

## “Egg-and-Banana Sign” on CT Scan for Diagnosis of Pulmonary Hypertension

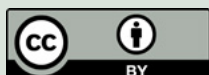
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### ABSTRACT

**OBJECTIVE** The “egg-and-banana” sign refers to an increased main pulmonary diameter (MPAD) seen in the main pulmonary artery (PA) at the same level as the most caudal point of the aortic arch. This study aimed to determine whether identification of the egg-and-banana sign on CT scans can help in the diagnosis of pulmonary hypertension (PH).

**METHODS** A retrospective study was conducted of 110 patients at Siriraj Hospital between January 2017 and November 2020. Clinical characteristics, CT scans, and echocardiograms were reviewed. The egg-and-banana sign, MPAD and ascending aorta were reviewed and their diagnostic performance as CT features of PH were analyzed.

**RESULTS** The egg-and-banana sign showed 41.6% sensitivity, 84.9% specificity, 86.5% positive predictive value and 38.4% negative predictive value for the detection of PH. When it was used together with MPAD > 29 mm and PA:AAo ratio > 1, specificity increased to 87.9%, sensitivity of MPAD was high (97.4%; AUC value, 0.866) and specificity of the PA:AAo ratio showed a high value (81.8%; AUC value, 0.838) for PH individually. The egg-and-banana sign was found to be related to a higher mean PA pressure (mPAP), a higher PA:AAo ratio, and a larger MPAD. Moderate correlations between mPAP and MPAD and between mPAP and PA:AAo ratio were found.

**CONCLUSIONS** The egg-and-banana sign may be useful in the detection of PH. It has high specificity and high PPV for PH. The use of the egg-and-banana sign in conjunction with other well-known CT features, the MPAD and PA:AAo ratio, can boost the specificity and PPV for detection of PH.

**KEYWORDS** egg-and-banana sign, pulmonary hypertension

### INTRODUCTION

Pulmonary hypertension (PH) is a condition characterized by a mean pulmonary artery pressure (mPAP) of 25 mmHg or higher at rest (1,2). PH causes various symptoms, including shortness of breath, syncope, and tiredness. Delayed diagnosis and treatment can lead to morbidity and mortality, so early detection and

accurate assessment are essential for achieving the best possible outcome.

The gold standard for the diagnosis of PH is right heart catheterization (RHC), but this is an invasive technique and it cannot be used frequently or repeatedly. Noninvasive tests, such as CT and echocardiography, also play a role in the screening and diagnosis of PH (3).

An alternative method to evaluate pulmonary hypertension is to measure the main pulmonary artery diameter (MPAD) and the ratio between the MPAD and the diameter of the ascending aorta (PA:AAo) using computed tomography (CT). Each method has demonstrated varying associations with RHC and echocardiography data (4,5). A new diagnostic CT finding for PH is the egg-and-banana sign (6,7), referring to an increased MPAD of the main PA occurring at the same level as the most caudal point of the aortic arch (Figure 1) (7,8). The distorted main PA and the aortic arch resemble an "egg" and a "banana", respectively, on the CT scan.

Chris et al. evaluated the performance of the egg-and-banana sign as a diagnostic CT finding for PH in a study in the USA and found that the egg-and-banana sign had a high specificity (85%) and high positive predictive value (85%) for PH (6).

Since no similar study has been conducted in a Thai population, the objective of this study was to determine whether the identification of the egg-and-banana sign on a CT scan could help the diagnosis of PH in Thai patients. A secondary objective was to study the relationship and diagnostic ability of the MPAD and the PA:AAo ratio both independently and in combination with the egg-and-banana sign.

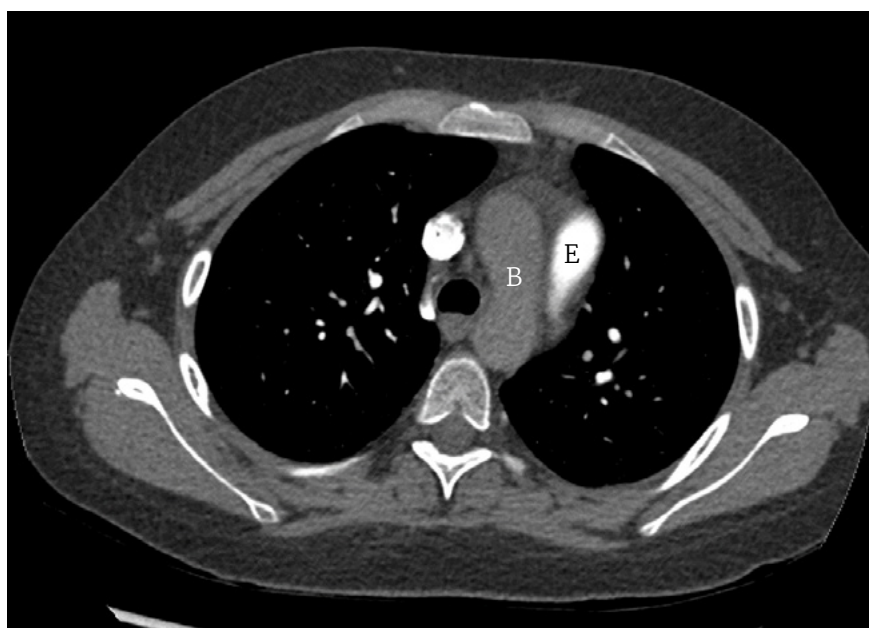
## METHODS

### Population

This study was performed with the approval of the Siriraj Institutional Review Board. The need for patient informed consent was waived as this was a retrospective study.

The records of 1,245 patients who underwent echocardiography from January 2017 through November 2020 at Siriraj Hospital were reviewed. Patients were included who had had echocardiography performed, who had the official report of mean pulmonary artery pressure (mPAP) and who also had a CT scan that covered the aortic arch and the most caudal point of the main PA within 6 months prior to or after the echocardiography. In the case of patients who had several CT scans, the study conducted closest to the echocardiography was chosen. For patients who went through numerous echocardiographies, the echocardiography with the latest imaging study was selected.

Patients were excluded if they had an ascending aortic aneurysm (> 5.0 cm in diameter), if they had undergone ascending aortic surgery or if they had significant anatomic abnormalities, e.g., severe kyphoscoliosis or pneumonectomy, as well as patients whose imaging studies had severe motion artifacts. Ultimately, 110 patients were included in this study.



**Figure 1.** 23-year-old woman with PH. CT pulmonary angiography image showing the egg-and-banana sign with the appearance of the main PA as the "egg" (E) at the level of the most caudal point of the aortic arch as the "banana" (B).

### Diagnosis of PH

GE Vivid 7 Dimension color Doppler ultrasonic diagnostic apparatus was used and the results were surveyed following a standard protocol by a cardiologist at Siriraj Hospital. According to the formula described by Abbas et al. (9,10), mean pulmonary artery pressure can be estimated by the peak pulmonary regurgitant velocity ( $mPAP = 4PRV2 + \text{right atrial pressure}$ ). All the included patients completed this examination. If  $mPAP \geq 25$  mmHg by the Abbas' method, PH was diagnosed.

### CT image acquisition

Conventional CT images were obtained using a 64-slice multi-detector CT system (Light-Speed VCT, GE Healthcare & Discovery CT750 HD, GE Healthcare, Chicago, IL, USA) or a 256-slice multi-detector CT system (Revolution CT, GE Healthcare, Chicago, IL, USA) using the 120 kVp and 250–400 mAs tube current time parameters. The slice thickness was 1.25 mm without a gap. High-resolution CT (HRCT) images were acquired using a 0.63 mm slice thickness without a gap. Spiral CT scans were obtained with or without contrast media administration.

### Imaging interpretation

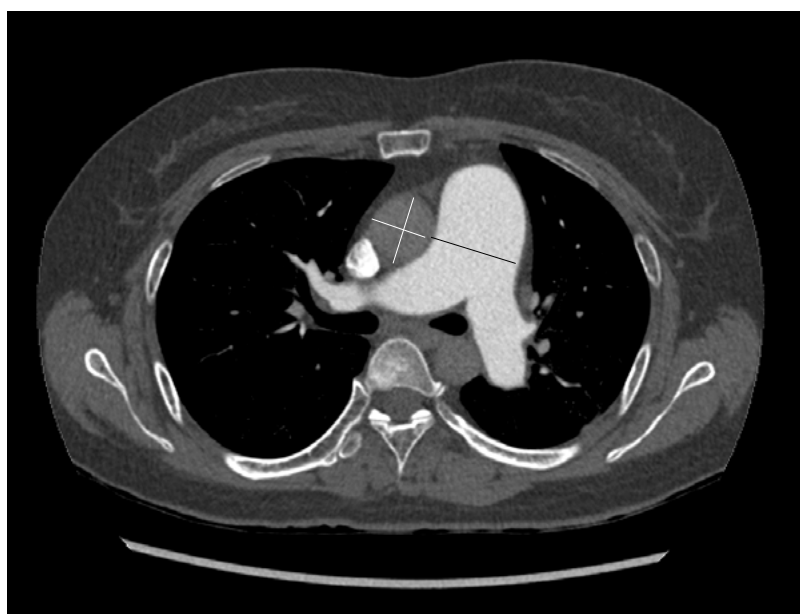
Two radiologists, with 21 and 13 years of experience, respectively, in chest imaging and

who were blinded to the related clinical data, individually interpreted the thinnest axial images on a mediastinal window (4) (level, 55; width, 426). If there was disagreement, the radiologists discussed the results to reach a consensus. The presence of the egg-and-banana sign was determined to be either positive or negative. The egg-and-banana sign was identified by detection of the lumen of the main PA at the caudal point of the most superior part of the aortic arch in at least one axial slice (6). The widest part of the main PA was measured within 2 cm of the bifurcation as was the diameter of the AAO within the same slice. The mean value of the two perpendicular measurements was used as the diameter of the AAO (Figure 2), then, the PA:AAo ratio was calculated.

### Statistical analysis

The software SPSS version 21.0 was used for data management and statistical analysis. The Cohen kappa coefficient was used to determine the interrater agreement between the two radiologists and an acceptable agreement of at least 0.60 was used as the criterion.

All the continuous variables are reported as mean  $\pm$  standard deviation (SD) or as median with ranges for their appropriate distributions. The categorical variables are reported as numbers or proportions.



**Figure 2.** Axial CT image showing the diameter of main pulmonary artery measurement at the level of bifurcation (black line) and the diameter of the ascending aorta measurement (white perpendicular lines).

Associations between the PH and non-PH groups, the egg-and-banana sign, and clinical characteristics were analyzed for statistical differences using either the independent t-test for the normally distributed parameters or the Mann–Whitney U test for the others, while the Chi-square test was performed for the categorical variables.

The relationship between the CT measurement and mPAP by echocardiography was measured by Pearson's correlation coefficient followed by linear regression analysis.

The overall diagnostic performance of the CT scans was reported in terms of sensitivity, specificity, positive and negative predictive values, area under the curve (AUC), and 95% confidence interval (CI).

To identify factors associated with PH, factors with a univariate  $p$ -value  $< 0.2$  were entered into the multivariate (multiple logistic regression) analysis using the Enter method. A 2-sided  $p < 0.05$  was considered to indicate statistical significance for all the tests.

## RESULTS

### Patient demographic data

For the included 110 patients who underwent echocardiography between January 2017 and November 2020, their demographic and clinical characteristics were recorded, including age, sex, time between imaging and echocardi-

graphy, and type of imaging study as summarized in Table 1.

Of these patients, 77 (70%) had been diagnosed with pulmonary hypertension with mPAP  $\geq 25$  mmHg by echocardiography (PH group), while 33 patients (30%) had no PH (non-PH group). Thus the mPAP was higher in those with PH as compared with the non-PH group. The group with PH had an mPAP of  $37.69 \pm 9.51$  mmHg vs.  $19.36 \pm 2.8$  mmHg for the group without PH.

There were no statistically significant differences between the PH and non-PH groups in terms of age, sex, or time between imaging and echocardiography. The rest of the patients' characteristics are shown in Table 1.

### Diameter of the main pulmonary artery and ratio of the pulmonary artery diameter to ascending aorta diameter

Reevaluation of the performance of the MPAD  $> 29$  mm in diagnosing PH found a 97.4% sensitivity, 63.6% specificity, 86.2% positive predictive value, and 91.3% negative predictive value for PH (11,12). The AUC value was excellent, measuring 0.86 (Table 2).

We also performed the same analysis for the PA:AAo ratio  $> 1$ . This had 75.3% sensitivity, 81.8% specificity, 90.6% positive predictive value, and 58.7% negative predictive value for the detection of PH. The AUC value was excellent,

**Table 1.** Patient demographic data

| Variable                                    | Number (%) or Mean $\pm$ SD |                        |                            | p-value   |
|---------------------------------------------|-----------------------------|------------------------|----------------------------|-----------|
|                                             | Total (n=110)               | PH <sup>a</sup> (n=77) | non-PH <sup>b</sup> (n=33) |           |
| Age (years)                                 | 56.48 $\pm$ 18.48           | 55.64 $\pm$ 20.06      | 58.45 $\pm$ 14.21          | 0.405     |
| Sex                                         |                             |                        |                            | 0.115     |
| Male                                        | 38 (34.5%)                  | 23 (29.9%)             | 15 (45.5%)                 |           |
| Female                                      | 72 (65.5%)                  | 54 (70.1%)             | 18 (54.5%)                 |           |
| Time between imaging and Echo (days, range) | 51 (0–177)                  | 52 (0–177)             | 48 (2–167)                 | 0.342     |
| Type of imaging study performed             |                             |                        |                            | 0.01      |
| CT of chest with or without contrast medium | 38 (34.5%)                  | 19 (24.7%)             | 19 (57.6%)                 |           |
| CT pulmonary angiography                    | 44 (40%)                    | 36 (46.8%)             | 8 (24.2%)                  |           |
| High resolution CT of chest (HRCT)          | 17 (15.5%)                  | 14 (18.2%)             | 3 (9.1%)                   |           |
| CT angiography of thoracic aorta            | 11 (10%)                    | 8 (10.4%)              | 3 (9.1%)                   |           |
| mPAP (mmHg)                                 | 32.19 $\pm$ 11.69           | 37.69 $\pm$ 9.51       | 19.36 $\pm$ 2.8            | $< 0.001$ |
| PA diameter (mm)                            | 33.77 $\pm$ 6.39            | 36.09 $\pm$ 5.52       | 28.36 $\pm$ 4.88           | $< 0.001$ |
| PA:AAo ratio                                | 1.08 $\pm$ 0.25             | 1.15 $\pm$ 0.24        | 0.9 $\pm$ 0.15             | $< 0.001$ |

Echo, echocardiography; PH, pulmonary hypertension; mPAP, mean pulmonary artery pressure; PA, pulmonary artery; AAo, ascending aorta

<sup>a</sup>Defined by a mPAP  $\geq 25$  mm Hg, <sup>b</sup>Defined by an mPAP  $< 25$  mmHg.

measuring 0.838 (Table 2).

### Egg-and-Banana sign

The egg-and-banana sign was observed in 32 of 77 of patients with PH (41.6%) and in 5 of 33 (15.2%) of patients without PH. The group with the positive egg-and banana sign had an mPAP about 8 mmHg higher than the group with the negative sign,  $36.68 \pm 11.62$  mmHg vs.  $29.92 \pm 11.13$  mmHg ( $p = 0.004$ ).

The main PA diameter in the group with the positive sign was 4.46 mm larger than the group with the negative sign ( $p < 0.001$ ) and the PA:AAo ratio was higher by about 0.23 ( $p < 0.001$ ) (Table 3). The correlations between the mean pulmonary artery diameter, the PA:AAo ratio, and the egg-and-banana sign were evaluated using boxplots (Figure 3).

Overall, the sensitivity of the egg-and-banana sign for the diagnosis of PH was 41.6% (95%CI 30.4–53.4%) and the specificity was 84.9% (95%CI 68.1–94.9%). The positive predictive value was 86.5% (95%CI 73.2–93.7%), and the negative predictive value was 38.4% (95%CI 32.9–44.1%).

The Kappa coefficient for inter-rater agreement between the two radiologists for detection of the egg-and-banana sign was 0.65, indicating substantial agreement.

A positive egg-and-banana sign in conjunction with MPAD > 29 mm had 84.9% specificity. The specificity increased to 87.9% and the positive predictive value increased to 87.9% when combined with the PA:AAo ratio > 1 (Table 2).

Correlations between the mean pulmonary artery pressure and the diameter of the main pulmonary artery and between the pulmonary artery diameter and the ascending aorta diameter ratio

Correlations between the mean pulmonary artery diameter, the PA:AAo ratio, and the mPAP were evaluated using linear regression. The correlation between the mPAP and the PA diameter showed a moderate degree of correlation ( $r = 0.58$ ,  $p < 0.001$ ). A moderate correlation between the mPAP and PA:AAo ratio was also observed, ( $r = 0.59$ ,  $p < 0.001$ ) (Figure 4).

## DISCUSSION

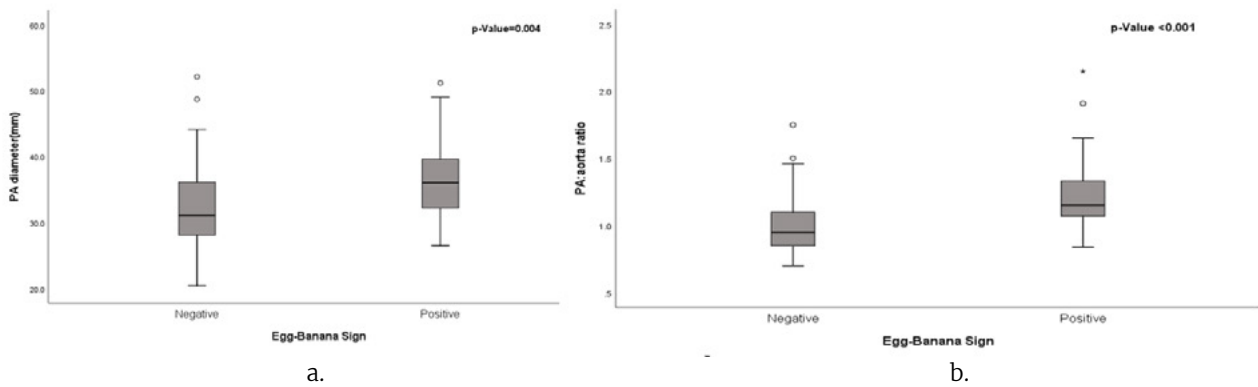
The gold standard for the diagnosis of PH is right-sided heart catheterization (RHC), but this is an invasive and costly procedure. Doppler echocardiography is by far the investigation of choice for the noninvasive diagnosis of PH (13) and can estimate the systolic pulmonary artery pressure from the maximum velocity of the tricuspid regurgitation (TR). Abbas et al. in 2013 (9,10) proposed using the classic Doppler equation formula, which shows a strong cor-

**Table 2.** Results of analysis of diagnostic tests

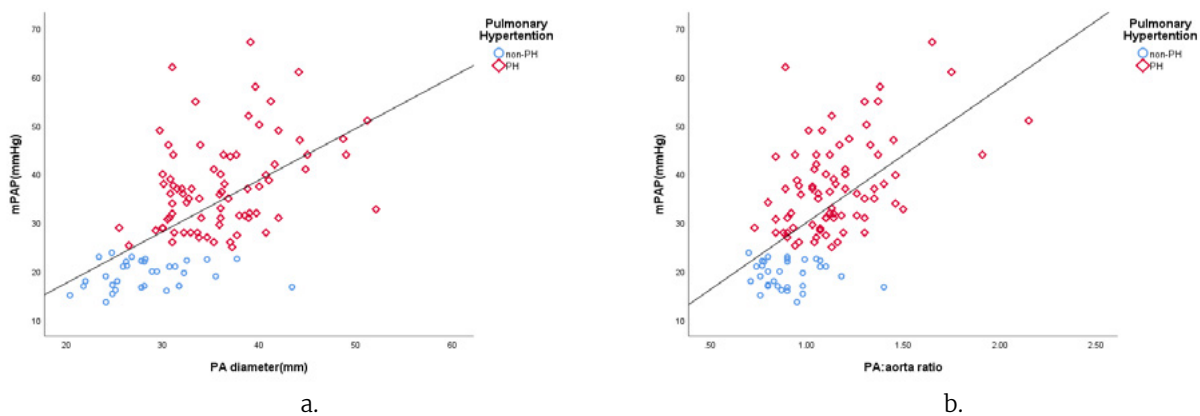
| CT feature                                        | Percentage (95%CI) |                  |                           |                           | AUC value |
|---------------------------------------------------|--------------------|------------------|---------------------------|---------------------------|-----------|
|                                                   | Sensitivity        | Specificity      | Positive predictive value | Negative predictive value |           |
| Main PA diameter > 29 mm                          | 97.4 (90.9–99.7)   | 63.6 (45.1–79.6) | 86.2 (79.9–90.8)          | 91.3 (72.3–97.7)          | 0.866     |
| PA:AAo ratio > 1                                  | 75.3 (64.2–84.4)   | 81.8 (64.5–93)   | 90.6 (82.3–95.3)          | 58.7 (48.2–68.4)          | 0.838     |
| Egg-and-banana sign                               | 41.6 (30.4–53.4)   | 84.9 (68.1–94.9) | 86.5 (73.2–93.7)          | 38.4 (32.9–44.1)          |           |
| Egg-and-banana sign plus main PA diameter > 29 mm | 40.3 (29.2–52)     | 84.9 (68.1–94.9) | 86.1 (72.6–93.6)          | 37.8 (32.5–43.5)          |           |
| Egg-and-banana sign plus PA:AAo ratio > 1         | 37.7 (26.9–49.4)   | 87.9 (71.8–96.6) | 87.9 (73.5–95)            | 37.7 (32.8–42.8)          |           |

**Table 3.** Associations between the egg-and-banana sign and clinical features

| Characteristic        | Mean±SD                      |                              | p-value |
|-----------------------|------------------------------|------------------------------|---------|
|                       | Positive egg-and-banana sign | Negative egg-and-banana sign |         |
| Mean mPAP (mmHg)      | 36.68±11.62                  | 29.92±11.13                  | 0.004   |
| Main PA diameter (mm) | 36.73±5.52                   | 32.27±6.32                   | < 0.001 |
| PA:AAo ratio          | 1.23±0.26                    | 1.00±0.21                    | < 0.001 |



**Figure 3.** Boxplots of the correlation between the egg-and-banana sign with (a) measured PA diameter values and (b) measured PA:AAo ratios



**Figure 4.** Scatterplots of the correlation between mPAP and (a) measured PA diameter values, (b) measured PA:AAo ratios

relation between the invasive PA pressure by RHC (mmHg) and the mean pulmonary artery pressure by echocardiography. Following that result, our study chose echocardiography instead of RHC for the standard diagnosis of PH.

Noninvasive methods to measure pulmonary arterial pressure and to detect pulmonary hypertension have benefits over invasive procedures that require access to the right heart structures (4). Due to the correlation between an increased MPAD and pulmonary hypertension, CT measurements of the pulmonary artery are performed as a diagnostic screening tool. The well-known CT findings are an enlargement of MPAD and an increased PA:AAo ratio. However, these parameters can show wide variation in their sensitivities and specificities, reported to be 50%–100% (4,14–16). Consequently, new diagnostic CT signs for PH have been proposed.

The egg-and-banana sign has been mentioned as a recently identified diagnostic CT feature for PH in a few reports (6,7) where it is described as an increased MPAD seen in the main PA at the same level as the most caudal point of the aortic arch (7,8). Chris et al. studied the predictive performance of the egg-and-banana sign and estimated that the egg-and-banana sign had a high and positive predictive value for the detection of PH (6).

This study found that the egg-and-banana sign had a sensitivity of 41.6%, specificity of 84.9%, positive predictive value of 86.5%, and negative predictive value of 38.4% for the detection of PH. Patients with a positive egg-and-banana sign had a higher mPAP and larger MPAD ( $p < 0.05$ ) which is in agreement with a previous study (6).

When evaluating the egg-and-banana sign combined with PA:AAo ratio  $> 1$ , the specificity and positive predictive value increased to

87.9%. When used in conjunction with MPAD  $> 29$  mm, the specificity increased from 63.6% when using MPAD  $> 29$  mm alone to 84.9% when used in conjunction with the egg-and-banana sign. This indicates that the use of the egg-and-banana sign in conjunction with the MPAD or PA:AAo ratio can substantially increase specificity and positive predictive value for the detection of PH.

The well-known CT signs of PH, namely MPAD  $> 29$  mm and a PA:AAo ratio  $> 1$ , had high sensitivity and specificity for the detection of PH, as reported in several of earlier reports (4, 7,8). As a secondary objective, we reevaluated these CT features and found a high sensitivity for PH with MPAD  $> 29$  mm, and a high specificity for PH for PA:AAo ratio  $> 1$ . The correlations between the mPAP, the PA:AAo ratio, and the MPAD were moderate, suggesting that these measurements could be useful as a diagnostic for PH.

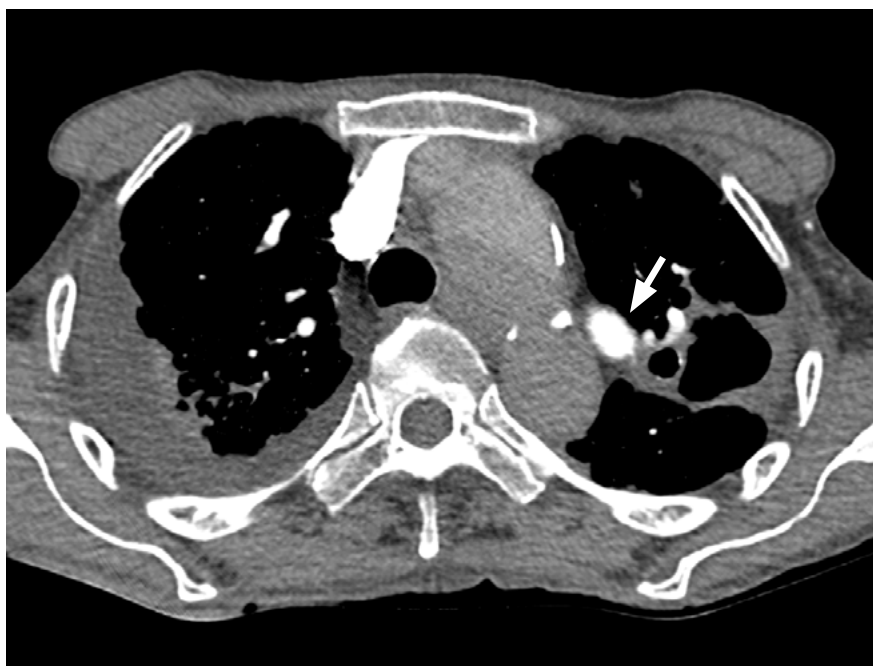
The interrater agreement for detection of the egg-and-banana sign was substantial. There were few causes of disagreement regarding the detection of the egg-and-banana sign in this study, e.g., misidentification of the left pulmonary artery as the main pulmonary trunk (Figure 5). Some cases had a small main pulmonary trunk at the level of the aortic arch

which could be the cause of the disparities in the detection of the egg-and-banana sign.

There were many limitations in this study. First, it was a retrospective study. Second, echocardiography was used as the basis of this study rather than RHC, the gold standard for PH. However, we applied echocardiography because of the strong correlation between mPAP by RHC and echocardiography as cited by Abbas et al. (9,10). Lastly, differing durations between echocardiography and CT scans may have provided time for treatment of the disease to lower the PA pressure. However, the potential for this confounding was minimized in our study by ensuring a relatively short time between the two measurements: most of the imaging in this study was completed with 1.5 months or less between the echocardiography and CT scans.

## CONCLUSIONS

This study shows the egg-and-banana sign has a high specificity and high positive predictive value for PH. The use of the egg-and-banana sign in conjunction with well-known CT features, e.g., the MPAD and PA:AAo ratio, can also raise the specificity and positive predictive value for the detection of PH and can assist in the early detection of PH.



**Figure 5.** Axial CT image showing the misidentification of the left pulmonary artery (arrow) as the main pulmonary trunk

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None

## CONFLICTS OF INTEREST

The authors declare no potential conflicts of interest relevant to this article.

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