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Predictive equations for ventilatory muscle strength in the Brazilian population: a systematic review

Equações preditivas da força muscular ventilatória na população brasileira: uma revisão sistemática

Ecuaciones predictivas de la fuerza muscular respiratoria en la población brasileña: una revisión sistemática

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ABSTRACT | Maximal inspiratory and expiratory pressures (MIP and MEP) assess the strength index of the respiratory muscles. These measures are relevant to assess respiratory muscle strength and for clinical monitoring. This study evaluates papers that suggest predictive equations of MIP and MEP for the Brazilian population. We included studies that established prediction equations for MIP and MEP for the healthy Brazilian population, aged from 4 to 90 years old, both men and women and that had the maximum respiratory pressures measured in a sitting position. A search was carried out in March 2020 on MEDLINE, LILACS, Cochrane, SciELO, CINAHL, Web of Science, and SCOPUS databases, without date or language filters. The descriptors used were "muscle strength," "equations," "predictive respiratory muscles" and their respective synonyms. Out of the 3,920 studies found in databases, 963 were duplicates, 2,779 were excluded, 178 had their full texts analyzed, and only 9 met the inclusion criteria. The predictive equations of ventilatory muscle strength analyzed in this review used age, weight, and stature as variables. However, the studies showed methodological weaknesses, such as lack of cross-validation of the equation, exclusion of outliers, and lack of familiarization of MIP and MEP.
Keywords | Predictive Equations; Ventilatory Muscles; Maximal Inspiratory Pressure; Maximal Expiratory Pressure.

RESUMO | As pressões respiratórias máximas (PImáx e PEmáx) avaliam o índice de força dos músculos respiratórios. Essas medidas são relevantes para a avaliação da força muscular respiratória e para o monitoramento clínico. O objetivo deste estudo foi avaliar os artigos que sugerem equações preditivas de PImáx e PEmáx para a população brasileira. Foram incluídos estudos que estabeleceram equações de predição para PImáx e PEmáx da população brasileira saudável, com idades entre 4 e 90 anos e de ambos os sexos, que mediam as pressões respiratórias máximas na posição sentada. Uma pesquisa foi realizada, em março de 2020, nas bases de dados MEDLINE, LILACS, Cochrane, SciELO, CINAHL, Web of Science e SCOPUS, sem filtros de tempo ou idioma. Os descritores utilizados foram "força muscular", "equações" e "músculos respiratórios preditivos", com seus respectivos sinônimos. Dos 3.920 estudos encontrados nas bases de dados, 963 eram duplicados e 2.779 foram excluídos, 178 tiveram seus textos analisados integralmente e apenas 9 atendiam aos critérios de inclusão. As variáveis utilizadas nas equações preditivas de força muscular ventilatória analisadas nesta revisão foram: idade, peso e estatura. No entanto, os estudos mostraram fragilidades metodológicas, como falta de validação cruzada da equação, exclusão de *outliers* e familiarização do PImáx e PEmáx.

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Palavras-chave | Equações Preditivas; Músculos Ventilatórios; Pressão Inspiratória Máxima; Pressão Expiratória Máxima.

RESUMEN | Las presiones inspiratoria y espiratoria máximas (PImáx y PEmáx) evalúan el índice de fuerza muscular respiratoria. Estas medidas son importantes en la evaluación de la fuerza muscular respiratoria y el seguimiento clínico. El objetivo de este estudio fue evaluar los artículos proponen ecuaciones predictivas para PImáx y PEmáx a la población brasileña. Se incluyeron estudios que establecieron ecuaciones predictivas para PImáx y PEmáx a la población brasileña sana de ambos sexos, de entre 4 y 90 años de edad, y que miden las presiones respiratorias máximas en posición sentada. Se realizó, en marzo de 2020, una búsqueda en las bases de datos MEDLINE, LILACS, Cochrane, SciELO, CINAHL, Web of Science y SCOPUS, sin año de publicación específico ni idioma. Los descriptores utilizados fueron "fuerza muscular", "ecuaciones" y "músculos respiratorios predictivos" y sus respectivos sinónimos. De los 3.920 estudios encontrados, 963 eran duplicados y se excluyeron 2.779, así se analizaron 178 textos en su totalidad y solo 9 cumplieron con los criterios de inclusión. Las variables edad, peso y talla fueron las que habían sido utilizadas en las ecuaciones predictivas de fuerza muscular respiratoria analizadas por esta revisión. Sin embargo, los estudios apuntaron limitaciones metodológicas, como falta de validación cruzada de la ecuación, exclusión de *outliers* y familiaridad de la PImáx y PEmáx.

Palabras clave | Ecuaciones Predictivas; Músculos Respiratorios; Presión Inspiratoria Máxima; Presión Espiratoria Máxima.

INTRODUCTION

Respiratory muscles are associated with the performance of the ventilatory mechanics[1] by changing the volume and the displacement of the chest wall. The measure of maximal static respiratory pressures (MSRP) evaluates the functionality in a simple and non-invasive way[2-4] using two measures: the maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP), which indicate, respectively, the inspiratory muscle force and the expiratory muscle force during maximum effort[4].

The measurement and analysis of these variables is relevant because they are directly related to the pulmonary diffusion capacity and bronchial hygiene, which will reduce the risk of respiratory infections[5-7]. Thus, it is a very useful tool for the diagnostic[8] and prognostic[5,9,10] in symptomatic[11,12] and healthy[3,13-16]individuals.

Studies[8,17-22] that proposed predictive equations to estimate respiratory muscle strength for the Brazilian population show great variability of the coefficients of determination (R^2), which explains the behavior of linear predictors[23,24]. This fact can be related to procedural conditions, such as the equipment model[25-27], variables selection[23,28,29], sample size, and statistical analysis[23,29]. Respiratory muscle strength is associated with the level of physical activity[8], as well as the level of morbidity due to neurological or infectious conditions[19]; making MIP and MEP an important evaluation system. Therefore, this review evaluates all studies that suggest predictive equations for MIP and MEP for the Brazilian population

METHODOLOGY

This review was designed based on the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)[30].

Protocol and registration

A review protocol was registered in the International Prospective Register of Systematic Reviews (CRD42018073082).

Inclusion criteria

We included studies that proposed predictive equations for MIP and MEP; with a sample of healthy Brazilian participants, aged from 4 to 90 years, of both sexes, and that had MIP and MEP measured in a sitting position.

Search strategy

Initially, the established descriptors were "muscle strength," "reference values," "respiratory function tests," "respiratory muscles," and their synonyms available in health sciences descriptors (DeCS) and

Medical Subject Headings (MeSH). The main terms were associated using the connectives "OR" (between the synonyms) and "AND" (between the descriptors). The terms "predictive equations," "maximal respiratory pressures," and "reference equations" were not found in the DeCS and MeSH, but they were added to the main descriptors due to their relevance in the scientific scenario and were modified to strengthen the search in the databases US National Library of Medicine (MEDLINE), Scientific Electronic Library Online (SciELO), Latin American Literature and the Caribbean Health Sciences (LILACS), The Cochrane Library, Cumulative Index to Nursing and Allied Health Literature (CINAHL), Web of Science, and SCOPUS without date limit or language filter. The Appendix shows the search process conducted in each database.

The search was conducted between February and March 2020. Following the inclusion criteria, titles and abstracts were analyzed, and those considered possibly eligible were retrieved in their full version for a more accurate assessment. The references of the original studies retrieved were investigated to complement this review. We also attempted to contact the authors of studies that were not available; however, we were unable to reach some.

Selection criteria

Since there is no methodological assessment scale for cross-sectional studies, we opted for the independent evaluation carried out by two experienced and qualified researchers, who considered the following methodological and statistical criteria: search strategy, study design, characteristics and sample size, procedures of MSRP evaluation, type of equipment used to measure MSRP, familiarization with the test, cross-validation, exclusion of outliers, coefficient of determination R^2, and standard error of estimate (SEE). Disagreements were solved by consensus.

RESULTS

In total, 3,920 studies were found with the search strategy. After the exclusion of duplicate titles (n=963), 2,957 titles were analyzed for eligibility. Then, 2,779 were excluded and 178 studies were selected for a more accurate assessment (full-text analysis). Subsequently, 169 were excluded and nine studies were included in the review by meeting the inclusion criteria. The exclusion criteria are described in Figure 1.

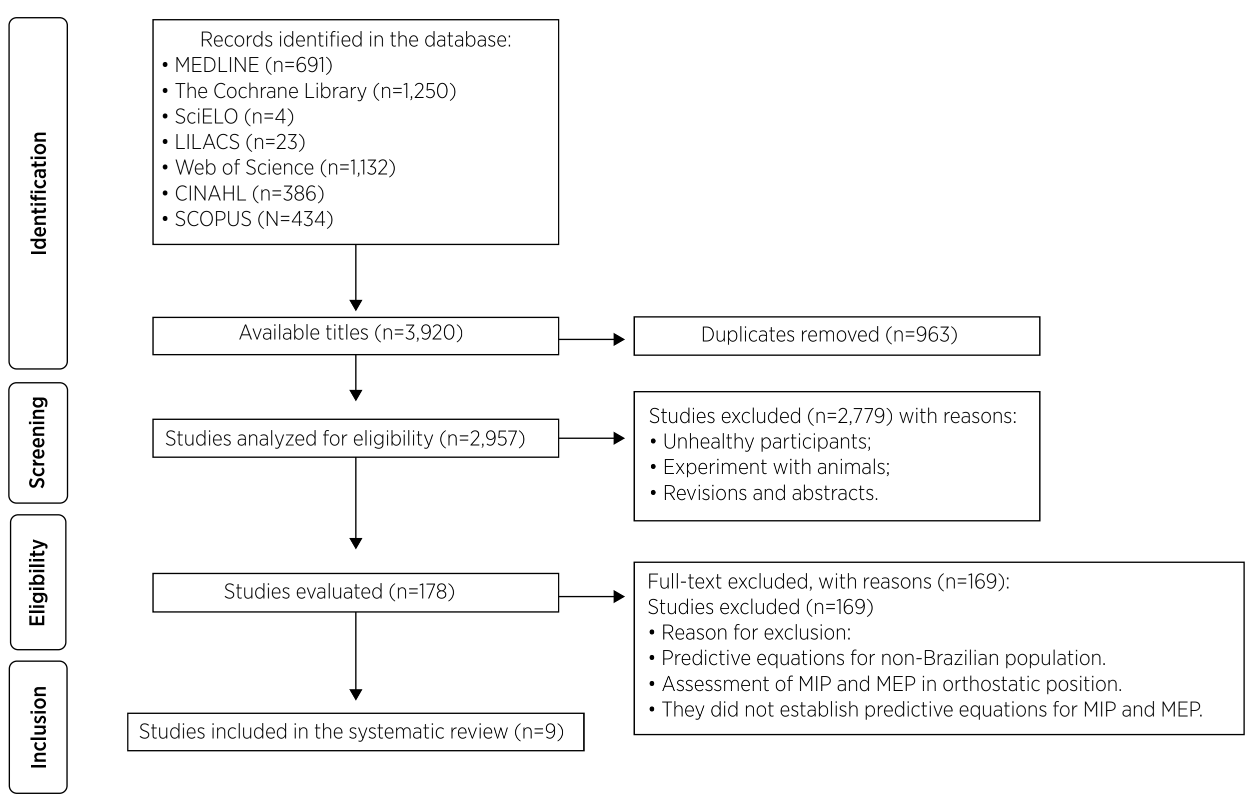

Figure 1. Flow diagram of the included studies

Among the nine articles included in this review, five[20-22,31,32] developed predictive equations for the Brazilian children and adolescents in the age groups between 4-12, 5-10, 7-10, 7-11, and 12-18 years. Four studies[8,17-19] were developed with adults and older adults, aged from 20 to 89 years. The characteristics of participants included in the studies are summarized in Table 1.

Table 1 describes the anthropometric characteristics of the participants. Table 2 shows methodological, procedural, and statistical aspects that can influence the results of the proposed prediction equations for MIP and MEP in different age groups. Table 3 and 4 show the results of the predictive equations proposed for MIP and MEP, respectively.

Table 1. Anthropometric and demographic characteristics of participants included in the studies

Study	Sample	Age	Body mass (kg)	Height (cm)	BMI (kg/m2)	Level of physical activity	Location
Rosa et al., 2017[31]	n=399 201 F/198 M 7-10 years	RAG	RAG	RAG	RAG	NR	Florianópolis
Borja et al., 2015[32]	n=144 F 81/63 M 7-11 years	M=9.0±1.2 F=8.7±1.2	RAG	RAG	RAG	NR	Rio Grande do Norte
Pessoa et al., 2014[18]	n=134 74 F/60M 20-89 years	M=47±18 F=43±16	M=77±9 F=61±8	M=174±0.08 F= 160±0.07	M=25±2 F=24±3	M=39% S F=51% S	Belo Horizonte
De Freitas et al., 2014[20]	n=148 5-10 years	RAG	RAG	RAG	RAG	NR	São Paulo
Mendes et al., 2013[21]	n=182 84 F/98 M 12-18 years	RAG	RAG	RAG	RAG	NR	Natal
Heinzmann-Filho et al., 2012[22]	n=171 88 F/83 M 4-12 years	RAG	M=31.37±11.66 F=33.75±13.32	F=129.78±13.63 M=132.15±16.69	M=18.09±3.41 F=18.52±3.39	NR	Porto Alegre
Simões et al., 2010[19]	n=140 70 F/70 M 20-89 years	RAG	RAG	RAG	RAG	IS	São Paulo
Costa et al., 2010[17]	n=120 60 F/60 M 20-80 years	RAG	RAG	RAG	RAG	NR	São Paulo
*Neder et al., 1999[8]	n=100 50 F/50 M 20-80 years	RAG	M=73.8±10.7 F=62.5±10.8	M=168.4±6.2 F=157.1±7.1	M=25.3±3.9 F=24.7±4.0	88 S and 12 A	São Paulo

M: male; F: female; RAG: reported by age group; NR: not reported; S: sedentary; A: active.
* The statistical analysis of the Neder et al.[8] is based on the study of Neder et al.[33]

Table 2. Methodological and statistical aspects that may influence the prediction of MIP and MEP

Study	Independent variables	Familiarization	Equipment	Calibration of the equipment	Cross validation	Exclusion of outliers	Statistical analysis
Rosa et al., 2017[31]	age, weight, and height	NR	Digital Manovacuometer	NR	NR	R	MLR
Borja et al., 2015[32]	Sex, age, and weight	NR	Digital Manovacuometer	NR	NR	NR	MLR
Pessoa et al.,[18] 2014	Sex, age, weight, and AC	NR	Digital Manovacuometer	Calibrated	NR	NR	MLR
De Freitas et al.,2014[20]	Age, height, and body mass	NR	Analog Manovacuometer	Calibrated	NR	NR	MLR
Mendes et al., 2013[21]	Sex and body mass	NR	Digital Manovacuometer	NR	NR	NR	MLR
Heinzmann-Filho et al., 2012[22]	Age, height, and body mass	NR	Digital Manovacuometer	Calibrated	NR	NR	MLR
Simões et al., 2010[19]	Age, height, and body mass	NR	Analog Manovacuometer	NR	NR	NR	MLR
Costa et al., 2010[17]	Age, height, and body mass	NR	Analog Manovacuometer	Calibrated	NR	NR	SLR
*Neder et al., 1999[8]	Age, height and body mass, Level of physical activity, VO_2máx, Leg strength	NR	Analog Manovacuometer	Calibrated	NR	NR	MLR

AC: abdominal circumference; R: reported; NR: not reported; MLR: multiple linear regression; SLR: simple linear regression.
*The statistical analysis of the Neder et al.[8] is based on the study of Neder et al.[33]

Table 3. Results of predictive equations for Maximum Inspiratory Pressure (MIP) of the selected studies

Study	Predictive equations	R^2	SEE (cmH_2O)	p-value
Rosa et al, 2017[31]	M=Log(MIP)=1.577+0.006×weight(kg) F=Log(MIP)=1.548+0.006×weight(kg)	14.1* 15.0*	0.033** 0.028**	NR
Borja et al, 2015[32]	MIP=62.1+15.4×Sex+7.3×Age F=0; M=1	0.15	NR	0.001 (sex) 0.028 (age)
Pessoa et al., 2014[18]	63.27−0.55(age)+17.96(Sex)+0.58(body mass); M=1; F=0	R^2=0.34	26	p<0.05
De Freitas et al., 2014[20]	M=−62.2+1.26(age)+0.50(body mass)+80.1(height) F=7.31+3.2(age)+0.47(body mass)+9.7(height)	R^2adj=0.63 R^2adj=0.48	NR NR	NR
Mendes et al., 2013[21]	53.8+26.1(Sex)+0.4(body mass) M=1; F=0	R^2adj=0.27	24	NR
Heinzmann-Filho et al., 2012[22]	M=17.879−[0.674×height]−[0.604xbody mass] F=14.226−[0.551×height]−[0.638×body mass]	R^2=0.58 R^2=0.59	13 15	NR
Simões et al., 2010[19]	M=−0.76(age)+125 F=−0.85(age)+80.7+(−0.3)(body mass)	R^2=0.72 R^2=0.84	15 42	p<0.05
Costa et al., 2010[17]	M=−1.14(age)+149.33 F=−0.46(age)+74.25	R^2=0.52 R^2=0.25	20 17	NR
Neder et al., 1999[8]	M=−0.80(age)+155.3 F=−0.49(age)+110.4	R^2=0.48 R^2=0.46	17 9	p<0.01

M: male; F: female; NR= not reported; R^2: determination coefficient; SEE: standard error of estimate; P<0.01/P<0.05= statistically significant difference;
*Values were normalized by base-10 logarithm transformation due to thenon-normal distribution of the dependent variables (MIP and MEP); ** Standard Error of the coefficient of regression.

Table 4. Results of predictive equations for Maximum Expiratory Pressure (MEP) of the selected studies

Study	Predictive equations	R^2	SEE (cmH_2O)	p-value
Rosa et al, 2017[31]	M=Log(MEP)=1.282+0.409×height(cm) F=Log(MEP)=1.6+0.013×age(y)+0.005×weight(kg)	13.9* 21.6*	0.097** 0.028**	NR
Borja et al, 2015[32]	MEP=73.7+16.5×Sex+9.5×Age F=0 ; M=1	0.18	NR	0.0001 (sex) 0.005 (age)
Pessoa et al., 2014[18]	−61.41+2.29(age)−0.03(age^2)+33.72(Sex)+1.40(abdominal circumference) M=1; F=0	R^2=0.49	33	p<0.05
De Freitas et al., 2014[20]	M=49.6+7.23(age)+0.47(body mass)+−37.3(height) F=10.8+4.05(age)+0.08(body mass)+30.4(height)	R^2adj=0.25 R^2adj=0.55	NR	NR
Mendes et al., 2013[21]	86.85+34.22(Sex) M=1; F=0	R^2adj=0.27	27	NR
Heinzmann-Filho et al., 2012[22]	M=47.417+[0.898 body mass]+[3.166×age] F=30.045+[0.749×body mass]+[4.213×age]	R^2=0.46 R^2=0.51	19 19	NR
Simões et al., 2010[19]	M=0.83(age)+87.69 F=−0.89(age)+125.1+(−0.18) body mass	R^2=0.84 R^2=0.77	15 12	p<0.05
Costa et al., 2010[17]	M=−1.26(age)+183.31 F=−0.68(age)+119.35	R^2=0.49 R^2=0.35	24 18	NR
Neder et al., 1999[8,33*]	M=−0.81(age)+165.3 F=−0.61(age)+115.6	R^2=0.48 R^2=0.48	15 11	p<0.05

M = male; F = female; NR = not reported; R^2 = coefficient of determination; SEE = standard error the estimate; P <0.01 / P <0.05 = statistically significant difference.
*Values were normalized by base-10 logarithm transformation due to thenon-normal distribution of the dependent variables (MIP and MEP); ** Standard Error of the coefficient of regression.

DISCUSSION

By analyzing the selected studies , we highlight the following aspects (Table 1): all studies[8,17-22,31,32] used the variables age, body weight, and stature—in this order—to predict the MIP and MEP. Only one study used abdominal circumference[18] and another found no correlation with age (R=0.07)[21]. The common use of these variables is related to the natural changes associated with aging, contributing to the improvement and continued increase of muscular strength and endurance in children[34,35]; the opposite occurs with adults, in which mass and muscle strength decrease due to the process of aging[36].

A weak correlation can influence the strength of the prediction[23,28,29], reinforcing the need for inclusion of new variables to predict the MIP and MEP, such as thoracic mobility. Despite its common application, the degree of relationship between some variables varied between the studies. The age presented a high correlation only in the study of Simões et al.[19]. On the other hand, in other studies[8,17,20,22,31,32] the correlation between age and ventilatory muscle strength ranged from low to high average. Body mass was expressed as below average and above average in some studies[8,17,19-22,32]. The results for stature showed a variation between low average and high average in some studies[8,17,19-22,32].

None of the studies[8,17-22,31,32] used thoracic abdominal mobility as anthropometric variable. As the measures of respiratory pressures are dependent on the expansion of the chest, thoracic abdominal mobility evaluates this area of the body. More recently, Lanza et al.[37] reported in their study a moderate correlation of this variable with the respiratory muscle strength, using it as a possible predictor variable for MIP and MEP.

Neder et al.[8], Costa et al.[17], and Simões et al.[19] showed similar results for the age group (20–89 years) and the predictive variables (age, body mass, and height). However, the R^2 was quite different; for Neder et al.[8], R^2 ranged from 0.46 to 0.48; for Costa et al.[17], from 0.25 to 0.52; whereas those of Simões et.[19] ranged from 0.72 to 0.84. The R^2 explains the total variation of the variables through the regression line[23]; the closer the R^2 value is to 1, the greater its power of prediction is[23]. Although Simões et al.[19] have obtained R^2 values greater than 0.70, the SEE ranged from 15 cmH_2O to 42 cmH_2O. If there is a large variation of the SEE, the value of R will be smaller[23].

The type of equipment used as well as some other methodological conditions may influence the equations, such as the standardization of reviews of MSRP. American Thoracic Society/European Respiratory Society ATS/ERS[2] and the Brazilian Society of Pulmonology and Phthisiology (*Sociedade Brasileira de Pneumologia e Tisiologia* – SBPT)[4] recommend the digital transducer model—offering greater precision in measurement. However, Neder et al.[8], Costa et al.[17], and Simões et al.[19] did not adopt the proposal[24], using an analog model instead.

The compression of facial muscles is one of the procedures for evaluating the MSRP, in order to avoid the action of the cheek muscles during MIP and MEP maneuvers [2,4,25]. However, this was mentioned only by Neder et al.[8]. No study reported controlling the temperature of the environment [8,17,19]. Simões et al were the only to control the duration of the tests.[19]. The pre-assessment of physical activity was controlled only by Neder et al.[8]. These factors could affect the variability of MIP and MEP and, consequently, affect their regression models[23].

The sample size can also influence the prediction models. The literature recommends at least 20 participants for each independent variable, with 40 participants representing the ideal sample size. An inadequate number of participants can reduce one's ability to generalize the equation[29]. Only the study of da Rosa et al.[31] used sample sizes larger than 40 participants per variable. Costa et al.[17] and Simões et al.[19] obtained a sample size close to the recommended (n=20), but three of studies[8,17,19] did not meet the ideal number of participants, nor did they apply any sample calculation technique[29].

In all studies[8,17,19-22,31,32], the participants were little familiarized with the MIP and MEP measurement and the authors did not perform cross-validation and exclusion of outliers. Participants familiarized with the measurement process may reduce the bias associated with the effects of learning[16], corroborating with the guidelines of the SBPT[4], in which the evaluations of the MSRP require a total understanding of the participants in the correct implementation of maximum effort. However, its absence can affect the quality of the final outcome[36].

Cross-validation is a fundamental technique for testing the accuracy of a regression equation on a separate sample from that which originated the equation[29,37]. It is important for applicability and predictive equations to assess its equivalence in other groups of individuals[38]; if it does not perform the same, it may lead to questionable results[29,39].

The outliers are discrepant values that deviate from the medium, being associated with errors in measurement or in the tests execution[40], and their exclusion can influence the results; therefore, the research team should identify and report such outliers[41]. Despite the significance of identifying outliers , only one study[31] reported such procedure. Finally, it is considered as limitations the lack of a methodological scale to assess the more accurate internal and external validity of the study.

CONCLUSION

The reviewed studies presented a high vulnerability of the evaluation methods for respiratory muscle strength, such as the lack of participants' familiarity with MIP and MEP, cross-validation, and exclusion of outliers, resulting in regression equations with low predictive power. Moreover, these studies did not consider the measurement of thoracic mobility, a significant anthropometric variable. Thus, these formulas can be considered weak to predict variables with high clinical applicability, such as MIP and MEP. It is necessary to update these equations by including new predictive variables—such as abdominal thoracic mobility—limiting its use in the clinical practice of Respiratory Physical Therapy. Therefore, it is suggested to conduct new prediction studies, considering the influence of abdominal circumference. Among the studies included in this review, the study by Simões et al.[19] showed the best coefficient of determination, being the most suitable, to date, for predicting respiratory muscle strength in the healthy Brazilian population.

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