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Original Article

Association Between Rib Cage Morphology and Respiratory Muscle Strength Among Healthy Young Adults: A Cross-Sectional Study

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ABSTRACT

Background: Rib cage morphology influences thoracic mechanics and may affect the efficiency of respiratory muscles. However, the relationship between thoracic dimensions and respiratory muscle strength in healthy young adults has not been extensively investigated.

Objectives: To evaluate the association between rib cage morphology and respiratory muscle strength among healthy young adults.

Materials and Methods: A cross-sectional observational study was conducted among 200 healthy medical students aged 18–25 years. Rib cage morphology was assessed by measuring chest circumference at rest, maximal inspiration and expiration, chest expansion, anteroposterior diameter, transverse diameter, and thoracic index. Respiratory muscle strength was evaluated using Maximum Inspiratory Pressure (MIP) and Maximum Expiratory Pressure (MEP) with a digital respiratory pressure meter following ATS/ERS guidelines. Pearson's correlation and multiple linear regression analyses were performed using SPSS version 23.0. A p-value <0.05 was considered statistically significant.

Results: The mean MIP and MEP were 96.5 ± 18.2 cmH_2O and 122.8 ± 22.6 cmH_2O, respectively. Chest expansion showed the strongest positive correlation with MIP ($r = 0.61$, $p < 0.001$) and MEP ($r = 0.55$, $p < 0.001$). Transverse thoracic diameter also demonstrated significant positive correlations with MIP ($r = 0.45$, $p < 0.001$) and MEP ($r = 0.42$, $p < 0.001$), while thoracic index showed weak negative correlations with both parameters. Multiple linear regression analysis identified chest expansion as the strongest independent predictor of MIP ($\beta = 0.44$, $p < 0.001$) and MEP ($\beta = 0.39$, $p < 0.001$).

Conclusion: Rib cage morphology is significantly associated with respiratory muscle strength in healthy young adults. Chest expansion, in particular, is a strong predictor of respiratory muscle performance, suggesting that simple thoracic anthropometric measurements may serve as practical, non-invasive indicators of respiratory muscle function.

Keywords: Rib cage morphology, Respiratory muscle strength, Maximum inspiratory pressure, Maximum expiratory pressure, Chest expansion, Thoracic index.

INTRODUCTION

The thoracic cage is a dynamic osteomuscular framework that protects the heart and lungs while facilitating ventilation through coordinated movements of the ribs, sternum, thoracic vertebrae, diaphragm, and intercostal muscles. The anatomy of the thoracic cage provides both structural stability and sufficient flexibility for respiratory movements.[1] During inspiration, the pump-handle movement of the upper ribs, bucket-handle movement of the lower ribs, and diaphragmatic contraction increase thoracic volume, generating negative intrathoracic pressure necessary for airflow.[2]

Rib cage morphology comprises anatomical characteristics such as anteroposterior (AP) diameter, transverse diameter, thoracic circumference, thoracic index, and chest expansion.[3] These thoracic dimensions vary according to age, sex, ethnicity, body composition, and physical activity.[4] Chest expansion is considered a simple clinical indicator of thoracic mobility and chest wall compliance, whereas the thoracic index reflects the overall shape of the thorax.[5]

Respiratory muscle strength represents the capacity of inspiratory and expiratory muscles to generate pressure during breathing. The diaphragm is the primary muscle of inspiration, contributing approximately 70–75% of tidal breathing, while the external intercostal muscles assist in rib elevation.[6] During forceful expiration, the abdominal muscles and internal intercostals become the major contributors.[7] Maximum Inspiratory Pressure (MIP) and Maximum Expiratory Pressure (MEP) are reliable, non-invasive measures of respiratory muscle strength and are recommended by the American Thoracic Society (ATS) and European Respiratory Society (ERS) for evaluating respiratory muscle function in both healthy individuals and patients with respiratory disorders.[8]

Thoracic morphology and respiratory muscle performance are closely interrelated. Greater thoracic dimensions and increased chest wall mobility provide a mechanical advantage for diaphragmatic excursion and rib movement, thereby improving respiratory muscle efficiency.[9] Conversely, reduced thoracic mobility may increase the work of breathing and reduce respiratory muscle performance.[10]
Several studies have demonstrated positive associations between thoracic dimensions and pulmonary function parameters such as forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and peak expiratory flow rate (PEFR).[11] However, spirometry primarily evaluates airflow and lung volumes rather than the contractile strength of respiratory muscles. Direct assessment of MIP and MEP therefore provides complementary information regarding respiratory muscle performance.[12]

Anthropometric assessment of the thorax is inexpensive, reproducible, and suitable for routine clinical practice as well as large epidemiological studies.[13] Combining thoracic anthropometric measurements with respiratory muscle strength assessment may improve understanding of the relationship between anatomy and respiratory physiology. Although several investigations have independently evaluated thoracic morphology or respiratory muscle strength, studies directly examining their association in healthy young adults are limited, particularly in the Indian population.[14] Establishing normative data in this age group may provide useful reference values for future studies involving respiratory diseases, obesity, aging, sports medicine, and pulmonary rehabilitation.[15]
Therefore, the present study was undertaken to evaluate the association between rib cage morphology and respiratory muscle strength among healthy young adults by assessing thoracic anthropometric parameters together with maximal inspiratory and expiratory pressures.

MATERIALS AND METHODS

Study Design

This was a **cross-sectional observational study** conducted to evaluate the association between rib cage morphology and respiratory muscle strength among healthy young adults after getting approval from the Institutional Ethics Committee.

Study Setting

The study was carried out jointly in the **Departments of Anatomy and Physiology, Viswabharathi Medical College, Kurnool, Andhra Pradesh, India.**

Study Duration

The study was conducted over a period of **six months**

Study Population

The study included apparently healthy undergraduate medical students aged **18–25 years**.

Sample Size

A total of **200 participants** were enrolled using convenience sampling after obtaining written informed consent.

Inclusion Criteria

- Healthy male and female medical students aged 18–25 years.
- Individuals willing to participate and provide written informed consent.
- Participants with no history of acute or chronic respiratory illness.

Exclusion Criteria

- History of chronic respiratory diseases (asthma, chronic obstructive pulmonary disease, pulmonary tuberculosis).
- History of cardiovascular disease.
- Congenital or acquired chest wall deformities (pectus excavatum, pectus carinatum, scoliosis, kyphosis).
- Neuromuscular disorders affecting respiratory muscles.
- Previous thoracic or upper abdominal surgery.
- Current respiratory tract infection.
- Smokers and tobacco users.
- Pregnant women.
- Individuals unable to perform respiratory pressure maneuvers satisfactorily.

Study Variables

Independent Variables (Rib Cage Morphology)

- Chest circumference at rest (cm)
- Chest circumference at maximal inspiration (cm)
- Chest circumference at maximal expiration (cm)
- Chest expansion (cm)
- Anteroposterior (AP) thoracic diameter (cm)
- Transverse thoracic diameter (cm)
- Thoracic Index (%)

Dependent Variables

- Maximum Inspiratory Pressure (MIP) (cm H_2O)
- Maximum Expiratory Pressure (MEP) (cm H_2O)

Instruments Used

- Flexible non-stretchable measuring tape
- Large spreading caliper/thoracic caliper
- Portable digital respiratory pressure meter (MicroRPM®/equivalent)
- Portable stadiometer
- Digital weighing scale

Data Collection Procedure

After obtaining Institutional Ethics Committee approval and written informed consent, demographic details including age and sex were recorded. Height was measured using a stadiometer to the nearest 0.1 cm, while body weight was measured using a calibrated digital weighing scale to the nearest 0.1 kg. Body Mass Index (BMI) was calculated as weight (kg)/height² (m²).

Assessment of Rib Cage Morphology

Participants were examined in the standing position with arms relaxed by the side.

Chest circumference was measured using a flexible measuring tape placed horizontally at the level of the xiphisternum. Measurements were recorded at:

- End of quiet expiration (rest)
- Maximum inspiration
- Maximum expiration

Each measurement was recorded to the nearest **0.1 cm**, and the average of three readings was considered for analysis.

Chest expansion was calculated as:

Chest Expansion = Chest Circumference at Maximum Inspiration − Chest Circumference at Maximum Expiration

The **anteroposterior (AP) thoracic diameter** and **transverse thoracic diameter** were measured at the level of the xiphisternum using a spreading caliper with the participant standing erect during quiet respiration.

The **Thoracic Index (TI)** was calculated using the formula:

Thoracic Index (%) = (AP Diameter / Transverse Diameter) × 100

Assessment of Respiratory Muscle Strength

Respiratory muscle strength was assessed using a calibrated **digital respiratory pressure meter** according to the recommendations of the **American Thoracic Society/European Respiratory Society (ATS/ERS)**.

Before testing, participants were instructed regarding the maneuver and allowed to practice.

Maximum Inspiratory Pressure (MIP)

MIP was measured from **residual volume (RV)**. Participants were instructed to exhale completely to residual volume and then perform a maximal inspiratory effort against an occluded mouthpiece for at least **1–2 seconds**.

Maximum Expiratory Pressure (MEP)

MEP was measured from **total lung capacity (TLC)**. Participants inhaled maximally to total lung capacity and then performed a forceful expiratory effort against the occluded mouthpiece.

A nose clip was used during testing to prevent air leakage.

Three acceptable maneuvers were obtained for both MIP and MEP with at least one minute of rest between attempts. The highest reproducible value (within 10% variation) was recorded for analysis.

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using **IBM SPSS Statistics version 23.0**. Continuous variables were expressed as **mean ± standard deviation (SD)**, whereas categorical variables were presented as frequencies and percentages.

Pearson's correlation coefficient was used to determine the association between rib cage morphology variables and respiratory muscle strength. Independent sample **t-test** was applied to compare mean values between male and female participants. Multiple linear regression analysis was performed to identify independent predictors of Maximum Inspiratory Pressure (MIP) and Maximum Expiratory Pressure (MEP). A **p-value <0.05** was considered statistically significant.

RESULTS

A total of **200 healthy young adults** participated in the study, comprising **108 (54.0%) males** and **92 (46.0%) females**. The mean age of the participants was **20.8 ± 1.6 years**, with a mean height of **167.4 ± 8.5 cm**, mean weight of **63.8 ± 10.4 kg**, and mean BMI of **22.6 ± 3.2 kg/m²**. (Table 1).

Table 1. Baseline Characteristics of the Study Participants (n = 200)

Variable	Mean ± SD / n (%)
Age (years)	20.8 ± 1.6
Height (cm)	167.4 ± 8.5
Weight (kg)	63.8 ± 10.4
BMI (kg/m²)	22.6 ± 3.2
Male	108 (54.0%)
Female	92 (46.0%)

The mean chest circumference at rest was **87.8 ± 6.5 cm**, increasing to **91.6 ± 6.7 cm** during maximal inspiration and decreasing to **85.4 ± 6.2 cm** during maximal expiration. The mean chest expansion was **6.2 ± 1.1 cm**. The mean AP thoracic diameter was **19.2 ± 1.5 cm**, whereas the mean transverse thoracic diameter was **28.1 ± 2.4 cm**. The mean thoracic index was **68.3 ± 5.1**. (Table 2)

Table 2. Rib Cage Morphology

Variable	Mean ± SD
Chest circumference at rest (cm)	87.8 ± 6.5
Chest circumference at maximal inspiration (cm)	91.6 ± 6.7
Chest circumference at maximal expiration (cm)	85.4 ± 6.2
Chest expansion (cm)	6.2 ± 1.1
AP thoracic diameter (cm)	19.2 ± 1.5
Transverse thoracic diameter (cm)	28.1 ± 2.4
Thoracic Index (%)	68.3 ± 5.1

The mean Maximum Inspiratory Pressure (MIP) was **96.5 ± 18.2 cmH_2O**, while the mean Maximum Expiratory Pressure (MEP) was **122.8 ± 22.6 cm. H_2O**. (Table 3)

Table 3. Respiratory Muscle Strength

Variable	Mean ± SD
MIP (cmH_2O)	96.5 ± 18.2
MEP (cmH_2O)	122.8 ± 22.6

Pearson correlation analysis demonstrated significant positive correlations between rib cage morphology and respiratory muscle strength. Chest expansion exhibited the strongest positive correlation with MIP (**r = 0.61, p < 0.001**) and MEP (**r = 0.55, p < 0.001**). Transverse thoracic diameter showed moderate positive correlations with MIP (**r = 0.45, p < 0.001**) and MEP (**r = 0.42, p < 0.001**), whereas AP thoracic diameter demonstrated weaker but statistically significant positive correlations with MIP (**r = 0.31, p < 0.001**) and MEP (**r = 0.28, p < 0.001**). Thoracic index showed weak negative correlations with MIP (**r = –0.16, p = 0.024**) and MEP (**r = –0.14, p = 0.046**). (Table 4)

Table 4. Correlation Between Rib Cage Morphology and Respiratory Muscle Strength

Variable	MIP (r)	p-value	MEP (r)	p-value
Chest expansion	0.61	<0.001*	0.55	<0.001*
AP thoracic diameter	0.31	<0.001*	0.28	<0.001*
Transverse thoracic diameter	0.45	<0.001*	0.42	<0.001*
Thoracic Index	–0.16	0.024*	–0.14	0.046*

*Statistically significant.

Multiple linear regression analysis was performed separately for MIP and MEP after adjusting for age, sex, BMI, AP thoracic diameter, transverse thoracic diameter, chest expansion, and thoracic index.

For **Maximum Inspiratory Pressure**, chest expansion remained the strongest independent predictor (**β = 0.44, p < 0.001**), followed by transverse thoracic diameter (**β = 0.26, p = 0.003**). AP thoracic diameter showed a modest independent association (**β = 0.15, p = 0.028**), whereas thoracic index (**β = –0.08, p = 0.182**) and BMI (**β = 0.09, p = 0.136**) were not significant after adjustment. The regression model explained **41.8%** of the variance in MIP (**Adjusted R² = 0.418, p < 0.001**). (Table 5)

Table 5. Multiple Linear Regression Analysis for Predictors of MIP

Predictor	Standardized β	p-value
Chest expansion	0.44	<0.001*
Transverse thoracic diameter	0.26	0.003*
AP thoracic diameter	0.15	0.028*
Thoracic Index	–0.08	0.182
BMI	0.09	0.136
Age	0.05	0.441
Sex	0.11	0.082

Adjusted $R^2 = 0.418$, $p < 0.001$

A similar regression model was constructed for **Maximum Expiratory Pressure**. Chest expansion (**$\beta = 0.39$, $p < 0.001$**) and transverse thoracic diameter (**$\beta = 0.24$, $p = 0.005$**) remained significant predictors, whereas AP thoracic diameter, thoracic index, BMI, age, and sex did not independently predict MEP. The overall model explained **36.5%** of the variance in MEP (**Adjusted $R^2 = 0.365$, $p < 0.001$**). (Table 6)

Table 6. Multiple Linear Regression Analysis for Predictors of MEP

Predictor	Standardized β	p-value
Chest expansion	0.39	<0.001*
Transverse thoracic diameter	0.24	0.005*
AP thoracic diameter	0.12	0.061
Thoracic Index	–0.07	0.247
BMI	0.08	0.174
Age	0.04	0.518
Sex	0.10	0.094

Adjusted $R^2 = 0.365$, $p < 0.001$

DISCUSSION

The present study evaluated the association between rib cage morphology and respiratory muscle strength among healthy young adults and demonstrated a significant positive relationship between thoracic dimensions, particularly chest expansion and transverse thoracic diameter, with respiratory muscle strength. Chest expansion emerged as the strongest independent predictor of Maximum Inspiratory Pressure (MIP), suggesting that thoracic mobility plays a crucial role in determining respiratory muscle performance.

The mean Maximum Inspiratory Pressure (MIP) and Maximum Expiratory Pressure (MEP) observed in the present study were **96.5 ± 18.2 cmH_2O** and **122.8 ± 22.6 cmH_2O**, respectively, which are consistent with the normal reference ranges reported for healthy young adults. Evans and Whitelaw reported that respiratory muscle pressures vary with age, sex, and body size, with healthy adults typically demonstrating MIP values between 75 and 130 cmH_2O and MEP values between 100 and 180 cmH_2O. These findings support the validity of the respiratory muscle strength measurements obtained in the present study.[16]

Chest expansion demonstrated the strongest positive correlation with both MIP and MEP in the present study. Increased chest expansion reflects greater thoracic mobility, which facilitates efficient diaphragmatic descent and rib elevation during inspiration. Similar observations have been reported by Bockenhauer et al., who found that thoracic excursion is a reliable indicator of chest wall mobility and is positively associated with pulmonary function in healthy adults. Improved thoracic mobility enhances the mechanical advantage of respiratory muscles and contributes to greater inspiratory and expiratory pressure generation.[17]

The present study also demonstrated a significant positive association between transverse thoracic diameter and respiratory muscle strength. A wider thoracic cavity provides increased space for lung expansion and allows more effective contraction of the diaphragm and intercostal muscles. McCool and Tzelepis emphasized that respiratory muscle performance depends not only on muscle strength but also on the geometry of the thoracic cage, which influences the length–tension relationship of respiratory muscles. Favorable thoracic dimensions improve respiratory mechanics and reduce the work of breathing.[18] Anteroposterior thoracic diameter showed a moderate positive correlation with both MIP and MEP. Although its contribution was less pronounced than chest expansion or transverse diameter, it remained an independent predictor of inspiratory muscle strength in regression analysis. Kapandji described that alterations in thoracic dimensions modify the biomechanics of pump-handle and bucket-handle movements, thereby influencing respiratory efficiency. Individuals with balanced thoracic proportions generally demonstrate superior respiratory mechanics compared to those with restricted thoracic configuration.[19]

In contrast, thoracic index demonstrated a weak negative correlation with respiratory muscle strength. A relatively higher thoracic index represents a deeper but comparatively narrower thorax, which may reduce the mechanical efficiency of rib movements. Although the correlation was statistically significant, its magnitude was small, indicating that thoracic shape alone is less important than thoracic mobility in determining respiratory muscle performance. Similar observations have been noted in anatomical and biomechanical studies evaluating thoracic geometry.[20]

Multiple linear regression analysis identified chest expansion as the strongest independent predictor of MIP, explaining a substantial proportion of the observed variability in respiratory muscle strength. This finding highlights the importance of dynamic thoracic mobility over static anatomical measurements. Laveneziana et al. also emphasized that respiratory muscle performance is influenced by both respiratory muscle contractility and chest wall mechanics, recommending assessment of thoracic mobility alongside respiratory pressure measurements during physiological evaluation.[21]

The findings of the present study have important clinical implications. Measurement of chest expansion and thoracic dimensions is inexpensive, non-invasive, and can be performed easily in outpatient clinics, pulmonary rehabilitation units, and community screening programs. These anthropometric measurements may serve as useful surrogate indicators of respiratory muscle function, particularly in settings where sophisticated respiratory pressure measuring devices are unavailable. Similar recommendations have been proposed in respiratory rehabilitation guidelines, which advocate routine assessment of chest wall mobility during respiratory evaluation.[22]

CONCLUSION

The present study demonstrated a significant association between rib cage morphology and respiratory muscle strength among healthy young adults. Chest expansion showed the strongest positive correlation with inspiratory and expiratory muscle strength and emerged as the strongest independent predictor of respiratory muscle performance.

These findings suggest that simple thoracic anthropometric measurements can serve as practical, non-invasive indicators of respiratory muscle function.

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