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MÉTODOS DE AVALIAÇÃO DA ASSINCRONIA TORACOABDOMINAL DURANTE A RESPIRAÇÃO ESPONTÂNEA: uma revisão crítica da literatura

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Monografia apresentada ao Curso de Graduação em Fisioterapia da Escola de Educação Física, Fisioterapia e Terapia Ocupacional da Universidade Federal de Minas Gerais, como requisito parcial à obtenção do título de Bacharel em Fisioterapia.

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RESUMO

Introdução: O movimento toracoabdominal normal é caracterizado pelos movimentos de expansão e retração da caixa torácica e do abdômen, de forma sincrônica, durante o ciclo respiratório. Quando esses deslocamentos deixam de ser harmônicos, este movimento passa a ser assincrônico. **Objetivo**: Realizar uma revisão crítica da literatura sobre os métodos de avaliação da assincronia toracoabdominal durante a respiração espontânea. **Método**: Foram realizadas buscas nas bases de dados *MEDLINE, SCIELO, LILACS* e *PEDro* com combinações de palavras-chave relacionadas ao assunto. Para serem incluídos, os estudos deveriam estar publicados em Português, Inglês, Espanhol ou Francês, até 12 de Abril de 2016, e terem avaliado a assincronia toracoabdominal durante a respiração espontânea. Como critérios de exclusão, foram considerados a avaliação da assincronia toracoabdominal durante a ventilação mecânica ou ventilação não invasiva e a avaliação da assincronia toracoabdominal realizada de forma não quantitativa. **Resultados**: Foram encontrados 7530 estudos e, após a verificação dos critérios estabelecidos, selecionaram-se 48 para análise, os quais foram agrupados em quatro categorias distintas: Ângulo de Fase, Amplitude Compartimental Máxima / Volume Corrente, Relação de Fase Inspiratória e Relação de Fase Expiratória, Relação de Fase durante a Respiração Total, Índice de Trabalho Respiratório, Índice de Assincronia Inspiratória e Índice de Assincronia Expiratória, Movimento Paradoxal, Função de Correlação Cruzada, Tempo Inspiratório Paradoxal, *Mirror Index,* Paradoxo Torácico e Atraso Torácico. A revisão não forneceu um consenso sobre esses métodos, mas foi capaz de demonstrar que vários métodos têm sido relatados na literatura para a avaliação de assincronia toracoabdominal durante a respiração espontânea. O uso da avaliação do Ângulo de Fase é predominante, e destaca-se pela diferença na quantidade de informações fornecidas, no entanto, há controvérsias quanto à precisão deste índice, além da falta de definições padronizadas sobre a precisão dos outros métodos apresentados. **Conclusão**: Há uma falta de consenso na avaliação de assincronia toracoabdominal, e a importância desta avaliação e as suas implicações na prática clínica ainda precisam ser mais exploradas.

Palavras-chave: Métodos de avaliação. Assincronia toracoabdominal. Abdômen. Caixa torácica.

LISTA DE ABREVIATURAS E SIGLAS

AB: Abdomen

AB: Abdômen

CCF: Cross-Correlation Function

COPD: *Chronic Obstructive Pulmonary Disease*

CT: Caixa torácica

DPOC: Doença Pulmonar Obstrutiva Crônica

EAI: Expiratory Asynchrony Index

IAI: Inspiratory Asynchrony Index

IP: Inspiratory Paradox Time

ITR: Índice de Trabalho Respiratório

LBI: Labored Breathing Index

LILACS: Literatura Latino-Americana e do Caribe em Ciências da Saúde

MCA: Maximal Compartmental Amplitude

MEDLINE: Medical Literature Analysis and Retrieval System Online

OEP: Optoelectronic Plethysmography

PEDro: Physiotherapy Evidence Database

PhAng: Phase Angle

PhREB: Phase Relation in Expiratory Breathing

PhRelTotal: Phase relation of the entire breath

PhRIB: Phase Relation in Inspiratory Breathing

PhRTB: Phase Relation during the Total Breath

POE: Pletismografia Optoeletrônica

PRI: Pletismografia Respiratória por Indutância

RC: Rib Cage

RIP: Respiratory Inductive Plethysmography

S: Sum

SciELO: Scientific Electronic Library Online

TAA: Thoracoabdominal Asynchrony

TCDR: Total Compartmental Displacement Ratio

TTA: Total Time spent in Asynchrony

VCw: Chest Wall Volume

VRCa: Abdominal Rib Cage Volume

VRCp: Pulmonary Rib Cage Volume

VT: Tidal Volume

SUMÁRIO

1 INTRODUÇÃO

O movimento toracoabdominal normal é caracterizado pela expansão e retração da caixa torácica (CT) e do abdômen (AB), de modo sincrônico, durante a inspiração e expiração, respectivamente[1]. Em indivíduos saudáveis, distorções da CT e do AB em relação a suas configurações normais são mínimas, e isso parece requerer a contração simultânea dos músculos inspiratórios da CT e do diafragma em uma ação coordenada[2]. Quando os deslocamentos dos compartimentos da parede torácica deixam de ser harmônicos, este movimento passa a ser assincrônico[1]. A assincronia toracoabdominal é descrita na literatura como o atraso de movimento entre os compartimentos torácico e abdominal durante a expansão e retração da CT e do AB[3]. Quando a assincronia é completa, o movimento entre os compartimentos passa a ser oposto e chamado de paradoxal[4].

Os primeiros estudos sobre a relação entre os movimentos da CT e do AB foram realizados no final do século XIX e início do século XX por Sewall e Pollard[5]que registraram os movimentos do AB e do tórax durante a respiração tranquila. Esses autores tentaram avaliar o componente diafragmático na respiração por meio da observação das mudanças nas circunferências do AB[6,7]. Herxheimer[8] sugeriu que existe uma dissociação dos movimentos do tórax e do diafragma, com um compartimento desempenhando papel predominante sobre o outro na ventilação dos pulmões em diferentes fases da respiração[8].

Nas décadas de 70 e 80, a qualidade do movimento toracoabdominal passou a ser avaliada por meio da observação das curvas de excursão da CT e do AB[4, 9]. Rome *et al.*[10] e Carlo *et al.*[11], utilizando o magnetômetro, caracterizaram como assincronia completa o movimento da CT superior para dentro, durante a expansão do AB[10, 11].Utilizando o mesmo instrumento, Gilmartin *et al.*[12]definiram o movimento paradoxal como uma mudança em qualquer dimensão que seja oposta a polaridade da mudança simultânea no volume pulmonar[12].

Em 1966, Agostoni e Mognoni[13] propuseram, pela primeira vez, um método de avaliação para quantificar a assincronia por meio de uma variável chamada mudança de fase, que, desde então, vem sendo um método muito utilizado para avaliação da assincronia toracoabdominal[13].

Embora diferentes propostas estivessem disponíveis na literatura para verificar a participação do AB e da CT no deslocamento da parede torácica, somente em 1967, com a introdução do método descrito por Konno e Mead[14], é que foi possível estudar de forma mais precisa a relação entre o movimento toracoabdominal e o volume deslocado durante a respiração[7,14]. Esses autores presumiram que a parede torácica era dividida em duas partes (CT e AB) que se movem cada qual como uma unidade, havendo considerável independência de movimento entre elas. Esses compartimentos podem acomodar volume de modo independente apresentando dois graus de liberdade de movimento. Konno e Mead[14] propuseram a exposição dos deslocamentos do tórax e do AB em um sistema cartesiano, e, este diagrama, permitiu relacionar o deslocamento da parede torácica ao volume pulmonar. As curvas Konno-Mead geradas pela análise representam o movimento do AB e do tórax no ciclo respiratório que é plotado em um traçado X-Y. Dessa forma, os dados são extraídos dessa curva e utilizados para o cálculo de índices específicos de assincronia[14,15].

Esse princípio fundamentou e permitiu o início da utilização da pletismografia respiratória por indutância (PRI) que foi o instrumento mais amplamente utilizado no passado para avaliação do movimento toracoabdominal. Esse método monitora os componentes de volume e tempo do padrão respiratório, por meio das mudanças na área de secção transversa que ocorrem na CT e no AB[16].

Mais recentemente, surgiu a Pletismografia Optoeletrônica (POE) que é um instrumento que não assume qualquer pressuposto do número de graus de liberdade da parede torácica e é capaz de fornecer com acurácia medidas indiretas dos volumes absolutos da parede torácica e de seus três compartimentos (CT pulmonar, CT abdominal e AB) em diferentes posições e situações a partir de medidas ópticas de um número finito de pontos posicionados na superfície externa do tronco. Por meio do *software* MATBLAB é possível obter dados relativos às variáveis que são utilizadas para avaliar a sincronia toracoabdominal[17, 18, 19].

A assincronia toracoabdominal pode ser observada na prática clínica em algumas doenças respiratórias e/ou na presença de disfunções da musculatura respiratória, sendo avaliada clinicamente como um sinal de desconforto respiratório e/ou aumento do esforço respiratório. A literatura aponta a obstrução de via aérea superior em crianças e a fraqueza muscular ou a paralisia de alguns músculos responsáveis pela respiração, como diafragma e intercostais, comumente observadas em pacientes com doença neuromuscular e quadriplegia, como possíveis causas da assincronia[20].

Em indivíduos com doença pulmonar obstrutiva crônica (DPOC), o sinal de *Hoover*[21], descrito como o movimento da CT inferior para dentro durante a inspiração, pode ser classicamente observado. Isso acontece porque nesses indivíduos o diafragma encontra-se fraco, dessa forma, a inspiração conta principalmente com os músculos intercostais, que resulta na deformação passiva do diafragma, ocasionando um movimento assincrônico. Esse padrão é observado principalmente em pacientes adultos com DPOC, mas também pode ser visto durante a insuficiência respiratória aguda[20, 21].

A presença de assincronia é um importante sinal da gravidade da doença, e está associada ao aumento do risco de insuficiência respiratória e pior prognóstico nesses indivíduos[3, 4, 22, 23]. De acordo com a literatura, pacientes com DPOC apresentam mais movimento toracoabdominal assincrônico quando comparado aos indivíduos saudáveis, seja em repouso [3, 24] ou durante o exercício[25], sendo a dispneia o sintoma primário limitante ao exercício nessa população[3, 26].

1.1 Justificativa

Até o presente momento, vários estudos envolvendo a avaliação da assincronia toracoabdominal, em diferentes situações clínicas foram realizados[3,15,20]. Neles, métodos diversificados e diferentes instrumentos foram utilizados, resultando em uma ausência de consenso na análise da assincronia. Considerando a importância da identificação da presença de assincronia toracoabdominal na prática clínica do fisioterapeuta, e o progresso científico da área, principalmente no que diz respeito à comparação das medidas obtidas em diferentes condições de saúde, foi percebida a necessidade de realizar uma revisão crítica da literatura sobre o tema.

1.2 Objetivo

Realizar uma revisão crítica da literatura sobre os diferentes métodos utilizados para avaliar a assincronia toracoabdominal durante a respiração espontânea e apontar os métodos mais utilizados, as vantagens e limitações de cada um dos métodos descritos.

2 MATERIAS E MÉTODO

Foram realizadas buscas nas bases de dados MEDLINE (via Pubmed), SciELO, LILACS e PEDro, com o objetivo de encontrar artigos que avaliaram a assincronia toracoabdominal durante a respiração espontânea. Foram utilizadas as seguintes combinações de palavras chave em cada base de dados: caixa torácica (*ribcage*) ou abdome / abdômen (*abdomen*) ou parede torácica (*chest wall*) ou toracoabdominal (*thoracoabdominal*) e cinética (*kinetics*) ou deslocamento (*displacement*) ou movimento (*movement*) ou assincronia (*asynchrony*). As buscas foram realizadas sem restrição de data inicial ou língua

Os critérios de inclusão dos estudos foram: ter sido encontrado pela estratégia de busca traçada até às 23h07 do dia 12 de abril de 2016, ter sido publicado nos idiomas português, espanhol, inglês ou francês e ter realizado avaliação da assincronia toracoabdominal durante a respiração espontânea. Como critérios de exclusão foram considerados a avaliação da assincronia toracoabdominal durante a ventilação mecânica ou ventilação não invasiva e a avaliação da assincronia toracoabdominal realizada de forma não quantitativa.

Para selecionar os estudos, de acordo com os critérios estabelecidos, foram utilizadas cinco etapas. A primeira consistiu na realização da busca nas bases de dados selecionadas, utilizando as combinações escolhidas. Em seguida, foi realizada a leitura do título de todos os estudos selecionados e exclusão daqueles que claramente não atendiam aos critérios de inclusão. Na terceira etapa, todos os títulos selecionados tiveram seus resumos analisados para confirmar aqueles que atendiam aos critérios de inclusão. A quarta etapa consistiu na leitura integral dos estudos potencialmente relevantes. A quinta e última etapa, consistiu na busca manual para checagem da lista de referências de todos os artigos incluídos, a fim de identificar estudos relevantes não encontrados na busca eletrônica.

Os avaliadores foram selecionados por conveniência e orientados a selecionar todos os artigos que avaliaram a assincronia toracoabdominal durante a respiração espontânea. Todas as etapas foram realizadas por dois avaliadores de forma independente (B.M.F.S e M.M.D.L.), e, na presença de discordâncias, foi consultado um terceiro examinador (L.P.S.M.) para consenso final.

2.1 Extração dos dados

Foram extraídos dos artigos:

1) Ano de publicação;
2) O instrumento utilizado para a avaliação da assincronia toracoabdominal;
3) As variáveis analisadas relacionadas à avaliação da assincronia toracoabdominal;
4) O método utilizado para avaliação destas variáveis.

3 RESULTADOS

3.1 Artigo

METHODS OF ASSESSMENT OF THORACOABDOMINAL ASYNCHRONY DURING SPONTANEOUS BREATHING: A CRITICAL LITERATURE REVIEW

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ABSTRACT

Introduction: The normal thoracoabdominal motion is characterized by the expansion and retraction of the rib cage and abdomen in a synchronic manner during the respiratory cycle. When these movements stop being harmonic, it becomes asynchronous. **Objective**:To carry out a critical literature review on methods to assess thoracoabdominal asynchrony during spontaneous breathing. **Methods**: The search was performed assessing *MEDLINE, SCIELO, LILACS* and *PEDro* databases with key words related to the subject. To be included, the studies would have to be published in Portuguese, English, Spanish or French until of April 12, 2016, and have performed evaluation of thoracoabdominal asynchrony during spontaneous breathing. The exclusion criterion included the assessment of thoracoabdominal asynchrony during mechanical ventilation or noninvasive ventilation, and the non-quantitative evaluation. **Results**: 7530 studies were found and after the verification of the established criteria, 48 were selected for the analysis, which were divided into eleven groups: Phase angle, Maximal compartmental amplitude/tidal volume, Phase Relation in Inspiratory Breathing and Phase Relation in Expiratory Breathing, Phase Relation during the Total Breath, Labored Breathing Index, Inspiratory asynchrony index and Expiratory Asynchrony Index, Paradoxical Motion, Cross-correlation function, Inspiratory Paradox Time, Mirror

Index, Thoracic Paradox and Thoracic Delay. The review provided no consensus regarding these methods, but it was able to demonstrate that several methods have been reported in the literature for evaluation of TAA during spontaneous breathing Despite these variety, the measurement of PhAng is predominant, and it is highlighted by the difference of information provided, however, there is controversy regarding the accuracy of this index estimating TAA, and lack of standardized definitions about the precision of the other methods presented.**Conclusion**: There is a wide variability exists in the evaluation of thoracoabdominal asynchrony and a lack of consensus in this evaluation. The importance of this evaluation and its implications in the clinics need to be explored further.

Keywords: Evaluation methods, thoracoabdominal asynchrony, abdomen, rib cage.

RESUMO

Objetivo: Realizar uma revisão crítica da literatura sobre os métodos de avaliação da assincronia toracoabdominal durante a respiração espontânea. **Métodos**: Foram realizadas buscas nas bases de dados *MEDLINE, SCIELO, LILACS* e *PEDro* com combinações de palavras-chave relacionadas ao assunto. Para serem incluídos, os estudos deveriam estar publicados em Português, Inglês, Espanhol ou Francês, até 12 de Abril de 2016, e terem avaliado a assincronia toracoabdominal durante a respiração espontânea. Como critérios de exclusão foram considerados a avaliação da assincronia toracoabdominal durante a ventilação mecânica ou ventilação não invasiva e a avaliação da assincronia toracoabdominal realizada de forma não quantitativa. **Resultados**: Foram encontrados 7530 estudos diferentes e, apósa verificação dos critérios estabelecidos, selecionaram-se 48 para análise, os quais foram agrupados em 4 categorias distintas: Ângulo de Fase, Amplitude Compartimental Máxima / Volume Corrente, Relação de Fase Inspiratória e Relação de Fase Expiratória, Relação de Fase durante a Respiração Total, L*abored Breathing Index*, Índice de Assincronia Inspiratória e Índice de Assincronia Expiratória, Movimento Paradoxal, Função de Correlação Cruzada, Tempo Inspiratório Paradoxal, *Mirror Index,* Paradoxo Torácico e Atraso Torácico. A revisão não forneceu um consenso sobre esses métodos, mas foi capaz de demonstrar que vários métodos têm sido relatados na literatura para a avaliação de assincronia toracoabdominal durante a respiração espontânea. O uso da avaliação do Ângulo de Fase é predominante, e destaca-se pela diferença na quantidade de informações fornecidas, no entanto, há controvérsias quanto à precisão deste índice, além da falta de definições padronizadas sobre a precisão dos outros métodos apresentados. **Conclusão**: Existe uma grande variabilidade na

avaliação da assinconia toracoabdominal e há uma falta de consenso nessa avaliação. A importância desta avaliação e as suas implicações na prática clínica ainda precisam ser mais exploradas.

Palavras-chave: métodos de avaliação, assincronia toracoabdominal, abdômen, caixa torácica.

INTRODUCTION

Normal thoracoabdominal motion is characterized by the synchronized expansion and retraction of rib cage (RC) and abdomen (AB) during the respiratory cycle[1], which seems to require simultaneous contraction of inspiratory muscles and diaphragm[2]. However, these movements may become abnormal, and a delay may occur in one compartment in relation to another, which can be classified as asynchrony[1]. When asynchrony is complete, and the movement between the compartments becomes opposite, the movement is called paradoxical[1,3].

Chest wall movements have been studied for a long time, and a significant amount of literature regarding the subject corroborates with that. The first studies related to the movements of chest and abdomen were performed by Sewall and Pollard [4]. These authors tried to evaluate the diaphragmatic component of breathing by observing the changes in abdominal circumference[5, 6].

In the 1970s and 1980s, the quality of thoracoabdominal motion was evaluated by observing the excursion curves of RB and AB. Rome *et al.*[7] e Carlo *et al.*[8], using magnetometer, characterized as a complete asynchrony, the inward movement of upper RC during abdominal expansion. Using the same instrument, Gilmartin *et al.*[9], defined paradoxical movement as a change in any dimension that is opposite to the polarity of simultaneous change in pulmonary volume[9].

In 1966, Agostoni and Mognoni[10], for the first time, brought a quantitative method for assessing thoracoabdominal asynchrony (TAA) through a variable called phase shift, which since then has been a widely method used for evaluation of thoracoabdominal asynchrony[10].

The relationship between the thoracoabdominal motion and the volume displaced during breathing could be studied in a more precise manner only in 1967, with the presentation of the method described by Konno and Mead[11,12]. These authors proposed expositing the RC and AB displacements in a Cartesian system, which provides loops representing the compartments movements in the respiratory cycle plotted on an X-Y recorder. Data are extracted from these loops, and used to calculate specific asynchrony indexes [11,13]. Furthermore, they assumed that the chest wall has two parts moving as separated units, with substantial independence between them, presenting two degrees of freedom[11].

This principle based and allowed the use of Respiratory Inductive Plethysmography (RIP), which was the most widely instrument used in the past to evaluate the thoracoabdominal motion. This method monitors the volume and time components of breathing pattern through changes in cross-sectional area occurring in RC and AB[14].

More recently, emerge Optoelectronic Plethysmography (OEP) which is an instrument that has no assumption of the number of the chest wall degrees of freedom and is able to provide with accuracy indirect measurements of the absolute volumes of chest wall and its three compartments (pulmonary RC, abdominal RC and AB) in different positions and situations from optical measures based on a finite number of points on the external surface of thorax[15, 16, 17, 18].

TAA can be observed in clinical practice in some respiratory diseases and/or in presence of respiratory musculature disorders, being clinically evaluated as a respiratory distress signal and/or increased respiratory effort. The literature points upper airway obstructions in children and muscle weakness or paralysis of some muscles responsible for breathing, as diaphragm and intercostals, as possible causes of asynchrony [3,19,20]. In individuals with chronic obstructive pulmonary disease (COPD) it is common to observe Hooverõs[21] sign, described as lower RC movement inwardly, during inspiration, especially during acute respiratory failure[21, 22].

The presence of asynchrony is an important sign of higher severity of the disease, and it is associated with increased risk of respiratory failure and worse prognosis in these patients[3, 20, 23, 24].

In the present moment, a number of studies involving the evaluation of the TAA in different clinical situations have been conducted[3, 13, 19, 22]. In these, various different methods and different instruments were used, resulting in a lack of consensus in the analysis of asynchrony. Considering the importance of identifying the presence of TAA in clinical practice of physical therapists, and scientific progress in the area, especially as regards the comparison of measurements obtained in different health conditions, the need for a critical review of the literature was perceived.

METHODS

The literature search was performed in the following databases: MEDLINE (via PubMed), SciELO, LILACS and PEDro, with the purpose to find articles that evaluated thoracoabdominal asynchrony during spontaneous breathing. Our keywords combinations for the search consisted of rib cage (caixa torácica) or abdomen (ou abdome) or chest wall (parede torácica) or thoracoabdominal (toracoabdominal) and kinetics (cinética) or displacement (deslocamento) or movement (movimento) or asynchrony (assincronia). No restrictions on initial date or language were applied.

Studies were eligible for inclusion in this review if they met the following criteria: being found by outlined search strategy until 11:07 p.m. of April 12, 2016, being published in Portuguese, Spanish, English or French and have performed evaluation of thoracoabdominal asynchrony during spontaneous breathing. As exclusion criteria was considered the assessment of thoracoabdominal asynchrony during mechanical ventilation or noninvasive ventilation, and the non-quantitative evaluation.

The protocol for this review was based on five stages, according to the established criteria. The first stage consisted in the databases search using the chosen combinations. Then, titles of all selected studies were screened and those that clearly did not meet the inclusion criteria were excluded. In the third stage, all selected titles had their abstracts analyzed to confirm those who met the inclusion criteria. The fourth step was the full reading of the potentially relevant studies. The fifth and final stage was manual searching of all articles included to check the references in order to identify relevant studies not found in the electronic search.

The reviewers were selected by convenience and instructed to select the studies that evaluated thoracoabdominal asynchrony during spontaneous breathing. All stages were performed by two reviewers (B.M.F.S and M.M.D.L), working independently, and in the presence of disagreement, a third examiner was referred (L.P.S.M) for a final consensus.

Key data extraction included the following items: year of publication, the instrument used for the evaluation of thoracoabdominal asynchrony, the variables associated to the evaluation of thoracoabdominal asynchrony and the method used to assess these variables.

RESULTS

On the basis of our search strategy a total of 7530 articles were found. There were 1248 duplicate references. On the second stage of the screening 6164 studies were excluded. A number of 118 abstracts were read, and at the end a total of 74 publications were suitable to be fully read, adding the three articles found with the manual search. Articles (26) were excluded for review because of the following reasons: they were not specific to evaluation of TAA, not spontaneous breathing, they did not evaluate TAA quantitatively, and one was not in article format. Figure 1 shows the flow chart of the studies included.

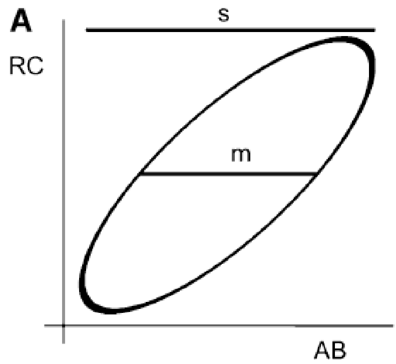
Thus, the 48 studies reviewed (Table1) were grouped in eleven categories, according to the variables analyzed: Phase angle (PhAng), Maximal compartmental amplitude/tidal volume (MCA/VT), Phase Relation in Inspiratory Breathing (PhRIB) and Phase Relation in Expiratory Breathing (PhREB), Phase Relation during the Total Breath (PhRTB), Labored Breathing Index (LBI), Inspiratory asynchrony index and Expiratory Asynchrony Index (IAI and EAI), Paradoxical Motion, Cross-correlation function (CCF), Inspiratory Paradox Time (IP), Mirror Index, Thoracic Paradox and Thoracic Delay.

Phase angle

Mounting evidence brings the considerable use of PhAng, a variable that reflects TAA. It can be calculated from the Lissajous figure or Konno-Mead diagrams, formed when AB and RC signals are plotted, respectively, on an X-Y recorder [1, 10, 11, 18, 19, 25-45]

According to Banovcin *et al.*[26], Selbie *et al.*[39]and Aliverti *et al. (2009)*[31]RC and AB signals were set to equal amplitudes to obtain the figure[26, 31, 39]. The width of the loop is the index of asynchrony and is quantified by dividing the distance between the intercepts of the RC-AB loop on a line drawn parallel to the X axis, which is placed at half the distance between the maximal and minimal RC excursions (m) by the maximal AB excursion (s) (Figure 2). In this way, for ◖<90°, sin ◖= *m/s,*for 90°<◖<180°, ◖= 180 - ε, where sin ε= m/s [10, 19, 26, 40]. Other variations for the calculation of phase angle have been also described using the equations: ◖= sin^{-1} (m/s), sin◖= m/s, ◖= arcsin (m/s) and the inverse tangent (Tan$^{ï 1}$) of the slope of the regression line (r/s$^{ï 1}$) [1, 25, 27-33, 35-37, 39, 41, 42, 45, 46].

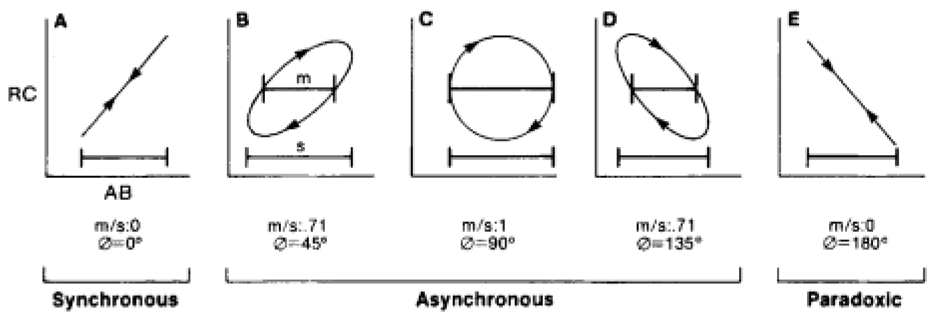
Figure 2-Lissajous figure schematic representation.



Note: Representation of rib cage (RC) excursion versus abdominal (AB) excursion plot. ñmò is the horizontal width of RCï AB loop at halfway between maximal and minimal RC and ñsò maximal AB excursion.
Source: Modified from Beydon et al.,[47] 2007, p. 1317.

When RC and AB are moving sinusoidally as a function of time during breathing, a 0° phase angle represents synchronous motion between RC and AB, and the Lissajous figure looks like a closed loop or line with a positive slope. As ◂increases toward 90°, the loop "opens" and becomes wider. As ◂exceeds 90° and approaches 180°, the loop again begins to narrow but the slope becomes negative. A 180° phase angle represents completely out-of-phase motion between RC and AB, being the expansion of one compartment opposite to that of the other compartment, corresponding to a paradoxical motion of one compartment during the respiratory cycle (Figure3). Paradoxical breathing is represented by a closed loop or line with a negative slope[18, 19, 28, 30, 31, 32, 33, 36, 37, 40, 41, 42, 44, 48, 49, 50, 51].

Figure 3- Lissajous figures according to the value of Phase Angle (PhAng).



Note: Examples of Lissajous figures as Phase Angle becomes increasingly asynchronous (A-E). (A) Synchronous motion between RC and AB. (B-D) Increasing asynchrony. (E) Paradoxical motion between RC and AB.
Source:Allen *et al.*[19]., 1990, p. 339.

The direction of the loop can be clearly identified and it was used as an indicator of relative timing between RC and AB during the respiratory cycle. A clockwise loop indicates that RC expansion precedes AB expansion, and a counterclockwise loop indicates the reverse [19, 30, 40, [44, 48]. The instrument used by most of the studies was RIP [1, 19, 25, 27, 28, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43,45, 46, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57]. OEP was also chosen [29, 30, 31, 32, 33, 44, 58]. Banovcin *et al.*[26]used Pressure sensor plethysmography to assess PhAng, and Agostoni and Mognoni used Mercury-in rubber Transducer[10, 26].

Maximal compartmental amplitude/tidal volume (MCA/VT)

The ratio MCA/VT assesses the paradoxical motion at isolated points in time. According to Franco *et al.*[59] it can be calculated by the equation VAB+VRC/VT, where the sum of AB and RC volumes are divided by tidal volume (VT). This agrees with Sackner *et al.*[35]and Tobin *et al.*[14], who reported that the absolute values from trough to peak of the RC and AB excursions added together, independent of their VT relation to the sum signal provide an index, the maximum compartmental amplitude. Castro *et al.*[60], Silva Neto *et al.*[52] and Itagaki *et al.*[28] *(2014)* also cited MCA/VT. All of the studies used RIP, and established that when the trough-to-peak amplitudes of the compartments are in phase, the ratio MCA/VT is equivalent to 1.0, but exceed this value when the RC and AB move out of phase [14, 28, 35, 52, 59, 60].

Phase Relation in Inspiratory Breathing (PhRIB) and Phase Relation in Expiratory Breathing (PhREB)

For evaluation of asynchrony the PhRIB and PhREB were also used [18, 41, 55, 56, 58, 61]. These thoracoabdominal coordination indexes are sine-wave independent values. Cavalcanti *et al.*[18]andVieira *et al.*[58] used OEP, while RIP was the instrument used by Oliveira *et al.*[56], Parreira *et al.*[55], França *et al*[61]. and Reber *et al*[41]. The five studies agreed that PhRIB reflects the percentage of time of inspiration in which the rib cage and abdomen move in opposite directions, and PhREB is associated with expiration [15, 18, 41, 55, 56, 58, 61]. A value of 0 indicates complete synchrony between compartments, and 100% is full asynchrony or paradoxical movement[18, 41, 61].

Phase Relation during the Total Breath (PhRTB)

Another index related to phase relation is PhRTB, which can also be used to evaluate the coordination between RC and AB. Of the articles surveyed five of them [19, 40, 41, 56, 61]quantified PhRTB using RIP. This index represents the respiratory cycle percentage in which the RC and AB present opposite directions[41, 56, 61]. Rusconi *et al.*[40]called this analysis Total Time in Asynchrony, but it has the same meaning as PhRTB, reason why both variables were grouped. The studies agreed that the values range from 0 to 100%, indicating total synchrony and complete asynchrony, respectively[19, 40,41,56,61].

Labored Breathing Index (LBI)

Some authors [42, 56, 57, 62, 63] quantified TAA using the labored breathing index as one of the variables on the RIP. LBI reflects the phasic relationships of RC and AB movement and the volume displacement due to that movement[42]. It has been known as the ratio of sum of the integrals of the absolute values of the derivatives of the inspiratory limbs of the rib cage and abdomen divided by the corresponding integral of the derivative of the inspiratory limb of the tidal volume[42, 63]. When there is perfect thoracoabdominal coordination LBI equals 1.0, and any presence of asynchrony between the compartments will increase LBI[42].

Inspiratory asynchrony index (IAI) and Expiratory asynchrony index (EAI)

The analysis of the asynchrony indexes is associated with differences in rate of change of RC and AB compartmental movements throughout the respiratory cycle. Sackner *et al.*[35] and Tobin *et al.*[1] used the manipulation of the Konno and Mead loops[11] in the determination of the indexes, where RC and AB movements are plotted as Y and X coordinates. Asynchrony during inspiration was examined by measuring the area enclosed by the inspiratory portion of the RC-AB loop and the straight line linking the beginning of inspiration to the point of end inspiration, which was normalized by dividing by tidal volume. EAI was obtained by similar use of the loop during expiration. For Rusconi *et al.*[40] IAI and EAI values are between -180 and 180, a negative value indicating that the RC movement preceded the AB movement, and 0 indicating perfect synchrony[40]. Stromberg and Nelson[27] also evaluated IAI and EAI, perfect synchrony between RC and AB would be equal zero, while asynchronous movement would give integer values[27]. RIP was the instrument used by all of them.

Paradoxical Motion

Gilmartin and Gibson[9] define Paradoxical Motion as any dimension change of opposite polarity to the simultaneous change in lung volume[9]. This concept corroborates with Sackner *et* al.[35] and Tobin *et al.*[1], in which the analyses of the paradoxical movement dealt with one compartment (RC or AB) moving in an opposite direction to the tidal volume. Phase relation of the entire breath (PhRelTotal) was the variable used by Upton *et al.*[64] to measure

TAA and it has the same meaning as paradoxical motion. RIP was the main instrument used [1, 35, 64], however Gilmartin and Gibson[9] used magnetometers to evaluate the chest wall motion[9].

Cross-correlation function (CCF)

Cross-Correlation Function is another index used for evaluation of asynchrony, which is determined by the delay in second (s) between the signals of RC and AB at each respiratory cycle [18, 61, 65]. Its calculation also does not depend on Konno-Mead loops[61, 65]. According to Millard[65], if the phase difference between the two explanatory signals is unknown, then by computing their average product, for a sequence of time delays of one signal with respect to the other, the temporal variation in their similarity, C_{rcab}, is obtained. The relative lag is indicated by the location of the maximum of the cross-correlation function (CCF). Thus for various Ű one calculates: C_{rcab}(Ű) =$N^{ï 1}$ × ærc^1 (t) æab^1 (t + Ű) for N simultaneously sampled pairs of rc^1 and ab^1 over a time-span *t*, where ***Ű*** is the chosen delay between the signals. Usually ***Ű*** would range from **ï** *i* to +*i* consecutive sample intervals, where *I*< N, being about half a breathing cycle. The prime denotes a standardized signal. Correlation C_{rcab} ſ C_{rcab}(0), the CCF value for the original signals when Ű= 0. For two sine waves CCF = cos(**ɤ Űï ʟ**).Values equal 0 reflect perfect thoracoabdominal synchrony, and values equal 0 reflect perfect thoracoabdominal synchrony. The higher the CCF index is, greater is the asynchronism between the compartments[65]. França *et al.*[61] used RIP and Cavalcanti *et al*[18]. used the Optoelectronic Plethysmography during the analysis of CCF[61,18].

Inspiratory Paradox Time (IP)

Aliverti *et al.* [31] and Binazzi *et al.* [66] used the comparison of the time-courses of the volume of the compartments (pulmonary RC and abdominal RC) to establish the presence of paradoxical lower ribcage motion. Inspiratory and expiratory phases of the breathing cycles were derived from the sum of the volumes signal (VCw), and asynchronous and paradoxical motion between the compartments was assessed by calculating the Inspiratory Paradox time (IP) using OEP. The IP is defined as the fraction of the inspiratory time during which the abdominal rib cage volume decreased[31, 66].

Mirror Index

De Groote *et al.*[67] defined a mirror index to evaluate TAA, where the sum of the thoracic and abdominal signals, respectively, divided by their amplitudes was calculated during each breathing cycle. The area between the curve S and the line connecting its ends was measured, and its values were maximal when in phase and minimal when out of phase. This index varies between 0 and 1. Impedance Pneumography was used to measure the variable cited[67].

Thoracic Paradox and Thoracic Delay

Asynchrony between rib cage and abdomen was also measured through the analysis of inward movements of the RC at the onset of inspiration. These movements were measured relative to the total displacement of the rib cage, which was in phase with inspiratory airflow. The magnitude of thoracic paradox is expressed as a percentage of the positive contribution of the thorax to inspiration. Benameur *et al.*[68] also bring the delay of the RC expiratory motion at the end of inspiration as a complementary index, the thoracic delay[68]. The delay of inward movement of the RC relative to the start of abdomen inward movement and decreasing lung volume at the end of inspiration was measured and expressed as a percentage of inspiratory time. Benameur *et al*[68] used RIP to evaluate these indexes[68].

DISCUSSION

Our critical review looked at the literature on methods of assessment of TAA during spontaneous breathing. The review provides no consensus regarding these methods, but it was able to demonstrate that several methods have been reported in the literature for evaluation of TAA during spontaneous breathing. Most of the variables found are already well described in the literature, with their descriptions as the major difference between them.

In general, the most used instrument to assess TAA was RIP. We also found that OEP is the instrument that has been more described in recent studies.

Phase angle is the highlighted variable due to the amount of information provided [1,10, 19, 25, 27, 28, 30, 34-46, 48-58].This index has the advantage of incorporating data from the whole of the respiratory cycle, but it assumes that the compartments excursions as sine waves [18, 19, 29, 36, 37, 40]. However, the motion of the chest wall is not sinusoidal, and thus RC-AB motion plotted against one another does not result in an ellipse shape [18, 19, 27, 29, 40], leading to ◖ distorted estimates due to unusual Konno-Mead loops patterns (e.g.: ñFigure-of-eightò, triangular or ñleaf-and-stalkò loops, inspiratory and expiratory branches crossing over) [18, 29, 40, 58, 61, 69]. Some authors suggest that to avoid any inaccuracies in the calculation of the phase angle due to the presence of these loops, a visual inspection should be performed, and those different figures excluded[40,69]. Rusconi *et al.*[40]concluded that PhAng may be inaccurate in estimating thoracoabdominal asynchrony, since they found discrepancy comparing PhAng and Total Time in Asynchrony (TTA) even with Figure-of-eight exclusion, indexes that would be similar if the RC and the AB compartments move sinusoidally as a function of time[40]. Allen *et al.*[19]disagree, stating that the m/s ratio can still be calculated and PhAng can be derived from non sinusoidal waveforms. This was concluded by an estimation of the influence of the unusual loops by quantitating the amount of time spent in RC-AB paradox as determined from scalar tracings, and comparing this with the phase angle derived from the Lissajous figure, showing similar results[19]. Contrasting to PhAng calculation, we have PhRIB e PhREB, parameters that have the advantage of quantifying thoracoabdominal asynchrony at each point of the respiratory cycle and of not depending on calculations derived from Konno-Mead loops[3, 41, 58]. PhRTB is another sine wave-independent index, which represents the time percentage during a respiratory cycle in which the rib cage and abdomen move in opposite directions [56, 61],[41]. Rusconi *et al.*[40] and Allen *et al.*[19] also evaluated this index, but at the time it was named total time spent in asynchrony (TTA), and as a percentage of time spent in asynchrony, respectively[19,40]. Cavalcanti *et al.* [18] and França *et al.*[3], determined the delay in seconds (s) between the signals of RC and AB at each respiratory cycle using the variable CCF, and it has also the advantage of not depending on Konno-Mead loops [65]. The variable phase angle has been also cited as phase shift, presenting the same meaning in some of this review studies[29, 32, 33, 39, 44, 52]. However, Seddon *et al.*[69] bring out that phase shift can be expressed as an angle, being the lag expressed in relation to the total respiratory cycle, and as %, when the lag is expressed in relation to inspiratory time. It is also relevant to note that most of the studies used PhAng to evaluate asynchrony between chest wall compartments (two or three compartments depending on the instrument utilized), but, Laviola *et al.*[69]introduced the calculation of the degree of asynchrony by Lissajous loop analysis between rib cage right and left parts[69].

The relation MCA/VT was one of the most common variables chosen to measure thoracoabdominal asynchrony, and is related to the sum of the maximal amplitudes of chest wall compartments, independent of VT [14, 28, 35, 52, 59, 60]. It was noticed that LBI is similar to this relation, but it takes into account the sum of the integrals of the absolute values of the derivatives of the compartments instead of the through to peak values.Another discrepancy between MCA/VT and LBI is that the first one takes into account the entire VT, and the second the inspiratory limb of the VT[42, 56 35, 57, 62,63] bring out the comparison between the ratio MCA/VT and IAI and EAI for the evaluation of thoracoabdominal asynchrony, cited earlier. The first one compares only values of the maximal compartmental amplitude of each compartment to VT, whereas the indexes consider the rate of change of compartmental motion throughout the entire respiratory cycle. It is important to highlight that IAI and EAI used the manipulation of the Konno and Mead loops[11], and are also waveform-independent, as PhRIB, PhREB and PhRTB outlined above[35]. Silva Neto *et al.*[52] also evaluated thoracoabdominal asynchrony using this concept of MCA/VT as the quantification manner. However, they bring total compartmental displacement ratio (TCDR) as the name of the variable.

Inspiratory paradox time, the variable related to the the fraction of the inspiratory time during which the VRCa decreased, has been also shown as rib distortion in 2008 by Binazzi *et al.*[66]. The similar was noticed between paradoxical motion and PhRelTotal, both regarding any dimension change of opposite polarity to the simultaneous change in lung volume [1,9, 35, 64].

Of the studies surveyed two of them, Benameur *et al.*[68], and De Groote *et al.*[67], brought little explored variables in the quantification of thoracobdominal asynchrony: Thoracic Paradox and Thoracic Delay and Mirrox index, respectively.

Thoracoabdominal asynchrony is observed in different clinical situations, between them: airflow limitation, system respiratory overload, and COPD[3],[24],[35,9, 14, 70]. The presence of asynchronous thoracoabdominal motion is an important sign related to COPD disease severity[14,24,20], and these patients present more TAA compared to healthy subjects [3]. In infants, asynchrony between the motion of the RC and AB are also useful signs of lung disease and have been used in scoring systems that estimate degree of respiratory distress and airway obstruction in this population[19,40].

As a limitation of our critical review, there is the possibility that studies evaluating TAA were missed by the searches, so we may have underestimated the variability in measurement TAA. This limitation would not influence the main finding of our study that there is a lack of consensus in this area. The number of databases from which we obtained the studies from was limited, excluding possible articles indexed in other databases. However, the ones we used are commonly used in journals relevant to physical therapy.

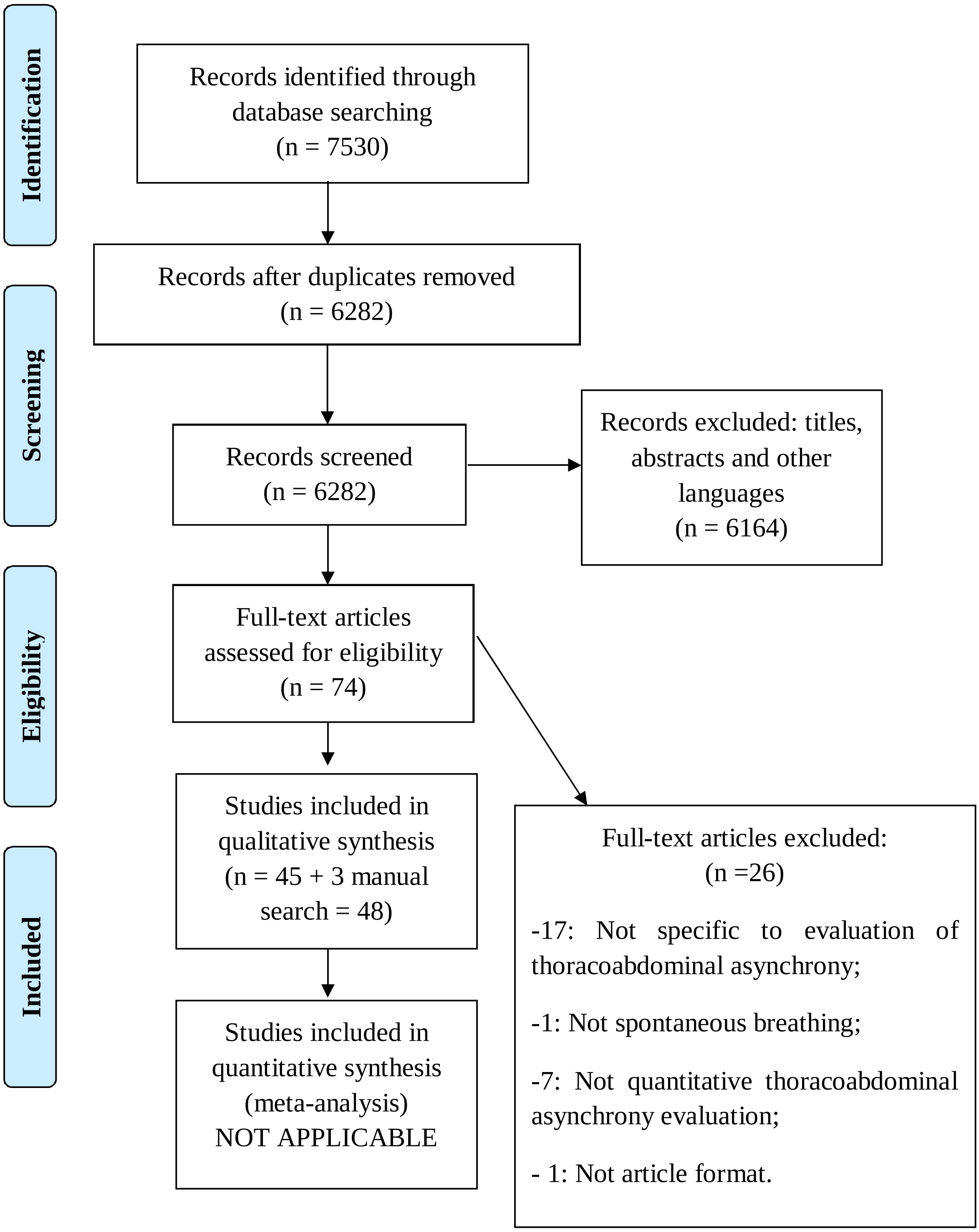
CONCLUSION

The variability among the variables and instruments described in the studies that were included is consistent with the lack of consensus regarding TAA evaluation found. Studies using different instruments in the evaluation of TAA were found, since simpler instruments as Mercury-in rubber transducer, until more sophisticated, as OEP.

Most of the variables found are already well described in the literature, with their descriptions as the major difference between them. In our study, we found that wide variability exists in the evaluation of TAA. In all the methods presented, the measurement of PhAng is predominant, and it is highlighted by the difference of information provided. However, there is controversy regarding the accuracy of this index estimating TAA, and lack of standardized definitions about the precision of the other methods presented.

The importance of asynchrony evaluation in the clinics has been shown in the literature, but its implications need to be explored further.

Figure 1. Flowchart of search and selection process



Source: elaborated by the authors.

Table 1. Overview of the articles reviewed.

Variables	Studies	Instruments
	Agostoni and Mognoni (1966)[10]	Mercury-in rubber Transducer
Phase angle (PhAng)	Tobin *et al* .(1987)[1]	Respiratory Inductive Plethysmography(Respitrace®)
	Allen *et al.* (1990)[19]	
	Sivan *et al.* (1990)[36]	
	Allen *et al.* (1991)[48]	
	Sivan *et al.*(1991)[37]	
	Brown *et al.*(1992)[46]	
	Wolfson *et al.* (1992)[43]	
	Davis *et al.* (1993)[34]	
	Sackner *et al.* (1984)[35]	
	Silva Neto *et al.* (1995)[52]	
	Rusconi *et al.* (1995)[40]	
	Selbie *et al.* (1997)[39]	
	Warren *et al.*(1997)[42]	
	Stromberg and Nelson (1998)[27]	
	Hunter *et al.* (1999)[53]	
	Maynard *et al.* (2000)[45]	
	Reber *et al.* (2002)[41]	
	Tomich *et al.* (2007)[38]	
	Alves *et al.* (2008)[25]	
	Brant *et al.* (2008)[49]	
	Mizuno *et al.* (2008)[50]	

Table 1. Cont.

	Oliveira *et al*. (2009)[56] Parreira *et al.* (2010)[55] Tomich *et al.* (2010)[57] Matos *et al.* (2012)[54] Chien *et al.* (2013)[51] França *et al.* (2013)[b61] Itagaki *et al.* (2014)[28]	
	Aliverti *et al.* (2009)[31] Binazzi *et al.* (2012)[b32] Binazzi *et al.* (2012)[a33] Cavalcanti*et al.*(2014)[18] LoMauro *et al.* (2014)[44] Vieira *et al.* (2014)[58] Laviola *et al.* (2015)[29] Miccinilli *et al.* (2016)[30]	Optoelectronic Plethysmography(BTS Bioengineering, Italy)
	Banovcin *et al.* (1995)[26]	Pressure Sensor Plethysmography
Maximal compartmental amplitude/tidal volume (MCA/VT)	Tobin*et al.*(1983)[14] Sackner*et al.*(1984)[35] Silva Neto *et al.*(1995)[52] Franco *et al.*(2012)[59] Castro *et al.*(2013)[60] Itagaki*et al.*(2014)[28]	Respiratory inductive plethysmography

Table 1. Cont.

Phase Relation in Inspiratory Breathing (PhRIB) and Phase Relation in Expiratory Breathing (PhREB)	Reber *et al.* (2002)[41] Oliveira *et al.* (2009)[56] Parreira *et al.* (2010)[55] França *et al.* (2013)[a3]	Respiratory Inductive Plethysmography
	Cavalcanti *et al.* (2014)[18] Vieira *et al.* (2014)[58]	Optoelectronic Plethysmography
Phase Relation during the Total Breath (PhRTB)	Allen *et al.* (1990)[19] Rusconi *et al.* (1995)[40] Reber *et al.* (2002)[41] Oliveira *et al.* (2009)[56] França *et al.* (2013)[b13]	Respiratory Inductive Plethysmography
Labored Breathing Index (LBI)	Warren *et al.* (1997)[42] Kohyama *et al.* (2000)[62] Kohyama *et al.* (2001)[63] Oliveira *et al.* (2009)[56] Tomich *et al.* (2010)[57]	Respiratory Inductive Plethysmography
Inspiratory asynchrony index and Expiratory Asynchrony Index (IAI and EAI)	Sackner *et al.* (1984)[35] Tobin *et al.* (1987)[1] Rusconi *et al.* (1995)[40] Stromberg and Nelson (1998)[40]	Respiratory Inductive Plethysmography

Table 1. Cont.

Paradoxical Motion	Sackner *et al.* (1984)[35] Gilmartin and Gibson (1986)[9] Tobin *et al.*(1987)[1]	Respiratory Inductive Plethysmography
	Upton *et al.*(2012)[64]	Magnetometer
Cross-correlation function (CCF)	França *et al.* (2013)[a3]	Respiratory Inductive Plethysmography
	Cavalcanti *et al.* (2014)[18]	Optoelectronic Plethysmography
Inspiratory Paradox Time (IP)	Aliverti *et al.* (2009)[17] Binazzi *et al.* (2008)[66]	Optoelectronic Plethysmography
Mirror Index	De Groote *et al.* (2002)[67]	Impedance Pneumography
Thoracic Paradox and Thoracic Delay	Benameur *et al.* (1993)[68]	Respiratory Inductive Plethysmography

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4 CONSIDERAÇÕES FINAIS

O objetivo do presente estudo foi realizar uma revisão crítica da literatura sobre os diferentes métodos utilizados para avaliar a assincronia toracoabdominal durante a respiração espontânea e apontar os métodos mais utilizados, as vantagens, desvantagens e limitações de cada um dos métodos descritos.

A assincronia toracoabdominal é descrita na literatura como o atraso entre os compartimentos torácico e abdominal durante a expansão e retração da CT e do AB. Quando a assincronia é completa, e o movimento entre os compartimentos passa a ser oposto, o movimento passa a ser chamado de paradoxal.

Os primeiros estudos sobre a relação entre os movimentos da CT e do AB foram realizados no final do século XIX e início do século XX, e, em 1966, foi proposto, pela primeira vez, um método de avaliação para quantificar a assincronia por meio de uma variável chamada mudança de fase. Desde então, diferentes métodos de avaliação da assincronia toracoabdominal foram propostos pela literatura.

A assincronia toracoabdominal pode ser observada na prática clínica em algumas doenças respiratórias e/ou na presença de disfunções da musculatura respiratória, sendo percebida clinicamente como um sinal de desconforto respiratório e/ou aumento do esforço respiratório. A literatura aponta algumas possíveis causas para a assincronia, tais como, obstrução de via aérea superior, fraqueza muscular ou a paralisia de alguns músculos responsáveis pela respiração, como diafragma e intercostais.

Pelos motivos apresentados, vários estudos envolvendo a avaliação da assincronia toracoabdominal, em diferentes situações clínicas foram realizados. Neles, métodos diversificados e diferentes instrumentos foram utilizados, resultando em uma ausência de consenso na análise da assincronia. Considerando a importância da identificação da presença de assincronia toracoabdominal na prática clínica do fisioterapeuta, e o progresso científico da área, principalmente no que diz respeito à comparação das medidas obtidas em diferentes condições de saúde, foi percebida a necessidade de realizar uma revisão crítica da literatura sobre o tema.

O objetivo desse estudo foi alcançado, pois foi desenvolvida uma ampla revisão da literatura onde foram descritos os métodos mais utilizados, as vantagens, desvantagens e limitações de cada um dos métodos encontrados.

Em nosso estudo, demonstramos que existe grande variabilidade na avaliação da assincronia toracoadominal. De todos os métodos apresentados, o ângulo de fase foi o método predominante, no entanto, há controvérsias quanto à precisão desse índice e pouca informação sobre a precisão dos demais métodos propostos.

Os resultados dessa revisão poderão contribuir para o progresso científico da área, gerando discussão das vantagens e desvantagens das variáveis utilizadas e consequente tentativa de padronização da avaliação do movimento toracoabdominal.

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