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Precise Prediction of Right Atrium Position within Expiratory Phase Thorax

Hirotsugu MIYOSHI[*1], Ryuji NAKAMURA[*1], Yukari TOYOTA[*1], Hiroshi KONDO[*1], Masako YASUDA[*1], Toshimichi YASUDA[*1], Noboru SAEKI[*1], Hiroshi HAMADA[*1] and Masashi KAWAMOTO[*1]

Summary : Fifteen patients who underwent CT during both the inspiratory and expiratory phases were retrospectively reviewed. The anterior posterior (AP) diameter of the thorax, the largest vertical distance from the uppermost RA level to the back surface (RA height), and the ratio of RA height to AP diameter of the thorax (RA thorax ratio) were determined. We then attempted to predict the expiratory RA height using the following 2 methods. Formula 1: Predicted expiratory RA height = Average inspiratory RA thorax ratio × Expiratory AP diameter of thorax. Formula 2: Predicted expiratory RA height = Each inspiratory RA thorax ratio × Expiratory AP diameter of thorax. In a Bland-Altman plot with Formula 1, the bias was –0.34 mm and limit of agreement ranged from –19.44 to 18.75 mm, whereas those were –1.31 mm and –9.72 to 7.10 mm with Formula 2. Our findings indicate that inspiratory CT imaging and expiratory phase thorax diameter can be used to precisely predict expiratory phase RA height in individual patients.

Key words : right atrium, central venous pressure, computed tomography imaging

Central venous pressure (CVP) is routinely used as an indicator of hemodynamics in anesthetic and intensive care patients. When measuring CVP in the supine position, it is necessary to adjust the location of the transducer to the uppermost level of the right atrium (RA).[1] As an external reference point for measurement of CVP (transducer installation position), various landmarks have been proposed, such as 10 cm from the dorsal to ventral aspect,[2,3] the intersection of the fourth intercostal line and mid-chest of the coronal plane,[4] the mid-axillary line,[5] and 5 cm below the left sternal border at the fourth intercostal line.[1] However, the validity of these indicators has not been sufficiently verified by use of an anatomical approach.

In clinical application, it is recommended to measure the CVP in some cases as a parameter for determining the treatment policy. For example, in the septic shock treatment guidelines, correction of CVP is recommended for initial treatment of septic shock.[6] Additionally, it has been reported that CVP is associated with intraoperative bleeding of hepatectomy.[7,8] It is recommended to maintain the CVP lower than 5 mmHg in order to reduce the intraoperative bleeding. Since the measurement range of the CVP is narrow, small installation error of transducer would cause a serious difference in the clinical outcome. Also, when discussing the usefulness of CVP, CVP must be accurately measured.

Recently, Seo et al. used computed tomography (CT) imaging and reported that the vertical position of the RA is located in approximately four fifths of the anterior posterior (AP) diameter of the thorax from the back.[9] However, those CT findings were obtained during the inspiratory phase. For a more accurate CVP value, measurement performed in the expiratory phase is considered able to avoid the influence of intrathoracic pressure, thus the transducer should be located at the uppermost level of the RA during the expiratory phase. Although they further suggested that the uppermost level of the RA is not influenced by respiration, their findings are not considered to be adequately valid because they were obtained with patients who had chronic obstructive pulmonary disease (COPD).

For the present study, we considered that the most appropriate predictive method for determining the location of the RA during expiratory phase by using inspiratory phase CT images obtained from non-COPD patients.

Materials and Methods

After obtaining approval from the institutional review board of Hiroshima University Hospital, the medical records of patients who underwent CT scanning during both the inspiratory and expiratory phases within the most

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[*1] Department of Anesthesiology and Critical Care, Hiroshima University Hospital, Hiroshima, Japan

recent 7 years were retrospectively reviewed. Patients with bullous emphysema, COPD shown by spirometric evaluation, cardiovascular disease such as cardiac failure or valvular disorder, or thoracic deformity were excluded from the study. All CT images were obtained with a width of 2 mm.

As the first step, we measured all distances and ratios using CT images obtained in both the inspiratory and expiratory phases. The AP diameter of the thorax was measured at the mid-sternum level, while the largest vertical distance from the uppermost RA level to the back surface was also measured as RA height (Fig. 1). RA thorax ratio was defined as the ratio of RA height to AP diameter of the thorax.

Next, we attempted to predict the expiratory RA height using inspiratory CT images and compared 2 predictive methods. One of those used the average inspiratory RA thorax ratio of all study patients (*Formula 1*), as follows.

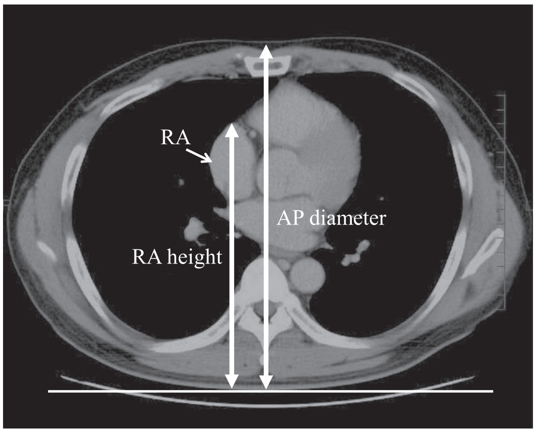

Fig. 1. Parameters measured using CT.
The anteroposterior (AP) diameter was determined as the distance of the thorax on the mid-sternum at the skin level. Right atrium (RA) height was considered to be the greatest distance of the upper most level of the RA vertically from the skin on the back of the arbitrary thorax. Although all parameters are shown on the same image for explanation, some parameters were measured using different computed tomography sections.

Predicted expiratory RA height =
Average inspiratory RA thorax ratio × Expiratory AP diameter of thorax ·····*Formula 1*

In the other method, we used each inspiratory RA thorax ratio (*Formula 2*), as follows.

Predicted expiratory RA height =
Each inspiratory RA thorax ratio × Expiratory AP diameter of thorax ·····*Formula 2*

Statistical analysis

For statistical analyses, we used an unpaired two-tailed t-test, and linear regression and Bland-Altman analyses, with the level of significance set at $p < 0.05$. In Bland-Altman plots, data are shown as bias, precision (1.96 SD), and limit of agreement (95% confidence interval: bias ± precision). Other data are shown as the mean ± SD or range.

Results

We analyzed the records of 15 patients (mean age 48.1 ± 24.7 years, 8 males). All patients were out patients and not intubated. Patient background data and the primary disease for undergoing the CT examination are shown in Table 1, while parameters measured on the CT images are shown in Table 2. The AP diameter of the thorax and RA

Table 1. Patient backgrounds and primary disease for undergoing CT examination.

Parameter	Value
Male/Female	8/7
Age (year)	48.1 ± 24.7 [15–87]
Height (cm)	158.1 ± 8.2 [145–172]
Weight (kg)	52.2 ± 13.1 [28–83]
Primary disease	
After bone marrowtransplantation	7
Poison-gas exposure	3
Bronchitis	3
Small nodular shadow	1
Hyperresponsive airway	1

Data are expressed as the number of patients or mean ± SD [range].

Table 2. Parameters measured on CT images

Parameter	Value		p value
	Inspiratory	Expiratory	
AP diameter (cm)	19.9 ± 3.0 [15.1–25.9]	18.9 ± 3.0 [14.5–25.3]	< 0.01
RA height (cm)	14.9 ± 1.7 [12.1–17.5]	14.3 ± 1.7 [11.6–17.7]	< 0.01
RA height/AP diameter (%)	75.7 ± 5.5 [65.2–86.7]	76.4 ± 5.1 [66.5–84.1]	0.22

Data are expressed as the mean ± SD [range]. P values are for comparison of inspiration with expiration. AP diameter; largest anteroposterior (AP) diameter of thorax, RA height; longest vertical distance from skin on back to most anterior portion of right atrium (RA), RA thorax ratio; ratio of RA height to AP. Both AP diameter of the thorax and RA height were significantly greater in the inspiratory as compared to the expiratory phase.

height during the inspiratory phase were larger than those during the expiratory phase. In contrast, there was no significant difference between inspiratory and expiratory phases for RA thorax ratio.

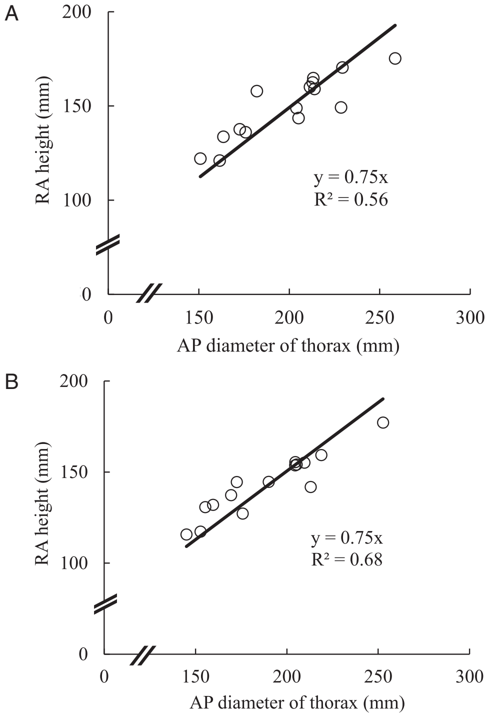

Fig. 2. Correlation between RA height and AP diameter in inspiratory and expiratory phases.

A. Inspiratory phase.

B. Expiratory phase.

A and B show the correlation between right atrium (RA) height and anteroposterior (AP) diameter of the thorax in inspiratory and expiratory phases, respectively. There was a linear correlation between RA height and AP diameter of the thorax in both phases. AP diameter; largest anteroposterior diameter of thorax, RA height; longest vertical distance from skin on back to most anterior portion of right atrium.

The results of linear regression analysis of RA height and AP diameter of the thorax in the inspiratory and expiratory phases are shown in Figure 2A and B. There was a strong correlation between RA height and AP diameter of the thorax in both phases (inspiratory phase: $R^2 = 0.56$, expiratory phase: $R^2 = 0.68$). Additionally, the coefficient of both regression lines were approximately the same at 0.75. The RA thorax ratio for the inspiratory and expiratory phases also showed a strong correlation ($R^2 = 0.80$) (Fig. 3).

The results of Bland-Altman analysis of measured and predicted RA height in the expiratory phase are shown in Figure 4. The bias was not different between the predicted expiratory RA height shown by *Formula 1* and predicted expiratory RA height shown by *Formula 2* (p = 0.73). However, the precision of the former was greater (19.09 vs. 8.41 mm).

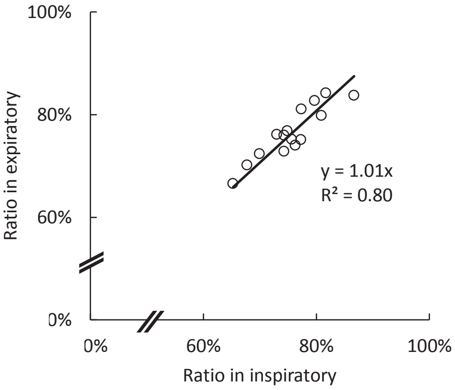

Fig. 3. Correlation of RA thorax ratio between inspiratory and expiratory phases.

RA thorax ratio; ratio of right atrium (RA) height to anteroposterior (AP) diameter, AP diameter; largest anteroposteror diameter of thorax, RA height; longest vertical distance from skin on back to most anterior portion of right atrium.

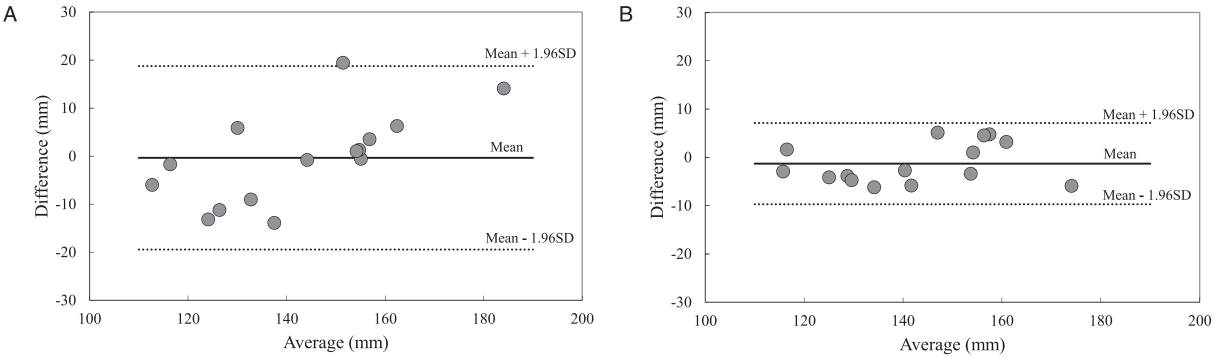

Fig. 4. Results of Bland-Altman analysis.

A. Comparison of right atrium (RA) height on expiratory CT images and predictive expiratory RA height determined by multiplying the average value with expiratory anteroposterior (AP) diameter measured on CT images. Bias was –0.34 mm, precision was 19.1 mm, and limit of agreement was –19.44 to 18.75 mm.

B. Comparison of RA height on expiratory CT image and predictive expiratory RA height determined by multiplying individually calculated RA thorax ratio with expiratory AP diameter measured on CT images. Bias was –1.31 mm, precision was 8.4 mm, and limit of agreement was –9.72 to 7.10 mm.

Discussion

Our results showed that the RA thorax ratio did not change between the inspiratory and expiratory phases. Standard CT imaging can only show the location of the RA in the inspiratory phase, because that scanning is usually performed during deep inspiration. However, the mediastinal structure location changes in accordance with respiratory cycle, thus it is important to understand such changes. Seo et al. previously reported findings similar to those in the present study,9) though they studied only COPD patients, while application to non-COPD patients is not clear. Our results indicate that the height of the RA in the expiratory phase can be predicted from inspiratory CT images and the AP diameter of the expiratory thorax, which can be measured extracorporeally, in non-COPD patients.

In the present study, the precision of the expiratory RA height value determined from the average inspiratory RA thorax ratio (*Formula 1*) was greater as compared to that determined from the RA thorax ratio in each patient (*Formula 2*). In Seo's study not only our study, individual differences for RA thorax ratio were large.9) In other words, our results showed that the average ratio of RA height was approximately three fourths of the AP diameter of the thorax and ranged from 65% to 87%. Thus, when using the value of 75% (average RA thorax ratio in our study) for each patient, a large error was noted in some cases. On the other hand, by multiplying the RA thorax ratio of each patient obtained during the inspiratory phase with the expiratory AP diameter of the thorax measured on CT images for estimation of expiratory RA height, the amount of error was reduced.

Both the AP diameter of the thorax and RA height were significantly greater in the inspiratory phase as compared to the expiratory phase, which are not consistent with the report of Seo,9) likely due to differences between the subject populations. We examined non-COPD patients, while they used patients with COPD. The lungs of COPD patients show expansion caused by emphysematous change, thus respiratory variations of the mediastinal organs are assumed to disappear.

In conclusion, our findings showed that the relative height of the RA and maximum AP distance of the thorax in the sagittal direction were not changed by respiratory cycle. Furthermore, they indicate that inspiratory CT imaging and expiratory phase thorax diameter can be used to precisely predict expiratory phase RA height.

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