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# Implications of expiratory muscle strength training for rehabilitation of the elderly: Tutorial

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**Abstract—**With age, physical functions decline, which influences respiratory performance. One of the physical changes associated with aging is sarcopenia, a reduction in muscle strength and power. Sarcopenia has been extensively studied in the elderly with regard to limb function but less with regard to respiratory function. Elderly individuals experience reduced muscle mass and strength in respiratory musculature, which may hinder the ability to generate adequate expiratory driving force for both ventilatory and nonventilatory activities. Increasing expiratory muscle strength may enhance an elderly individual's ability to generate and maintain the expiratory driving force critical to cough, speak, and swallow. Previous studies demonstrate that expiratory muscle strength training (EMST) improves ventilatory and nonventilatory functions. This paper discusses the potential impact that EMST can have on the rehabilitation of respiratory muscle decline, particularly in the elderly. This tutorial reviews an EMST paradigm, its physiological underpinnings, and its potential outcomes.

**Key words:** cough, elderly, expiratory muscle strength training (EMST), maximum expiratory pressure (MEP), muscle, rehabilitation, sarcopenia, speech, strength, swallow.

## INTRODUCTION

With aging, physiological capacities can become greatly limited, resulting in increased incidence of disease and disability [1]. The United States has a population of 280.5 million, and among them, approximately 12 percent (33.6 million) are 65 years and older [2]. Additionally, our population is growing fast, with the fastest growing group being those over 85 years of age [1]. Within the next 10 years, the number of people aged 85 and older is estimated to increase by more than 6 million [3].

Respiration is a function that is critical for sustaining life but also significantly important for generating the pressure needed to cough, speak, and swallow. For clinicians, knowledge of age-related changes in the respiratory system is important to gain, since these changes can increase the chance of respiratory disease and aggravate acute or chronic respiratory failure conditions [4–6]. Thus, this paper reviews the physiologic changes that occur in the respiratory system as a function of age. Additionally, we describe an innovative treatment paradigm used to specifically target improving strength of the respiratory muscles.

**Abbreviations:** EMST = expiratory muscle strength training, ERV = expiratory reserve volume, $FEV_1$ = forced expiratory volume in 1 second, FVC = forced vital capacity, IMST = inspiratory muscle strength training, MEP = maximum expiratory pressure, MIP = maximum inspiratory pressure.

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## RESPIRATORY SYSTEM CHANGES

The main functional changes in the respiratory system with aging are associated with an increase in lung compliance (i.e., a decrease of the lungs elastic recoil) [7–13] and a decrease in compliance of the chest wall (i.e., an increase of the chest wall stiffness) [10,13–15]. Both result in a progressive decline of forced vital capacity (FVC), forced expiratory volume in 1 second ($FEV_1$), forced expiratory flow, and an increase in functional residual capacity due to rises in both residual volume and expiratory reserve volume (ERV) [16–19]. Respiratory muscle function also significantly decreases [8,15,20–23]. Because of the difficulty in accurately quantifying the age-related changes to respiratory muscles, specific changes in either morphological or functional properties of respiratory muscles with aging have not been reported extensively [20]. Most of the deficits of the respiratory muscle, composed mainly of skeletal muscle, much like the upper and lower limbs, are estimated by measures of the deficits that occur in the limbs [24–25]. The most common change in skeletal muscles with aging is muscle fiber atrophy, especially with a disproportionate atrophy of the fast-twitch fibers (i.e., Type II fibers). Type II fibers are responsible for fast and powerful movements.

### Respiratory Muscle Atrophy and Strength in the Elderly

Skeletal muscle atrophy (i.e., a reduction in skeletal muscle mass) causes a reduction in muscle strength and power, which is referred to as sarcopenia [26–28]. First coined by Rosenberg [29], sarcopenia is highly prevalent in the elderly population. Generally, the prevalence of sarcopenia ranges from 6 to 30 percent in persons over the age of 60 [30–32] and varies depending on measurement and definition as well as the gender of the individual. Furthermore, some studies have postulated that it increases more than 50 percent in persons after 80 years of age [30,33]. Even though the possible causes of sarcopenia are not clearly known, major contributing factors are known, including decreased physical activity, altered neuromuscular function (e.g., motor units innervating muscle), and inadequate nutrition, as well as changes in molecular status (e.g., mitochondrial volume and activity) and anabolic hormonal status (e.g., testosterone, dehydroepiandrosterone, growth hormone, insulin growth factor-I) with age [34].

Characterized by decreases in muscle mass (cross-sectional area) and a decrease in the number and size of muscle fibers [35], sarcopenia results in a skeletal muscle cross-sectional area decrease by 20 to 40 percent between the ages of 20 and 60 [36–40]. By age 80, muscle mass is dramatically reduced, by up to one-half of the total muscle mass [37]. Most muscle atrophy and reductions in the number and size of muscle fibers with age are explained by either age-related physical inability or neuromuscular changes that include a decreased number of motor units, changes in neuromuscular junctions, and loss of peripheral motor neurons [41].

Skeletal muscles, in general, consist of several different muscle fiber types of which the characteristics are determined by the properties of the motor units innervating them. The type of fibers in skeletal muscles is mostly composed of Type I and Type II. Type I, slow oxidative (slow-twitch), fibers are innervated by slow fatigue resistant motor units, and Type II (fast-twitch) fibers are subcategorized into Type IIa (fast oxidative-glycolytic) fibers innervated by fast fatigue-resistant motor units and Type IIb (fast glycolytic) fibers innervated by fast fatigable motor units [26].

Age-related atrophy is predominantly shown in Type II fibers [25,34,37,41–43]. Type I fibers also decrease in the number and size with age; however, the extent of their reduction is much less than that of Type II fibers, particularly Type IIa [43]. Previous studies demonstrate that the mean area of Type II fibers in individuals age 70 decreases from 20 to 50 percent [36–37] and the percentage of Type II fibers relative to total muscle fibers also decreases by 41 percent in elderly aged 60 years and above [44–45]. The decrease in the proportion of Type II fibers can be explained by either a direct loss in the total number of Type II fibers due to decreases in muscle protein synthesis or the conversion from Type II to Type I fibers due to selective denervation [25,36,41]. With aging, progressive loss of motor neurons in the spinal cord results in denervation of fast-twitch fibers along with reinnervation of these fibers by axonal sprouting from adjacent slow-twitch motor neurons [20].

Muscle strength is defined as the maximum force generation capacity of an individual and is divided into isometric (static) and dynamic (including isokinetic) muscle strengths [46]. Isometric strength is the maximum force when there is no change in muscle length, while dynamic strength is the maximum force generated from actions and accounts for the maximum power that is the product of force and speed of muscle contraction when movement exists [46]. Several studies have shown that muscle strength of both the isometric and dynamic types declines with aging. Isometric muscle strength decreases

by 20 to 40 percent in elderly individuals after age 60 [39–40,47–48] and maximally up to 76 percent [49–50]. In addition, losses in dynamic muscle strength have been reported with an almost 50 to 60 percent loss of isokinetic strength in persons between the ages of 30 and 80 [48,51]. Changes in proportion of fiber types may also explain a reduction of lower tension and velocity of contraction and relaxation compared with those of young muscles [52–53], which can reduce power of the skeletal muscles. Sarcopenia of the respiratory muscles also decreases their potential muscle strength. Chen and Kuo indicated that respiratory muscle strength and endurance decreases by approximately 20 percent in persons by the age of 70 years [22].

The respiratory muscles include the inspiratory and expiratory muscle groups. The diaphragm, internal intercostals of the parasternal region, external intercostals, and other accessory muscles mainly constitute the inspiratory muscles. The lateral internal intercostals and abdominal muscles constitute the expiratory muscles [54]. These muscles not only act as the major pump for ventilation, but they also play a role in nonventilatory activities.

A decrease in respiratory muscle strength with aging can deteriorate ventilatory as well as nonventilatory functions [54–55]. Nonventilatory functions include coughing, sneezing, Valsalva maneuver, talking, singing, swallowing, and other functions that are accompanied by expiratory effort. During expiration at rest, the passive elastic recoil of the lungs is typically used to generate expiratory force. However, the expiratory muscles must contract to produce the necessary lung pressure during nonventilatory activities [55] and contract below the functional residual capacity [56]. Mizuno reported that the mean cross-sectional area of expiratory internal intercostal muscles decreases by approximately 7 to 20 percent in persons about 50 years of age because of a reduction of both Type I and Type II fibers, predominantly Type II fibers [54]. Other studies demonstrate no or less change in muscle mass and no change in muscle fiber types in diaphragmatic muscle and inspiratory external intercostal muscles with aging [5,57–59]. In a postmortem study of elderly respiratory muscle, Type II fiber atrophy was observed in abdominal muscles, but not in the diaphragm [54]. These studies present evidence that suggests the expiratory muscles are more affected by the aging process than the inspiratory muscles.

Declining lung and chest wall functions, whether due to aging or disease, would require more muscular effort in both expiratory and inspiratory phases. In an early study of lung and chest wall compliance, Turner, Mead, and Wohl examined changes in lung elasticity as a function of age [13]. Their findings concur with more recent reviews of lung recoil and chest wall compliance by Janssens, Pache, and Nicod [15] that show decreased chest-wall compliance and decreased static elastic recoil of the lungs with aging. With decreases in chest-wall compliance and lung elasticity, respiratory muscles will be required to work more to move the chest wall during breathing. Thus strengthening respiratory muscles should help minimize the physical changes associated with chest-wall compliance as a function of age, since respiratory muscle contraction is necessary for moving the chest wall and the lungs.

## Measurement of Respiratory Muscle Strength

While directly measuring the number and size of muscle fibers might be useful in the assessment of respiratory muscle strength related to muscle mass, doing so would require invasive procedures for the direct measurement of the morphology of the respiratory muscles in vivo. Direct measurement of the force output of the human respiratory muscles is also impractical [25]. Therefore, the morphological changes that occur in respiratory skeletal muscles with aging have been studied in rodents or other animals. Available data on the morphological aspects of human respiratory muscles with aging come largely from the results of Mizuno's postmortem study [54]. Another less invasive way to measure the strength of the overall respiratory muscles is by testing the function of respiratory muscles using indexes, such as maximum inspiratory pressures (MIPs) and maximum expiratory pressures (MEPs) [21–23,60–65]. These measures provide an indirect way of examining maximum strength of the respiratory muscles. Researchers use MIPs to measure inspiratory muscle strength at the level of either functional residual capacity or residual volume and use MEPs to measure expiratory muscle strength at the level of total lung capacity.

After the study of Ringqvist [65], many others have investigated the relationship between age and MIPs or MEPs. Black and Hyatt observed respiratory muscle strength declines at a rate between 0.25 and 0.79 cm $H_2O$ a year for MIPs and between 1.14 and 2.33 cm $H_2O$ a year for MEPs in both men and women, respectively [60]. Enright et al. also found similar age-related decrements in both MIPs and MEPs with a rate of decline in MIPs about 1 cm $H_2O$ a year and for MEPs about 2 to 3 cm $H_2O$ a year for those persons between 65 to 85 years of age [23].

Results from other studies indicate no statistically significant negative relationship between age and MIPs and MEPs because of other variances, such as the number of subjects or body surface area; however, some degree of decreased MEPs was found, especially in men over 55 years of age in their studies [61,64]. **Table 1** summarizes the decline of MEP levels in both men and women as a function of age. Obvious differences were found in the MEPs across the studies in **Table 1**. All studies demonstrated higher MEPs in men than in women. Some factors that may be related to the differences obtained in MEPs across the studies follow. The subjects in the Chen and Kuo study [22] were Asian and physically were of smaller stature than those in the Black and Hyatt [60] and the

**Table 1.**
Normal maximum expiratory pressure (MEP) values with age.

| Age Range | Ringqvist[1] | | Black & Hyatt[2] | | Chen & Kuo[3] | | Enright et al.[4] | | Berry et al.[5] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Men (*n*) | Women (*n*) | Men (*n*) | Women (*n*)* | Men (*n*) | Women (*n*) | Men (*n*) | Women (*n*) | Men (*n*) | Women (*n*) |
| 18–29 | 247 ± 41 (37) | 170 ± 29 (33) | — | — | 141.2 ± 8.8 (20) | 97.9 ± 5.4 (20) | — | — | — | — |
| 30–39 | 248 ± 38 (12) | 163 ± 29 (8) | — | — | 136.6 ± 8.9 (20)† | 92.8 ± 4.2 (20)† | — | — | — | — |
| 40–49 | 253 ± 52 (15) | 178 ± 33 (12) | — | — | — | — | — | — | — | — |
| 50–59 | 252 ± 32 (13) | 157 ± 28 (12) | 218 ± 74 (5) | 145 ± 40 (8) | 133.6 ± 8.9 (20)‡ | 88.4 ± 6.2 (20)‡ | — | — | — | — |
| 60–64 | 209 ± 49 (16)§ | 157 ± 27 (17)§ | 209 ± 74 (3) | 140 ± 40 (4) | 117.4 ± 7.4 (20)¶ | 75.1 ± 5.1 (20)¶ | — | — | — | — |
| 65–69 | — | — | 197 ± 74 (7) | 135 ± 40 (6) | — | — | 188 (113) | 125 (176) | 190 ± 55** (44) | 125 ± 36** (57) |
| 70–74 | 200 ± 42 (13) | 165 ± 29 (10) | 185 ± 74 (10) | 128 ± 40 (10) | — | — | 179 (105) | 121 (119) | — | — |
| 75–79 | — | — | — | — | — | — | 161 (59) | 102 (85) | — | — |
| 80–84 | — | — | — | — | — | — | 142 (43) | 84 (34) | — | — |
| 85+ | — | — | — | — | — | — | 131 (9) | 94 (13) | — | — |

Note: Mean MEP or mean MEP ± standard deviation (in cm $H_2O$) included.
[1]Ringqvist T. The ventilatory capacity in healthy subjects. An analysis of causal factors with special reference to the respiratory forces. Scand J Clin Lab Invest Suppl. 1966;88:67.
[2]Black LF, Hyatt RE. Maximal respiratory pressures: Normal values and relationship to age and sex. Am Rev Respir Dis. 1969;99(5):698–99.
[3] Chen HI, Kuo CS. Relationship between respiratory muscle function and age, sex, and other factors. J Appl Physiol. 1989;66(2):945.
[4]Enright PL, Kronmal RA, Manolio TA, Schenker MB, Hyatt RE. Respiratory muscle strength in the elderly. Correlates and reference values. Cardiovascular Health Study Research Group. Am J Respir Crit Care Med. 1994;149(2 Pt 1):432.
[5]Berry JK, Vitalo CA, Larson JL, Patel M, Kim MJ. Respiratory muscle strength in older adults. Nurs Res. 1996;45(3):155. Linear regression for men, MEPs = 360 – 2.47 × age; for women, MEPs = 242 –1.75 × age.
*Number of subjects in each group in this column was not defined in original paper, so we estimated number of subjects from figure shown in published manuscript.
†Range of age = 31–45.
‡Range of age = 46–60.
§Range of age = 60–69.
¶Range of age = 61–75.
**Range of age = 65 and older.

Ringqvist [65] studies, which included Caucasian subjects. Second, the study of Chen and Kuo was done 20 years following the Ringqvist and the Black and Hyatt studies. Differences in the types of pressure transducers, their sensitivity, and other measurement protocol issues could certainly contribute to the database variations.

Since MIPs and MEPs are used to reflect an individual's respiratory muscle strength, these indexes can be used to study the relationship between strength and ventilatory and nonventilatory functions. A recent study supports that MEPs are the most appropriate index for quantifying respiratory muscle strength in the elderly [63]. Ability to generate maximal expiratory force plays a critical role for nonventilatory tasks, such as cough, speech, and swallow [23,62], which are important functions with which elderly patients demonstrate problems, particularly those poststroke or with other neuromuscular diseases such as Parkinson's disease, spinal cord injury, or multiple sclerosis.

## RESPIRATORY MUSCLE STRENGTH TRAINING IN THE ELDERLY

Given the age-related declines in respiratory muscle strength, a mechanism for training the muscles might be beneficial and actually aid and/or prevent a certain degree of muscle wasting. Resistance training of skeletal muscles has resulted in significant improvements in skeletal muscle strength in the young, elderly, and even in the frail elderly [66–70]. Training is associated with a combination of both central (neural) and peripheral (muscle mass) adaptations. After a person completes a few days to a few weeks of training, a rapid improvement of muscle strength is noticed without hypertrophy. This rapid improvement relates to neural adaptations, including increases in the number of motor neurons and recruitment of motor units, an increased discharge rate of motor units, or fiber type transitions from Type IIb to Type IIa fibers, which are associated with the acquisitions in muscle strength observed in the early stage of training [24]. The result of neural adaptations has been consistently demonstrated across studies in elderly and young subjects. However, the exact mechanisms of central adaptations are not clearly understood. Preliminary studies provide indirect evidence of neural adaptations from measuring maximal voluntary neural activation recorded on surface electromyography [71–73] as well as motor unit discharge rate with the use of an indwelling electrode [74–75] in both short- and long-term muscle strength training programs. In these studies, neural activities and maximal motor unit discharge rates of trained muscles were significantly increased with maximal voluntary contraction after muscle strength training.

The peripheral adaptations are related to muscle hypertrophy and increased contractile capacity and occur in later stages of muscle strength training programs. Research has shown that strength training promotes an increase in muscle protein synthesis, resulting in muscle hypertrophy; an increase in muscle strength with an overload stimulus [76]; and a cross-sectional area increase in both Type I and II single muscle fibers of skeletal muscles of the elderly [77]. In addition, satellite cells, which are important for muscle fiber regeneration and hypertrophy, are also increased in their proportion and activities [78].

Interest in the potential of a training program to increase the strength and/or endurance of respiratory muscles in an elderly population has increased in the last few decades [25]. Respiratory muscle strength training programs are similarly based on the paradigms used for training the limbs. In the late 1970s, Leith and Bradley were one of the first to attempt to train respiratory muscles by performing strength and endurance training to target specific ventilatory muscle groups [79]. Subjects were trained 5 days a week for 5 weeks maintaining $CO_2$ levels at a specific level. The training required extensive equipment to monitor the $CO_2$ levels.

Consequently, other respiratory muscle strength training programs were developed to overstep the limitation of Leith and Bradley's complex equipment requirement. Commonly executed respiratory muscle strength training programs are flow-independent pressure-threshold training and flow-dependent resistance training. Pressure-threshold training of respiratory muscles involves a subject performing a certain number of repetitions a week with a specific number of exercise sets of training in each day. This training requires that an individual produce a certain amount of lung pressure to open a one-way valve on the training device so that air from the lungs flows through the device. Resistance training does not depend on the lung pressure generated by respiratory muscles but depends on the airflow, which travels through the training device. Baker postulated that pressure-threshold training would result in greater training effect than resistance training because it requires a higher level of force to meet the load presented at a specific level compared to resistance training [80].

Most training paradigms with the elderly have used inspiratory resistive or threshold loading [25,81–89]. These have focused especially on inspiratory muscle strength training (IMST) in elderly patients with pulmonary disease (e.g., asthma, chronic obstructive pulmonary disease) or respiratory muscle weakness (e.g., multiple sclerosis, Parkinson's disease) with expectations to improve ventilatory capacity. However, interest in expiratory muscle strength training (EMST) has developed more recently, particularly for improving nonventilatory functions such as coughing, speaking, and swallowing. Evidence that EMST increases expiratory muscle strength has been shown in other studies of healthy adults [80,90–91], hypotonic children [92], high-risk performers [93], high school band students [94], patients with chronic obstructive pulmonary disease [95], multiple sclerosis [96–97], Parkinson's disease [98], and myasthenia gravis [99]. These studies demonstrated that EMST is effective in increasing the strength of expiratory muscles resulting in augmenting the expiratory driving pressure used for cough, speech, or swallow (**Table 2**). Little outcome data are available on respiratory muscle strength training in the healthy elderly in either an inspiratory or expiratory direction, and use of respiratory muscle strength training may be beneficial for prevention or treatment of normal age-related respiratory muscular weakness [25]. Watsford et al. trained 26 older female subjects (mean age = 64.4) with both IMST and EMST [100]. They obtained significant increases in FVC, $FEV_1$, maximum voluntary ventilation, MIPs, MEPs, and other performance assessments such as time-to-rate of perceived exertion 15 walking test. However, this study only documented healthy elderly female performance. To date, no study has examined the effect of EMST on expiratory muscle strength in healthy elderly males and females and only a few have attempted to train elderly persons with disease [95].

## EXPECTED OUTCOMES WITH EMST

Promising results from preliminary studies investigating the effects of expiratory muscle strength in different groups of subjects suggest that EMST is able to increase expiratory muscle strength, improve cough function, positively affect speech characteristics, and promote swallow performance in healthy young and clinical populations [80,92–93,96–98]. Hence, one would expect that EMST would improve respiratory function as well as the ability to clear the airway, speak, and swallow in the elderly.

To expect that EMST would improve respiratory function by enhancing expiratory muscle strength in the elderly population is reasonable. FVC, $FEV_1$, and ERV would be likely affected. With age, expiratory force is diminished because of reduced elastic recoil of the lungs, compliance of the chest wall, and expiratory muscle strength. Consequently, residual volume increases up to 50 percent and vital capacity decreases by about 75 percent maximally as adults reach age 70 [18]. Strengthening expiratory muscles by EMST would enhance the ability of the elderly to generate more expiratory force and compress the rigid chest wall to a smaller volume as a compensatory mechanism, resulting in an increase in FVC, $FEV_1$, and ERV. As shown in **Table 2**, MEP levels were increased by a significant amount regardless of the training program, duration of training, and training load.

We anticipate that EMST would also increase peak expiratory flow rate during cough production. Coughing is a reflexive protective mechanism to clear foreign substances or excessive mucous in the airways to reduce respiratory infection. Reduced mucociliary clearance function [101–102], decreased sensitivity of pharyngoglottal closure reflex [103], and a diminished laryngeal-valving mechanism [104] are the major causes of accumulation of phlegm or aspiration in intrathoracic airways, which eventually increases the mortality or morbidity of the elderly population from respiratory diseases. To counteract these regressed mechanisms, coughing plays an important role in expelling foreign materials or secretions [105]. Ineffective coughing is also possibly related to reduced expiratory flow rates as well as lengthened laryngeal compression time [105]. McCool and Leith noted that decreased expiratory peak flow is closely related to decreased inspiratory or expiratory muscle strength [105]. Specific methods for increasing cough strength and timing have not been studied in the literature to date. The implications are nontrivial for the elderly population. An improvement in cough function should significantly reduce the occurrence of respiratory infections, thus enhancing the overall health of the elderly. We anticipate that EMST with the elderly has the potential to decrease or delay the development of respiratory complications by increasing respiratory muscle strength and increasing the ability to clear the airway with a strong cough. Cough magnitude is directly related to the amount of expiratory driving pressure, and expiratory pressure is the direct target of the respiratory training technique.

**Table 2.**
Summary of expiratory muscle strength training (EMST) studies.

| Study | Subjects | *N* | Training Program | Training (wk) | Training Load | MEP Gain From Baseline (%) | Within Subject Significance Level | Functional Outcome |
|---|---|---|---|---|---|---|---|---|
| O'Kroy & Coast* | Healthy subjects | 6 | RT | 4 | 32% of MEP | NS | NS | Not applicable |
| Suzuki et al.† | Normal subjects | 6 | PT | 4 | 30% of MEP | 25 | $p < 0.01$ | Not applicable |
| Cerny et al.‡ | Hypotonic children | 9 | RT | 6 | 2.5 cm $H_2O$ to 7.5 cm $H_2O$ | 69 | $p = 0.0003$ | Improvement of speech |
| Smeltzer et al.§ | Multiple sclerosis | 10 | PT | 12 | Not reported | 37 | No testing completed | Improvement of cough (subjective report) |
| Gosselink et al.¶ | Multiple sclerosis | 9 | PT | 12 | 60% of MEP | 35 | NS | Improvement of cough (subjective report) |
| Hoffman-Ruddy** | High-risk performers | 8 | PT | 4 | 75% of MEP | 84 | No testing completed | Improvement in speech |
| Sapienza et al.†† | High school band students | 26 | PT | 2 | 75% of MEP | 47 | $p = 0.000$ | Not applicable |
| Baker‡‡ | Healthy young adults | 32 | PT | 4 to 8 | 75% of MEP | 50 | $p = 0.000$ | Improvement in speech and cough |
| Salem et al.§§ | Parkinson patients | 6 | PT | 4 | 75% of MEP | 24 to 74 | No testing completed | Improvement in speech, cough, and swallow |

*O'Kroy JA, Coast JR. Effects of flow and resistive training on respiratory muscle endurance and strength. Respiration. 1993;60(5):279–83.
†Suzuki KS, Sato M, Okubo T. Expiratory muscle training and sensation of respiratory effort during exercise in normal subjects. Thorax. 1995;50(4):366–70.
‡Cerny FJ, Panzarella K, Stathopoulos ET. Expiratory muscles conditioning in hypotonic children with low vocal intensity levels. J Med Speech Lang Pathol. 1997;5:141–52.
§Smeltzer SC, Lavietes MH, Cook SD. Expiratory training in multiple sclerosis. Arch Phys Med Rehabil. 1996;77(9):909–12.
¶Gosselink R, Kovacs L, Ketelaer P, Carton H, Decramer M. Respiratory muscle weakness and respiratory muscle training in severely disabled multiple sclerosis patients. Arch Phys Med Rehabil. 2000;81(6):747–51.
**Hoffman-Ruddy B. Expiratory pressure threshold training in high-risk performers [dissertation]. Gainesville (FL): University of Florida; 2003.
††Sapienza CM, Davenport PW, Martin AD. Expiratory muscle training increases pressure support in high school band students. J Voice. 2002;16(4):495–501.
‡‡Baker SE. Expiratory muscle strength training and detraining: effects on speech and cough production [dissertation]. Gainesville (FL): University of Florida; 2003.
§§Salem AF, Rosenbek JC, Davenport P, Shrivastav R, Hoffman-Ruddy B, Okun MS, Sapienza CM. Expiratory muscle strength training in patients with idiopathic Parkinson's disease [poster session]. Conference on Motor Speech: Motor Speech Disorders; 2004 March 18–24; Albuquerque, New Mexico.
MEP = maximum expiratory pressure
*N* = number of subjects who were trained with EMST program
PT = pressure-threshold training
RT = resistance training
NS = not significant

Specifically, we expect that EMST would increase the peak rate of expiratory flow during coughing as a result of overcoming high peripheral airway resistance. In addition, EMST should decrease the laryngeal compression time. Changed afferent inputs in pressure are transferred to the central cough centers [101], and this process should alter efferent outputs to the adductory laryngeal muscles. As a result, laryngeal compression time may decrease [80]. These potential effects would decrease the chance of aspiration and decrease potential of respiratory infection. Baker [80] and Salem et al. [98] found that a 4-week EMST program improved peak expiratory flow and

reduced laryngeal compression time during voluntary cough in healthy young adults and patients with Parkinson's disease. In a study of patients with multiple sclerosis, increased expiratory pressure achieved with a 3-month pressure threshold EMST program was effective in increasing cough function, although the reports were subjective [96]. This effect was also demonstrated in another study of an EMST program with patients with multiple sclerosis [97]. Ten subjects in this study reported diminished choking events post-EMST.

Our previous work with the strength-training program in other patient groups indicates improvements in pressure support for voice and speech quality adductory strength training [93–94,98], including increases in phrase duration, increased sound pressure level, decreased frequency variability, and reductions in breathlessness and in vocal fatigue. With regard to speech, improvements in sound quality, speech intelligibility, duration, and intensity are a function, to some extent, of the degree of expiratory pressure that can be developed [106–107]. Chest wall rigidity associated with aging results in compromised lung volumes available for speech. Specifically, normal inspiratory volumes cannot be obtained, thus limiting the available passive recoil pressure available for speech and high-effort tasks. When inspiratory volumes are limited and the subglottal pressure demand for particular speech tasks cannot be met (e.g., long durations of speech or loud speech), active expiratory muscles must be recruited to generate the positive airway pressure for these tasks [55]. When an individual increases expiratory muscle strength, chest-wall rigidity may reduce because the individual is able to move the chest wall with greater force [108]. This rigidity reduction should result in increased sound durations, greater sound pressure level, and improved voice quality and speech intelligibility.

We expect that EMST will improve swallow function. Swallow dysfunction can be a major life-threatening problem. Explicit evidence exists regarding age-related changes in structure and physiology of swallowing, resulting in a high risk of swallowing problems in individuals over the age of 60. Significantly deteriorated efficiency of all phases of swallowing (oral preparatory, oral transit, pharyngeal, and esophageal phases) has been reported in several studies. These changes include increased duration of the oral stage of swallowing [109], reduced reflexes to trigger laryngeal closure (e.g., pharyngeal reflex, pharyngo-upper-esophageal sphincter contractile reflex) [103,110], reduced laryngeal and hyoid anterior and vertical (superior) movement (i.e., reduced neuromuscular reserve) [111–112], diminished laryngeal-valving capacity [104,113], decreased pharyngeal flexibility (i.e., reduced pharyngeal contraction) [111], increased duration and width of cricopharyngeal opening [114], and delayed and less efficient esophageal transit and clearance [115]. Elderly individuals are more likely to aspirate if they have any circumstances of medical conditions, such as neurologic or neuromuscular diseases.

An EMST program should contribute to the reduction of the mechanisms of age-related neuromuscular deterioration in the swallowing structures. Several possible mechanisms are expected to improve the swallow function with the EMST program. As predicted previously, EMST will increase expiratory lung volume and force, resulting in high expiratory airflow. In turn, this would increase the afferent stimulus on the sensory receptors of the tongue and oropharynx, leading to an increase in the activation of the swallow center located in the brainstem [109,116]. The efferent information from the swallow center is delivered to motor units participating in the swallow function. The increased activity of motor units would improve the efferent motor activities of oropharyngeal, velar, and laryngeal musculatures as well as the speed of oropharyngeal swallow. Consequently, the improved activities and movement speed of swallowing structures would reduce the general duration of swallowing.

Another possible mechanism for improvement in the swallow function would be related to increasing hyolaryngeal displacement with increased expiratory force as a result of the EMST program. During the oropharyngeal swallowing phase, the hyoid bone is pulled up, which elevates the larynx anteriorly and vertically by the contraction of submental muscle group, including suprahyoid muscles, in other words, laryngeal elevator muscles [109]. This muscle group is composed of the anterior belly of the digastric, mylohyoid, and geniohyoid muscles. Yokoyama et al. suggested that vertical hyolaryngeal movement causes the laryngeal closure so as to protect the lower airway and that anterior hyolaryngeal movement contributes to decreasing the upper-esophageal sphincter pressure to enable a bolus into upper-esophageal sphincter readily [112]. In turn, anterovertical hyolaryngeal movement associated with the contraction of submental muscles is important for effective and safe passage of a bolus to the esophagus. As mentioned previously, elderly individuals have a decrease in hyolaryngeal displacement, which can reduce the laryngeal closure and cause a bolus to escape into other cavities, resulting in a high risk of aspiration [111–112]. However, hyolaryngeal

displacement would be increased by forced expiration with EMST. Fink and Demarest noted that laryngeal displacement is induced by the respiratory cycle [117], with inspiration associated with downward movement and expiration with upward movement. Particularly, upward laryngeal movement is related to the mechanical contribution of laryngeal elevator muscles. If expiratory force increases, it would enhance the activities and strength of laryngeal elevator muscles, resulting in enhancing hyolaryngeal displacement. With increased hyolaryngeal displacement during swallowing, the glottal closure should be enhanced, thus moving the bolus into the esophagus more easily.

Furthermore, the activities of muscles involving laryngeal adduction and velopharyngeal closure during swallowing possibly would be enhanced by the EMST program. A previous study reported that increases in lung volume and force influence the activation of the lateral cricoarytenoid muscle and the levator veli palatini muscle [118]. The lateral cricoarytenoid muscle is a laryngeal adductor muscle that induces the vocal folds to close tightly. The levator veli palatini is a major muscle that elevates and retracts the velum to implement velopharyngeal closure. Levator veli palatini muscle activity is enhanced with expiratory phase like other expiratory muscles [119]. The adequate function of the levator veli palatini is important to reduce or prevent aspiration during swallowing. In addition, Kuna and Vanoye noticed that elevated expiratory force increased the activities of the laryngeal adductor muscles [120]. Generally, research has shown that laryngeal-valving capacity is reduced in the elderly [104,113,121–122]. Reduced laryngeal-valving capacity would increase the risk of aspiration during swallowing. However, increasing lung volume and force during EMST should improve the capacities of laryngeal adduction and velopharyngeal closure during swallowing in the elderly, leading to a reduction of aspiration.

## CONCLUSIONS

Elderly persons lose strength in skeletal muscle including the respiratory muscles. This loss of strength appears to be related to loss of muscle mass, due to an age-related factor as well as neuromuscular changes such as reductions in the number of motor neurons and the fibers innervated by a motor neuron. Structures and proportions of fiber types observed in respiratory muscles are similar to those observed in limb skeletal muscles. In addition to loss of muscle mass, the respiratory system in the elderly is changed in several aspects.

Strength training of limb muscles has been shown to be very effective for increasing muscle hypertrophy, indicating that strength training of respiratory muscles may induce the same effect as strength training of limb muscles.

Even healthy young people exercise regularly to maintain their health and prevent possible age-related loss of muscle strength. We recommend that the elderly maintain their skeletal muscle functions to a specific level to prevent age-related regression below that level, especially with regard to the respiratory muscles. Respiratory muscles are vitally important for ventilatory and nonventilatory functions.

EMST is focused on improving strength of the respiratory muscles not normally exposed to loaded exercise. Until now, very few studies have sought to quantify real therapeutic gains directly attributable to the interventions that have employed respiratory muscle strength training with regard to breathing, cough, speech, and swallow. The rationale and hypotheses for studying this phenomenon in the elderly were covered in this paper and suggest that clinical trials focused on studying the outcomes of respiratory muscle strength training may be worthwhile.

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