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The association between spinal column deformity and breathing function: A systematic review

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1. Introduction

“Spinal column deformity” includes conditions such as idiopathic juvenile scoliosis, congenital scoliosis, post-traumatic lesions and other spinal deformities such as kyphosis (Szopa and Domagalska-Szopa, 2017). People with many types of spinal deformities, reported a high incidence of dyspnea on exertion and reduced vital capacity (VC). There is a significant risk of mortality and death in people with untreated scoliosis (Lin et al., 2004).

Scoliosis is considered a common disorder with an overall prevalence of 0.47%–5.2% (Konieczny et al., 2012). The rib cage and spine can be affected (Lenke et al., 2002). Back pain, poor body image, and impaired pulmonary function are reported to be the most considerable complication of an idiopathic scoliosis (McPhail et al., 2015).

Bad posture seems to be one of the most common paradigms in physical therapy, adversely affecting the musculoskeletal system, resulting in the development of breathing disorders and death from cor-pulmonale (Rizzi et al., 1997). The tidal volume (TV) and minute ventilation (MV) in erect sitting position are considered to be more than in the curved sitting posture (Landers et al., 2003). Due to the kyphosis or kypho-scoliosis, forward compression of the ribs on both sides of the chest (McPhail et al., 2015; Rizzi et al., 1997), posterior translation of the pelvis, hip extension, knee flexion and ankle dorsiflexion occur (Bruno et al., 2012). Therefore, the vertical excursion and lateral expansion of the rib wall seems to be reduced and is associated with an increasing kyphosis angle (McMaster et al., 2007). Additionally, Compression of the rib cage decreases the curvature of the diaphragm and impairs its movement (Janssens et al., 2005; McMaster et al., 2007).

The ability of the thorax to expand and return into a resting position during inspiration and exhalation depends on the thoracic spine and rib cage mobility (Upadhyay et al., 1995). A thoracic spine malalignment may alter the mechanics of the chest wall, and the thorax expansion will be decreased. Previous studies conducted on scoliosis demonstrated a significant correlation between thoracic spine posture and subsequent lung volumes (Landers et al., 2003).

Some factors have a strong relationship with the development of cardiopulmonary dysfunction in patients with spinal deformity as follows: the angle of scoliosis, the kyphotic angle, the number of vertebrae included in the scoliotic curve, the degree of spinal rotation, the obliquity of the pelvic and unbalanced spine, the age at onset, the duration of the deformity, the respiratory muscle strength and concurrent respiratory disorders (Graham, 1988; Kearon et al., 1993).The thoracic deformity can damage the pulmonary vessels and lead to the inhibition of the alveoli growth and a decrease in the pulmonary volume (Rizzi et al., 1997). Associated with the progression of the thoracic deformity, a higher breathing effort will be needed and will result in restrictive pulmonary disease-causing alveolar hypoventilation (Shannon, 1970; Winter et al., 1975; Rawlins et al., 1996; Kim et al., 2005).

The multidimensional effects of spinal deformities on the physical and psychological aspects of the human body were demonstrated in a number of studies (Lin et al., 2004; Vitale et al., 2008; Rizzi et al., 1997; Sperandio et al., 2015; Szeinberg et al., 1988; Szopa and Domagalska-Szopa, 2017). In previous investigations, a significant correlation was reported between the

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degree of the spinal column deformity and breathing function (Johnston et al., 2011; Leong et al., 1999; Pehrssonet al., 1991; Smyth et al., 1984). Some studies demonstrated a weak or not-significant correlation (Newton et al., 2005; Redding et al., 2008), resulting in a number of disagreements. According to the above-mentioned relationship, the purpose of this study was to systematically review the published studies between 1960 and 2018 carried out on the association between spinal column deformities and breathing function.

2. Methods

2.1. Search strategy

The available databases such as Web of Science, Science Direct, PubMed, Scopus, Physiotherapy Evidence Database (PEDro), Clinical Key, Ovid, Medline and ProQuest were searched to find relevant articles from 1960 to the November 2018. The following key words were used: “spinal column deformity”, congenital abnormalities of the spine, congenital deformities of the spine, “breathing function”, “respiratory function”, “breathing physiology”, “respiratory physiology”, “breathing disorders”, “scoliosis”, “kyphosis” and “kyphoscoliosis”. The search strategy was carried out according to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Liberati et al., 2009) (Fig. 1).

2.2. Study selection

The inclusion criteria of the present systematic review considered studies published in the English language, studies which investigated the breathing function in people with spinal deformities without pulmonary diseases, case–control, cohort or cross-sectional studies conducted on the association between the spinal column deformities and the breathing function. Studies were eligible if information based on population, intervention, comparison, outcomes, and study design (PICOS) appeared in the title or abstract. The PICO was considered as follows: P: patients with spinal deformity, I: pulmonary function tests, C: association between spinal deformity and pulmonary disorders, O: factors related to the pulmonary function such as VC, TV etc. The articles were published in other languages were not included in the present systematic review. The study protocol was determined as a randomized control trial and the abstracts of articles published in conference or seminar proceedings were excluded from the present systematic review.

2.3. Data extraction and quality assessment

Two reviewers KhK and FR) independently searched the databases to find potential relevant studies. The third reviewer (MR) checked the articles found by the two reviewers. Kappa statistics were used to assess agreement between the two reviewers on article selection. Kappa values less than 0.4 indicate low association; values between 0.4 and 0.75 indicate medium association, and values greater than 0.75 indicate high association between the two raters (Maher et al., 2003). Selected articles categorized based on population, outcome, and study design. Then, a discussion panel was held to resolve any disagreement in the outcomes. A variety of study designs such as cohort, case control and case

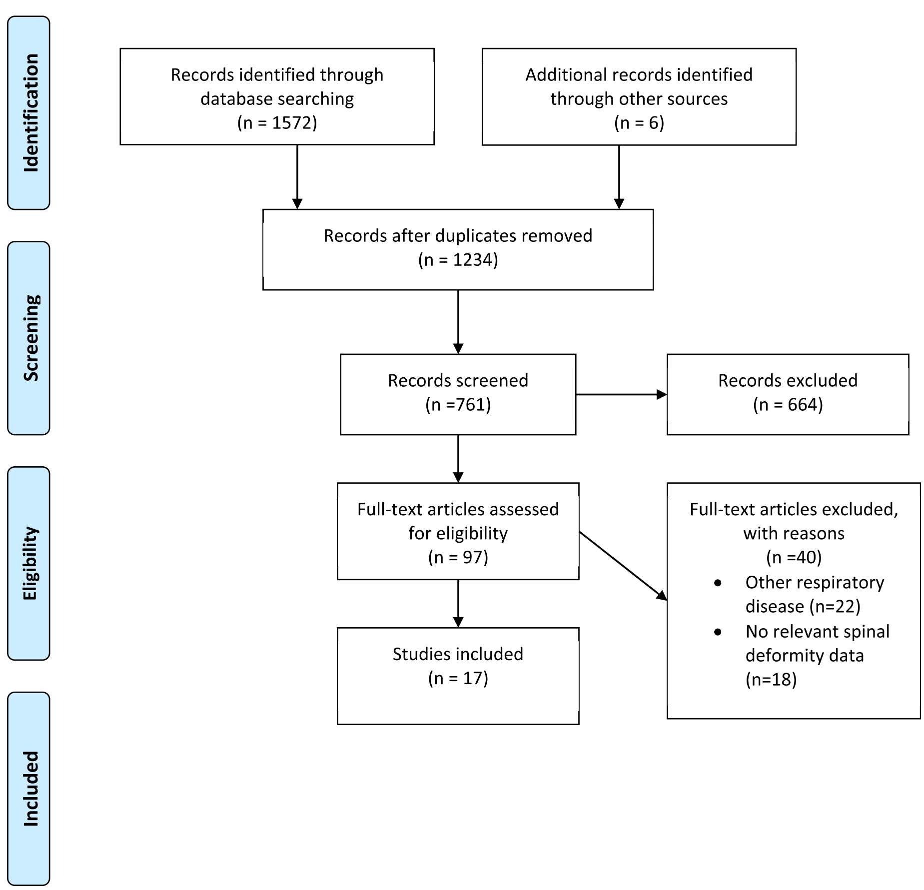

Fig. 1. PRISMA flow digram of search strategy.

study were included in the present systematic review. The Critical Appraisal Skills Program (CASP) with a brief checklist was used to evaluate the quality of the included articles. These checklists were downloaded for free, with their use under the "Creative Commons License" according to the CASP UK website and easy (Nadelson S and Nadelson LS, 2014). This scale consisted of 11 questions for case-control and cross-sectional studies and 12 questions for cohort studies. The first two questions are screening questions and can be answered quickly. If the answer to both is "yes", it is worth proceeding with the remaining questions. There is some degree of overlap between the questions, "yes", "no" or "can't tell" to the most of the questions can be answered. Then, the discussion panel was held to resolve any disagreement in the outcomes. Disagreements on methodological quality were resolved with discussion or by the third reviewer.

3. Results

1579 articles were found in the initial search. Of these articles, 383 duplicates were excluded from the study and another, 1179 articles were excluded according to the screening of the titles and abstracts of the studies. Finally, 17 relevant articles remained to be reviewed. The details of the relevant studies were listed in Table 4. Based on the CASP tool, all cohort and case-control studies and four of the five cross-sectional studies (80%)were assessed as being of high clinical applicable studies. Of these, only one cross-sectional study remained without the potential of clinical applicability. 16 of 17 studies(94.11%)satisfied the quality assessment tool items. All studies conducted on children with spinal deformities had "high clinical applicability" (Boyer et al., 1996; Redding et al., 2008; Szopa and Domagalska-Szopa, 2017). Of all studies investigated on adults (Alves et al., 2009; Caro and DuBois, 1961; Farrell and Garrido, 2018; Johari et al., 2016; Kotani et al., 2004; Leong et al., 1999; Martinez-Llorens et al., 2010; McMaster et al., 2007; Pehrsson et al., 1991; Newton et al., 2005; Smyth et al., 1984; Sperandio et al., 2015; Szeinberg et al., 1988), only one article remained with "potential clinical applicability" (Johnston et al., 2011). The CASP results are summarized in Tables 1–3.

3.1. Study design

Six of the 17 articles were cohort (Johari et al., 2016; Alves et al., 2009; Redding et al., 2008; Newton et al., 2005; Boyer et al., 1996; Pehrsson et al., 1991), six articles were case-control (Farrell and Garrido, 2018; Martinez-Llorens et al., 2010; Kotani et al., 2004; Leong et al., 1999; Szinberg et al., 1988; Caro and DuBois, 1961) and five articles were cross-sectional studies (Szopa and Domagalska-Szopa, 2017; Sperandio et al., 2015; Johanston et al., 2011; McMaster et al., 2007; Smyth et al., 1984).

3.2. Study population

In three studies of the seventeen included articles, children participated to be evaluated (Boyer et al., 1996; Redding et al., 2008; Szopa and Domagalska-Szopa, 2017), and in the remaining 14 articles adolescents were investigated (Alves et al., 2009; Caro and DuBois, 1961; Farrell and Garrido, 2018; Johari et al., 2016; Johnston et al., 2011; Kotani et al., 2004; Leong et al., 1999; Martinez-Llorens et al., 2010; McMaster et al., 2007; Pehrsson et al., 1991; Newton et al., 2005; Smyth et al., 1984; Sperandio et al., 2015; Szeinberg et al., 1988).

3.2.1. Scoliosis

14 studies met the inclusion criteria and were conducted on patients with an idiopathic scoliosis disorder (Alves and Avanzi, 2009; Boyer et al., 1996; Caro and DuBois, 1961; Farrell and Garrido, 2018; Johari et al., 2016; Johnston et al., 2011; Kotani et al., 2004; Leong et al., 1999; Martinez-Llorens et al., 2010; Pehrsson et al., 1991; Newton et al., 2005; Smyth et al., 1984; Sperandio et al., 2015; Szeinberg et al., 1988; Szopa and Domagalska-Szopa, 2017), one of them was conducted on the patients suffering from congenital scoliosis (Redding et al., 2008).

3.2.2. Kyphosis and kypho-scoliosis

Two of seventeen studies included in the present systematic review were carried out in patients with kyphoscoliosis (Caro and DuBois, 1961; McMaster et al., 2007).

3.3. Outcome

Some breathing parameters were measured as the static and dynamic volumes in the reviewed articles. Five studies investigated the Total Lung Capacity (TLC) (McMaster et al., 2007; Newton et al., 2005; Leong et al., 1999; Pehrsson et al., 1991; Smyth et al., 1984), three of seventeen studies were evaluated the VC (Szopa and

Table 1
Critical appraisal skill program(CASP) for assessing the methodological quality for the cohort studies.

Study / Criterion	Johari et al. (2016)	Alves et al. (2009)	Redding et al. (2008)	Newton et al. (2005)	Boyer et al. (1996)	Pehrsson et al. (1991)
Clearly focused issue	Yes	Yes	Yes	No	Yes	Yes
Acceptable recruitment	Yes	Yes	Yes	Yes	Yes	
Exposure accurately measure to minimize bias	Yes	Yes	Yes	Yes	Yes	Yes
Outcome accurately measure to minimize bias	Yes	Yes	Can't tell	Yes	Yes	Yes
Confounding factors Identified	Can't tell	Yes	Yes	Can't tell	Yes	Can't tell
Confounding factors in the design and/or analysis accounted	Can't tell	Yes	Yes	Can't tell	Yes	Can't tell
Complete follow up	Yes	Can't tell	No	Yes	Can't tell	Yes
Follow up duration	Yes	No	No	Yes	No	Yes
Results	Yes	Yes	Yes	Yes	Can't tell	Yes
Precise of the results	Yes	Yes	No	Yes	Yes	Yes
Reliability of the results	Yes	Yes	Yes	Yes	Yes	Yes
Ability to generalize results	Yes	Yes	Yes	Yes	Yes	Yes
Interpretation related to the existing evidence	Yes	Yes	Yes	Yes	Yes	Yes
Practical implication	Yes	Yes	Yes	Yes	Can't tell	Yes
Total score	13	12	10	12	11	12
Applicability	Highly	Highly	Highly	Highly	Highly	Highly

Table 2
Critical appraisal skill program(CASP) for assessing the methodological quality for the case-control studies.

Study / Criterion	Farrell et al. (2018)	Martinez et al. (2010)	Kotani et al. (2004)	Leong et al. (1999)	Szinberg et al. (1988)	Caro et al. (1961)
Clearly focused issue	Yes	Yes	Yes	Yes	Yes	Yes
Appropriate method	Yes	Yes	Yes	Yes	Yes	Yes
Acceptable recruitment	Yes	Yes	Yes	Yes	No	Yes
Acceptable control	Yes	Yes	Yes	Yes	Yes	Yes
Exposure accurately measure to minimize bias	Yes	Yes	Yes	Yes	Yes	Yes
Groups treated equally	Yes	Yes	Yes	Yes	Yes	Yes
Confounding factors accounted	Yes	Yes	Yes	Can't tell	Yes	Can't tell
Treatment effect	Can't tell	Yes	Can't tell	Can't tell	Yes	Can't tell
Precise of treatment effect	Yes	Yes	No	Yes	Yes	Can't tell
Reliability of the results	Yes	Yes	Yes	Yes	Yes	Yes
Ability to generalize results	Yes	Yes	Yes	Yes	Yes	Yes
Interpretation related to the existing evidence	Yes	Yes	Yes	Yes	Yes	Yes
Total score	11	12	10	11	11	10
Applicability	Highly	Highly	Highly	Highly	Highly	Highly

Table 3
Critical appraisal for the cross-sectional studies.

Study / Criterion	Szopa et al. (2017)	Sperandio et al. (2015)	Johnston et al. (2011)	McMaster et al. (2007)	Smyth et al. (1984)
Clearly focused questions/issue	Yes	Yes	Yes	Yes	Yes
Appropriate method	Yes	Yes	Yes	Yes	Yes
Clearly described the method of subject selection	Yes	Yes	Yes	Yes	Yes
Sample selection bias	No	No	No	No	Can't tell
Ability to generalize to the population	Yes	Yes	Yes	Yes	Yes
Statistical power	Can't tell	Can't tell	Can't tell	Can't tell	Can't tell
Satisfactory response rate	Yes	Yes	Yes	Yes	Yes
Validity and reliability of measurements	Yes	Yes	No	Yes	Yes
Assessment of statistical significance	Yes	Yes	Yes	Yes	Yes
Explanation of confidence interval	Yes	No	No	No	No
Confounding factors accounted	No	Yes	No	Yes	Can't tell
Ability to generalize results	Yes	Yes	Yes	Yes	Yes
Total score	9	9	7	9	9
Applicability	Highly	Highly	Potentially	Highly	Highly

Domagalska-Szopa, 2017; Leong et al., 1999; Caro and DuBois, 1961), Forced Expiratory Volumes in One Second (FEV1) was studied in nine articles (Szopa and Domagalska-Szopa, 2017; Johari et al., 2016; Johnnston et al., 2011; McMaster et al., 2007; Newton et al., 2005; Boyer et al., 1996; Pehrsson et al., 1991; Szinberg et al., 1988; Smyth et al., 1984), Forced Vital capacity (FVC) was assessed in nine studies (Szopa and Domagalska-Szopa, 2017; Leong et al., 1999; Johari et al., 2016; Johnnston et al., 2011; McMaster et al., 2007; Szinberg et al., 1988; Smyth et al., 1984; Boyer et al., 1996; Newton et al., 2005), in two studies the FEV1 to FVC ratio (FEV1/FVC) was investigated (Szopa and Domagalska-Szopa, 2017; Martinez-Llorens et al., 2010).

To assess the angle of scoliosis the cobb angle was used. In seven articles the cobb angle was measured (Johari et al., 2016; Redding et al., 2008; McMaster et al., 2007; Newton et al., 2005; Smyth et al., 1984; Szinberg et al., 1988; Caro and DuBois, 1961), breathing muscles strength test was used in one study (Sperandio et al., 2015), diaphragm and chest wall movement test was investigated in one article (Kotani et al., 2004), only one study measured the Maximal Voluntary Ventilation (MVV) (Smyth et al., 1984),arterial oxygen partial pressure (P_ao_2) and arterial carbon dioxide partial pressure ($P_a\ co_2$) were evaluated in one article (Pehrsson et al., 1991), Maximal inspiratory pressure (MIP) and Maximal Expiratory Pressure (MEP) were investigated in three studies (Martinez-Llorens et al., 2010; Smyth et al., 1984; Szinberg et al., 1988), specific airway conductance (sGaw), plethysmography (pleth) and Forced Expiratory Flow (FEF) were used for evaluation in only one study (Boyer et al., 1996), Blood Pressure (BP), Heart Rate (HR) and Respiratory rate (RR) were investigated in one article (Alves and Avanzi, 2009), also, two studies used the oximetry oxygen saturation (S_PO_2) in the evaluation process (Alves and Avanzi, 2009; Martinez-Llorens et al., 2010), diffusing capacity of the lung for carbon monoxide was used in one article (Martinez-Llorens et al., 2010), two articles investigated the Residual Volume (RV) (Leong et al., 1999; Pehrrson et al., 1991), Residual volume to total Lung Capacity ratio (RV/TLC) was assessed in two studies (Martinez-Llorens et al., 2010; Boyer et al., 1996) and only one article used the Functional Residual Capacity (FRC) (Pehrrson et al., 1991).

4. Discussion

This study was carried out to review the published studies and investigated the correlation between spinal column deformities and breathing function. Seventeen studies were included and reviewed. The results of this systematic review indicated a significant correlation between spinal column deformities and breathing function in patients with scoliosis, kyphosis and kypho-scoliosis. The findings were discussed based on population.

4.1. Scoliosis patients

The restrictive effect of thoracic scoliosis on breathing function was determined to be multi-factorial due to the combination of decreased chest wall compliance (Caro and DuBois, 1961; Farrell and Garrido, 2018), restricted rib movement (Farrell and Garrido, 2018; Kotani et al., 2004; Leong et al., 1999), breathing muscle

Table 4
Details of studies in the order of time from the latest study to the oldest study.

Author & Year of Publication	Purpose	Research Design	Sample Size	Age &Gender	Evaluated Parameters	Results& Conclusion
Farrell and Garrido (2018)	To measure the 3D relationship between the spine and airways in patients with idiopathic right thoracic scoliosis.	Case-control	51 (34 S, 14 H)	17.6 ± 9.0 y (S) 16.3 ± 5.1y (H) F & M	Breathing function tests	Airways caudally displaced in patients with scoliosis.The loss of thoracic kyphosis might due to right-sided airway narrowing. A negative correlation was found between loss of kyphosis, (FEV1/FVC), FVC/(FVC predicted) and FEV1/(FEV1 predicted).
Szopa et al. (2017)	To recognize whether the 3-dimensional displacement of the spine and trunk may diminished the respiratory function in children with mild idiopathic scoliosis.	cross-sectional	68 (S)	10 to 12 y F & M	Body posture examination and spirometry examination (VC, FVC, FEV1 and FEV1/FVC)	Reduction in lung volumes might be related to the increased angle of the lateral curvature and the degree of thoracic kyphosis loss. Decreased kyphosis depthcombined with lung VC reduction, could be a risk factor for scoliosis progression in the children with mild IS.
Johari et al. (2016)	To examine the relationship between the preoperative pulmonary function, Cobb's angle, the location of apical vertebrae and age in patients with AIS.	Cohort	38 (S)	16.68 ± 6.04 y F & M	Cobb' angle, FEV1 and FVC	Inverse relationship was identified between the degree of the Cobb's angle, FVC and FEV1. Moderate to severe pulmonary impairment was associated with the severity of thoracic curvature, number of vertebrae involved in the curvature, thoracic hypokyphosis and coronal imbalance asrisk factors.
Sperandio et al. (2015)	To evaluate the correlation between functional exercise capacity, lung function and geometry of the chest at different stages of AIS.	Cross-sectional	27 (S)	11-18 y F& M	Chest wall deformity, lung function test and breathing muscles strength test	Significant correlation was found between chest wall deformity, lung function and breathing muscles strength. The deformity could possibly alter the ventilatory efficiency and compromise the physical ability in AIS patients.
Johnston et al. (2011)	To determine the incidence of clinically relevant pulmonary impairment in patients with AIS.	Cross-sectional	858 (S)	8.5—22.5 y F& M	Coronal, sagittal, and axial plane deformities, FEV1 and FVC	Breathing functional Tests were clinically impaired in patients with AIS and were significantly correlated with the sagittal plane deformity. A significant difference was found in preoperative PFTs between juvenile- and adolescent-onset patients. patients with JIS had lower % predicted FEV1 and FVC than patients with AIS.
Martınez-Llorens et al. (2010)	To describe skeletal muscle function and its relationship with lung function, exercise capacity, body composition and spinal deformity in young patients with pronounced thoracic AIS.	Case-control	85 (25 H, 60 S)	17-23y	FEV1/FVC, Predicted FEV1, Predicted FVC, Predicted FRC, Predicted TLC, RV/TLC, S_PO_2, Predicted DLco, MIP and MEP	AIS as a spinal disorder which only affects the physical performance of patients when a severe ventilatory defect is present. Further understanding of the causes and systemic consequences of AIS will enable clinicians to recommend more effective therapies.
Alves et al. (2009)	To assess the cardiopulmonary response of patients with AIS using 6-min walk test.	Cohort	126 (40 H, 86 S)	14.39y F.& M.	BP, HR, RR, S_PO_2	The cardiorespiratory restrictions were reported with 6-Minute walk test in patients with AIS. A statistically significant difference was found between patients with AIS and healthy subjects for the following variables: RR, SpO2, Borg scoreand final distance achieved.
Redding et al. (2008)	To describe the frequency of asymmetric lung perfusion and ventilation among children with congenital or infantile thoracic scoliosis before surgical treatment and the relationship between Cobb's angle and asymmetry of lung function.	Cohort	39 (S)	children 1 y 8 mo to 15 y 6 mo F & M	Cobb's angle and lung function	No significant correlation was found between the severity of lung function and the degree of cobb's angle, but also, lung function might be affected by spinal deformity.
McMaster et al. (2007)	To quantify the respiratory compromise in patients with a congenital kyphosis or kyphoscoliosis in whom the major deformity is the kyphosis.	Cross-sectional	41 (K, K—S)	8 y 7 mo to 25 y F& M	Breathing function test (TLC, FVC, FEV1) and scoliosis angle	A significant correlation was presented between the increased kyphosis and breathing impairments in patients with kyphosis and kyphoscoliosis.
Newton et al. (2005)	To test if increased thoracic deformity is associated with decreased pulmonary function and to determine that radiographic measurements of deformity will predict pulmonary impairments.	Cohort	630 (S)	14.5 ± 2.1 y F & M	Breathing function test (TLC, FVC, FEV1) and scoliosis angle	Weak correlation was demonstrated between the scoliosis angle and decreased of breathing function.
Kotani et al. (2004)	To investigate the motions of the chest wall and the diaphragm during deep breathing in patients with idiopathic scoliosis.	Case-control	27 (S)	11-20 y F & M	Chest wall movement and diaphragm motion	Decreased chest wall movement in scoliosis subjects was displayed. A breathing dynamic MRI is a dynamic and noninvasive method that is useful for assessing respiratory mechanisms.
Leong et al.	To determine the changes in shape and size of the chest and the motion pattern of the	Case-control		10-21y F.& M.		The chest cage and the spinal range of movementswere more limited in patients

Table 4 (*continued*)

Author & Year of Publication	Purpose	Research Design	Sample Size	Age &Gender	Evaluated Parameters	Results& Conclusion
(1999)	thoracic spine during deep breathing using a 3-D kinematic method.		61 (20 H, 41 S)		FVC, Predicted FVC,VC, Predicted VC, TLC, Predicted TLC, RV and Predicted RV	with scoliosis. The stiffness of the chest cage and spine may contribute to the mechanical inefficiency and impairment of pulmonary function in scoliotic patients.
Boyer et al. (1996)	To examine the pulmonary function of children with idiopathic scoliosis for evidence of airflow obstruction and trapped gas.	Cohort	59 (S)	10-18y F.& M.	FVC, FEF, sGaw, FEV1, FRC_{pleth} and RV/TLC	The residual volume-total lung capacity ratio and total gas volume assessed by plethysmography were demonstrated to be significantly decreased.
Pehrsson et al. (1991)	To identify the risk factors for the development of respiratory failure and decreased lung function in patients with IS.	Cohort	24 (S)	15-67y F.& M.	VC, predicted VC, FEV1, FRC, RV, TLC, VC supine, predicted MIP, predicted MEP, PaO2, $PaCo_2$ and standard bicarbonate	Respiratory failure developed in adults suffering from scoliosis with a large angle and a low vital capacity. when normal aging reduces the ventilatory capacity further.
Szinberg et al. (1988)	To assess the possible relationship between vital capacity, the angle of scoliosis and respiratory muscle pressure in patients with a mild to moderate IS.	Case-control	62	13.6 ± 1 −14.8 ± 1.6 y F.	FVC, Predicted FVC, MEP, MIP and Cobb's Angle	Reduction in lung volumes could be related to the degree of thoracic deformity but not be associated to impaired respiratory muscle strength. A mechanical disadvantage was imposed on the inspiratory muscles due to the chest deformity rather than intrinsic inspiratory muscle weakness.
Smyth RJ. et al. (1984)	To evaluate relationship between FVC, MVV, and muscle force in a group of young patients with mild idiopathic scoliosis	Cross-sectional	44 (S)	16.7 ± 4.7 F.& M.	Cobb's Angle, FVC, TLC, MVV, MIP, MEP, proportion of predicted FVC, proportion of predicted TLC and proportion of predicted MVV	Ventilatory function might be impaired in patients with mild, idiopathic scoliosis. The respiratory muscles force was considered to be a more important determinant of this impairment than the radiologic changes in the spinal curvature.
Caro CG.& Dubois AE. (1961)	To determine the functional alterations of the chest wall and lung in patients with kyphoscoliosis.	Case-control	38 (K –S)	<21y & 31-58y F&M	Cobb's Angle VC, TV, maximal exploratory flow rate, maximal mid-exploratory flow, maximal breathing capacity and respiratory frequency	In kyphoscoliosis patients, the lung volumes and lung compliance were reduced.

Abbreviations: S: scoliosis, H: healthy, K: kyphosis, K–S: kypho-scoliosis, Y: year, F: female, M: male, AIS: adolescent idiopathic scoliosis, PFTs: pulmonary function tests, FEV1: forced expiratory volume in first second, FRC: functional residual capacity, FVC: forced vital capacity, TLC: total lung capacity, RV: residual capacity, IS: idiopathic scoliosis, JIS: juvenile idiopathic scoliosis, MVV: maximal voluntary ventilation, $P_a O_2$: arterial oxygen partial pressure,$\Delta A_a PO_2$: alveolar arterial oxygen pressure difference, $P_a co_2$: arterial carbon dioxide partial pressure, MIP: maximal inspiratory pressure, MEP: maximal expiratory pressure, sGaw: specific airway conductance, Pleth: plethysmography, FEF: forced expiratory flow, BP: blood pressure, HR: heart rate, RR: respiratory rate, S_PO_2: oximetry oxygen saturation, DL,co: diffusing capacity of the lung for carbon monoxide.

weakness and reduced lung capacities (Martinez-Llorens et al., 2010; Smyth et al., 1984; Sperandio et al., 2015; Szeinberg et al., 1988). According to the results of biomechanical evidence, some changes in antero-posterior and transverse diameter of the chest wall during inspiration are associated with vertebral rotation (Leong et al., 1999; Vitale et al., 2008), the lateral flexion plus rotation of the vertebrae around a vertical axis are involved in scoliosis (Leong et al., 1999), and also, the chest wall and spine range of motion become limited (Kotani et al., 2004; Leong et al., 1999). This limitation of motion may contribute to the mechanical inefficiency and impairment of breathing function in patients with scoliosis (Leong et al., 1999). Kotani et al., (2004), assessed the chest wall movements and the diaphragm motion during deep breathing in patients with adolescent idiopathic scoliosis(AIS).The results demonstrated that the chest wall movements were significantly restricted in patients with scoliosis, however the reduction in the diaphragm motion was not statistically significant. Chest wall and diaphragm motions had critical roles in maintaining ventilation. Dynamic breathing magnetic resonance imaging is considered to be a good technique to measure these movements. There was a conflict between the results of studies because of technical differences in collecting data (Kotani et al., 2004). Leong et al., (1999), determined changes in the shape and size of the chest and the motion pattern of the thoracic spine during deep breathing. They reported the chest wall and spine ranges of motion were more limited in patients with scoliosis. A close relationship was reported between lung function and chest wall motions. The reduction in the chest wall and spinal motions might contribute to the mechanical inefficiency of inspiratory muscles that led to the lung function impairment in these patients (Leong et al., 1999).

Scoliosis reduces the chest wall compliance directly, the lung compliance indirectly and then leads to chronic breathing failure (Caro and DuBois, 1961; Koumbourlis, 2006), and therefore results in progressive atelectasis and air-trapping (Boyer et al., 1996; Koumbourlis, 2006), and also, breathing muscle weakness (Martinez-Llorens et al., 2010; Smyth et al., 1984; Sperandio et al., 2015; Szeinberg et al., 1988) and abnormal diaphragmatic function (Vitale et al., 2008).

Scoliosis may be due to the displacement or rotation of the intra-thoracic trachea and/or main bronchial stem, therefore, a mechanical airway obstruction was identified (Koumbourlis, 2006). Newton et al. (2005), investigated the correlation between the severity of a thoracic deformity and lung function in patients suffering from scoliosis. They explained a weak correlation between the scoliosis angle and decreased breathing function. The major curves could distort the orientation and function of the diaphragm or the mechanics of the chest wall. The inflexible curves might adversely affect the chest kinematics as a potential contributing factor of lung dysfunction. No correlation between the location of the curve of the apex and the lung function was found. The number of vertebrae in the curve was the most significant predictor of FVC and FEV1. Severe chest wall deformity secondary to the scoliosis could correlate with providing multiple alveoli and affecting breathing function in terms of FVC and FEV1(McMaster et al., 2007).These findings might be attributed to the vertebral rotation and total three-dimensional changes in the chest wall (Newton et al., 2005).

Szopa et al., (2017), assessed the correlation between a spinal deformity and the respiratory system function in children with mild scoliosis. The results showed that the flattening of normal kyphosis and a decrease in the depth of kyphosis in the thoracic region seemed to be combined with VC lung reduction as a risk factor of scoliosis progression in children with mild idiopathic scoliosis (IS). Pehrsson et al., (1991), described the risk factors for the development of respiratory failure and decreased lung function in patients with idiopathic Scoliosis. A strong and inverse correlation was demonstrated between cobb's angle, VC, TLC and respiratory failure in adults suffering from scoliosis. A large angle scoliosis and a low vital capacity were increased and the ventilatory capacity was reduced along with increasing age. The VC reduction associated with increasing age could provide breathing impairments in patients with severe idiopathic scoliosis (Pehrsson et al., 1991).

Johnston et al., (2011), reported a strong and inverse correlation between the thoracic main curve and FEV1 and FVC. The more degrees of deformity there are may produce a greater risk of breathing impairment. Pulmonary function tests (PFTs) were correlated with the thoracic curve angle and hypokyphosis. A flat kyphosis $<10^\circ$ is required for negative effects on PFTs. In patients with PFTs<50%, the pulmonary morbidity and mortality rate was reported to be high. In 19% of patients with AIS, PFTs were clinically impaired, and were significantly correlated with the severity of thoracic and sagittal plane deformity, but no correlation between axial plane deformity and PFTs impairment was found (Johnston et al., 2011).

In a study carried out by Sperandio et al., (2015), the correlation between functional exercise capacity, lung function and geometry of the chest was investigated in patients with AIS. The results of the study showed a significant correlation between body posture and breathing pattern in these patients. The scoliosis may alter the ventilatory efficiency and compromise the physical ability due to the relation between peak oxygen consumption and chest wall shape (Sperandio et al., 2015). Martinez-Llorens et al., (2010), investigated the relationship between muscle weakness, breathing impairment and exercise tolerance in patients with AIS. The findings demonstrated generalized skeletal muscle weakness and exercise limitation, even in the absence of major ventilatory defects in these patients. The main predictor of exercise limitation in these patients was considered to be muscle function which was not affected by the degree of the scoliosis angle. The causes of muscle impairment in AIS has not been clear yet but it seems that muscle impairment may be as a result of systematic factors like abnormalities in the neural mechanisms of postural control (Martinez-Llorens et al., 2010).

Alves and Avanzi. (2009), assessed the cardio-respiratory function in patients with AIS. A cardio-respiratory restriction was identified in patients with AIS. A significant difference was found between patients with AIS and healthy subjects for RR and SpO2, Borg score and final distance achieved. Physical activity in these patients was limited by respiratory problems as a consequence of reduced maximum aerobic capacity and FVC. The decreased cardiovascular fitness affected the TV, and led to an increasing respiratory rate to compensate the greater oxygen demand. The increased respiratory rate in these patients result in an asymmetric relationship between inspiration and exhalation which may lead to weak air trapping in the lungs because of reduction in the exhalation time (Alves and Avanzi, 2009). Redding et al., (2008), evaluated the relationship between cobb's angle and the asymmetry of lung function. A Non-significant correlation was reported between the lung function asymmetry and the degree of cobb's angle, but lung function asymmetry might be correlated to the spinal deformity. It was believed that regional lung function could not be predicted based on the concavity or convexity of the lung detected by spinal radiograph (Redding et al., 2008). Johari et al., (2016), evaluated the relationship between preoperative pulmonary function and the cobb angle, the location of apical vertebrae and the age in patients with AIS. A negative relationship was found between cobb's angle and FVC and FEV1, albeit the relationship was not statistically significant. Four factors are associated with increased risk of moderate to severe breathing impairment as follows: the severity of thoracic curvature, number of involved vertebrae, thoracic hypokyphosis and frontal imbalance. An angle of scoliosis greater than 40° was associated with increased pain and decreased FVC; also, FVC reduction was correlated with curve rigidity (Johari et al., 2016).

The possible relationship between VC, angle of scoliosis and respiratory muscle pressure in patients with mild to moderate IS was evaluated by Szeinberg et al., (1988). A weak inverse correlation between the scoliosis angle and FVC was reported. The reduction in lung volumes could be related to the degree of thoracic deformity but not be associated to impaired respiratory muscle strength. A mechanical disadvantage was imposed on the inspiratory muscles due to the chest deformity rather than intrinsic inspiratory muscle weakness (Szeinberg et al., 1988). In a study carried out by Smyth et al., (1984), the relationship between FVC, MVV and muscle force was investigated in young patients with mild IS. The results demonstrated impaired ventilatory function in these patients. The respiratory muscles force was considered to be a more important determinant of this impairment than the radiologic changes in the spinal curvature. Abnormal development of the spine increased the elastic force of the respiratory system on the respiratory muscles during maximum inhalation and exhalation (Smyth et al., 1984). Boyer et al., (1996), examined the lung function, airflow obstruction and trapped gas in children with IS. According to the results, scoliosis might lead to decreased lung compliance, faulty mechanical coupling of inspiratory muscles that leads to a decreased in respiratory muscle function and contribute to the restrictive properties. Also, residual volume (RV) - TLC ratio and total gas volume were significantly decreased (Boyer, 1996).

In summary, the relationship reported between scoliosis and lung function is considered to be complex and multi-factorial (Szopa and Domagalska-Szopa, 2017). Several possible mechanisms were presented for the association between scoliosis and lung volume in previous studies such as: the abnormal development of the chest wall, the increased elastic force of the respiratory system that oppose the inspiratory and expiratory muscle force (Smyth et al., 1984), and also, a lack of spinal flexibility was shown to be a potential factor contributing to pulmonary dysfunction (Leong et al., 1999; Newton et al., 2005). A large scoliosis angle was associated with reduced VC (Caro and DuBois, 1961; Johari et al., 2016; Leong et al., 1999; Pehrsson et al., 1991; Szopa and Domagalska-Szopa, 2017) and changed FVC (Harrison et al., 2007).

4.2. Kyphosis and kypho-scoliosis patients

Normal thoracic kyphosis is necessary for the physiological mobility of the spine. It can provide proper static and a body center of gravity distribution in the sagittal plane, and therefore support the spine against the deformity (Szopa and Domagalska-Szopa, 2017). In a study carried out by Farrell and Garrdio (2018), patients with hypo-kyphosis, normal kyphosis and hyper-kyphosis were evaluated in terms of breathing function. The results demonstrated that location of the deformity, degree of scoliosis curvature and loss of thoracic kyphosis were significantly correlated with breathing function impairment. Hypokyphosis leads to the narrowing of the airways more proximally at the bronchus intermedius, influencing the value of airflow into the right middle and lower lobes (Farrell and Garrido, 2018). McMaster et al. (2007), carried out a study to investigate the relationship between congenital kyphosis and kyphoscoliosis and respiratory function according to the age of participants, site and severity of the spinal deformity. Based on the results, the lung function in young congenital kyphosis or kyphoscoliosis patients became more severely impaired along with an increased kyphosis angle. Caro and DuBois (1961), determined the functional alterations of the chest wall and lung in patients with kyphoscoliosis. The lung volumes and lung compliance were reduced regardless of age, etiology of the spinal curvature and present or absence of pulmonary infection. Mechanical disadvantage of the respiratory muscles might be attributed to the distortion of the skeletal attachments (Caro and DuBois, 1961).

Therefore, the mechanical disadvantage of breathing muscles was demonstrated in scoliosis and other spinal deformities (Koumbourlis, 2006; Martinez-Llorens et al., 2010; Smyth et al., 1984; Sperandio et al., 2015; Szeinberg et al., 1988). Spinal deformity may alter the ventilatory efficiency, decrease the exercise tolerance, reduce maximum aerobic capacity and FVC and therefore, compromise the physical ability in patients with spinal deformities (Sperandio et al., 2015). Thoracic deformity increased the chest wall stiffness, decreased respiratory muscle force, distorted orientation and function of the diaphragm and therefore resulted in increasing mechanical dysfunction (Johari et al., 2016; Pehrsson et al., 1991; Newton et al., 2005). The spinal deformity could change the inspiratory muscles mechanical coupling (Boyer et al., 1996) and length–force relationships which may increase mechanical loads on these muscles (Martinez-Llorens et al., 2010).

5. Conclusion

According to the results of the present systematic review, breathing function was altered in patients with spinal deformities and a relationship was found between spinal deformities and lung function. The location of the deformity, degree of scoliosis angle and the loss of thoracic kyphosis might be significantly correlated with the loss of breathing function. The early detection of these deformities, can prevent their adverse effects. Therefore, routine screening of the spine and pulmonary function should be started early with regular body posture examination and continued until the child reaches skeletal maturation.

Declaration of competing interest

No conflicts of interest were reported for this study.

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