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Uppermost Blood Levels of the Right and Left Atria in the Supine Position

Implication for Measuring Central Venous Pressure and Pulmonary Artery Wedge Pressure

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Background: **To eliminate the influence of hydrostatic pressure, proper transducer positions for central venous pressure and pulmonary artery wedge pressure are at the uppermost blood levels of right atrium (RA) and left atrium (LA). This study was performed to investigate accurate reference levels of central venous pressure and pulmonary artery wedge pressure in the supine position.**

Methods: **Chest computed tomography images of 96 patients without history of cardiothoracic surgery, heart disease, or cardiothoracic anatomical abnormality were retrospectively reviewed. The anteroposterior (AP) diameter of the thorax and the vertical distances from the skin on the back to the most anterior portion of RA (RA height) and LA (LA height) were measured. Their ratios were abbreviated, respectively, as RA height/AP diameter and LA height/AP diameter. Data are expressed as mean ± SD (range).**

Results: **There was a significant difference [4.6 ± 1.0 (1.6–6.4) cm; $P < 0.001$] between RA and LA heights. AP diameter was positively correlated with RA and LA heights ($R^2 = 0.839$ and 0.700, respectively; $P < 0.001$). There was also a significant difference between RA height/AP diameter [0.83 ± 0.03 (0.71–0.91)] and LA height/AP diameter [0.62 ± 0.04 (0.52–0.72)] ($P < 0.001$).**

Conclusion: **In the supine position, a central venous pressure transducer should be positioned approximately 4.6 cm higher than a pulmonary artery wedge pressure transducer. The external reference level for central venous pressure seems to be at approximately four fifths of the AP diameter of the thorax from the back, and that for pulmonary artery wedge pressure seems to be at approximately three fifths of the AP diameter.**

CENTRAL venous pressure (CVP) and pulmonary artery wedge pressure (PAWP) are measured to approximate right atrial pressure and left atrial pressure, respectively. One of the most important technical considerations for accurate measurement of CVP and PAWP is appropriate positioning of pressure transducers. To eliminate the influence of hydrostatic pressure, the proper transducer levels should be at the uppermost fluid level in the chamber or the vessel in which pressures are being measured.[1–3] Therefore, the valid reference levels would be the uppermost blood level of the right atrium (RA) for CVP and the uppermost blood level of the left atrium (LA) for PAWP.

Various external reference levels have been proposed for measuring CVP or PAWP in the supine position as follows: 10 cm anterior to the skin of the back,[4,5] the intersection of the fourth intercostal space and the midchest level of supine patients,[6] the midaxillary line,[7,8] and 5 cm below the left sternal border at the fourth intercostal space.[1] Thus, there is inconsistency about the quoted vertical levels. In addition, the aforementioned reference levels do not accurately reflect the uppermost blood levels of both atria.

The purposes of this study were (1) to investigate the accurate reference levels of CVP and PAWP that reflect the uppermost blood levels of the RA and LA in the supine position using computed tomography (CT) images and (2) to suggest simple guidelines on the external reference levels of CVP and PAWP.

Materials and Methods

After institutional review board (Seoul National University College of Medicine/Seoul National University Hospital, Seoul, Korea) approval was obtained (patients' informed consent was waived by the institutional review board), chest CT data were retrieved from our clinical data repository system. Patients who had undergone chest CT examination from January 2005 to July 2005 were enrolled. Patients with history of cardiothoracic surgery, heart disease, thoracic anatomical abnormality, and poor CT image quality were excluded. Contrast-enhanced chest CT images with section thickness of 5 mm were retrospectively reviewed. Soft-copy images were displayed at mediastinal windows (width: 400 Hounsfield units; level: 25 Hounsfield units) on a 21-inch flat-panel liquid crystal display monitor of the digital picture archiving communication system (Infinitt Co., Ltd., Seoul, Korea) with a one-on-one format. Thereafter, density of the CT images was modified to optimize visualization of the RA and LA.

We examined all CT sections, which included any portion of the heart. The anteroposterior (AP) diameter of the thorax was measured vertically from the skin on the back to the skin on the midsternum (fig. 1). Of these, the largest AP diameter of the thorax was used for the study. A CT section with the highest uppermost blood

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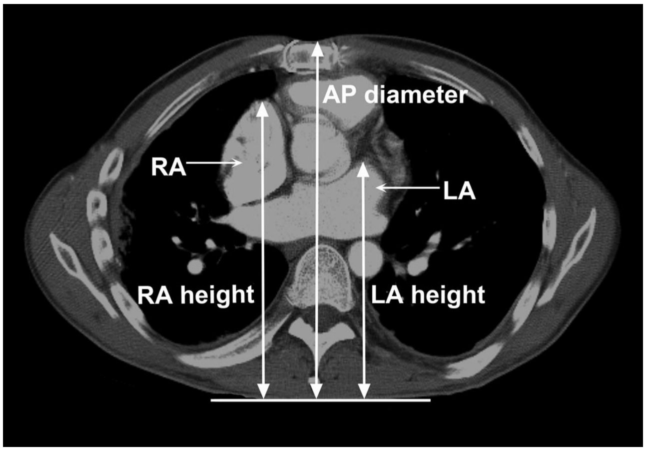

Fig. 1. A chest computed tomography section showing right atrium (RA) height, the anteroposterior diameter of the thorax (AP diameter), and left atrium (LA) height. Although all parameters are displayed on the same section for explanation, each parameter may have been measured on different computed tomography sections.

level of atrium was selected to respectively measure the RA or LA heights. On the selected CT sections with the highest uppermost blood level of atrium, vertical distances from the skin on the back to the uppermost blood level of atrium were measured and abbreviated as RA or LA heights (fig. 1). Ratio of RA height to AP diameter of the thorax (RA height/AP diameter) and ratio of LA height to AP diameter of the thorax (LA height/AP diameter) were calculated to check whether RA or LA heights had a steady relation to the chest size of the body in the supine position. The CT sections, on which the RA or LA heights or the AP diameter of the thorax were measured, were determined with regard to the rib or intercostal space level on the parasternal border. In the same way to measure the RA or LA heights, vertical distance from the skin on the back to the uppermost blood level of the right main pulmonary artery (PA) was measured and abbreviated as PA height.

Statistical Analyses

A definite difference between RA and LA heights was observed in a pilot study (n = 10; RA height = 18.1 ± 2.2 cm and LA height = 13.6 ± 1.4 cm). In this study, 96 sets of data were retrieved for descriptive statistics. A paired *t* test was used to compare between both atrial heights and between RA height/AP diameter and LA height/AP diameter. Simple linear regression analysis was used to evaluate correlation between RA or LA heights and AP diameter of the thorax. SPSS software (version 12.0; SPSS Inc., Chicago, IL) was used for statistical analyses. Data were expressed as mean ± SD (range). A value of $P < 0.01$ was considered statistically significant.

Supplementary Study

A supplementary study was retrospectively performed to assess whether the RA and LA heights might change with ventilatory phases. After institutional review board (Seoul National University College of Medicine/Seoul National University Hospital, Seoul, Korea) approval was obtained (patients' informed consent was waived by the institutional review board), chest CT data of chronic obstructive pulmonary disease patients, who had undergone chest CT examination at both full inspiration and expiration from January 2005 to July 2005, were retrieved from our clinical data repository system. Any patients who had the same exclusion criteria as in the main study were excluded. In addition, because they were included only when chronic obstructive pulmonary disease was mild or moderate,[9] 44 consecutive patients (32 males) were finally enrolled.

Using the picture archiving communication system, the same parameters as in the main study were measured on each chest CT image of both inspiratory and expiratory phases. A paired *t* test was used to compare between the atrial heights at full inspiratory and expiratory phases. Data were expressed as mean ± SD (range). A value of $P < 0.01$ was considered statistically significant.

Table 1. Patient Characteristics

Parameter	Value
Male/female	59/37
Age, yr	58 ± 16 (19–86)
Height, cm	164 ± 9 (144–188)
Weight, kg	61 ± 11 (37–92)
Body mass index, kg/m^2	22.6 ± 3.1 (16.9–32.8)

Data are expressed as number of patients or mean ± SD (range).

Results

Chest CT images from 96 patients were used for the main study (table 1). There were significant differences between RA and LA heights [4.6 ± 1.0 (1.6–6.4) cm; $P < 0.001$] and between LA and PA heights [0.5 ± 0.8 (−2.1 to 2.1) cm; $P < 0.001$] (table 2). The RA and LA heights were positively correlated with the AP diameter of the thorax (for RA height: $R^2 = 0.839$, $P < 0.001$; for LA height: $R^2 = 0.700$, $P < 0.001$) (fig. 2).

The transverse level, on which the RA or LA heights were measured, ranged between the third rib and the fifth intercostal space (median: fourth intercostal space) on the parasternal border (fig. 3). In 40 of 96 patients (41.7%), both atrial heights were measured at the level of the fourth intercostal space.

In the supplementary study, the patients' age was 61 ± 13 (32–88) yr, height was 165 ± 6 (154–175) cm, weight was 64 ± 9 (43–83) kg, and body mass index was 23.4 ± 2.8 (16.5–28.2) kg/m^2. There was a significant difference in the AP diameter between inspiratory and expiratory phases [23.2 ± 2.2 (19.6–27.5) cm *vs.* 22.2 ± 2.6 (17.5–26.3) cm; $P < 0.001$]. However, there were no significant differences in the RA height [18.3 ± 1.7

Table 2. Parameters Measured on the Chest Computed Tomography

Parameter	Value
AP diameter, cm	21.7 ± 2.1 (16.9–26.3)
RA height, cm	18.0 ± 1.8 (12.7–22.2)
LA height, cm	13.5 ± 1.4 (9.7–16.6)*
PA height, cm	14.0 ± 1.5 (10.3–17.7)
RA height/AP diameter	0.83 ± 0.03 (0.71–0.91)
LA height/AP diameter	0.62 ± 0.04 (0.52–0.72)†

Data are expressed as mean ± SD (range).

* $P < 0.001$ *vs.* RA or PA heights. † $P < 0.001$ *vs.* RA height/AP diameter.

AP diameter = the largest anteroposterior diameter of the thorax; LA height = the longest vertical distance from the skin on the back to the most anterior portion of the left atrium; LA height/AP diameter = ratio of LA height to AP diameter; PA height = the longest vertical distance from the skin on the back to the most anterior portion of the right main pulmonary artery; RA height = the longest vertical distance from the skin on the back to the most anterior portion of the right atrium; RA height/AP diameter = ratio of RA height to AP diameter.

(15.3–21.6) cm *vs.* 18.0 ± 1.9 (14.3–21.6) cm; P = 0.365] or the LA height [14.0 ± 1.4 (11.3–16.9) cm *vs.* 13.7 ± 1.6 (10.8–16.6) cm; P = 0.290] between inspiratory and expiratory phases. There were also no significant differences in the RA height/AP diameter [0.80 ± 0.04 (0.72–0.88) *vs.* 0.81 ± 0.04 (0.73–0.89); P = 0.109] or the LA height/AP diameter [0.61 ± 0.04 (0.55–0.68) *vs.* 0.62 ± 0.03 (0.56–0.68); P = 0.196] between inspiratory and expiratory phases.

Discussion

In this study, we found a mean difference of approximately 4.6 cm between the uppermost blood levels of both atria in the supine position, which produces a hydrostatic pressure difference of approximately 3.4 mmHg. Therefore, pressure transducers should be positioned at the different external reference levels to accurately measure the right and left heart filling pressures.

To determine the height to the most anterior portion of the atrium of supine patients, this had to be measured on the transverse plane of the body. Therefore, in this study, CT was used for accurate measurements. Because echocardiography was used in the previous studies,[1,8,10] a small deviation of the ultrasonic beam from the transverse plane could result in overestimation of the distance, and an ultrasonic window, which may not be in accord with the most anterior portion of the atrium, may have augmented inaccuracy. Moreover, some previous studies did not select the most anterior portion of the atrium as reference levels for measurements, *e.g.*, mid-RA,[8,11] mid-LA,[7] or the most anterior portion of the left ventricle.[1] In addition, the anterior surface of the chest wall may not be horizontal in the supine position, which may add some inaccuracy to the aforementioned previous studies.[1,7,8,10,11] Last, there is no study that measured and compared both the atrial reference levels simultaneously.

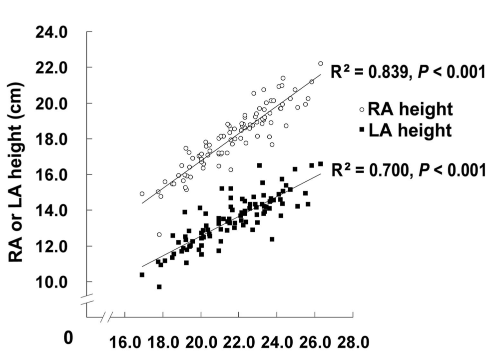

Fig. 2. Correlation between RA or LA heights and AP diameter. AP diameter = the largest anteroposterior diameter of the thorax; LA height = the longest vertical distance from the skin on the back to the most anterior portion of the left atrium; RA height = the longest vertical distance from the skin on the back to the most anterior portion of the right atrium.

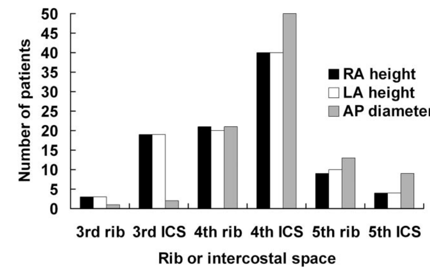

Fig. 3. Distribution of the rib or intercostal space level on the parasternal border where RA or LA heights and AP diameter were respectively measured. AP diameter = the largest anteroposterior diameter of the thorax; ICS = intercostal space; LA height = the longest vertical distance from the skin on the back to the most anterior portion of the left atrium; RA height = the longest vertical distance from the skin on the back to the most anterior portion of the right atrium.

In this study, the longest RA or LA heights were most frequently present at the fourth intercostal space level. This fact is in accord with the previous studies,[1,6,8] which described that the reference levels should be determined on the fourth intercostal space of the left sternal border. However, because CVP and PAWP are usually measured in the supine position, the rib or intercostal space levels do not seem to be so important.

One of the most important elements in measuring CVP and PAWP at the bedside is identifying a uniform and easily reproducible external reference level.[12,13] In this study, AP diameter of the chest was highly correlated with the RA and LA heights. This result corresponds with a previous study,[11] which reported that AP diameter of the chest had a strong association with the vertical distance from the sternal angle to the mid-RA. The uppermost blood levels of both the atria in the supine position may be roughly rounded as four fifths of the AP diameter for the RA (RA height/AP diameter = 0.83) and three fifths for the LA (LA height/AP diameter = 0.62) from the skin on the back. These are suggested as an easy way to memorize the external reference levels of CVP and PAWP regardless of AP diameter of the thorax.

One distinct purpose for measuring PAWP is to provide an estimate of a hydrostatic filtration pressure within the pulmonary capillaries that largely controls the formation of pulmonary edema.[14] However, if the PAWP reference level is maintained to be the same as that for CVP, measured PAWP will be lower than the true value resulting in misinterpretation of the Starling law of transcapillary exchange. Besides, because PAWP is an important parameter for calculating pulmonary vascular resistance, errors in PAWP of this magnitude (4.6 cm H_2O) may lead to inappropriate decisions about pulmonary vascular resistance.

For PAWP to be a valid estimate of left atrial pressure, a continuous, static column of blood, which may be subject to extramural pressure exerted by the surrounding alveoli, must connect the wedged PA catheter tip and the draining pulmonary vein. Fortunately, PA catheters are usually used in the supine position, which favors the creation of zone 3 conditions.[14] In addition, to bypass the influence of alterations in intrathoracic pressure, CVP and PAWP should always be measured in the end-expiratory phase of ventilation.

Adequate measurement of hemodynamic data is a prerequisite for correct interpretation and appropriate management. Because inability or failure to adopt bedside guidelines by medical personnel is a major source of error during PAWP measurements,[15] importance of continuing medical education about the use of PA catheters cannot be overemphasized. More importantly, in the hemodynamic therapeutic interventions to optimize cardiovascular function, guidelines on fluid challenge may be revised about the suggested PAWP value. Afterward, usefulness of PA catheters, which is currently a matter for debate, may be reevaluated.

Clinically, PA pressure is measured through the distal end of PA catheters at the wedging position. At this time, the PA pressure transducer should be aligned with a PA branch, the pressure of which we want to measure. However, which PA branch the zero reference point should be assigned to has never been determined. Considering that most catheters float to the right PA because of gravitational and anatomical factors,[16,17] the right main PA, which receives more pulmonary blood flow, may be a candidate site for measuring PA pressure. In this study, the difference between LA and PA heights was only 0.5 cm, which may be clinically negligible. In addition, under normal circumstances, the PA pressure at the end of diastole equilibrates with downstream pressure in the pulmonary veins and LA.[18,19] Therefore, diastolic PA pressure has been often used as an alternative to PAWP as an estimate of left ventricular filling pressure. In this perspective, the same reference level between PAWP and PA pressure may be advisable.

The limitation of this study is that RA and LA heights could not be measured in the expiratory phase of the normal population. However, because there were no significant differences in the RA and LA heights between inspiratory and expiratory phases in mild to moderate chronic obstructive pulmonary disease patients, the supplementary study shows that both atrial heights did not change with ventilatory phases. Therefore, the results of the main study are considered to be reliable even though they had been measured in the inspiratory phase.

Even a slight change in the atrial filling pressure can be regarded as significant in clinical status. Compared with the systemic arterial pressure, small errors during measurements would greatly distort the measured venous pressure because venous pressure is small and narrowly ranged. Therefore, it is important to place the venous pressure transducer at the proper reference level. We may conclude that the external reference levels for CVP and PAWP seem to be at approximately four fifths and at approximately three fifths of the AP diameter of the thorax from the skin on the back in the supine position.

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