2,6,7] Body position is an important extrinsic factor closely associated with chest wall motion.[2,12-14] Changes in body position directly disturb respiratory muscle performance, adapt movement surrounding the chest wall, and the pattern of breathing.[2,12,14,15] Therefore, body position is an important technique that effectively enhances respiratory function[4,5,12,16] There are a number of body positions commonly used in clinical practice. These include the sitting, Fowler, side lying, supine, and prone positions for preserving and promoting chest wall and lung function, thereby reducing the risk of respiratory complications.[4,5,7]

Previous studies reported that changing body positions influences chest wall motion.[7,14] Transition from the sitting to the lying position reduced local chest wall compliance and motions.[7,14] Despite the studies not describing which part or parts of the chest wall change with specific body positions. Furthermore, a systematic review by Nielsen et al[5] found evidence that upright positions versus reclining positions improved lung function in subjects after surgery. However, they found one study[5] in which the supine position resulted in greater abdominal volume variation relative to the Fowler position; another study found no difference between both positions in subjects after surgery. Therefore, the evidence with respect to the influence of body position on chest wall motion is contradictory.

Regardless of these important preliminary findings, there remains little knowledge regarding the effects of body positions on chest wall motion with respect to the 2 compartments of the chest wall. In addition, there has been no meta-analysis that has yet been performed to understand the effects of body positions on chest wall motion in healthy adults. To address these knowledge gaps, we conducted a meta-analysis to provide insight into which body position is most effective for improvements on chest wall motion. The results of this review provide important empirical evidence for the clinician to tailor treatments as well as highlight additional knowledge gaps that require future research.

Methods

Search Strategy

This study was performed according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines.[17,18] A literature search (up to January 31, 2018) was conducted with 5 online databases: ProQuest, Scopus, PubMed, ScienceDirect, and Web of Science. Search terms used MeSH (medical subject headings) and key words. The following key words were combinations of ("body position" or "body posture") and ("chest wall motion" or "ribcage motion" or "chest wall movement" or "chest wall kinematics" or "thoracoabdominal motion"). The search process was conducted by 2 independent reviewers (RS, TK).

Selection of Eligible Studies

First, the 2 reviewers (RS, TK) independently screened titles and abstracts from the search process; second, the reviewers obtained the full texts of the relevant studies and independently evaluated each study by using the inclusion criteria. The included studies were English full-text articles and met the inclusion criteria by following the PICO (population, interventions, comparators, outcomes) model[17,18]:

Population: Adults ages $\geq$ 18 y old; non-smoking or ex-smoking at least 1 y
Interventions: Performed body position during quiet breathing
Comparators: Between body positions
Outcomes: Chest wall motion was examined as follows:

- Anteroposterior (AP) diameter changes at the rib cage ($AP_{rib\ cage}$) and the abdomen ($AP_{abdomen}$)
- Mediolateral (ML) diameter changes at the rib cage ($ML_{rib\ cage}$) and the abdomen ($ML_{abdomen}$)
- Volume (V) variations at the rib cage ($V_{rib\ cage}$) and the abdomen ($V_{abdomen}$)
Study Designs: No restriction on design and publication years

Studies were excluded if they investigated patients or animals. Letters, abstracts, books, conference proceedings, and poster presentations were also excluded.

Discrepancies were resolved by discussion between the 2 reviewers (RS, TK). If there was disagreement between the reviewers, then a third reviewer (PT) made the decision.

Methodological Quality Assessments

Methodological quality was assessed with the validated checklist for health care intervention developed by Downs and Black.[19,20] This tool measured quality in terms of reporting, external validity, internal validity, and power. This study adopted 18 of the 27 items Downs and Black checklists that are applicable for experimental trials.[19,20] From the original version, items 8, 9, 13, 14, 15, 16, 19, 25, and 26 were excluded because these items are related to the observational study. The score in each item was 0 (no), 0 (unable to determine), and 1 (yes), except for item 5 (0 [no], 1 [partial], and 2 [yes]). The score of studies with ≥50% of met items or with ≥9 points indicated high methodological quality.[20-23]

Data Extraction and Synthesis

Data were directly extracted by the 2 reviewers (RS, TK). The studies' characteristics were reported according to authors, publication year, study design, number of participants, body positions, main findings, and methodological quality level. A meta-analysis, by using the generic inverse variance method,[20,24] was performed by pooling the estimated means of all the outcomes. Heterogeneity across studies was assessed by the I^2 value, for which $<$ 40% indicated homogeneity and $>$ 40% represented heterogeneity.[20,24] The fixed-effects model was used to calculate the pooled estimates for each outcome if data were considered homogeneous ($P \geq .05$), whereas the random-effects model was used if the outcome showed heterogeneity ($P < .05$).[20,25] The overall magnitude effects of body positions were reported in mean differences (95% CIs). GetData graph digitizer 2.26 software (RIPE Network coordination centre, Russian Federation) was used to estimate the mean ± SD[26,27] because some included studies[2,15] did not present mean ± SD.

If the included studies were not appropriate for conducting meta-analysis due to presence only one study, then qualitative synthesis was reported in mean differences (95% CIs) for the results. Publication bias across the studies was judged by visual analysis of funnel plots, which were evaluated by using Review Manager 5.3 (The Cochrane collaboration, Westminster, London). Symmetrical funnel plots indicated low risk, whereas asymmetrical funnel plots showed a high risk of publication bias.[28,29] Quality of evidence for all outcomes was evaluated by using the GRADE (Grades of Recommendation, Assessment, Development and Evaluation) approach.[30-32]

Five domains of quality were rated for each comparison: limitations of study design, inconsistency, indirectness, imprecision, and publication bias.[30-32] The quality of evidence started at high for randomized controlled trials or experimental trials, and at low for all observational studies.[30-32] This study began with high quality due to the included studies being experimental trials. The quality of evidence could be downgraded for studies if there were limitations across studies due to a risk of bias, inconsistency, indirectness, imprecision, or publication bias.[30-32] The overall quality of evidence was defined according to the GRADE approach[32] and was presented through the summary of findings.[33]

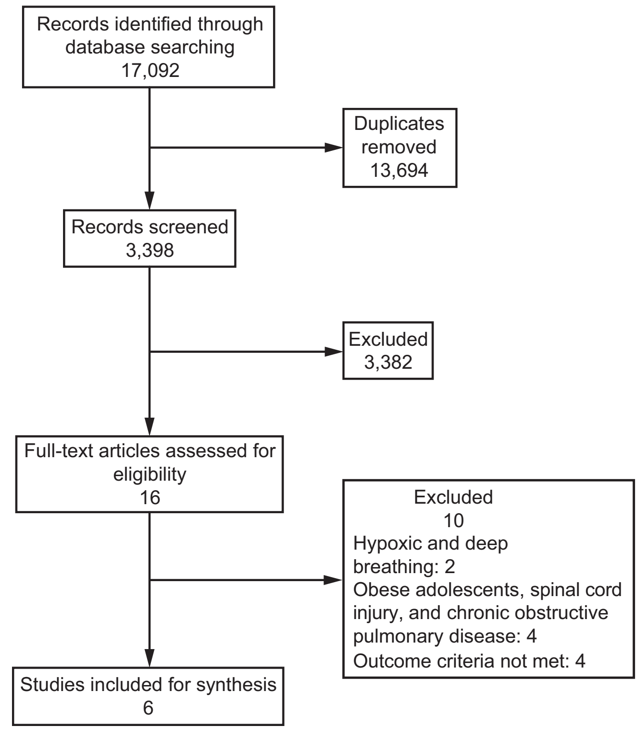

Fig. 1. Flow diagram of the searching and screening process.

Results

Search Strategy

The literature search identified articles published from 1955 to January 31, 2018. After removing duplicates, 3,398 studies were screened. A total of 6 studies met the inclusion criteria and were evaluated for methodological quality and data extraction. All stages of reference selection are displayed in Figure 1.

Methodological Quality of the Studies

The total score of individual studies was between 6 and 14. Five studies indicated high quality,[2,34-37] whereas one study showed low quality[15] (Table 1). No studies reported on allocation concealment.[2,15,34-37] Two studies reported the population source and participant selection,[2,36] whereas we were unable to determine this information in 4 studies[15,34,35,37] Five studies did not report a power analysis.[2,15,34,35,37] Furthermore, 2 studies did not present the actual P values.[34,37] One study did not describe the distribution of confounding factors.[15] We found no publication bias using funnel plot analysis.

Table 1. Methodological Quality of Included Studies

Study, y	Reporting Bias: 8 Items								External Validity: 2 Items		Internal Validity: 7 Items							Power: 1 Item	Total Score (19)	Quality of Study
	1*	2†	3‡	4§	5‖	6¶	7**	8††	9‡‡	10§§	11‖‖	12¶¶	13***	14†††	15‡‡‡	16§§§	17‖‖‖	18¶¶¶		
Aliverti et al,[34] 2001	√	√	√	√	√	√	√	x	x	√	?	√	√	√	?	?	?	?	11	High
Hagman et al,[35] 2016	√	√	√	√	√	√	√	√	?	√	√	√	√	?	?	?	?	?	12	High
Kaneko and Horie,[36] 2012	√	√	√	√	√	√	√	√	√	√	?	√	√	√	?	√	?	x	14	High
Romei et al,[2] 2010	√	√	√	√	√	√	√	√	?	√	√	√	√	?	?	?	x	?	12	High
Takashima et al,[37] 2017	√	√	√	√	√	√	√	x	?	x	?	√	√	?	?	√	?	?	10	High
Vellody et al,[15] 1978	√	√	√	√	x	x	x	√	?	x	?	√	x	?	?	?	?	?	6	Low

The 18 items which adopted from Down and Black checklist in this study were as followed.[19]
* Is the hypothesis, aim, objective of the study clearly described?
† Are the main outcomes to be measured clearly described in the introduction or methods section?
‡ Are the characteristics of the patients included in the study clearly described?
§ Are the interventions of interest clearly described?
‖ Are the distributions of principal confounders in each group of subjects to be compared clearly described?
¶ Are the main findings of the study clearly described?
** Does the study provide estimates of the random variability in the data for the main outcomes?
†† Have actual probability values been reported (eg, .035 rather than <.05) for the main outcomes except when the probability value is <.001?
‡‡ Were the subjects asked to participate in the study representative of the entire population from which they were recruited?
§§ Were those subjects who were prepared to participate representative of the entire population from which they were recruited?
‖‖ If any of the results of the study were based on "data dredging," was this made clear?
¶¶ Were the statistical tests used to assess the main outcomes appropriate?
*** Were the main outcome measures used accurate (valid and reliable)?
††† Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population?
‡‡‡ Were study subjects in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time?
§§§ Were study subjects randomized to intervention groups?
‖‖‖ Was the randomized intervention assignment concealed from both subjects and health-care staff until recruitment was complete and irrevocable?
¶¶¶ Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is <5%?
√ = yes (1 score)
√ = partial of item 5 (1 score)
x = no (0 score)
? = unable to determine (0 score)

Study Characteristics

Six studies were experimental trials.[2,15,34-37] A total of 204 participants, which involved 117 men and 87 women ages between 18 and 74 y (Table 2). Five studies recruited both sexes.[2,15,34-36] One study recruited only male participants.[37] The body positions were standing, sitting, Fowler, side lying, supine, and prone positions. There were different methods for assessing chest wall motion. One study used a linear magnetometer,[15] 1 study used a laser-based technique,[35] 1 study used a 3-dimensional motion system,[36] and 3 studies used optoelectronic plethysmography.[2,34,37] Chest wall motion outcomes included diameter changes and volume variations.

With regard to diameter changes, 1 study evaluated the standing position on AP diameter changes.[35] Five studies investigated the sitting position on AP and ML diameter changes.[2,15,35-37] Five studies explored the supine position on AP and ML diameter changes.[2,15,35-37] Two studies assessed the side-lying position on AP and ML diameter changes.[15,37] One study reported on the prone position on AP and ML diameter changes.[15] One study evaluated the Fowler position on AP and ML diameter changes.[2] Regarding volume variations, 1 study evaluated sitting, Fowler, and supine positions on volume variations.[2] Another study analyzed supine and prone positions on volume variations.[34]

Effects of Body Positions on Chest-Wall–Diameter Changes and Volume Variations

Meta-analyses revealed very low to low evidence for effects of the sitting, supine, and side-lying positions on chest wall–diameter changes. Qualitative synthesis reported low-to-moderate evidence for effects of standing, sitting, Fowler, supine, and prone positions on chest-wall–diameter changes, whereas moderate evidence was reported for effects of sitting, Fowler, supine, and prone positions on volume variations.

Diameter Changes: $AP_{rib\ cage}$ and $AP_{abdomen}$. The diameter changes $AP_{rib\ cage}$ and $AP_{abdomen}$ are presented in Table 3.

- Sitting versus supine: The sitting position had significantly greater $AP_{rib\ cage}$ than the supine position; however, $AP_{abdomen}$ had no difference with low evidence (Fig. 2).[2,15,35-37]
- Sitting versus side lying: There was no difference on $AP_{rib\ cage}$; however, $AP_{abdomen}$ in the sitting position was significantly higher than with the side lying position with very-low evidence (Fig. 3).[15,37]
- Supine versus side lying: Supine and side lying positions had no difference on $AP_{rib\ cage}$ and $AP_{abdomen}$ with very-low evidence (Fig. 4).[15,37]

Table 2. Characteristics of Included Studies

Study, y	Study Design	No. Participants	Age, mean ± SD y	Body Position	Main Findings	Methodological Quality of Study
Aliverti et al,[34] 2001	Experimental (within subject)	$N = 10$ (5 men, 5 women)	28 ± 4.5	Supine and prone	$V_{rib\ cage}$: supine $\leftrightarrow$ prone; $V_{abdomen}$; supine $\leftrightarrow$ prone	High
Hagman et al,[35] 2016	Experimental (within subject)	$N = 20$ (10 men, 10 women)	40 ± 10	Sitting, supine, and standing	$AP_{rib\ cage}$: sitting $>$ supine*, Standing $>$ supine*, sitting $\leftrightarrow$ standing; $AP_{abdomen}$: sitting $<$ supine*, standing $<$ supine*, sitting $\leftrightarrow$ standing	High
Kaneko and Horie,[36] 2012	Experimental (within subject)	$N = 100$ (50 men, 50 women)	44.8 ± 16.5	Sitting and supine	$AP_{rib\ cage}$: sitting $>$ supine* $AP_{abdomen}$: sitting $<$ supine* $ML_{rib\ cage}$: sitting $>$ supine* $ML_{abdomen}$: sitting $<$ supine*	High
Romei et al,[2] 2010	Experimental (within subject)	$N = 34$ (17 men, 17 women)	32.1 ± 8	Sitting, supine, and Fowler position	$AP_{rib\ cage}$: sitting $>$ supine*, Sitting $>$ Fowler*, Fowler $>$ supine* $AP_{abdomen}$: sitting $<$ supine*, Sitting $>$ Fowler*, Fowler $<$ supine* $ML_{rib\ cage}$: sitting $>$ supine*, Sitting $>$ Fowler*, Fowler $\leftrightarrow$ supine $ML_{abdomen}$: sitting $>$ supine*, Sitting $>$ Fowler*, Fowler $\leftrightarrow$ supine $V_{rib\ cage}$: sitting $>$ supine*, Sitting $>$ Fowler*, Fowler $>$ supine* $V_{abdomen}$: sitting $<$ supine*, Sitting $<$ Fowler, Fowler $<$ supine*	High
Takashima et al,[37] 2017	Experimental (within subject)	$N = 15$ (15 men)	27.5 ± 4.6	Sitting, supine, and side lying	$AP_{rib\ cage}$: sitting $>$ supine*, Sitting $\leftrightarrow$ side lying, side lying $>$ supine*; $AP_{abdomen}$: sitting $>$ supine*, sitting $>$ side lying*, side lying $>$ supine* $ML_{rib\ cage}$: sitting $\leftrightarrow$ supine, sitting $>$ side lying*, side lying $<$ supine*; $ML_{abdomen}$: sitting $\leftrightarrow$ supine, sitting $>$ side lying*, side lying $<$ supine*	High

(*continued*)

Table 2. Continued

Study, y	Study Design	No. Participants	Age, mean ± SD y	Body Position	Main Findings	Methodological Quality of Study
Vellody et al,[15] 1978	Experimental (within subject)	N = 25 (20 men, 5 women)	29 ± 5	Sitting, supine, side lying, and prone	$AP_{rib\ cage}$: sitting > supine* Sitting > side lying* Side lying ↔ supine, supine ↔ prone; $AP_{abdomen}$: sitting < supine*, sitting > side lying*, side lying < supine*, supine > prone* $ML_{rib\ cage}$: sitting > supine*, sitting > side lying*, side lying > supine*, supine > prone*; $ML_{abdomen}$: sitting < supine*, sitting < side lying*, side lying > supine*, supine > prone*	Low

* Significant ($P < .05$).
$V_{rib\ cage}$ = volume variation at the rib cage
$V_{abdomen}$ = volume variation at the abdomen
↔ = no difference
$AP_{rib\ cage}$ = anteroposterior diameter change at the rib cage
$AP_{abdomen}$ = anteroposterior diameter change at the abdomen
> = increase
< = decrease
$ML_{rib\ cage}$ = mediolateral diameter change at the rib cage
$ML_{abdomen}$ = mediolateral diameter change at the abdomen

- Standing versus sitting: The standing and sitting positions had no difference on $AP_{rib\ cage}$ and $AP_{abdomen}$ with moderate evidence[35]
- Standing versus supine: The standing position had significantly higher $AP_{rib\ cage}$ but lower $AP_{abdomen}$ than the supine position with moderate evidence[35]
- Fowler versus sitting: The Fowler position had significantly lower $AP_{rib\ cage}$ and $AP_{abdomen}$ than the sitting position with moderate evidence[2]
- Fowler versus supine: The Fowler position had significantly higher $AP_{rib\ cage}$ but significantly lower $AP_{abdomen}$ than the supine position with moderate evidence[2]
- Prone versus supine: Low evidence was reported, showing that there was no difference in $AP_{rib\ cage}$ but that there was significantly lower $AP_{abdomen}$ in the prone than in the supine position[15]

Diameter changes: $ML_{rib\ cage}$ and $ML_{abdomen}$. The Diameter changes $ML_{rib\ cage}$ and $ML_{abdomen}$ are presented in Table 3.

- Sitting versus supine: The sitting and supine positions had no difference on $ML_{rib\ cage}$ and $ML_{abdomen}$ with low evidence (Fig. 2)[2,15,36,37]
- Sitting versus side lying: The sitting and side lying positions had no difference on $ML_{rib\ cage}$ and $ML_{abdomen}$ with very-low evidence (Fig. 3)[15,37]
- Supine versus side lying: The supine and side lying positions had no difference on $ML_{rib\ cage}$ and $ML_{abdomen}$ with very-low evidence (Fig. 4)[15,37]
- Fowler versus sitting: The Fowler position was significantly lower on $ML_{rib\ cage}$ and $ML_{abdomen}$ than the sitting position with moderate evidence[2]
- Fowler versus supine: Fowler and supine positions had no difference on $ML_{rib\ cage}$ and $ML_{abdomen}$ with moderate evidence[2]
- Prone versus supine: The prone position had significantly lower $ML_{rib\ cage}$ and $ML_{abdomen}$ than the supine position with low evidence[15]

Volume Variations: $V_{rib\ cage}$ and $V_{abdomen}$. There were 2 studies that investigated the effects of body positions on volume variations.[2,34] There was moderate evidence that identified that the prone and supine positions resulted in no differences on $V_{rib\ cage}$ and $V_{abdomen}$.[34] There was moderate evidence reported that showed that the sitting position had significantly greater $V_{rib\ cage}$ but lower $V_{abdomen}$ than the supine position.[2] For the Fowler position, there was no difference in $V_{rib\ cage}$, but there was a significantly lower $V_{abdomen}$ than with the supine position.

Table 3. Summary of Evidence for the Effects of Body Position on Chest-Wall– Diameter Changes and Volume Variations

Outcome	Comparator (position)	Mean Difference (95% CI)	Participants, n (no. studies)	Quality of Evidence (GRADE)	Summary of Both Effects and Quality of the Evidence
$AP_{rib\ cage}$, mm	Sitting vs supine	0.93 (0.13 to 1.73)	194 (5)	⊕⊕⊖⊖ (low*†)	Sitting position may positively increase $AP_{rib\ cage}$ more than the supine position
	Sitting vs side lying	0.75 (−0.83 to 2.33)	40 (2)	⊕⊖⊖⊖ (very low*†‡)	$AP_{rib\ cage}$ might be no difference between the sitting and side lying positions
	Supine vs side lying	−0.23 (−0.53 to 0.06)	40 (2)	⊕⊖⊖⊖ (very low*†‡)	$AP_{rib\ cage}$ might be no difference between the supine and side lying positions
	Standing vs sitting	0.0 (−0.09 to 0.09)	20 (1)	⊕⊕⊕⊖ (moderate†)	There is probably no difference in $AP_{rib\ cage}$ between the standing and sitting positions
	Standing vs supine	0.3 (0.30 to 0.30)	20 (1)	⊕⊕⊕⊖ (moderate†)	Standing position has greater $AP_{rib\ cage}$ than the supine position
	Fowler vs sitting	−2.30 (−2.36 to −2.24)	34 (1)	⊕⊕⊕⊖ (moderate†)	The Fowler position had lower $AP_{rib\ cage}$ than the sitting position
	Fowler vs supine	0.86 (0.80 to 0.92)	34 (1)	⊕⊕⊕⊖ (moderate†)	The Fowler position had higher $AP_{rib\ cage}$ more than the supine position
	Prone vs. supine	0.02 (0.00 to 0.04)	25 (1)	⊕⊕⊖⊖ (low†‡)	There may be no difference in $AP_{rib\ cage}$ between the prone and supine positions
$AP_{abdomen}$, mm	Sitting vs supine	−1.91 (−4.11 to 0.29)	194 (5)	⊕⊕⊖⊖ (low*†)	There may be no difference in $AP_{abdomen}$ between the sitting and supine positions
	Sitting vs side lying	0.78 (0.15 to 1.41)	40 (2)	⊕⊖⊖⊖ (very low*†‡)	The sitting position could positively increase $AP_{abdomen}$ compared with the side lying position
	Supine vs side lying	1.17 (−1.97 to 4.31)	40 (2)	⊕⊖⊖⊖ (very low*†‡)	There may be no difference in $AP_{abdomen}$ between the supine and side lying positions
	Standing vs sitting	0.0 (−0.13 to 0.13)	20 (1)	⊕⊕⊕⊖ (moderate†)	There is probably no difference in $AP_{abdomen}$ between the standing and sitting positions
	Standing vs supine	−2.7 (−3.01 to −2.39)	20 (1)	⊕⊕⊕⊖ (moderate†)	The standing position would probably decrease $AP_{abdomen}$ more than the supine position
	Fowler vs sitting	−0.30 (−0.33 to −0.27)	34 (1)	⊕⊕⊕⊖ (moderate†)	The Fowler position would probably decrease $AP_{abdomen}$ more than the sitting position
	Fowler vs supine	−0.80 (−0.81 to −0.79)	34 (1)	⊕⊕⊕⊖ (moderate†)	The Fowler position would probably reduce $AP_{abdomen}$ than the supine position
	Prone vs supine	−3.09 (−3.12 to −3.06)	25 (1)	⊕⊕⊖⊖ (low†‡)	The prone position may decrease $AP_{abdomen}$ than the supine position
$ML_{rib\ cage}$, mm	Sitting vs supine	0.79 (0.02 to 1.56)	174 (4)	⊕⊕⊖⊖ (low*†)	There may be no difference in $ML_{rib\ cage}$ between the sitting and supine positions
	Sitting vs side lying	0.27 (0.00 to 0.53)	40 (2)	⊕⊖⊖⊖ (very low*†‡)	There is no difference in $ML_{rib\ cage}$ between the sitting and side lying position
	Supine vs side lying	−0.26 (−1.59 to 1.07)	40 (2)	⊕⊖⊖⊖ (very low*†‡)	There is no difference in $ML_{rib\ cage}$ between the supine and side lying position
	Fowler vs sitting	−0.88 (−0.94 to −0.82)	34 (1)	⊕⊕⊕⊖ (moderate†)	The Fowler position would probably reduce $ML_{rib\ cage}$ than the sitting position
	Fowler vs supine	0.03 (0.00 to 0.06)	34 (1)	⊕⊕⊕⊖ (moderate†)	There probably is no difference in $ML_{rib\ cage}$ between the Fowler and supine positions
	Prone vs supine	−0.10 (−0.16 to −0.04)	25 (1)	⊕⊕⊖⊖ (low†‡)	The prone position may lower $ML_{rib\ cage}$ more than the supine position
$ML_{abdomen}$, mm	Sitting vs supine	−0.30 (−1.50 to 0.90)	174 (4)	⊕⊕⊖⊖ (low*†)	There may be no difference in $ML_{abdomen}$ between the sitting and supine positions
	Sitting vs side lying	−0.39 (−1.98 to 1.20)	40 (2)	⊕⊖⊖⊖ (very low*†‡)	There were no difference in $ML_{abdomen}$ between the sitting and side lying position
	Supine vs side lying	−0.26 (−1.53 to 1.01)	40 (2)	⊕⊖⊖⊖ (very low*†‡)	There is no difference in $ML_{abdomen}$ between the supine and side lying position
	Fowler vs sitting	−0.52 (−0.64 to −0.40)	34 (1)	⊕⊕⊕⊖ (moderate†)	The Fowler position would probably decrease $ML_{abdomen}$ more than the sitting position
	Fowler vs supine	−0.06 (−0.02 to 0.14)	34 (1)	⊕⊕⊕⊖ (moderate†)	There is probably no difference in $ML_{abdomen}$ between the Fowler and supine positions
	Prone vs supine	−0.50 (−0.51 to −0.49)	25 (1)	⊕⊕⊖⊖ (low†‡)	The prone position may decrease $ML_{abdomen}$ than the supine position
$V_{rib\ cage}$, L	Sitting vs supine	0.17 (0.15 to 0.19)	34 (1)	⊕⊕⊕⊖ (moderate†)	The sitting position would probably increase $V_{rib\ cage}$ than the supine position
	Fowler vs sitting	−0.21 (−0.26 to −0.16)	34 (1)	⊕⊕⊕⊖ (moderate†)	The Fowler position would probably decrease $V_{rib\ cage}$ than the sitting position
	Fowler vs supine	0.04 (0.00 to 0.08)	34 (1)	⊕⊕⊕⊖ (moderate†)	There is probably no difference in $V_{rib\ cage}$ between the Fowler and supine positions
	Prone vs supine	−0.01 (−0.02 to 0.00)	10 (1)	⊕⊕⊕⊖ (moderate†)	There is probably no difference in $V_{rib\ cage}$ between the prone and supine positions
$V_{abdomen}$, L	Sitting vs supine	−0.12 (−0.15 to −0.09)	34 (1)	⊕⊕⊕⊖ (moderate†)	The sitting position would probably decrease $V_{abdomen}$ than the supine position
	Fowler vs sitting	−0.03 (−0.03 to −0.03)	34 (1)	⊕⊕⊕⊖ (moderate†)	The Fowler position would probably reduce $V_{abdomen}$ than the sitting position
	Fowler vs supine	−0.04 (−0.07 to −0.04)	34 (1)	⊕⊕⊕⊖ (moderate†)	The Fowler position would probably decrease $V_{abdomen}$ than the supine position
	Prone vs supine	−0.02 (−0.03 to 0.00)	10 (1)	⊕⊕⊕⊖ (moderate†)	There is probably no difference in $V_{abdomen}$ between the prone and supine positions

* Serious inconsistency (eg, significant heterogeneity between the trials; $I^2 > 75\%$ or $P < .05$).
† Serious imprecision (eg, total sample size of <400).
‡ Serious limitations of the study design (eg, <75% of the participants had a low risk of bias).
GRADE = Grading of Recommendations Assessment, Development and Evaluation
$AP_{rib\ cage}$ = anteroposterior diameter changes at the rib cage
⊕⊕⊖⊖ = low evidence
⊕⊖⊖⊖ = very-low evidence
⊕⊕⊕⊖ = moderate evidence
$AP_{abdomen}$ = anteroposterior diameter changes at the abdomen
$ML_{rib\ cage}$ = mediolateral diameter changes at the rib cage
$ML_{abdomen}$ = mediolateral diameter changes at the abdomen
$V_{rib\ cage}$ = volume variation at the rib cage
$V_{abdomen}$ = volume variation at the abdomen

Study or Subgroup	Mean Difference	SE	Weight	Mean Difference IV, Random, 95% CI
AP diameter at ribcage				
Vellody 1978	171	0.02	20.0%	1.71 (1.67–1.75)
Romei 2010	1.99	0.04	20.0%	1.99 (1.91–2.07)
Kaneko 2012	0.43	0.06	19.9%	0.43 (0.31–0.55)
Hagman 2016	0.2	0.04	20.0%	0.20 (0.12–0.28)
Takashima 2017	0.32	0.005	20.0%	0.32 (0.31–0.33)
Subtotal (95% CI)			100%	0.93 (0.14–1.72)
Heterogeneity: $Tau^2 = 0.81$; $Chi^2 = 6130.97$, df = 4 ($P < .001$); $I^2 = 100\%$				
Test for overall effect: Z = 2.30 ($P = .02$)				
AP diameter at abdomen				
Vellody 1978	−2.67	0.006	20.0%	−2.67 (−2.68 to −2.66)
Romei 2010	−1.98	0.05	20.0%	−1.98 (−2.08 to −1.88)
Kaneko 2012	−3.1	0.02	20.0%	−3.10 (−3.14 to −3.06)
Hagman 2016	−2.7	0.09	20.0%	−2.70 (−2.88 to −2.52)
Takashima 2017	0.9	0.002	20.0%	0.90 (0.90–0.90)
Subtotal (95% CI)			100%	−1.91 (−4.13–0.31)
Heterogeneity: $Tau^2 = 6.41$; $Chi^2 = 355251.83$, df = 4 ($P < .001$); $I^2 = 100\%$				
Test for overall effect: Z = 1.69 ($P = .09$)				
ML diameter at ribcage				
Vellody 1978	1.07	0.022	25.0%	1.07 (1.03–1.11)
Romei 2010	1.63	0.002	25.0%	1.63 (1.63–1.63)
Kaneko 2012	0.47	0.001	25.0%	0.47 (0.47–0.47)
Takashima 2017	−0.02	0.005	25.0%	−0.02 (−0.03 to −0.01)
Subtotal (95% CI)			100%	0.79 (0.02–1.56)
Heterogeneity: $Tau^2 = 0.62$; $Chi^2 = 289639.18$, df = 3 ($P < .001$); $I^2 = 100\%$				
Test for overall effect: Z = 2.00 ($P = .05$)				
ML diameter at abdomen				
Vellody 1978	−0.29	0.034	25.0%	−0.29 (−0.36 to −0.22)
Romei 2010	0.82	0.036	25.0%	0.82 (0.75–0.89)
Kaneko 2012	−1.74	0.033	25.0%	−1.74 (−1.80 to −1.68)
Takashima 2017	0.02	0.083	24.9%	0.02 (−0.14–0.18)
Subtotal (95% CI)			100%	−0.30 (−1.50–0.90)
Heterogeneity: $Tau^2 = 1.50$; $Chi^2 = 2826.83$, df = 3 ($P < .001$); $I^2 = 100\%$				
Test for overall effect: Z = 0.49 ($P = .63$)				

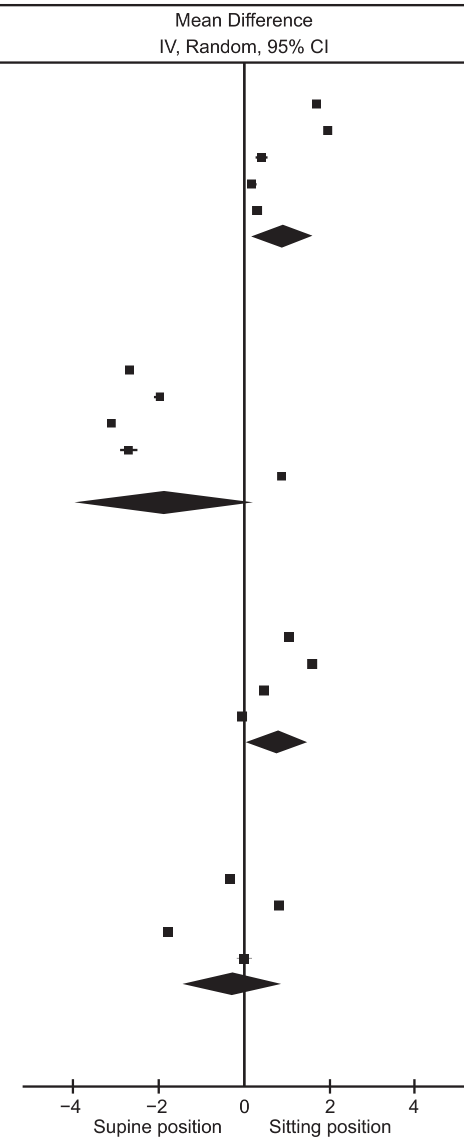

Fig. 2. Meta-analysis of the results of the effects of the body positions on chest-wall–diameter changes between the sitting and supine positions. AP = anteroposterior; ML = mediolateral.

Furthermore, comparison of the Fowler and sitting positions revealed that the Fowler position had significantly lower $V_{rib\ cage}$ and $V_{abdomen}$ than did the sitting position (Table 3).

Discussion

To our knowledge, this study was the first meta-analysis to investigate the effects of body positions on chest wall motion in healthy adults. A systematic search revealed 6 experimental trials[2,15,34-37] with low to high quality. There were 6 body positions examined: standing, sitting, Fowler, side lying, supine, and prone. The current findings supported the assertion that body positions impact chest-wall–diameter changes and volume variations.[2,15,34-37] The evidence in this study was very low to moderate. Our findings demonstrated that the sitting position resulted in greater improvements in chest-wall–diameter changes and volume related to rib-cage function versus other body positions (very low to moderate evidence). The supine position resulted in enhancement in part of the abdomen compared with other body positions. A previous systematic review by Nielsen et al[5] reported evidence on the influence of these body positions on chest wall motion and found that the supine position had more abdominal volume variation than the Fowler position. Some information was similar to our review. However, our review conducted a meta-anal-

Study or Subgroup	Mean Difference	SE	Weight	Mean Difference IV, Random, 95% CI
AP diameter at ribcage				
Vellody 1978	1.56	0.12	49.7%	1.56 (1.32–1.80)
Takashima 2017	−0.05	0.005	50.3%	−0.05 (−0.06 to −0.04)
Subtotal (95% CI)			100%	0.75 (−0.83–2.33)
Heterogeneity: Tau² = 1.29; Chi² = 179.69, df = 1 (*P* < .001); I² = 99%				
Test for overall effect: Z = 0.93 (*P* = .35)				
AP diameter at abdomen				
Vellody 1978	1.1	0.032	50.0%	1.10 (1.04–1.16)
Takashima 2017	0.46	0.026	50.0%	0.46 (0.41–0.51)
Subtotal (95% CI)			100%	0.78 (0.15–1.41)
Heterogeneity: Tau² = 0.20; Chi² = 240.94, df = 1 (*P* < .001); I² = 100%				
Test for overall effect: Z = 2.44 (*P* = .01)				
ML diameter at ribcage				
Vellody 1978	0.13	0.018	49.8%	0.13 (0 09–0.17)
Takashima 2017	0.4	0.002	50.2%	0.40 (0.40–0.40)
Subtotal (95% CI)			100%	0.27 (0.00–0.53)
Heterogeneity: Tau² = 0.04; Chi² = 222.26, df = 1 (*P* < .001); I² = 1 00%				
Test for overall effect: Z = 1.97 (*P* = .050)				
ML diameter at abdomen				
Vellody 1978	−1.14	0.06	49.9%	−1.14 (−1.26 to −1.02)
Takashima 2017	0.42	0.01	50.1%	0.42 (0.40–0.44)
Subtotal (95% CI)			100%	−0.36 (−1.89–1.17)
Heterogeneity: Tau² = 1.21; Chi² = 657.73, df = 1 (*P* < .001); I² = 100%				
Test for overall effect: Z = 0.46 (*P* = .65)				

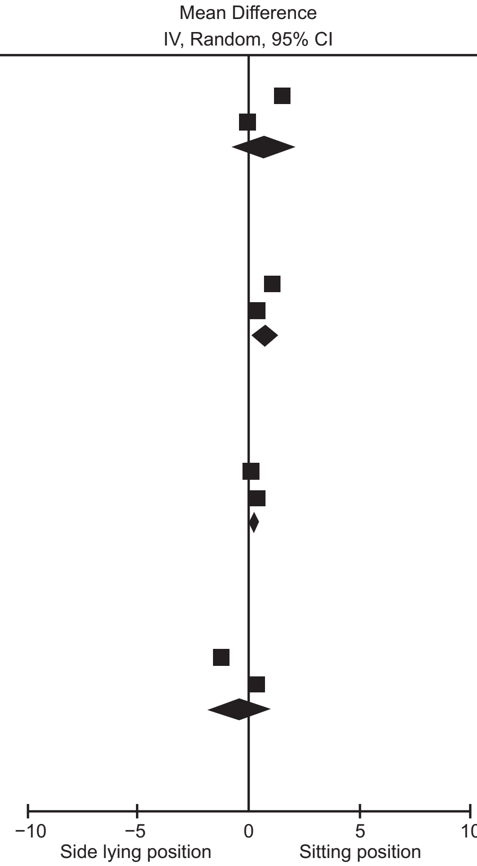

Fig. 3. Meta-analysis of the results of effects of the body positions on chest wall–diameter changes between the sitting and side lying positions. AP = anteroposterior; ML = mediolateral.

ysis of all published studies to date to determine more-robust estimates of the strength of the effect of 6 body positions on 2 directions of chest-wall–diameter changes and volume variations.

Methodological Considerations

Six included studies were rated as low to high quality.[2,15,34-37] Factors that contributed to the risk of bias in this study were unreported allocation concealment, source population and participant selection, distribution of confounding factors, the actual *P* value, and power analysis. All studies were not reported the concealed assignments.[2,15,34-37] Allocation concealment should be performed to minimize selection bias. Furthermore, the lack of experimental blinding might have affected the estimated effects of the results.[38] Moreover, 1 study (17%) did not report means ± SDs and effect size to determine the power analysis.[36] This could not be determined in 5 studies (83%).[2,15,34,35,37] Performing power analysis is critical because, without these calculations, the precision of the results of the sample size could be lacking.[39]

Source population and selection of participants could not be determined in 4 studies (67%).[15,35-37] The source population and sampling methods provided external validity. The influence of the lack of a reporting source and sampling methods of the participants was that the results were not generalizable to the population.[39] One study (17%) did not describe the distribution of the main confounding factors, for example, sex and age.[15] The lack of controlling confounding factors could directly under- or overestimate the effects of the results.[2,7,36] Furthermore, 2 studies (33%) did not present actual *P* values.[34,37] The actual *P* value should be stated to eliminate reporting bias. If it is not, then the results might not be representative of the true significant effects.[39] Therefore, concealed assignment, source population and participant selection, power analysis, confounding factors, and actual *P* values to eliminate bias should be incorporated into the research and be reported in the articles.

Study Characteristics

The 6 included studies were mixed regarding sex and age.[2,15,34-37] Sex and age differences could affect chest

Study or Subgroup	Mean Difference	SE	Weight	Mean Difference IV, Random, 95% CI
AP diameter at ribcage				
Vellody 1978	−0.05	0.14	39.9%	−0.05 (−0.32–0.22)
Takashima 2017	−0.36	0.01	60.1%	0.36 (−0.38 to −0.34)
Subtotal (95% CI)			100%	−0.24 (−0.53–0.06)
Heterogeneity: $Tau^2 = 0.04$; $Chi^2 = 4.88$, df = 1 ($P < .001$); $I^2 = 80\%$				
Test for overall effect: Z = 1.56 ($P = .12$)				
AP diameter at abdomen				
Vellody 1978	2.77	0.04	50.0%	2.77 (2.69–2.85)
Takashima 2017	−0.43	0.02	50.0%	−0.43 (−0.47 to −0.39)
Subtotal (95% CI)			100%	1.17 (−1.97–4.31)
Heterogeneity: $Tau^2 = 5.12$; $Chi^2 = 5120.00$, df = 1 ($P < .001$); $I^2 = 100\%$				
Test for overall effect: Z = 0.73 ($P = .46$)				
ML diameter at ribcage				
Vellody 1978	−0.94	0.024	50.0%	−0.94 (−0.99 to −0.89)
Takashima 2017	0.42	0.003	50.0%	0.42 (0.41–0.43)
Subtotal (95% CI)			100%	−0.26 (−1.59–1.07)
Heterogeneity: $Tau^2 = 0.92$; $Chi^2 = 3176.71$, df = 1 ($P < .001$); $I^2 = 100\%$				
Test for overall effect: Z = 0.38 ($P = .70$)				
ML diameter at abdomen				
Vellody 1978	−0.91	0.078	50.1%	−0.91 (−1.06 to −0.76)
Takashima 2017	0.39	0.093	49.9%	0.39 (0.21–0.57)
Subtotal (95% CI)			100%	−0.26 (−1.53–1.01)
Heterogeneity: $Tau^2 = 0.84$; $Chi^2 = 114.71$, df = 1 ($P < .001$); $I^2 = 99\%$				
Test for overall effect: Z = 0.40 ($P = .69$)				

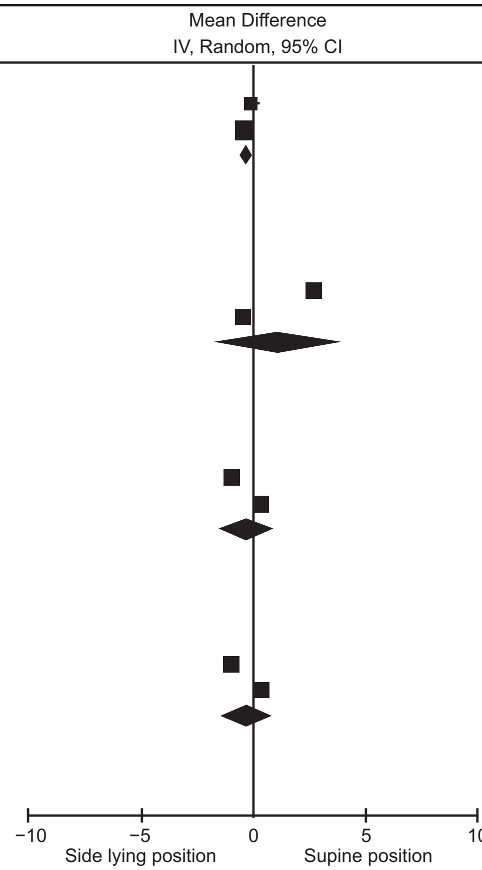

Fig. 4. Meta-analysis of the results of effects of body positions on chest-wall–diameter changes between the supine and side lying positions. AP = anteroposterior; ML = mediolateral.

wall motion.[2,7,36] Previous studies found that females had smaller dimensions of the chest wall and motion[2] and a more costal breathing pattern than males.[40] Furthermore, the participants in this study varied in age (range, 18–74 y), and this could affect the results of chest wall motion. Although pooled estimates data in this study presented heterogeneity ($I^2 > 40\%$), we used a random-effects model for adjusting the variation of data. The random-effects model was employed for reducing heterogeneous of data.[20,25]

Methods to measure chest wall motion, including diameter and volume, also varied among the included studies: linear magnetometer,[15] 3-dimensional motion system,[36] and optoelectronic plethysmography.[2,34,37] The linear magnetometer is a simple and inexpensive method that assesses only 1-dimensional chest wall changes and is inadequate for estimating chest wall volumes, whereas the 3-dimensional motion and optoelectronic plethysmography systems are complex and expensive methods able to evaluate 3-dimensional chest wall changes and estimate chest-wall volume changes. Although the studies used different methods, all the methods had good reliability and validity compared with spirometers.[9,41,42]

Effects of Body Positions on Chest Wall Motion

Diameter Changes: $AP_{rib\ cage}$ and $AP_{abdomen}$. We found very low to moderate evidence for the sitting position having superior improvement in $AP_{rib\ cage}$ compared with other reclining positions.[2,15,35-37] This result agreed with previous studies that found the sitting position had higher $AP_{rib\ cage}$ than the lying positions.[6,7] The improvement of $AP_{rib\ cage}$ in the sitting position may be due to less gravitational compression around the thorax, which results in higher chest-wall compliance, greater mechanical advantage of intercostal muscle length, and contraction and lower resistance to diaphragmatic contraction than the supine position.[1,14,16,43-45] Moreover, elevated venous return in the lying positions may increase intrapulmonary pressure from intrathoracic accumulation of blood flow, which may cause resistance to lung inflation, which results in decreased $AP_{rib\ cage}$.[46] In addition, the results showed very low to moderate evidence that the supine position was superior in enhancing $AP_{abdomen}$ compared with the other positions. This was probably caused by a stiffer rib cage than the abdomen compartment.[45] Furthermore, magnetic resonance imaging showed that the supine position was associated with greater motion in the posterior part of the diaphragm, which results in greater chest wall motion in part of the abdomen than when in the sitting position.[47] The evidence of body positions on AP diameter changes indicated that the sitting position could lead to more improvements in the $AP_{rib\ cage}$ than the lying positions. Furthermore, the supine position could be superior in enhancing $AP_{abdomen}$ than the other body positions. Nevertheless, the evidence was very low to moderate. More studies are needed to confirm these effects of the sitting and supine positions.

Diameter Changes: $ML_{rib\ cage}$ and $ML_{abdomen}$. The results of $ML_{rib\ cage}$ and $ML_{abdomen}$ changes were the same as $AP_{rib\ cage}$ and $AP_{abdomen}$, which revealed very low to moderate evidence for higher $ML_{rib\ cage}$ in the sitting position and $ML_{abdomen}$ in the supine position.[2,15,35-37] An increase of $ML_{rib\ cage}$ in the sitting position might be due to the lower gravitational forces that act on the chest wall, which results in greater rib cage compliance, greater intercostal muscle performance, and smaller resistance to diaphragmatic excursion than in the supine position.[1,14,16,43-45] In addition, our results showed very low to moderate evidence that the supine position was superior for enhancing $ML_{abdomen}$ compared with the other positions. It was possible that a stiffer rib cage and higher motion in the posterior part of the diaphragm resulted in higher $ML_{abdomen}$ in supine position than the other positions.[45] This study recommends that $ML_{rib\ cage}$ could predominate in the sitting position compared with the lying positions, whereas $ML_{abdomen}$ was superior in the supine position. However, the evidence was very low to moderate. Further studies are required to expand the level of evidence.

Volume Variations: $V_{rib\ cage}$ and $V_{abdomen}$. Only 2 studies investigated the effects of body positions on volume variations.[2,34] One study found that there was no difference in volume variations between the prone and supine positions (moderate evidence).[34] Although there was no difference, prone positioning tended to be associated with lower volume variations due to diminishing anterior chest-wall compliance and diaphragm motion compared with the supine position. Another study with moderate evidence showed that the sitting position had higher $V_{rib\ cage}$ than the supine and Fowler positions, whereas supine position had greater $V_{abdomen}$ than the other positions.[2] Increased $V_{rib\ cage}$ in the sitting position was in line with a previous study that indicated that the sitting position had significantly higher $V_{rib\ cage}$ than $V_{abdomen}$.[48] This might be because the sitting position had less effect of gravitation but more rib cage compliance and better intercostal muscle function, which led to increased $V_{rib\ cage}$ than the other body positions.[2,7] Furthermore, there was moderate evidence that $V_{abdomen}$ in the supine position improved compared with other body positions. This finding concurred with a previous study that the supine position had significantly higher $V_{abdomen}$ than $V_{rib\ cage}$.[49] In addition, $V_{abdomen}$ in the supine position had strong correlation with diaphragmatic excursion.[49] It is possible that there was less tension when in the supine position between the diaphragm and the abdominal wall, which resulted in more diaphragmatic excursion and abdominal wall motion than the other body positions.[45,50] When considering volume variations, the sitting position probably improves $V_{rib\ cage}$, whereas $V_{abdomen}$ may be greater in the supine versus the other body positions, although these results came from a single study[2] (moderate evidence). Further studies should focus on the effects of body positions on volume variations.

Limitations

There are 3 main methodological limitations of this study. First, systematic searching included only full texts in English. Language restrictions may result in a lack of related research written in other languages that may affect the results of this study. Second, well-designed studies (randomized controlled trials) were not identified in this review. Randomized controlled trials would help to identify the causal effects of body positions on chest wall motion. Third, Existing systematic reviews and meta-analysis are limited in number of studies and quality of evidence. The findings in this study should be interpreted with care because some of the evidence came from a single study. More studies are needed to upgrade the quality of the evidence and clarify the findings.

Conclusions

This study supported the assertion that body positions influence chest wall motion, including diameter changes and volume variations. Our findings revealed that the sitting position had more positive improvements on chest wall motion in part of the rib cage, whereas the supine position was able to more positively enhance chest wall motion in part of the abdomen than the other body positions with very low to moderate evidence. These changes in the body's position could have some effect on the movements of the rib cage and abdomen, and the variations in lung volumes. The results of this systematic review need to be interpreted with caution when considering implementation into the clinical setting. Moreover, the physiologic basis of the changes in respiratory function should be considered. Furthermore, the evidence in this study is limited in terms of the numbers and quality of studies. Therefore, more high-quality evidence is required to elucidate the effects of the body positions.

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