Clinical Note

Breath-Holding in Healthy and Pulmonary-Compromised Populations: Effects of Hyperventilation and Oxygen Inspiration

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Suspension of respiration during end-expiration often is recommended to minimize body organ displacement between sequential image acquisitions. The purpose of this report is to evaluate techniques for end-expiratory breath-holding applicable to a pulmonary-compromised population. Eighty-seven consecutive outpatients with chronic pulmonary diseases and 31 healthy nonsmoking volunteers were recruited for the study. All subjects were asked to hold their breath in end-expiration while in the supine position (29 after breathing room air, 29 after hyperventilating room air for six breaths, and 29 after breathing O_2 from a portable oxygen tank via nasal cannula until pulse-oximeter readings stabilized or reached 100%). Each volunteer was tested with all three methods. The mean length of time for a breath-hold on room air without hyperventilation was 9.2 seconds for the patients and 31.7 seconds for the volunteers. A breath-hold after hyperventilation of room air was timed at 12.3 seconds for the patients and 41.2 seconds for the volunteers, and after O_2 administration, the breath-hold was 22.4 seconds for the patients and 60.9 seconds for the volunteers. No adverse effects occurred. The pulmonary-compromised patient can suspend respiration most successfully after O_2 administration ($P < .0001$), whereas hyperventilation seems to be less beneficial. Nonpulmonary-compromised volunteers can hold their breath for longer periods of time.

Index terms: Abdomen • Chest • Pulmonary • Lung • Breath holding • Motion artifact

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Abbreviations: ANOVA = analysis of variance, COPD = chronic obstructive pulmonary disease, PLSD = pairwise least significant test.

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BREATH-HOLDING IS IMPORTANT for abdominal and thoracic imaging. Prolonged breath-holding required during the performance of certain imaging examinations is a formidable challenge for certain patients, especially those with compromising lung disease. The choice between using end-expiration versus deep inspiration is one of finding a breath-holding scheme that will give consistency to the position of abdominal organs and extend the breath-holding period. It is easier to hold one's breath in deep inspiration, and maximal expansion is desirable for thoracic imaging. However, variable organ placement during sequential breath-holding can be problematic. End-expiration tends to result in more consistent organ position and therefore is often chosen as the strategy of choice for abdominal imaging (1).

A recent study investigated the ability of outpatients and inpatients to suspend respiration in deep inspiration (2) but did not address the problem with the usual strategy of end-expiration (3). The investigators also did not evaluate the potential utility of using hyperventilation or O_2 administration, although Sadatoh et al (4) investigated O_2 assisted breath-holding in CT scanning. We have studied the ability of the pulmonary-compromised patients of one pulmonary medicine practice to hold their breath in end-expiration during one of three breath-holding protocols; (*a*) plain breath-holding with constant coaching, (*b*) breath-holding after hyperventilation, and (*c*) breath-holding after administration of O_2. Additionally, we studied end-expiration breath-holding capabilities of young healthy volunteers using the three breath-holding schemes.

• MATERIALS AND METHODS

Eighty-seven consecutive patients with chronic pulmonary disease of one outpatient pulmonary medicine practice, with a mean age of 60 years (47–75 years), and 31 healthy volunteers, with a mean age of 27.6 years (22–39 years) were recruited for a breath-holding study. Most of the patients were in the practice of the pulmonologist for more than 1 year with a mean period of 4 years.

The patients and volunteers gave verbal consent (approved by our Institutional Review Board) after an explanation of the procedure and the minimal risks. All patients and volunteers were given a pulmonary function test (The Schiller Spirometer/EKG, model AT-6, Switzerland), and were monitored with a pulse oximeter (Pulse-Oximeter, model 300, Palco Labs, Santa Cruz, CA), which was attached to a distal finger during the breath-holding (Fig. 1). The pulse rate and O_2 saturation were demonstrated simultaneously (Fig. 1). Of the 103 patients approached regarding inclusion in the study, 13 patients refused inclusion in the study and three patients were not included in the study because of their inability to hold their breath due to severe dyspnea.

All groups were instructed in the procedure of breath-holding while in the supine position by the same radiologist, the noses were occluded with a spring rubber padded nasal occluder, and a mouth piece from a spirometer (Ohio 822 Spirometer, Madison, WI) was placed in each subject's mouth with the lips tightly placed around the mouth piece (Fig. 1).

All groups were encouraged identically during breath-holding by continual coaching. The unenhanced breath-holding group was studied after normally breathing room air while the procedure was explained to them. The hyperventilation group was studied after six rapid deep inhalations of room air. The oxygen-

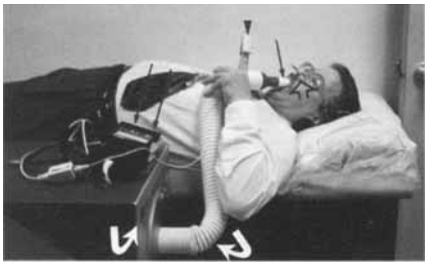

Figure 1. An asymptomatic volunteer lying supine on a table in the position of the patients and tabulated volunteers with the spirometer tube in place in his mouth (straight arrow), the nasal occluder in place on his nose (open arrow), and the pulse oximeter sensor in place on his fingertip (arrow head). The Ohio spirometer (curved arrows) and pulse oximeter casing with readout window (long arrows) are shown.

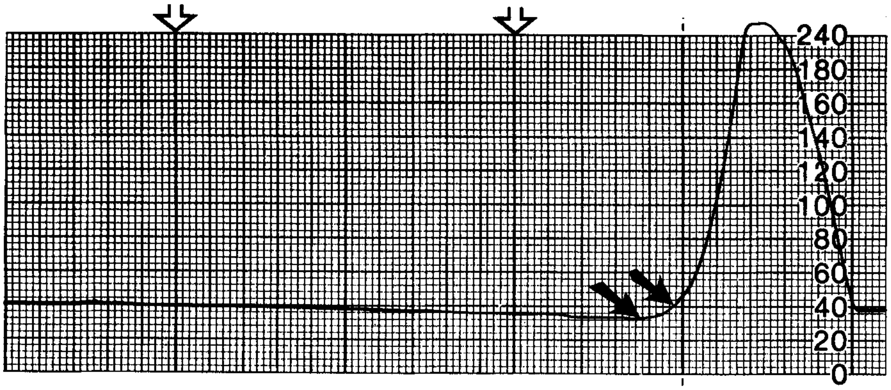

Figure 2. Spirometer graph demonstrates the upturn of the straight line (arrows) signifying the cessation of breath-holding. The distance between the open arrows represents 1 second.

breathing group was given O_2 United States Pharmacopeia from a portable oxygen tank via nasal cannula at a rate of 2 l/minute until their pulse oximeter readings reached 100% or stabilized for at least 1 minute, and then they were studied for their breath-holding capability. The breath-hold was recorded on the spirometer graph, and the cessation of the breath-hold was signaled with an upturn of the straight line (Fig. 2). The graph was read independently by two observers (B.M., J.P.S.) to determine the length of breath-holding. All disputes about the length of the breath-hold were resolved by consensus.

Volunteers had no history of cigarette, cigar, or pipe smoking and were recruited from the freshman class of a medical school and the staff of the pulmonary medicine practice. The volunteers were assigned all three breath-holding protocols, and the order of administering the three methods of breath-holding was randomized to compensate for the possible training effect of previously performing the procedure. Volunteers were given additional motivation by awarding a prize of $25.00 to the man and woman in each breath-holding group who held his or her breath the longest. Otherwise, the volunteers were treated exactly as the patients.

Pulse rate changes, along with O_2 saturation determinations on the pulse oximeter, were recorded.

The Kruskal-Wallace test was used to determine whether any one of the protocols for breath-holding showed a significant difference in suspension of respiration. After the Kruskal-Wallace test, the Fisher's pairwise least significant difference (PLSD) method was used to determine which protocol was significantly different from the other protocols.

Statistical analysis using the repeated-measures analysis of variance (ANOVA) was used for evaluating the influence of training on breath-holding. Fisher's PLSD was used for determining a significant difference between all three breath-holding methods, and the paired *t* test was used to evaluate the significance of the dissimilarity of the three methods of breath-holding.

The relationship of pulse rate changes with O_2 concentration and breath-hold time was probed by linear regression.

• RESULTS

There was agreement between the two observers to within .5 second in all determinations of the length of breath-holding. These minimal disputes were resolved by consensus.

The mean breath-holding time for pulmonary compromised patients without O_2 administration or hyperventilation was 9.1 seconds (2.0–16.5 seconds); for patients on the hyperventilation protocol, the mean breath-holding time was 12.5 seconds (3.5–20.0 seconds); and for patients having O_2 administered, the mean time of breath-holding was 20.9 seconds (8.0–42.0 seconds). These results are summarized in Figure 3.

Volunteers had longer mean times. The mean time of breath-holding for volunteers without hyperventilation or O_2 administration was 31.7 seconds (13.0–73.5 seconds); for volunteers after hyperventilation, the mean time of breath-holding was 41.2 seconds (17–106.0 seconds); and the mean time for breath-holding after O_2 administration was 60.9 seconds (20.0–147.0 seconds). These results are summarized in Figure 4.

The Kruskal-Wallace test determined that at least one of the protocols for breath-holding of the patients was significantly different from the other two protocols ($P < .00001$). The PLSD method, performed after the Kruskal-Wallace test, demonstrated that the O_2 protocol had a significantly increased time of breath-holding when compared with the other two protocols ($P < .05$), and the hyperventilation protocol was not significantly different from the protocol of room air breath-holding without O_2 administration ($P > .05$).

The interaction measure, of the one-way repeated-measures ANOVA, demonstrated no significant effect of the order of the breath-holding protocols on the ability of volunteers to hold their breath ($P = .9879$). The paired *t* test demonstrated a significant difference between the various protocols (O_2 versus hyperventilation [$P < .0001$], O_2 versus plain breath-holding [$P < .0001$], and hyperventilation versus plain breath-holding [$P = .0012$]).

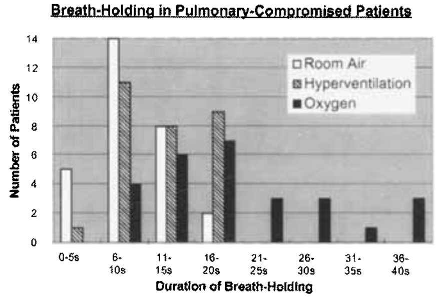

Figure 3. Bar graph representing the number of pulmonary-compromised patients in room air, hyperventilation, and oxygen, grouped by 5-second increments of breath-hold duration.

Linear regression analysis of the relationship between O_2 saturation and pulse rate (as demonstrated on the pulse oximeter) indicated that the correlation was less than .01.

• DISCUSSION

Subjects who were not pulmonary compromised could hold their breath, when properly motivated, for a mean time period of 31.7 seconds. When hyperventilation was added to the formula, this increased by approximately 30%, and when O_2 was added, the mean time increased almost 100%. For MRI, oxygen can be administered by a long tube while the patient lies in the gantry. For helical CT scanning or angiography, the equipment to monitor the patient can be brought into the examining room.

The pulmonary-compromised patients suspended respirations for shorter durations when compared with nonpulmonary-compromised patients, as would be expected (Figs. 3 and 4). The mean time of breath-holding was approximately 9.1 seconds before hyperventilation and O_2 administration. Hyperventilation increased the time period by approximately 40% and O_2 administration increased the time period by 130%. These findings suggest that with appropriate technique, pulmonary-compromised patients can hold their breath for substantial periods of time (Fig. 3), but they should be asked to hold their breath for approximately half the time of

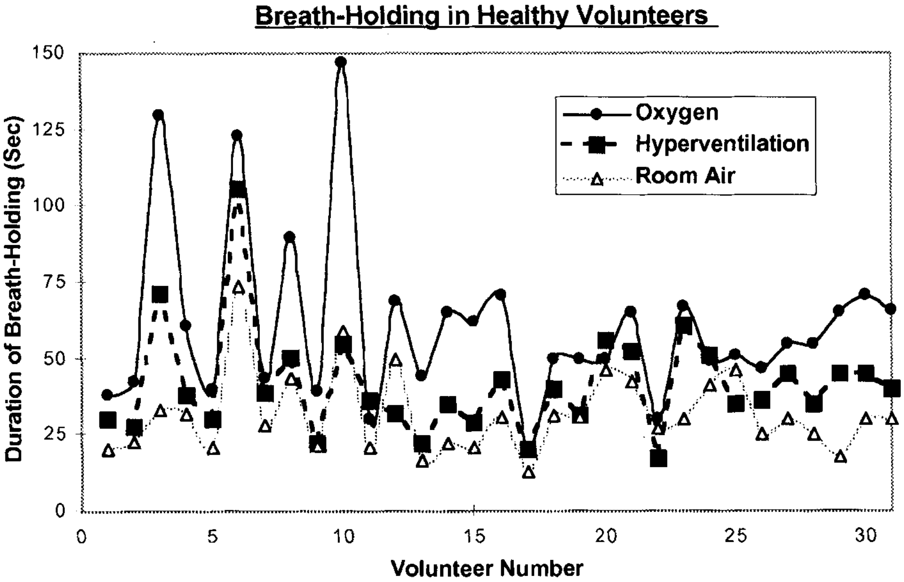

Figure 4. Scatter graph representing, for each healthy volunteer, the duration of breath-holding after normal breathing of room air, hyperventilation, or oxygen inspiration. The data points are connected for each of the three parameters of ventilation to facilitate comparison.

the nonpulmonary-compromised population. If O_2 is administered, the patient who is pulmonary compromised should be able to hold his or her breath for approximately 20 seconds.

The subjects experienced no significant sequelae to the breath-holding experience or to oxygen administration, other than a transient drop in pulse rate, which has been described previously (2). Several theories for the O_2-induced drop in pulse-rate phenomenon have been advanced (5–9). We found, as did Gay et al, that the normal volunteers were the only tested subjects who demonstrated a drop in pulse rate (2). The pulse rates of all of the pulmonary-compromised patients were stable, except for occasional minimal increases (2–4 bpm). Complications due to the administration of O_2 to patients with chronic obstructive pulmonary disease (COPD) (10) were not experienced in this study, but the possibility should be considered. Apnea, which is potentially life-threatening (10), has been described in patients with COPD who are sensitive to O_2 (10), but if the patient is closely monitored and O_2 is administered at a rate of 2 l/minute, this complication can be avoided (10). Bradycardia and depressed oxygen saturation were halted by having the volunteer start breathing with administration of O_2. No lasting sequelae have been reported due to bradycardia because of breath-holding (2,5,7–9,11) and no relationship between O_2 and pulse rate was determined (correlation $< .01$).

The highly motivated volunteers' ability to hold their breath for a mean of 31.7 seconds without hyperventilation or O_2 enhancement suggests that patient-doctor interrelationship should increase the length of breath-holding, as suggested by Gay et al (2), although we did not investigate that particular question (1). The use of O_2 protocols might be helpful for pulmonary-compromised patients or sick patients who have difficulty in holding their breath ($P < .05$).

We therefore conclude that the pulmonary-compromised patient can suspend respiration most successfully after O_2 administration, with hyperventilation being less beneficial, and nonpulmonary-compromised subjects can hold their breath for longer periods of time with an increase of 30% after hyperventilation and 97.8% after O_2 administration.

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