

# Correlation between Peak Expiratory Flow and Abdominal Muscle Thickness

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**Abstract.** [Purpose] The purpose of this study was to determine whether forced expiration is correlated with abdominal muscle thickness. [Subjects] Twenty-three healthy male volunteers participated in this study. [Methods] The peak expiratory flow (PEF) was obtained using a peak flow meter with subjects in the sitting position. The thicknesses of the right rectus abdominis, external oblique, internal oblique, and transverse abdominis muscles were measured using B-mode ultrasonography at the end of a relaxed expiration in the supine position. [Results] Among the abdominal muscles, only the thickness of the external oblique muscle displayed a significant correlation with PEF. [Conclusion] It appears that the thickness of the external oblique muscle might be associated with PEF during forced expiration.

**Key words:** Peak expiratory flow, Ultrasound imaging, Abdominal muscle thickness

*(This article was submitted Mar. 18, 2014, and was accepted May 19, 2014)*

## INTRODUCTION

Adequate clearance of airway secretions is an essential component of the defense mechanism of the respiratory tract against infection. Coughing and huffing are expiratory maneuvers that use high expiratory pressure and flow rates to aid secretion clearance. Physiotherapists encourage patients to cough and huff as part of a strategy to clear these secretions in order to minimize complications. Forced expiration maneuvers (huffs) are more effective than cough at improving clearance from patients with hypersecretion<sup>1)</sup>. Because maximal intrapleural pressures are lower during huff than either a voluntary or induced cough<sup>2)</sup>, the improved effectiveness of forced expiration vs. coughs may be due to lesser airway collapse in the former maneuver. Increased airway collapse, especially in those with obstructive disease, may transiently cause complete obstruction of some airways, making removal of mucus by cough difficult<sup>2)</sup>. On the other hand, the peak flows of forced expirations tend to be less than those of voluntary coughing, presumably because of the lesser airway compression and the absence of glottal closure, which are important components for producing supramaximal flows. With age, physical functions decline, influencing respiratory performance<sup>3)</sup>, and physiotherapists need data regarding the expiratory muscles producing the

high-force expiratory airflow velocity during huffs.

The abdominal muscles with significant expiratory activity are those in the ventrolateral wall of the abdomen. These include the rectus abdominis (RA), ventrally, and the external oblique (EO), internal oblique (IO), and transverse abdominis (TrA), laterally. As respiratory muscles, they have two principle actions. First, as they contract, they pull the abdominal wall inward and produce an increase in intra-abdominal pressure (IAP). Because the abdominal contents are virtually incompressible, this causes the diaphragm to move cranially into the thoracic cavity<sup>4)</sup>. This displacement, in turn, results in an increase in pleural pressure and a decrease in lung volume<sup>4)</sup>. The activity of the TrA is significantly related to changes in IAP<sup>5-7)</sup>. The other function of the abdominal muscles in relation to breathing is to displace the rib cage. Isolated stimulation of the RA produces a caudal displacement of the sternum and a decrease in the rib cage anteroposterior diameter<sup>8)</sup>. The EO causes a caudal displacement and a decrease in the rib cage transverse diameter<sup>8)</sup>. As described above, the abdominals are major muscles of expiration and play important roles in activities such as forced expiration. However, little is known about the contribution of each abdominal muscle to forced expiration. Though previous studies have shown the activity levels of the abdominal muscles normalized to maximal voluntary contraction during forced expiration as measured by surface electromyography (EMG)<sup>9)</sup>, the relative EMG values cannot be used to determine the force-generating level of each individual abdominal muscle. It is not possible to make direct force measurements to compare the strength of the individual abdominal muscles, but size may provide an indirect measurement of force-generating capac-

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ity, as has been demonstrated for various muscles<sup>10-18</sup>. The abdominal muscles are too large to allow measurement of their cross-sectional area using ultrasound imaging, and thus, muscle thickness is measured<sup>19</sup>. Ultrasound imaging measurements correlate well with those made using magnetic resonance imaging<sup>20</sup>. Therefore, we used ultrasound muscle-thickness measurements to estimate muscle size. The diaphragm is the principal muscle of the inspiration, and the descent of the diaphragmatic dome during inspiration expands the thoracic cavity. Because there is a positive association between the strength of inspiratory muscles and diaphragmatic thickness<sup>14, 18</sup>, we hypothesized that there are associations between huff strength and the thicknesses of the abdominal muscles at rest. In general, programs of expiration muscle strength training use a pressure threshold device and respiratory maneuvers<sup>3, 21</sup>. If there are different degrees of association of individual abdominal muscles with forced expiration, nonrespiratory exercises to strengthen the muscle that associates most strongly with forced expiration could be selected. Peak expiratory flow (PEF) has been used as a measure of huff strength<sup>22</sup>. This study was conducted using a healthy young population to determine whether PEF is correlated with abdominal muscle thickness at rest before further investigations of elderly subjects.

## SUBJECTS AND METHODS

Twenty-three healthy male volunteers participated in this study. Their age, height, and weight (mean  $\pm$  SD) were 21.1  $\pm$  3.0 years, 172.2  $\pm$  7.2 cm, and 65.7  $\pm$  10.9 kg, respectively. The subjects provided their written informed consent prior to participation in this study. The protocol for this study was approved by the Ethics Committee of the Kawasaki University of Medical Welfare.

PEF was measured using a peak flow meter (Assess, Full range; Philips Respironics G.K. Tokyo, Japan). Subjects sat and wore nose clips while PEF was measured. PEF was measured from the total lung capacity. Subjects were allowed to practice until they could perform the task consistently, then measurements were taken three times. The maximum value of the three trials was used in the analysis.

A B-mode ultrasound imaging system (Aloka, SSD-3500SX; Aloka Co. Ltd. Tokyo, Japan) with a 10-MHz transducer was used to perform ultrasound imaging of the thicknesses of RA, EO, IO, and TrA. To perform ultrasound imaging of the abdominal muscles at rest, the subjects were positioned in the supine position. The RA was measured four centimeters lateral to the umbilicus on the right side of the body<sup>23</sup>. The EO, IO, and TrA were measured 2.5 cm anterior to the midaxillary line and at the midpoint between the inferior rib and iliac crest<sup>24</sup>. A recent study indicated that inward pressures of the transducer during ultrasound imaging resulted in measured values of thicknesses of the abdominal muscles being lower than their actual values<sup>25</sup>. Therefore a large quantity of gel was applied between the transducer and the skin, and care was taken to avoid contact between the transducer and skin when imaging<sup>26</sup>. Because the activity of abdominal muscles is modulated by ventilation, the thickness of the abdominal muscles increases dur-

**Table 1.** Abdominal muscle thicknesses and their correlations with PEF values

Muscles	Muscle thickness (mm) <sup>a</sup>	Correlation coefficient
Rectus abdominis	13.1 $\pm$ 2.6	0.348
External oblique	10.8 $\pm$ 1.9	0.530 **
Internal oblique	9.0 $\pm$ 2.2	0.362
Transverse abdominis	3.3 $\pm$ 0.8	0.278

<sup>a</sup>Values are expressed as mean  $\pm$  SD. \*\* p < 0.01

ing expiration<sup>27</sup>. Measurement of abdominal muscle thicknesses was performed at the end of a relaxed expiration. The abdominal muscle images were collected three times. The average values of the three trials were used in the analysis.

IBM SPSS Statistics 22.0 was used for statistical analyses. The correlations between PEF and the abdominal muscle thickness were determined using Pearson's correlation coefficient. Values were considered statistically significant at p < 0.05.

## RESULTS

The mean PEF was 604.8  $\pm$  66.9 L/min. The abdominal muscle thicknesses and their correlations with PEF are listed in Table 1. There was a significant positive correlation between PEF and the thickness of the EO muscle.

## DISCUSSION

We investigated the relationships between PEF and the thicknesses of the abdominal muscles. Among the abdominal muscles, only the EO muscle displayed a significant correlation with PEF. This result might indicate that, among the abdominal muscles, the thickness of the EO at the end of relaxed expiration most strongly associates with PEF during forced expiration. Previous studies have indicated that the activity of the EO mildly exhibited some correlates with IAP, albeit not as much as TrA<sup>7</sup>, and EO acts to contract the rib cage along its transverse dimension<sup>8</sup>. The action of the EO on the rib cage might have a greater association with forced expiration than with the increase in IAP. The action of the RA produces a decrease in the anteroposterior diameter of the rib cage, and the action of the EO causes a decrease in the transverse diameter of the rib cage<sup>8</sup>. McCool et al.<sup>28</sup> reported that during forced expiration, rib-cage deformation consisted of a rounding of the lower rib cage with the transverse dimension decreasing more rapidly than the lower anteroposterior dimension. The results of this study, the action of the EO on the rib cage is associated with PEF. Previous research demonstrated that sit-ups can strengthen the expiratory muscles in healthy individuals<sup>29</sup>. Sit-ups provide a good challenge for the RA, but not for the EO<sup>30</sup>. Asymmetrical exercises such as the isometric side bridge strengthen oblique activity, with little effect on RA<sup>30</sup>. Increases in the activities of the abdominal muscles (RA, EO, and IO) occurred with maximum expiration when compared with resting expiration during side bridge exercise<sup>31</sup>.

These results indicate that training with nonrespiratory maneuvers such as side bridge exercise with maximum expiration might more effectively strengthen PEF than sit-ups.

One limitation of this study was the measurement of muscle thickness for determining the size of trunk muscles. In general, muscle size is believed to accurately reflect force-generating capacity. However, little is known about correlations between abdominal muscle size and their strength in IAP. Therefore, the causes of the lack of correlation between the thicknesses of the TrA and IO muscles and PEF are unclear, even though the activities of these two muscles are related to changes in IAP<sup>5-7</sup>). Another limitation of this study is the fact that only males were included in the analysis. Regardless of the state of the muscle (rest or contracted), healthy males have both thicker TrA and total lateral abdominal muscles than females<sup>32</sup>). However, the TrA forms a greater proportion of the lateral abdominal muscles at rest and while contracted in females<sup>32</sup>). The influence of gender on the extent to which abdominal muscle thickness associates with PEF remains unknown.

As part of the normal aging process, there is an overall decline in skeletal muscle mass and strength. This decline has also been documented for the muscles of respiration<sup>33</sup>). This age-related change in the respiratory muscles is often combined with a sedentary lifestyle. Inactivity due to lack of physical exercise may accelerate reductions in respiratory muscle force generating capacity<sup>34</sup>). A previous study reported that the EO muscle was significantly thinner in a walking independent elderly group than in a young group, and the thickness of the EO in a walking dependent elderly group was significantly smaller than that in the walking independent elderly group<sup>35</sup>). Further study is necessary to determine whether forced expiration and abdominal muscle thickness are correlated in elderly people.

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