Evaluation of role of computed tomography (CT) in the diagnosis of pulmonary hypertension

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Introduction Pulmonary hypertension (PH) has significant morbidity and mortality. Chest computed tomography (CT) scans are increasingly used in the evaluation of patients with dyspnea, including those with suspected PH.

Aim The aim was to study the signs of PH shown by CT scans, and to correlate the data obtained with echocardiography in suspected patients with PH in a trial to select patients who are eligible for right-heart catheterization and to confirm the diagnosis of PH in those patients who cannot tolerate right-heart catheterization.

Patients and methods This study included 60 patients (50 patients with pulmonary hypertension and 10 patients with no PH) aged 32–70 years. They underwent high-resolution CT (23 cases) and computed tomography pulmonary angiography (37 cases) using 16 multidetector computed tomography scanner for the evaluation of their pulmonary parenchyma and mediastinal structures to detect different diagnostic criteria, causes, associations, and complications of PH. All the 60 patients underwent echocardiography.

Results The main pulmonary artery (MPA) was larger than 29 mm in 94% of the echo-positive cases and in 30% of the echocardiography-negative cases. A more than 1 : 1 relationship between the segmental pulmonary artery and the bronchus in at least three pulmonary lobes was seen in 84% of positive cases and in none of the negative cases. A more than 1 : 1 relationship between the MPA and the aorta was seen in 80% of positive cases and in 20% of negative cases. Correlation between MPA diameter in CT and the pulmonary artery systolic pressure measured by echocardiography in all cases showed significant correlation, with a *P* value of up to 0.001.

Conclusion Although right-heart catheterization is the gold standard for the measurement of pulmonary artery pressure, this procedure is not without risk and expense. Multidetector computed tomography (computed tomography pulmonary angiography or high resolution CT (HRCT) can reliably be used, in addition to echocardiography, for the routine evaluation of patients with PH.
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Introduction

Pulmonary hypertension (PH) is defined as a mean pulmonary artery pressure greater than 25 mmHg at rest, or greater than 30 mmHg with exercise. Normal pulmonary arterial systolic pressure ranges from 15 to 30 mmHg, diastolic pressure ranges from 4 to 12 mmHg, and normal mPAP is less than or equal to 20 mmHg. Many clinicians consider mPAP of 21–24 mmHg as borderline elevated and of uncertain clinical significance [1].

A low threshold for suspicion is critical for the diagnosis of PH. Once a patient is suspected of having PH, extensive diagnostic testing before right-heart catheterization is generally performed. This evaluation is aimed at confirming the presence of PH, measuring its severity, and identifying its cause [2].

Echocardiography is performed to estimate the pulmonary artery systolic pressure (PASP) and to assess right ventricular size, thickness, and function. In addition, echocardiography can evaluate right atrial size, left ventricular systolic and diastolic function, and valve function, while detecting pericardial effusions and intracardiac shunts [3]. It should always be performed in the case of suspected PH [4].

Computed tomography (CT) offers anatomic information about the size of the pulmonary arterial tree, and echocardiography identifies the functional consequences of PAH, evaluating secondary tricuspid regurgitation. Because right-sided heart catheterization is an invasive test, there is a need for accurate noninvasive markers that can be used appropriately to stratify patients for referral for right-sided heart catheterization [5].

Aim

The aim of this work was to study the signs of PH shown by CT scans, and to correlate the data obtained

with echocardiography in suspected patients with PH in a trial to select patients who are eligible for right-heart catheterization and to confirm the diagnosis of PH in those patients who cannot tolerate right-heart catheterization.

Patients and methods

This study included 60 patients; 50 patients with pulmonary hypertension (28 male and 22 female, age range: 32–70 years, mean: 55.35 years) and 10 patients with no PH as a control group (age range: 33–65 years). Patients were admitted at Chest, Cardiology and Internal Medicine Departments of Banha University Hospitals. They were referred to the Radiology Department to perform HRCT (23 cases) and computed tomography pulmonary angiography (CTPA) (37 cases).

All patients were subjected to the following: history taking and physical examination, as well as routine laboratory investigations (complete blood count (CBC), erythrocyte segmentation rate (ESR), and liver and kidney function tests).

Transthoracic echocardiography

Transthoracic echocardiography was performed using the VIVID 7 machine with a multifrequency transducer equipped with the DTI software (Echo Pac; GE Vingmed, Horten, Norway). All images were recorded digitally to allow off-line quantitative analysis and assessment of interlaboratory reproducibility of measurements. Each measurement was averaged over three consecutive beats during sinus rhythm.

Multidetector computed tomography examination

Either CT Pulmonary Angiography (CTPA), (37) or High Resolution CT (HRCT), (23) was used. The procedure was conducted using a multidetector Toshiba 16 Activion scanner with 16 detector arrays (Toshiba, Japan).

Additional investigations

The following additional investigations were performed in individual cases when indicated:

(1) Pulmonary function tests (spirometry).
(2) Serological tests (antinuclear antibodies (ANA), rheumatoid factor (RF), anti-necrophilic cytoplasmic antibodies (ANCA), anti-cardiolipin antibodies (ACL), anti-phosfolipid antibodies (APL)).
(3) Ventilation–perfusion scan (V/Q).

(4) Right-heart catheterization.
(5) Thoracoscopic lung biopsy.

Data analysis and interpretation

In each case, the following was considered according to Grosse and Grosse [6] and Peña *et al.* [7]:

(1) CT criteria of the PH:
   (a) Measurement of the widest diameter of main pulmonary artery (MPA) at the site of bifurcation, which was divided into the following:
      (1) ≤3.5 cm.
      (2) 3.5–<4 cm.
      (3) ≥4 cm.
   (b) Relationship between segmental pulmonary arteries and bronchus in different lung lobes, which was divided into the following:
      (1) Normal (when it is 1 : 1 in all lobes).
      (2) One (when it is >1 : 1 in one lobe).
      (3) Two (when it is >1 : 1 in two lobes).
      (4) Three (when it is >1 : 1 in three lobes).
   (c) Relationship between MPA and adjacent aorta (AO) diameter, which was divided into the following:
      (1) Normal (when it is <1 : 1).
      (2) Increased (when it is >1 : 1).

Results

Table 1 shows the diagnosis of 50 cases of PH and 10 cases with no PH: the PH cases included 16 cases of diffuse parenchymal lung disease representing 32% of cases, diagnosed by clinical history and examination, CT

Table 1 Diagnosis of the studied groups (50 patients with pulmonary hypertension and 10 patients with no pulmonary hypertension)

Diagnoses	N (%)
Pulmonary hypertension cases	
Diffuse parenchymal lung disease	16 (32)
Left-sided heart disease	16 (32)
COPD	10 (20)
Bronchiectasis	2 (4)
Obesity hypoventilation syndrome (OHS)	1 (2)
CTEPH	2 (4)
Sarcoidosis	1 (2)
Idiopathic primary pulmonary hypertension	2 (4)
Nonpulmonary hypertension cases (control group)	
Acute pulmonary embolism	2 (20)
Bronchial asthma	5 (50)
Pneumonia	3 (30)

*COPD = Chronic Obstructive Pulmonary Disease.
*CTEPH = Chronic Thrombo- Embolic Pulmonary Hypertension.

signs of alveolitis or interstitial fibrosis, and some cases diagnosed by thoracoscopic lung biopsy; 16 cases of left-sided heart disease representing 32% of cases diagnosed by clinical history and examination and transthoracic echocardiography; 10 cases of COPD representing 20% of cases diagnosed by clinical history and examination, pulmonary function tests, and radiological signs of hyperinflation; two cases of bronchiectasis representing 4% diagnosed by clinical history and examination and HRCT; one case of obesity hypoventilation syndrome representing 2% diagnosed by clinical history and examination, pulmonary function tests, overnight pulse oximetry, and echocardiography; two cases of Chronic Thrombo-Embolic Pulmonary Hypertension (CTEPH) representing 2% diagnosed by clinical history and examination, V/O scan, and CTPA; one case of sarcoidosis representing 2% diagnosed by clinical history and examination, CT scan, and thoracoscopic lung biopsy; two cases of idiopathic pulmonary arterial hypertension representing 4% diagnosed by clinical history and examination, echocardiography, pulmonary function tests, chest CT, laboratory investigations for collagen vascular diseases (ANA, RF, APL antibodies, anti-cardiolipin antibodies), and pulmonary artery catheterization measuring right atrial pressure, pulmonary artery pressure, and pulmonary capillary wedge pressure (PCWP).

Table 2 shows MPA diameter in all cases. MPA diameter is more than 29 mm in 28 (82.3%) male and 22 (84.6%) female patients, whereas MPA is 29 mm or less in six (17.6%) male and four (15.4%) female patients, with no significant difference between male and female patients ().

Table 3 shows the relation between diameters of MPA and adjacent AO, which is normal in eight (23.5%) male and 10 (38.5%) female patients, and is increased in 26 (76.5%) male and 16 (61.5%) female patients, with no significant difference between male and female patients.

Table 4 shows the relation between segmental pulmonary arteries and adjacent bronchi in all cases. The ratio between segmental pulmonary arteries and related bronchi is normal in all lobes in three (8.8%) male and three (11.5%) female patients, whereas it is more than 1 in one lobe in four (11.8%) male and two (7.7%) female patients, more than 1 in two lobes in three (8.8%) male and three (11.5%) female patients, and it is more than 1 in three lobes in 24 (70.6%) male and 18 (69.2%) female patients. There is no significant difference between male and female patients.

Table 2 Computed tomography measurement of main pulmonary artery diameter in all cases

MPA diameter (mm)	Male [n (%)]	Female [n (%)]	Total [n (%)]
>29 to ≤35	17 (50)	14 (53.8)	31 (51.7)
>35 to <40	5 (14.7)	2 (7.7)	7 (11.7)
≥40	6 (17.6)	6 (23.1)	12 (20)
≤29	6 (17.6)	4 (15.4)	10 (16.7)

MPA, main pulmonary artery. FET=0.965. P=0.855.

Table 3 Relation between main pulmonary artery and adjacent aorta in all cases

Relation between MPA and aorta	Male [n (%)]	Female [n (%)]	Total [n (%)]
Normal (<1:1)	8 (23.5)	10 (38.5)	18 (30)
Increased (>1:1)	26 (76.5)	16 (61.5)	42 (70)

MPA, main pulmonary artery. χ^2=1.56. P=0.211.

Table 4 Relation between segmental pulmonary arteries and adjacent bronchi in all cases

Relation between segmental pulmonary arteries and bronchus	Male [n (%)]	Female [n (%)]	Total [n (%)]
Normal (1:1)	3 (8.8)	3 (11.5)	6 (10)
>1:1 in one lobe	4 (11.8)	2 (7.7)	6 (10)
>1:1 in two lobe	3 (8.8)	3 (11.5)	6 (10)
>1:1 in three lobe	24 (70.6)	18 (69.2)	42 (70)

FET=0.669. P=1.0.

Table 5 Echocardiography results of pulmonary hypertension in all cases

Echocardiography results	Male [n (%)]	Female [n (%)]	Total [n (%)]
Positive	28 (82.4)	22 (84.6)	50 (83.3)
Negative	6 (17.6)	4 (15.4)	10 (16.7)

FET=0.0. P=1.0.

Table 6 Relation between echocardiography results and main pulmonary artery measurement

MPA measurement (cm)	Echocardiography result [n (%)]		Total [n (%)]
	Positive	Negative	
<2.9	3 (6)	7 (70)	10 (16.7)
2.9–3.5	28 (56)	3 (30)	31 (51.7)
>3.5 to <4	7 (14)	0 (0)	7 (11.7)
≥4	12 (24)	0 (0)	12 (20)

MPA, main pulmonary artery.

Table 5 shows echocardiography results in all cases. Fifty patients who are positive for PH have PASP more than 36 mmHg, including 28 male and 22 female patients, and 10 patients who are negative for PH have PASP 36 mmHg or less, including six male and four female patients. There is no significant difference between male and female patients.

Table 6 shows the relation between echo results and MPA diameter; there is a significant difference in MPA diameter between positive and negative PH cases diagnosed by echocardiography. In the non-PH group, seven (70%) cases had an MPA diameter less than 2.9 cm and three (30%) cases had an MPA diameter of 2.9–3.5 cm, whereas in the PH group three (6%) cases had MPA less than 2.9 cm, 28 (56%) cases had an MPA diameter of 2.9–3.5 cm, seven (14%) cases had an MPA of 3.5–4 cm, and 12 (24%) cases had an MPA 4 cm or more.

Table 7 shows the mean value and the standard deviation of PASP measured by echocardiography in positive and negative cases; there is a significant difference between positive and negative cases.

Table 8 shows the correlation between MPA diameter and PASP; there is a significant correlation between MPA and PASP ($P=0.001$).

There is a highly significant difference between the two groups as regards the relation between segmental arteries and bronchi in three lobes; 42 (84%) positive cases had an increased ratio in three lobes, whereas no negative cases had an increased ratio in three lobes, with a P value of 0.001 (Table 9).

Table 10 shows no significant difference between positive and negative cases as regards normal ratio between MPA and AO diameter, whereas there is a highly significant difference between positive and negative cases as regards the increased ratio between MPA and AO diameter; 40 (80%) positive cases had an increased ratio, whereas only two (20%) negative cases had an increased ratio, with P value of 0.001.

Table 11 shows the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) for MPA more than 29 as a parameter for PH. The sensitivity of MPA diameter in the diagnosis of PH is 94%, whereas the specificity is 70%.

Table 7 Mean value of pulmonary artery systolic pressure measured by echocardiography in positive pulmonary hypertension cases ($n=50$) and in negative cases ($n=6$)

	Echocardiography result		Student's *t*-test	*P*
	Positive	Negative		
PASP (mean±SD)	63.0±16.69	28.6±2.07	6.46	0.001**

PASP, pulmonary artery systolic pressure. ** highly significant.

Table 8 Correlation between main pulmonary artery diameter measured by computed tomography and pulmonary artery systolic pressure measured by echocardiography in all cases

MPA	*R*	*P*
PASP	0.556	0.001**

MPA, main pulmonary artery; PASP, pulmonary artery systolic pressure.

Table 9 Correlation between echocardiography results of pulmonary hypertension and the relation between segmental pulmonary arteries and related bronchi

Relation between segmental pulmonary artery and bronchus	Echocardiography result [*n* (%)]		Total [*n* (%)]	FET	*P* value
	Positive	Negative			
Normal (1:1)	0 (0)	6 (60)	6 (10)	27.0	0.001**
>1:1 in one lobe	2 (4)	4 (40)	6 (10)	8.33	0.003**
>1:1 in two lobe	6 (12)	0 (0)	6 (10)	0.333	0.56
>1:1 in three lobe	42 (84)	0 (0)	42 (70)	24.14	0.001**

** highly significant.

Table 10 Correlation between echocardiography results of pulmonary hypertension and the relation between main pulmonary artery diameter and aorta

Relation between MPA and aorta	Echocardiography result [*n* (%)]		Total [*n* (%)]	*Z*	*P* value
	Positive	Negative			
Normal (<1:1)	10 (20.0)	8 (80.0)	18 (30.0)	0.474	0.32
Increased (>1:1)	40 (80.0)	2 (20.0)	42 (70.0)	13.77	0.001**

MPA, main pulmonary artery.

Table 11 Evaluation of different parameters; sensitivity, specificity, positive predictive value, and negative predictive value for main pulmonary artery more than 29

MPA	Echocardiography result		Total
	Positive	Negative	
>29 [n (%)]	47 (94)	3 (30)	50 (83.3)
≤29 [n (%)]	3 (6)	7 (70)	10 (16.7)
Sensitivity (%)	94		
Specificity (%)	70		
PPV (%)	94		
NPV (%)	70		
Accuracy (%)	90		

MPA, main pulmonary artery; NPV, negative predictive value; PPV, positive predictive value.

Table 12 Evaluation of different parameters: sensitivity, specificity, positive predictive value, and negative predictive value for main pulmonary artery more than 29+P/A more than 1

MPA	Echocardiography result		Total
	Positive	Negative	
MPA>29+P/A>1 [n (%)]	39 (78)	1 (10)	40 (66.7)
Others [n (%)]	11 (22)	9 (90)	20 (33.3)
Sensitivity (%)	78		
Specificity (%)	90		
PPV (%)	97.5		
NPV (%)	45		
Accuracy (%)	80		

MPA, main pulmonary artery; NPV, negative predictive value; PPV, positive predictive value.

Table 13 Evaluation of different parameters: sensitivity, specificity, positive predictive value, and negative predictive value for main pulmonary artery more than 29+SA/SB more than 1 in three lobes in computed tomography scan

MPA>1+Sa/SB>1 in 3 lobes	Echocardiography result		Total
	Positive	Negative	
Positive [n (%)]	36 (72.0)	0 (0.0)	36 (60.0)
Negative [n (%)]	14 (28.0)	10 (100.0)	24 (40.0)
Sensitivity (%)	72		
Specificity (%)	100		
PPV (%)	100		
NPV (%)	41.7		
Accuracy (%)	76.7		

MPA, main pulmonary artery; NPV, negative predictive value; PPV, positive predictive value.

Table 12 shows sensitivity, specificity, PPV, and NPV for MPA more than 29 and P/A more than 1 as a parameter for PH; the two signs are less sensitive but more specific than MPA more than 29 mm alone.

Table 13 shows sensitivity, specificity, PPV, and NPV for MPA more than 29 mm and SA/SB more than 1 in three lung lobes in CT scan; the two signs are less sensitive but more specific than MPA more than 29 mm alone.

Table 14 shows sensitivity, specificity, PPV, and NPV for MPA more than 29 mm, P/A more than 1, and SA/SB more than 1 in three lung lobes in CT scan; the three signs together are less sensitive but more specific than MPA more than 29 mm and P/A more than 1 together as parameters of PH.

Table 15 shows the number of patients in each group of PH according to European Respiratory Society (ERS) classification 2015: group 1 included two patients, representing 4%; group 2 included 16 patients, representing 32%; group 3 included 29 patients, representing 58%; group 4 included two patients, representing 4%; and group 5 included one patient, representing 2% of the PH cases.

(1) In this study, the PPV of MPA more than 29 mm in the diagnosis of PH is 94%, the sensitivity is 94%, and the specificity is 70%.
(2) MPA more than 29 mm+MPA/AO more than 1 has a PPV for the diagnosis of PH of 97.5%, a NPV of 45%, a sensitivity of 78%, and a specificity of 90%.
(3) The sensitivity, specificity, and PPV of MPA more than 29 with an increase in MPA/AO more than 1 ratio and at least three lobes showed an increased ratio between segmental arteries and neighboring bronchi of 64, 100, and 100%, respectively.
(4) The importance of multidetector computed tomography (MDCT) lies not only in the diagnosis of PH but also in detecting the type, causes, and complications of PH, and according to this treatment and prognosis they are differing significantly.

Discussion

PH is a challenge for clinicians and radiologists, with a variety of possible underlying causes, each with its own specific treatment. MDCT can play a vital role in elucidating underlying cardiac, vascular, and pulmonary causes [8].

Many conditions that cause PH have suggestive findings at MDCT; some causes may be surgically treatable, whereas others may demonstrate adverse reactions to vasodilator therapies used during the course of treatment. Therefore, the radiologist plays an important role in evaluating patients with this disease [7].

The aim of this study was to evaluate the role of MDCT (as a highly sensitive and specific modality) in the diagnosis of PH and to be familiar with the

Table 14 Evaluation of different parameters: sensitivity, specificity, positive predictive value, and negative predictive value for main pulmonary artery more than 29+P/A more than 1+SA/SB more than 1 in three lobes in computed tomography scan

MPA	Echocardiography result		Total
	Positive	Negative	
MPA>29+P/A>1+SA/SB>1 in 3 lobes in CT scan [*n* (%)]	32 (64)	0 (0)	32 (53.3)
Others [*n* (%)]	18 (36)	10 (100)	28 (46.7)
Sensitivity (%)		64	
Specificity (%)		100	
PPV (%)		100	
NPV (%)		35.7	
Accuracy (%)		70	

CT, computed tomography; MPA, main pulmonary artery; NPV, negative predictive value; PPV, positive predictive value.

Table 15 Number of patients in each group of pulmonary hypertension according to European Respiratory Society 2015 classification

Groups	*N* (%)
Group 1: Pulmonary arterial hypertension	2 (4)
Group 2: Pulmonary venous hypertension	16 (32)
Group 3: Pulmonary hypertension due to hypoxic pulmonary disorders	29 (58)
Group 4: CTEPH	2 (4)
Group 5: Miscellaneous disorders with multifactors	1 (2)

CTEPH = Chronic Thrombo-Embolic Pulmonary Hypertension.

radiological picture of its causes (precapillary or postcapillary), idiopathic or secondary.

In the current study, 60 patients (34 male and 26 female) were examined by either HRCT or CTPA using a multidetector Toshiba 16 Activion scanner with 16 detector arrays in the Radiology Department, Banha University.

The study included 34 male and 26 female patients; there is no significant difference between male and female patients as regards Mean Pulmonary Artery (MPA) diameter, Aorta (AO) diameter, and MPA/AO ratio, and the relation between segmental pulmonary arteries and neighboring bronchi or Pulmonary Artery Systolic Pressure (PASP) was assessed by echocardiography.

In agreement with our study, Sabri *et al.* [9] found that there was no significant difference between male and female patients as regards these parameters.

In this study, patients were divided into two groups: group 1, which comprised patients with positive PH as diagnosed by echocardiography, included 50 patients with PASP measured by echo-Doppler more than 36 mmHg according to European Society of Cardiology (ESC) and European Respiratory Society (ERS) [10], and group 2, which comprised patients with negative PH as diagnosed by echocardiography, included 10 patients with PASP measured by Echo-Doppler less than 36 mmHg. This study showed a

highly significant difference between the two groups as regards MPA diameter, MPA/AO ratio, and ratio between segmental arteries and neighboring bronchi (*P*=0.001). There was a highly significant difference as regards PASP (*P*=0.001).

The measurement of the widest diameter of MPA at the level of its bifurcation was the first criteria used in this study for CT diagnosis of PH. This was also the first criteria used in the diagnosis of PH in studies conducted by Devaraj *et al.* [11], Grosse and Grosse [6], Peña *et al.* [7], and Sabri *et al.* [9].

In this study, the mean value and standard deviation of MPA diameter in all cases was 33.83±5.45 mm, whereas in echocardiography-positive cases it was 34.95±5.2 mm.

In this study, the PPV of MPA more than 29 mm in the diagnosis of PH was 94%, the sensitivity was 94%, and the specificity was 70%. This was in agreement with the studies conducted by Jassal *et al.* [12], Schiebler *et al.* [13], Truong *et al.* [14], Grosse and Grosse [6], and Sabri *et al.* [9].

Jassal *et al.* [12] determined that the MPA of 29 mm or larger, as shown on a CT scan, has a sensitivity of 69% and a specificity of 100% for predicting PH. The widest portion of the MPA within 3 cm of the bifurcation was used to determine the value. In addition, Schiebler *et al.* [13] demonstrated that individuals with intrinsic lung

disease can be identified as having PH if the MPA is greater than 29 mm. The upper limit of normal for the diameter of the pulmonary artery is 28.6 mm. A value greater than 28.6 mm suggests increased pressures in the pulmonary system [13].

Grosse and Grosse [6] stated that a pulmonary artery with a diameter more than 29 mm has a PPV of 97%, a sensitivity of 87%, and a specificity of 89% for the diagnosis of PH. In the study of Sabri et al. [9], the mean value and SD of MPA diameter in all cases was 3.6338±0.67422 cm, whereas in echocardiography-positive cases it was 3.7683±0.62899 cm. The PPV of MPA more than 29 mm in the diagnosis of PH was 82%, with a sensitivity of 100% and a specificity of 10% [9].

For easier assessment and correlation, this was further divided into three categories. This division was derived from the study conducted by Devaraj et al. [11], in which they correlated the dimension of the MPA with AO and nearby vertebral body (assumed to be 3 cm). The MPA diameter was measured in workstation using electronic caliper.

First category was less than or equal to 3.5 cm ($n=31$; 51.7%).

Second category was more than 3.5 and less than 4 cm ($n=7$; 11.7%).

Third category was more than or equal to 4 cm ($n=12$; 20%).

Ten patients had MPA less than 2.9 cm, with a percentage of 16.7%, which included seven negative cases and three positive cases.

In our study, 70% ($n=7$) of the negative cases had MPA less than 2.9 cm and 30% ($n=3$) had MPA 2.9–3.5 cm, whereas 6% ($n=3$) of positive cases had MPA less than 2.9 cm, 56% ($n=28$) had MPA 2.9–3.5 cm, 14% ($n=7$) had MPA more than 3.5 to less than 4 cm, and 24% ($n=12$) had MPA more than or equal to 4 cm.

The first category (2.9–3.5 cm) is the largest; this is because our cases mostly presented early.

The AO is the largest artery in the body, and normally the MPA is smaller in diameter than the AO. When there is an increase in the pulmonary pressure, the MPA artery diameter may become larger than that of the AO and the relation between them becomes more than 1:1.

In this study, the increased ratio between MPA and the AO is seen in 80% ($n=40$) of positive cases and in 20% ($n=2$) of the negative cases, with a significant difference between positive and negative cases ($P=0.001$).

The ratio was normal in 20% ($n=10$) of positive cases, their age ranged between 45 and 70 years (eight of them were older than 50 years; as the measuring of the AO increases with age), and the measurement of the MPA was less than 4 cm.

Data from the Framingham Heart Study showed that in healthy individuals the ratio of mean±SD PA to ascending AO diameter was 0.77±0.09, with a 90th percentile cutoff value of 0.91. The main PA over aortic diameter was significantly greater in patients with PH compared with control subjects [15]. This ratio better predicted the mean PA pressure (mean PA pressure=3.7+24×main PA diameter/aortic diameter) than the diameter of the main PA or the diameter of main PA over body surface area [15]. A retrospective analysis of 50 patients with pulmonary and cardiovascular diseases found that a ratio of main PA to ascending AO diameter greater than 1 was associated with a mean PA pressure of 20 mmHg or above, with a sensitivity of 70%, specificity of 92%, and a PPV of 96% [5].

In agreement with this study, Peña et al. [7] stated that 'At CTPA, a MPA diameter larger than that of the AO was also a sign of pulmonary hypertension, with a positive predictive value of 96% and specificity of 92%, especially in patients younger than 50 years old'.

Devaraj et al. [11] suggested that the ratio of the diameter of the MPA to the diameter of the AO was an accurate marker of mPAP because confounding variables, such as patient size, influence the size of the pulmonary artery and ascending AO equally, enabling a form of 'internal correction.

In the study conducted by Mao et al. [16], they measured the AO in 1442 cases, of whom 900 cases were aged between 41 and 60 years; the AO was measured to be between 30 and 34 mm in female patients and between 33 and 37) in male patients, and in 434 cases more than or equal to 60 years old the AO was measured to be 32–36 mm in female patients and 35–38 mm in male patients.

The normal relation between MPA and AO was seen in 13% ($n=5$) of the positive echocardiography cases, and in all of them the MPA measurement was less than

or equal to 3.5 cm. Four of these five cases were older than 45 years (one is 46 and three are ≥60 years old) and one was 30 years old.

In this study, MPA more than 29 mm+MPA/AO more than 1 has a PPV for the diagnosis of PH of 97.5%, NPV of 45%, sensitivity of 78%, and specificity of 90%.

In a study by Sabri *et al.* [9], the relation between MPA and AO was normal in 34% (*n*=17) of all cases and it was increased in 66% (*n*=33) of all cases; the sensitivity, specificity, and PPV of MPA more than 1+MPA/AO more than 1 were 87, 100, and 100%, respectively.

In this study, the presence of this relation in three lobes was seen in 84% (*n*=42) of positive cases; however, this relation was seen only in two lobes in 12% (*n*=6) and in one lobe in 4% (*n*=2) of the cases. The normal artery/bronchus ratio in all lobes was not found in positive cases. However, 60% (*n*=6) of negative cases had normal artery/bronchus ratio in all lobes and 40% (*n*=4) had increased ratio in only one lobe. There was no significant difference between male and female cases, but there was a significant difference between positive and negative cases as regards increased ratio between segmental arteries and bronchi in at least three lobes. In the study conducted by Pérez-Enguix *et al.* [17], they found that the enlargement of the segmental arteries, measured by making a subjective comparison with the size of the adjacent bronchus, occurred in patients with PH. In addition, the study conducted by Devaraj *et al.* [11] suggested that segmental arterial size is a reliable marker of mPAP and in practice the comparison with adjacent bronchus is more convenient.

In this study, MPA more than 29 mm+segmental artery-to-bronchus ratio was greater than 1 : 1 in at least three lobes, and it had a PPV of 100% for the diagnosis of PH, NPV of 41.7%, sensitivity of 72%, and specificity of 100%.

According to Grosse and Grosse [6] and Peña *et al.* [7], PH can be reliably predicted when the CT demonstrated the diameter of the MPA to be greater than 29 mm and the segmental artery-to-bronchus ratio to be greater than 1 : 1 in three of four pulmonary lobes (specificity of 100%) [6,7].

The combinations of three CT criteria for the diagnosis of PH increase the specificity and PPV while decreasing the sensitivity for diagnosis. In this study, the sensitivity, specificity, and PPV of MPA more than

29 with an increase in MPA/AO more than 1 ratio and at least three lobes showed an increased ratio between segmental arteries and neighboring bronchi of 64, 100, and 100%, respectively.

In agreement with our study, Sabri *et al.* [9] stated that the sensitivity, specificity, and PPV of MPA more than 29 with an increase in MPA/AO more than 1 ratio and at least three lobes showed that the increased ratio between segmental arteries and neighboring bronchi were 60, 100, and 100%, respectively.

In this study, PH could be predicted in 94% of cases depending on the measurement of MPA alone, in 97.5% of cases if there is an associated increase in the ratio between MPA and AO, and in 100% of cases if there is an associated increase in the ratio between segmental pulmonary arteries and related bronchi in at least three lobes.

In this study, there was a significant correlation between PASP measured by echocardiography and MPA with a *P* value of 0.005, a significant relation between echocardiography results and the relation between segmental arteries and bronchi with a *P* value of 0.001, and a significant relation with the MPA/AO ratio with a *P* value of 0.001.

In agreement with our results, Sabri *et al.* [9] stated that PH can be predicted in 82% of cases depending on the measurement of MPA alone, in 100% of cases if there is also an associated increase in the relation between MPA and AO (regardless of the age), and in 100% of cases if there is an associated increase in the ratio between segmental pulmonary arteries and bronchi in at least three lobes.

Conclusion

Although right-heart catheterization is the gold standard for the measurement of pulmonary artery pressure, this procedure is not without risk and expense. There is a need for accurate noninvasive tools that can be used appropriately to stratify patients for referral for right-sided heart catheterization. Echocardiography is usually more relied upon to identify PH, although it can also substantially lead to an underestimation or overestimation of systolic pulmonary arterial pressure. MDCT (CTPA or HRCT) can reliably be used, in addition to echocardiography, for the routine evaluation of patients with PH. As a noninvasive test, CT is performed routinely in patients being

investigated for a possible diagnosis of PAH. It also has the potential to provide the first diagnosis of the condition. CT and echocardiography provide complementary information regarding PH.

Recommendations

There is a need for accurate noninvasive tools that can be used appropriately to stratify patients for referral for right-sided heart catheterization. We should be familiar with the different CT signs of PH, especially if we know that the sensitivity and specificity of prediction of PH increases when the different criteria are present at the same time. Further studies are needed to assess the utility of CT in the follow-up and in patients' response to therapy.

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Conflicts of interest

There are no conflicts of interest.

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