Comparison Among Different Methods on Measurement of Total Lung Capacity in COPD

To the Editor:

I read the article by O’Donnell and coworkers1 recently published in CHEST (May 2010). Their conclusions about the accuracy of two functional methods (plethysmographic and dilutional) to measure lung volumes (in this case, total lung capacity [TLC]) in patients with severe airway obstruction are based on the assumption that CT scan is the reference method.

Several doubts exist that CT scan may be adopted as a gold standard for measuring TLC, especially in the above-mentioned study, for the following reasons.

1. No spirometric control of lung volume was performed during the CT image acquisition in H2 and H3 centers where two-thirds of patients with airflow obstruction were recruited.

2. At H1, center lung volume was spirometrically controlled, but for an average acquisition time of 20 s, the unconscious loss of air could be substantially high at TLC (without a shutter); the correction made by the authors for this unavoidable problem is unclear and possibly inaccurate. It should be stressed that measuring correctly a slow vital capacity after 20 s of breath-hold time implies the use of a pneumotachograph (or spirometer) with a prolonged zero stability of the flow (or volume) signal. For most of the commercially available instruments for lung function testing, a threshold value of ±25 mL/s is accepted as zero,2 meaning a potential drift of ±500 mL for 20 s, if this problem is not adequately checked and fixed.

3. There was a relatively long time interval (up to 2 months) between the TLC measurements performed by CT scan and those obtained during pulmonary function testing.

4. There was no mention of the measurement of anatomic dead space when computing TLC by CT scan (“from apex to base of each lung”). Anatomic dead space (that encompasses also upper airways and extrathoracic trachea) amounts to 150 to 200 mL and even more at TLC, and it is included in the plethysmographic and dilutional measurements of TLC.

5. There was no technical description of the CT scanners that were used (kilovolt peak, milliamperes) and no mention of the density threshold limits prefixed to perform the CT scan volumetric measurements of the lung. It has been shown that in a three-dimensional model of the lung the gas volume increases about 230 mL for each 100 Hounsfield units of change in the higher limit of the density mask.3

6. The effect of body position on TLC has been mentioned by the authors. It should be clearly stressed that in the supine position TLC can be reduced up to 500 mL,4 essentially because of the blood shift from legs to thorax.

7. Finally, it must be remembered that TLC by CT scan is measured just once, whereas TLC by plethysmographic or dilutional method is always the mean of two or, even better, three measurements.

Taking account of these sources of error (which all potentially contribute to underestimating TLC obtained by CT scan) is mandatory in this kind of study. Such effort seems only marginally accomplished in the work of O’Donnell and colleagues.1 Therefore, the mean difference between the plethysmographic and CT scan measurements of TLC reported by the authors in the patients with more severe airflow obstruction (>1.07 L) could be substantially less and very likely not significant. In this case, any judgment about the plethysmographic method as systematically overestimating TLC in the presence of airway obstruction would be highly questionable and unwarranted.

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Response

To the Editor:

We thank Dr Tantucci for the interesting points raised in his letter regarding our article in CHEST.2 We agree with the “doubts” he expresses: “…that CT scan may be adopted as the gold standard for measuring [total lung capacity] TLC...” In fact, we clearly state in our discussion: “Measurement of absolute lung volume lacks any gold standard for comparison.” We address the potential limitations of CT scan measurements and include several more paragraphs to detail the strengths and limitations of plethysmography and helium dilution volume measurement as well. We thus take exception to the statement that our efforts in this regard seem marginal, especially as the criticisms contained in his communication are not well supported by citation to relevant literature.

We acknowledge a lack of spirometric monitoring during CT image acquisition at two institutions (H2, H3). However, we point out that subjects at H2 received breathing instruction from a prepared script and practiced breath-hold maneuvers prior to imaging. The effectiveness of this approach to improve patient performance has been validated.3 Furthermore, patients at H3 were evaluated as part of a longitudinal study involving repeated chest CT scans and were thus very familiar with the procedure.

The author supposes that unconscious loss of air and substantial unidirectional volume signal drift during breath hold among subjects at H1 may result in underestimation of “corrected” TLC. Volume was monitored using a dry-seal, volume-displacement spirometer. The device was calibrated and leak tested prior to each study. While wearing nose clips, subjects breathed through a large flanged rubber mouthpiece held in place by one of the investigators (C. O.), and breath hold at full inhalation was monitored by real-time observation of direct writing pen on paper. Following image acquisition, while still connected to the device, subjects were instructed to inhale maximally and slowly exhale all the way. The resulting vital capacity measure was compared with the largest vital capacity obtained independently in the upright sitting position with a volume displacement spirometer during pulmonary function testing. The mean difference of these upright vs supine vital capacities was approximately 80 mL with upper 95% CI < 200 mL.

The longest time between pulmonary function testing and CT scan was < 2 months. In fact, 80% of subjects were tested on the same day, 90% within 1 week, and only six subjects (< 5%) at > 2 weeks.

Our CT scan volume estimates did not include the extrathoracic airways, intrathoracic trachea, or main stem bronchi. This exclusion may have contributed to the reported average 240 mL difference between CT scan and helium dilution estimates of TLC, but not to observed differences between helium and plethysmography.

The author wonders whether an inappropriate density threshold limit was applied during our CT scan analysis and cites results published by Zampatori et al4 that suggest a 250-mL increase of measured air volume per 100 Houndfield units (HU) of change in the higher limit of the density mask. First, we referenced tracheal air on each individual scan and used this value to identify tissue density on each section. Thus, we did not assume that any given mask density was uniformly accurate. Second, Zampatori et al5 studied 17 patients with airflow obstruction by comparing CT scan-derived volume estimates at masks densities of 200, 300, and 400 HU with volumes measured plethysmographically. In effect, they assumed that plethysmography was the gold standard and concluded that CT scan volume estimates obtained with a 200-HU density mask were most accurate (“The upper threshold was more correct...”) because they most closely corresponded with those measured by body box. Their CT scan-derived TLC estimates obtained with a 200-HU mask density averaged 573 mL less than those obtained by plethysmograph. This is precisely equivalent to the mean plethysmographic-to-CT scan volume difference we report in Table 2.

Regarding upright to supine change in TLC, the author references Denison et al4 for evidence of a 500-mL change in TLC because of blood shift from legs to thorax. Denison et al4 did not measure upright supine differences and merely included references within table legends that refer to two other studies, one of which was conducted > 50 years ago.5,6 We are unaware of currently accepted evidence that there is such a substantial reduction in TLC while supine due to a central shift of blood volume.

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