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PULMONARY FUNCTION TESTING

Respiratory Muscle Strength in the Physically Active Elderly

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Abstract Advancing age is associated with a decline in the strength of the skeletal muscles, including those of respiration. Respiratory muscles can be strengthened with nonrespiratory activities. We therefore hypothesized that regular exercise in the elderly would attenuate this age-related decline in respiratory muscle strength. Twenty-four healthy subjects older than 65 years were recruited (11 males and 13 females). A comprehensive physical activity survey was administered, and subjects were categorized as active ($n = 12$) or inactive ($n = 12$). Each subject underwent testing of maximum inspiratory and expiratory pressures (PI_{max} and PE_{max}). Diaphragmatic thickness (tdi) was measured via two-dimensional B-mode ultrasound. There were no significant differences between the active and inactive groups with respect to age (75 vs. 73 years) or body weight (69.1vs. 69.9 kg). There were more women (9) than men (3) in the inactive group. Diaphragm thickness was greater in the active group (0.31 ± 0.06 cm vs. 0.25 ± 0.04 cm; $p = 0.011$). PE_{max} and PI_{max} were also greater in the active group (130 ± 44 cm H_2O vs. 80 ± 24 cm H_2O; $p = 0.002$; and 99 ± 32 cm H_2O vs. 75 ± 14 cm H_2O; $p = 0.03$). There was a positive association between PI_{max} and tdi ($r = 0.43$, $p = 0.03$). Regular exercise was positively associated with diaphragm muscle thickness in this cohort. As PE_{max} was higher in the active group, we postulate that recruitment of the diaphragm and abdominal muscles during nonrespiratory activities may be the source of this training effect.

Keywords Geriatrics · Elderly · Exercise · Respiratory · Muscle strength · Diaphragm strength

Introduction

As part of the normative aging process, there is an overall decline in skeletal muscle mass and strength. This decline has also been documented for the muscles of respiration. Prior studies have described a negative association between age and measurements of respiratory muscle strength in older adults [1–8]. These investigations have been largely in the form of cohort studies. Discrepancies among them include differences in the age of onset of decline as well as the degree to which the respiratory muscles weaken. These discrepancies may in part be attributable to methodologic differences in assessing respiratory muscle strength or to uncontrolled variables such as physical activity. As training with nonrespiratory maneuvers has been shown to have a positive effect on the strength of the muscles of respiration [9, 10], we hypothesized that elderly individuals with a greater level of daily physical activity would concomitantly possess greater respiratory muscle strength.

The most commonly used noninvasive means to assess respiratory muscle strength include measurements of maximal static inspiratory pressure (PI_{max}) and maximal static expiratory pressure (PE_{max}). These maneuvers require significant subject learning and cooperation.

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Table 1 Anthropomorphic and spirometric data

ID	Group	Gender	Age	Height (cm)	Weight (kg)	BMI (kg/m^2)	FEV1% Pred	FVC% Pred
1	Active	Male	76	175.3	79.1	25.8	77	78
2	Active	Male	82	167.0	67.3	24.1	95	89
3	Active	Male	77	167.6	85.5	30.4	85	88
4	Active	Male	70	170.0	67.3	23.3	106	103
5	Active	Male	74	177.8	75.5	23.9	65	71
6	Active	Male	72	172.7	60.5	20.3	100	89
7	Active	Male	72	165.1	73.6	27.0	87	93
8	Active	Male	71	175.3	84.1	27.4	90	92
9	Active	Female	74	157.0	68.0	27.6	127	125
10	Active	Female	79	153.2	63.2	26.9	88	83
11	Active	Female	85	147.3	46.4	21.4	89	93
12	Active	Female	70	157.5	59.1	23.8	83	86
13	Inactive	Male	76	166.9	86.3	31.0	101	101
14	Inactive	Male	73	154.9	67.3	28.0	89	91
15	Inactive	Male	70	195.6	82.7	21.8	92	88
16	Inactive	Female	73	154.9	61.4	25.6	98	96
17	Inactive	Female	74	163.0	86.2	32.4	102	99
18	Inactive	Female	67	152.4	65.5	28.2	83	94
19	Inactive	Female	71	161.2	66.8	25.7	104	104
20	Inactive	Female	75	156.2	62.8	25.7	101	99
21	Inactive	Female	79	149.9	61.8	27.5	113	120
22	Inactive	Female	67	167.6	63.6	22.6	99	91
23	Inactive	Female	78	157.5	69.1	27.9	76	82
24	Inactive	Female	71	168.8	65.0	22.8	98	97

Recently, a high degree of correlation has been noted between the maximal transdiaphragmatic pressure (Pdi$_{max}$) and diaphragm thickness (tdi) in the zone of apposition of the diaphragm to the rib cage as measured via two-dimensional (2-D) ultrasound [11]. Because measurement of tdi via ultrasound is noninvasive and does not require the active cooperation of the subject, it may help to overcome some of the technical barriers to measurement of diaphragmatic strength. We therefore included this measurement as part of our testing.

Methods

Twenty-five volunteers older than age 65 years were enrolled in the study (14 women and 11 men) (Table 1). Because anthropometric data were not available for one subject, only 13 women were included in the final analysis. Subjects were recruited from among 1300 community-dwelling older adults participating in the Study of Exercise and Nutrition in Older Rhode Islanders (SENIOR) physical activity and nutrition investigation. Inclusion criteria for the SENIOR study included age greater than 65 years and residence in one selected community and its immediate environs within the state of Rhode Island. The SENIOR study population was representative of the demographics of the elderly population within this community as a whole [12]. The subjects in the present investigation formed a subset of the larger study. Volunteers were excluded only in the presence of known pulmonary or cardiac disease. The Institutional Review Board at the study site approved the study and informed consent was obtained from all subjects.

Physical Activity Score

Subjects were asked to complete a general health questionnaire and a detailed physical activity questionnaire, the Yale Physical Activity Survey (YPAS) [13]. The YPAS is an interviewer-administered physical activity survey validated for use in older adults. Based on their participation in regular vigorous cardiovascular endurance (aerobic) activity, subjects were assigned to either an active (group 1) or an inactive (group 2) category. Subjects who reported 30 min or more of vigorous physical activity three or more days per week, consistent with the recommendations of the American College of Sports Medicine [14, 15], were classified as active. Those not meeting this criterion were considered inactive.

Lung Volumes, Spirometry, and Pressure Measurements

Forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1) were measured using the Collins Medical CPLPF spirometer (Ferraris; Louisville, CO, USA). At least three acceptable maneuvers were performed by each subject until the difference between the largest and the second largest values was less than or equal to 0.150 L [16]. The maximal effort was then recorded. Lung volumes were measured by body plethysmography (Collins Medical BPd; Ferraris). At least three values within a 5% level of agreement were obtained and the mean value recorded [17]. PI_{max} was measured by instructing subjects to forcefully inhale against an occluded mouthpiece for 3 s or more (maximal Mueller maneuver). Inspiratory efforts were initiated from residual volume (RV) [3, 18]. Artifactual measurements of airway opening pressure (P_{ao}) due to buccal muscle use were prevented by a small leak at one end of the mouthpiece [3]. PE_{max} was measured at total lung capacity (TLC). The subjects were instructed to forcefully exhale against an occluded mouthpiece for 3 s or more (maximal expulsive maneuver). Effort was maximized by providing visual feedback of P_{ao} on an oscilloscope during the Mueller and expulsive maneuvers. The maximal value of PI_{max} and of PE_{max} following a minimum of six attempts that varied by less than 10% was then recorded [18]. Pressure transducers were calibrated with a water manometer before studying each subject.

Measurements of Diaphragm Thickness

Diaphragm thickness was measured via 2-D B-mode ultrasound at the zone of apposition between the diaphragm and the rib cage. A 7.5-10.0-MHz transducer was applied over the eighth to ninth intercostal space in the right midaxillary line. The diaphragm was visualized as a relatively nonechogenic central muscular layer sandwiched between the peritoneum and the diaphragmatic visceral pleura. The diaphragm was identified immediately superficial to the liver. Images obtained at end-expiration were selected for clarity and parallelism of the three layers. Diaphragm thickness was measured at FRC as the perpendicular distance (to the nearest 0.1 mm) between the superficial edge of the diaphragmatic pleura and the deep edge of the peritoneum. Reproducibility of measurements was approximately 10% [19].

Statistical Analysis

SPSS version 11.0 (SPSS Inc., Chicago, IL, USA) was used for the statistical analyses. Descriptive statistics were derived using the descriptives subroutine. Comparisons of demographic and anthropomorphic data were made using an independent-samples *t* test. Levine's test of equal variance was calculated to determine the need for correction of the *t* test for unequal variances between the groups. Cross tabulations were used to compare gender between groups, and the likelihood ratio and Fisher's exact test were calculated. Univariate analyses of covariance (ANCOVA) using general linear models were performed to determine whether tdi, PI_{max}, PI_{max} expressed as % predicted, PE_{max}, and PE_{max} expressed as % predicted differed between groups. Post-hoc power analyses for the ANCOVA analyses on the primary variable of interest, tdi, was 79%. Power for the secondary variables, PE_{max} and PI_{max}, were 91% and 62%, respectively.

Results

Thirteen women and 11 men aged 66–84 years were included in the final analysis. Twelve subjects (8 men and 4 women) were classified as active and 12 subjects (3 men and 9 women) were inactive. There were more women than men in the inactive group. However, as depicted in Table 1, there were no significant differences between the active and inactive groups with respect to age (75 ± 5 vs. 73 ± 4 years), height (165.5 ± 9.7 vs. 162.4 ± 12.1 cm), weight (69.1 ± 11.2 vs. 69.9 ± 9.5 kg), BMI (25.1 ± 2.9 vs. 26.6 ± 3.3 kg/m^2), FEV_1 (91 ± 13 vs. 97 ± 9% predicted), or FVC (91 ± 15 vs. 96 ± 10% predicted).

Measures of respiratory muscle strength were significantly greater in the active group. As shown in Figure 1, expiratory muscle strength in the active group was nearly double that in the inactive group (PE_{max} [mean ± SD] = 130 ± 44 cmH_2O compared to 80 ± 24 cmH_2O, $p = 0.002$). Inspiratory muscle strength was also greater in the active group (PI_{max} = 99 ± 32 cmH_2O vs. 75 ± 14 cmH_2O, $p = 0.03$) (Fig. 2). The greater inspiratory muscle strength found in the active group may be related to increased tdi (0.31 ± 0.06 cm vs. 0.25 ± 0.04 cm, $p= 0.01$), as shown in Figure 3. This assertion is supported by the significant positive association between tdi and PI_{max} ($r = 0.43$; $p = 0.035$).

Because there was a gender difference between the active and inactive groups, we evaluated differences in inspiratory and expiratory muscle strength as % predicted PI_{max} and % predicted PE_{max}. When performing this gender-corrected analysis, respiratory muscle strength remained significantly greater in the active group for % predicted PI_{max} ($p = 0.036$) and % predicted PE_{max} ($p = 0.005$). To further evaluate the potential effect of gender on strength, ANCOVA was performed, adjusting for gender in each group. This analysis also demonstrated that

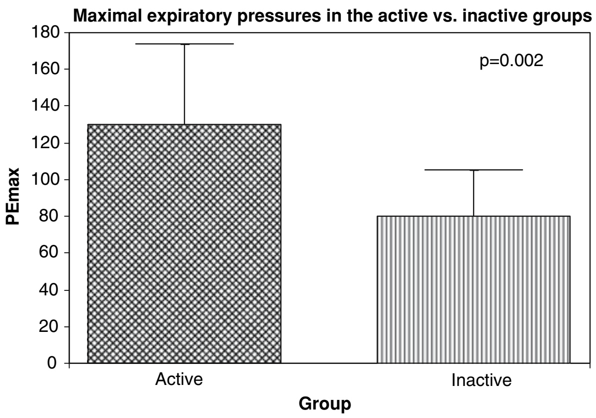

Fig. 1 Mean maximal expiratory pressure (PE_{max}) is indicated by the bars. The standard deviation is shown as the line above the bar

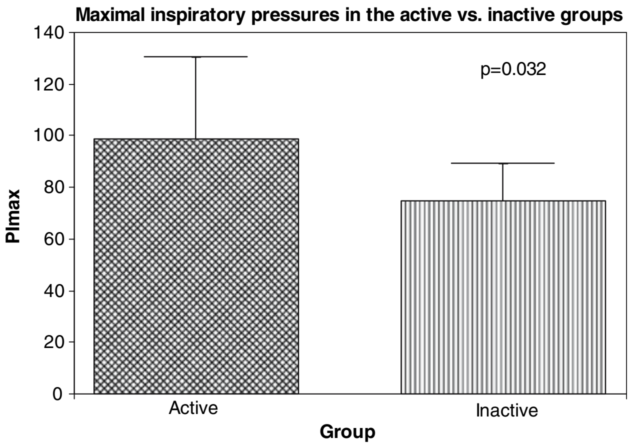

Fig. 2 Mean maximal inspiratory pressure (PI_{max}) is indicated by the bars. The standard deviation is shown as the line above the bar

respiratory muscle strength remained significantly greater in the active group (p = 0.031 for PI_{max} and p= 0.047 for PE_{max}).

Discussion

With normative aging comes an overall decline in skeletal muscle mass and strength, although this decline is attenuated by regular physical exertion [14]. The underlying etiology of aging-related sarcopenia is unknown but may be related to alterations in one or more of the following: muscle protein metabolism, endocrine system and hormonal milieu, neural control, gene expression, and apoptosis [21]. The majority of evidence to date indicates that this decline does not spare the muscles of respiration [1–8, 22]. Interventions that minimize the loss of respiratory muscle strength in the elderly may be important in reducing morbidity from common respiratory illnesses such as pneumonia and COPD.

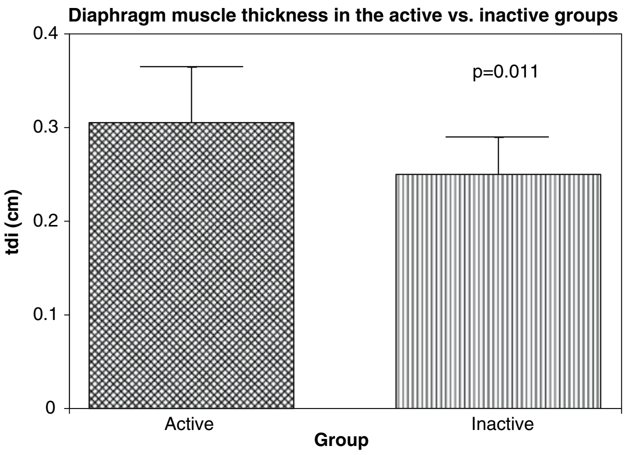

Fig. 3 Mean diaphragm muscle thickness (tdi) is indicated by the bars. The standard deviation (SD) is shown as the line above the bar

In this small cohort of older healthy adults ranging in age from 66 to 84 years, regular exercise was associated with stronger inspiratory and expiratory muscles as well as significantly greater diaphragm muscle thickness. These findings are consistent with the notion that routine engagement in physical activity can increase respiratory muscle mass and strength in the elderly. These adaptations by the respiratory muscles are similar to the increases in quadriceps strength and mass noted in elderly individuals following resistive strength training [23, 24] and suggest that the age-related decline in muscle strength may be attenuated by routine vigorous physical activity.

We postulate that recruitment of the abdominal muscles during nonrespiratory activities may have been the source of the strength training stimulus on the diaphragm and expiratory muscles. When performing maneuvers that raise intra-abdominal pressure, the diaphragm is activated to minimize the transmission of high intra-abominal pressures into the thorax. By minimizing the rise in intrathoracic pressure, adverse hemodynamic consequences of high intrathoracic pressure are averted. Diaphragm recruitment can be seen during nonrespiratory maneuvers involving the upper extremities and trunk, such as lifting or performing situps. The magnitude of Pdi attained during these nonrespiratory maneuvers is dependent on the type of maneuver performed, its intensity, and abdominal compliance. The degree to which Pdi increases during these maneuvers can be great enough to provide a strength training stimulus to the diaphragm. Similarly, the level of intra-abdominal pressures attained during these activities can be high enough to provide a strength-training stimulus to the expiratory abdominal muscles in healthy volunteers [9, 10].

In general, measurements of PE_{max} assess the strength of the abdominal and expiratory intercostal muscles, and PI_{max} reflects the strength of the diaphragm and inspiratory muscles of the rib cage. If our active elderly subjects routinely engaged in activities that raised intra-abdominal pressure, they would strengthen both the diaphragm and the expiratory abdominal muscles. Our finding of an increase in tdi, PI_{max}, and PE_{max} in the active elderly group is similar to the finding of increased diaphragm muscle mass in more muscular younger individuals [20, 25] and to the observation that inspiratory and expiratory muscle strength increase in younger healthy individuals following training with biceps curls and situps [10]. Further study with invasive determinations of gastric pressure (P_{ga}), esophageal pressure (P_{es}), and Pdi_{max} might be helpful in further clarifying the strength-training stimulus in the elderly.

The results of two previous investigations in older adults support our findings. The largest study to date that examined respiratory muscle strength in the elderly was the Cardiovascular Health Study. In that study PI_{max} was measured in 4443 and PE_{max} in 790 ambulatory adults aged 65 and older. Measurements of PI_{max} correlated not only with age and gender, but with handgrip strength, a measure that correlates well with overall muscle strength [5]. Similarly, the Baltimore Longitudinal Study of Aging investigators found a high degree of correlation between forearm circumference, a surrogate measure of muscle mass, and PI_{max} [8].

The results of our study need to be confirmed by studying a much larger cohort of elderly individuals. Because there were more men in the active group, it might be postulated that some of our results might be related to this gender difference between the subjects of the two groups. However, given that PI_{max} and PE_{max} remained significantly greater in the active group when the analyses were adjusted for gender as well as when expressed as % predicted, it is unlikely that gender could explain the differences between the two groups.

We conclude that general exercise in the elderly is associated with an increase in diaphragm thickness. It has been shown that cardiovascular and resistance exercise as well as specific respiratory muscle training is beneficial in patients with respiratory disease [26, 27]. The results of the present study support the postulate that an overall greater level of activity and generalized exercise may be beneficial in maintaining muscle mass and perhaps diaphragm strength in the elderly.

References

1. Cook CD, Mead J, Orzalesi MM (1964) Static volume-pressure characteristics of the respiratory system during maximal efforts. J Appl Physiol 19:1016–1022
2. Rinqvist T (1966) The ventilatory capacity in healthy subjects. Scand J Clin Lab Invest 18:1–179
3. Black LF, Hyatt RE (1969) Maximal respiratory pressures: normal values and relationship to age and sex. Am Rev Respir Dis 99:696–702
4. Hautmann H, Hefele S, Schotten K, Huber RM (2000) Maximal inspiratory mouth pressures (PIMAX) in healthy subjects – what is the lower limit of normal? Respir Med 94:689–693
5. Enright PL, Kronmal RA, Manolio TA, Schenker MB, Hyatt RE, for the Cardiovascular Health Study Research Group (1994) Respiratory muscle strength in the elderly. Correlates and reference values. Cardiovascular Health Study Research Group. Am J Respir Crit Care Med 149:430–438
6. Tolep K, Higgins N, Muza S, Criner G, Kelsen SG (1995) Comparison of diaphragm strength between healthy adult elderly and young men. Am J Respir Crit Care Med 152:677–682
7. Polkey MI, Harris ML, Hughes PD (1997) The contractile properties of the elderly human diaphragm. Am J Respir Crit Care Med 155:1560–1564
8. Harik-Khan RI, Wise RA, Fozard JL (1998) Determinants of maximal inspiratory pressure. The Baltimore longitudinal study of aging. Am J Respir Crit Care Med 158:1469–1464
9. Al-Bilbeisi F, McCool FD (2000) Diaphragm recruitment during nonrespiratory activities. Am J Respir Crit Care Med 162:456–459
10. DePalo VA, Parker AL, Al-Bilbeisi F, McCool FD (2004) Respiratory muscle strength training with nonrespiratory maneuvers. J Appl Physiol 96:731–734
11. McCool FD, Conomos P, Benditt JO, Cohn D, Sherman CB, Hoppin FG (1997) Maximal inspiratory pressures and dimensions of the diaphragm. Am J Respir Crit Care Med 155:1329–1334
12. Clark PG, Nigg CR, Greene G, Riebe D, Saunders SD, for the Study of Exercise, Nutrition in Older Rhode Islanders Project Team (2002) The study of exercise and nutrition in older Rhode Islanders (SENIOR): translating theory into research. Health Educ Res 17(5):552–561
13. DiPietro LC, Caspersen AM, Ostfeld AM, Nadel EM (1993) A survey for assessing physical activity among older adults. Med Sci Sports Exerc 25:628–642
14. American College of Sports Medicine Position Stand (1998) Exercise and physical activity for older adults. Med Sci Sports Exerc 30:992–1008
15. American College of Sports Medicine Position Stand (1998) The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness and flexibility in healthy adults. Med Sci Sports Exerc 30:975–991
16. ATS/ERS Task Force (2005) Standardisation of spirometry. Eur Respir J 26:319–338
17. ATS/ERS Task Force (2005) Standardization of the measurement of lung volumes. Eur Respir J 26:511–522
18. ATS/ERS (2002) Statement on respiratory muscle testing. Am J Respir Crit Care Med 166:518–624
19. Cohn D, Benditt JO, Eveloff S, McCool FD (1997) Diaphragm thickening during inspiration. J Appl Physiol 83:291–296
20. McCool FD, Benditt JO, Conomos P, Anderson L, Sherman CB, Hoppin FG (1997) Variability of diaphragm structure among healthy individuals. Am J Respir Crit Care Med 155:1323–1328
21. Marcell TJ (2003) Sarcopenia: causes, consequences, and preventions. J Gerontol A Biol Sci Med Sci 58:M911–916
22. Tolep K, Kelsen SG (1993) Effect of aging on the respiratory skeletal muscles. Pulmonary disease in the elderly patient. Clin Chest Med 14:363–377
23. Fiatarone MA, Marks EC, Ryan ND, Meredith CN, Lipsitz LA, Evans WJ (1990) High-intensity strength training in nonagenarians: effects on skeletal muscle. JAMA 263:3029–3034
24. Fiatarone MA, O'Neill EF, Ryan ND, Clements KM, Solares GR, Nelson ME, Roberts SB, Kehayias JJ, Lipsitz LA, Evans WJ (1994) Exercise training and nutritional supplementation for physical frailty in very elderly people. New Engl J Med 330:1769–1775

25. Arora NS, Rochester DF (1982) Effect of body weight and muscularity on human diaphragm muscle mass, thickness, and area. J Appl Physiol 52:64–70
26. American College of Chest Physicians and American Association for Cardiovascular and Pulmonary Rehabilitation (1997) Pulmonary rehabilitation. Joint ACCP and AACVPR evidence-based guidelines. Chest 112:1363–1396
27. American Thoracic Society (1999) Pulmonary rehabilitation – 1999. Am J Respir Crit Care Med 159:1666–1682