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RESEARCH ARTICLE

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The association between pulmonary artery enlargement and mortality in an Emergency Department population undergoing computed tomography pulmonary angiography

Brittany M. Scarpato[1,2] | **Brian W. Locke**[1,2] | **Joseph Bledsoe**[3,4] | **Daniel B. Knox**[2] | **Karen Conner**[5] | **Gregory J. Stoddard**[6] | **Meghan M. Cirulis**[1,2,7] | **Charles Gregory Elliott**[2,7] | **Mark W. Dodson**[2,7]

[1]Division of Pulmonary and Critical Care Medicine, University of Utah, Salt Lake City, Utah, USA

[2]Department of Pulmonary and Critical Care Medicine, Intermountain Medical Center, Murray, Utah, USA

[3]Division of Emergency Medicine, Intermountain Medical Center, Murray, Utah, USA

[4]Department of Emergency Medicine, Stanford Medicine, Stanford, California, USA

[5]Division of Radiology, Intermountain Medical Center, Murray, Utah, USA

[6]Division of Epidemiology, University of Utah, Salt Lake City, Utah, USA

[7]Department of Pulmonary and Critical Care Medicine, Pulmonary Hypertension Care Center, Intermountain Medical Center, Utah, Murray, USA

Correspondence
Brittany M. Scarpato, Division of Pulmonary and Critical Care Medicine, Intermountain Medical Center, 5121 S Cottonwood St. Murray, UT 84107, USA.
Email: Brittany.scarpato@hsc.utah.edu

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Abstract

Findings of an enlarged pulmonary artery diameter (PAd) and increased pulmonary artery to ascending aorta ratio (PA:AA) on contrast-enhanced computed tomography pulmonary angiography (CTPA) are associated with increased mortality in particular groups of patients with cardiopulmonary disease. However, the frequency and prognostic significance of these incidental findings has not been studied in unselected patients evaluated in the Emergency Department (ED). This study aims to determine the prevalence and associated prognosis of enlarged pulmonary artery measurements in an ED cohort. We measured PA and AA diameters on 990 CTPA studies performed in the ED. An enlarged PA diameter was defined as >27 mm in females and >29 mm in males, while an increased PA:AA was defined as >0.9. Poisson regression was performed to calculate prevalence ratios for relevant comorbidities, and multivariable Cox regression was performed to calculate hazard ratios (HR) for mortality of patients with enlarged pulmonary artery measurements. An enlarged PAd was observed in 27.9% of 990 patients and was more commonly observed in older patients and in patients with obesity or heart failure. Conversely, PA:AA was increased in 34.2% of subjects, and was more common in younger patients and those with peripheral vascular disease or obesity. After controlling for age, sex, and comorbidities, both enlarged PAd (HR 1.29, 95% CI 1.00–1.68, $p = 0.05$) and PA:AA (HR 1.70, 95% CI 1.31–2.22 $p < 0.01$) were independently associated with mortality. In sum, enlarged PAd and increased PA:AA are common in patients undergoing CTPAs in the ED setting and both are independently associated with mortality.

KEYWORDS
contrast media, diagnostic techniques and monitoring, epidemiology, imaging, mortality

INTRODUCTION

Enlargement of the pulmonary arteries as detected by contrast-enhanced computed tomography pulmonary angiography (CTPA) provides prognostic information in patients with various forms of cardiopulmonary disease. Enlargement of the pulmonary artery diameter (PAd) or increased ratio of the PAd to aorta diameter (PA:AA) has been associated with increased mortality in patients with chronic obstructive pulmonary disease (COPD),[1,2] interstitial lung disease,[3–5] pulmonary arterial hypertension (PAH),[6,7] chronic thromboembolic pulmonary hypertension (CTEPH),[7,8] chronic systolic heart failure,[9] and severe COVID-19 infection.[10] This is not surprising, as pulmonary artery enlargement on CTPA has been shown to correlate with other better defined assessments of pulmonary hypertension, including echocardiography and right heart catheterization,[11–19] and the presence of pulmonary hypertension is associated with a poor prognosis in many of these conditions.[20–23] However, pulmonary artery enlargement has not been associated with increased mortality in the general population.[2]

Patients who undergo CTPA in the Emergency Department (ED) are often evaluated for cardiorespiratory symptoms. While CTPA studies are most often performed to evaluate for pulmonary embolism (PE), the majority performed in the ED are negative for acute PE.[24] However, these studies may provide other clues to a patient's symptoms. As noted above, pulmonary artery enlargement can be found in association with other known comorbidities like COPD or ILD, or could indicate the presence of an undiagnosed condition, such as PAH.

To date, no studies have addressed the frequency or prognostic significance of PA enlargement detected incidentally in patients undergoing CTPA in the ED, and this knowledge gap limits our ability to interpret the importance of incidental PA enlargement in ED patients. We performed a systematic assessment of PAd and PA:AA in consecutive patients undergoing CTPA in the ED, in whom the CTPA was negative for acute PE, and examined the association of this finding with subsequent mortality risk.

METHODS

Study site and population

The cohort used for this study derives from a previously published cohort of 3500 consecutive patients who underwent CTPA in the EDs of Intermountain Medical Center, a tertiary referral hospital in Murray, Utah, or LDS Hospital, a community hospital in Salt Lake City, Utah, between May 2009 and June 2010.[24] Both hospitals sit at approximately 4300 feet in elevation. Among the 3500 consecutive CTPAs, 340 were interpreted as positive for acute PE; we excluded these patients since PA enlargement in the setting of acute PE could reflect effects of acute PE rather than an underlying condition.

We determined that review of 1000 CTPAs was feasible within the available timeframe for completing the study. Given the use of a binary outcome (mortality) and both categorical and continuous predictors, we based our power analysis on correlation, which can be applied to all studied associations. This sample size provided 80% power to detect a correlation as small as Pearson $r = 0.09$ ($r^2 = 0.008$). Had we increased this to $n = 1500$ patients, we would have had 80% power to detect $r = 0.07$ ($r^2 = 0.005$), indicating that we were at a point of diminishing returns. Therefore, we selected a random sample of 1000 patients with available images out of a possible 3160 patients to achieve a representative sample of scans. Our final n was 990 because some patients had more than one CTPA (Figure 1); the earliest CTPA was assessed in these patients. Follow-up data, including survival through October 2021, were extracted from the electronic

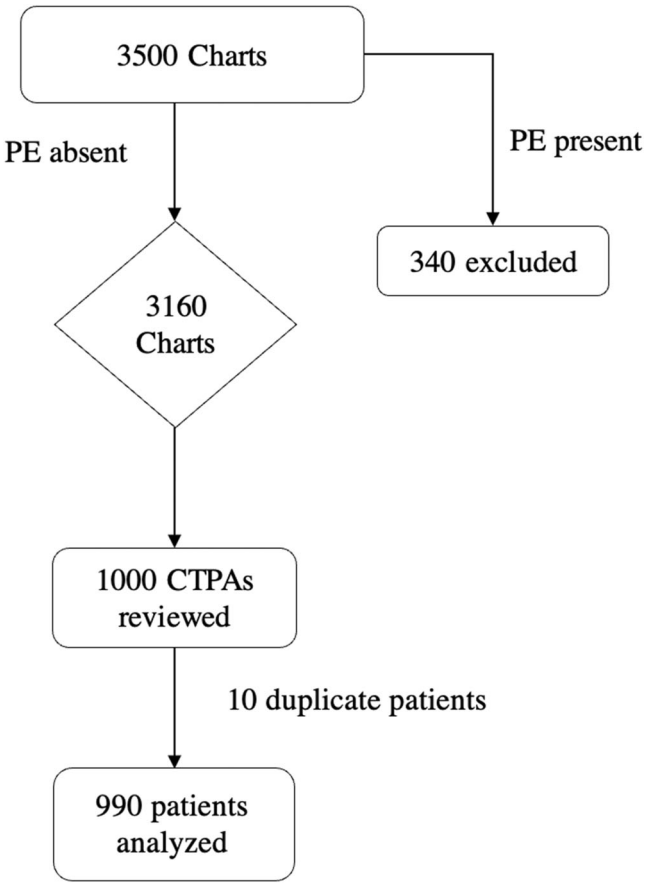

FIGURE 1 Consort diagram. CTPA, computed tomography pulmonary angiography; PE, pulmonary embolism.

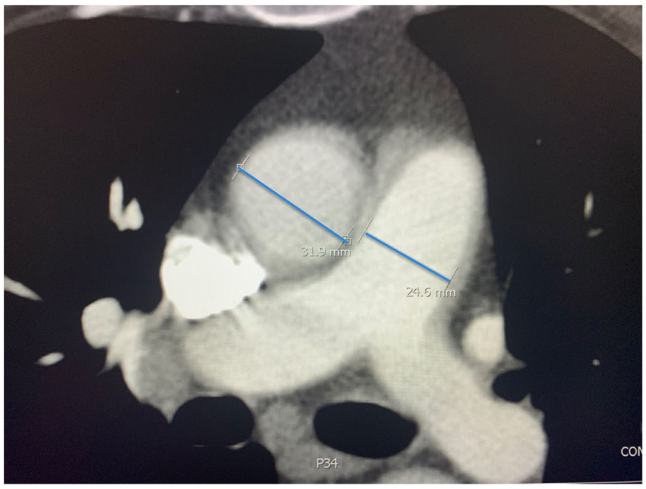

FIGURE 2 Measurement of the pulmonary artery and ascending aorta at the level of left and right pulmonary artery bifurcation on axial computed tomography pulmonary angiography imaging.

health record (EHR). Only comorbidities diagnosed at the time of the index CTPA were included. Mortality data were obtained from Utah State death records.

The Intermountain Medical Center Institutional Review Board approved this study under a waiver of informed consent.

Pulmonary artery measurements

All CTPAs were performed on 65 detector row CT scanners. The pulmonary artery and ascending aorta on all 990 CTPAs were measured manually. These measurements were made at the bifurcation of the left and right pulmonary arteries (Figure 2), as this method has been shown to be highly reproducible.[13] If the left pulmonary artery bifurcated early, the measurement of the main pulmonary artery was made at the right pulmonary artery bifurcation. The ascending aorta was measured at the same level as the pulmonary artery measurement. We defined a normal PAd and PA:AA as values less than the 90th percentile from a healthy referent population from the Framingham cohort: PAd < 27 mm in females, PAd < 29 mm in males, and PA:AA < 0.9 in both males and females.[25]

Statistical analysis

Age and sex were recorded at the time of the CTPA study. Baseline comorbidities are described based on Elixhauser comorbidity data using ICD coding algorithms, which were extracted from the EHR at the time of the CTPA study in 947 of the patients (Supporting Information: Table 1).[26] Obesity status was determined either by a documented body mass index (BMI) > 30 within 1 year of the index study or from an ICD-9 code. Length of follow-up was determined based on the last date of follow-up in the EHR, with an absolute cutoff date of October 1, 2021. Follow-up encounters that were captured by our EHR search included outpatient visits, ED visits, hospitalizations, and death records.

Independent group t tests were used to compare continuous variables, and χ^2 tests were used to compare categorical variables between those with and without increased pulmonary artery measurements. Poisson regression with robust standard errors[27] was used to estimate the prevalence ratio (PR) of enlarged PAd and increased PA:AA while adjusting for potential confounding variables.

Only patients with follow-up after the index study were included in Cox regression models ($n = 912$ patients with follow-up, $n = 889$ patients with comorbidities and follow-up). Stratified (by decade of age) proportional hazards regression models were fit to compare mortality rates in patients with normal PA:AA to those with increased PA:AA, and to compare patients with normal PAd to increased PAd. Unadjusted hazard ratios (HRs) are presented. However, there would be limited scientific value or clinical use if PA size were associated with death only as a surrogate for age or sex. Therefore, models adjusting for age and sex (Model 1) and additionally controlling for potential confounding conditions (Model 2) were analyzed. For both the Poisson regressions and proportional hazards regressions, potential confounding variables were included in the adjusted models if they had biologic plausibility as confounders,[28] had $p < 0.20$,[29] or changed the HR >10% for the primary predictor variable after including the covariate in the model.[29,30]

All analyses were performed in Stata 16.1 (Stata Corp.). $p < 0.05$ were considered statistically significant.

RESULTS

The median age of patients in the cohort was 52 years (interquartile range [IQR] 37–67), and 62.6% of the 990 subjects included were female (Table 1). The most common indications for CTPAs were chest or back pain (690/990, 70%) and dyspnea (457/990, 46%). Comorbidities were common, including systemic hypertension and pulmonary disease in greater than 50% of subjects (Table 1). The overall cohort median PAd was 25.2 mm (IQR 22.5–28.2), and PA:AA ratio was 0.85 (IQR 0.76–0.93). Using the sex-specific 90th percentile cut off from the healthy referent population in the Framingham

TABLE 1 Baseline characteristics in patients with normal and increased pulmonary artery diameter and pulmonary aorta to ascending aorta ratio.

	Entire cohort ($N = 947$)	Normal pad ($N = 678$)	Increased pad ($N = 269$)	p Value[a]	Normal PA:AA ($N = 631$)	Increased PA:AA ($N = 316$)	p Value[a]
Age (years), median (IQR)[b]	52 (37–67)	48 (34–63)	62 (46–76)	<0.01	55 (42–69)	42 (30–61)	<0.01
Male[b]	370 (37.4%)	265 (37.1%)	105 (38.0%)	0.79	250 (38.4%)	120 (35.4%)	0.35
Obesity	330 (34.6%)	205 (30.0%)	125 (46.3%)	<0.01	198 (31.2%)	132 (41.4%)	<0.01
Hypertension	518 (54.7%)	341 (50.3%)	177 (65.8%)	<0.01	364 (57.7%)	154 (48.7%)	0.02
Diabetes	229 (24.2%)	132 (19.4%)	97 (36.1%)	<0.01	153 (24.2%)	76 (24.05%)	0.85
Heart failure	170 (18.0%)	82 (12.1%)	88 (32.7%)	<0.01	117 (18.5%)	53 (16.8%)	0.50
Pulmonary disease	483 (51.0%)	329 (48.5%)	154 (57.3%)	0.02	321 (50.9%)	162 (51.3%)	0.91
Pulmonary circulation disorders[c]	143 (15.1%)	89 (13.1%)	54 (20.1%)	<0.01	92 (14.6%)	51 (16.1%)	0.53
Peripheral vascular disease	103 (10.9%)	54 (8.0%)	49 (18.2%)	<0.01	65 (10.3%)	38 (12.0%)	0.42
Renal failure	61 (16.4%)	30 (4.4%)	31 (11.5%)	<0.01	43 (6.8%)	18 (5.7%)	0.51

Abbreviations: IQR, interquartile range; PA:AA, pulmonary artery to ascending aorta ratio; PAd, pulmonary artery diameter.

[a]p Values compare groups with normal measurements versus increased measurements.

[b]990 patients included in analysis of age and sex.

[c]ICD code breakdown of pulmonary circulation disorders (Supporting Information: Table 2).

cohort, we found that PAd was enlarged in 28.4% of males and 27.6% of females, while PA:AA ratio was increased in 32.4% of males and 35.3% of females. 60.5% of patients with an enlarged PAd had an increased PA:AA and 49.3% of patients with an increased PA:AA had an enlarged PAd. There was no difference in rates of overlap by sex.

Patients with an enlarged PAd were older (median age 62 years, IQR 46–76) than those with a normal PAd (median age 48 years, IQR 34–63, $p < 0.01$), and were more likely to have any of the comorbidities included in our analysis, including hypertension, heart failure, pulmonary disease, and renal disease (Table 1). Conversely, patients with an increased PA:AA tended to be younger (median age 42 years, IQR 30–61) than those with a normal PA:AA (median age 55 years, IQR 42–69, $p < 0.01$). AA diameter increased more with age (mean 0.13 mm per 1-year increase) than PAd (mean 0.06 mm per 1-year increase in age). Those with increased PA:AA were more commonly obese ($p < 0.01$), and less commonly had hypertension ($p = 0.02$). No other significant differences in the frequencies of other comorbidities were observed in those with normal versus increased PA:AA.

We used Poisson regression to calculate PRs for increased PAd and increased PA:AA after controlling for other covariates. In these analyses, older patient age and the presence of obesity and heart failure were predictors of increased PAd (Table 2). Conversely, younger patient age predicted increased PA:AA ratio, as did the presence of peripheral vascular disease or obesity (Table 2).

There were 263 deaths (26.6%) in the overall cohort over a mean of 7.1 years of patient follow-up. The unadjusted frequency of all-cause mortality was nearly twice as high in those with increased PAd (40.9%) compared with those with normal PAd (21.0%; $p < 0.01$). The same was not observed for increased PA:AA, in which the frequency of all-cause mortality was equivalent between those with increased (26.8%) compared with normal PA:AA (26.4%; $p = 0.89$). The median time from the index CTPA to death was 3.53 years (IQR 1.26–6.20) for patients with enlarged PAd, 3.28 years (IQR 1.04–6.15) for patients with an increased PA:AA, and 3.55 years (1.15–6.57 years) for the entire cohort.

In the Cox regression analysis accounting for age and sex, both enlarged PAd (HR 1.48, 95% CI 1.15–1.90, $p < 0.01$) and increased PA:AA (HR 1.77, 95% CI 1.36–2.30, $p < 0.01$) were associated with increased risk of death (Figure 3). After further accounting for possible confounding comorbidities, both PAd and PA:AA remained independently associated with mortality (HR 1.29, 95% CI 1.00–1.68, $p = 0.05$ and HR 1.70, 95% CI 1.31–2.22, $p < 0.01$, respectively).

TABLE 2 Prevalence ratios of increased pulmonary artery measurements after adjusting for comorbidities.

	Increased PAd, PR (95% CI)	*p* Value	Increased PA:AA, PR (95% CI)	*p* Value
Age	1.02 (1.01–1.02)	<0.01	0.98 (0.98–0.99)	<0.01
Male	0.99 (0.81–1.21)	0.95	0.89 (0.74–1.07)	0.24
Obesity	1.65 (1.33–2.05)	<0.01	1.29 (1.06–1.56)	0.01
Hypertension	0.82 (0.63–1.06)	0.13	0.97 (0.77–1.21)	0.76
Diabetes				
Uncomplicated	1.27 (1.00–1.59)	0.05	1.07 (0.82–1.40)	0.61
Complicated	1.12 (0.82–1.55)	0.48	0.91 (0.62–1.33)	0.62
Heart failure	1.44 (1.14–1.83)	<0.01	1.10 (0.82–1.48)	0.51
Pulmonary disease	1.01 (0.83–1.25)	0.89	1.00 (0.83–1.20)	0.98
Pulmonary circulation disorders	1.07 (0.83–1.37)	0.62	1.02 (0.80–1.31)	0.86
Peripheral vascular disease	1.15 (0.90–1.48)	0.55	1.52 (1.13–2.04)	<0.01
Renal failure	1.28 (0.95–1.74)	0.11	0.97 (0.65–1.45)	0.89

Abbreviations: CI, confidence interval; PA:AA, pulmonary artery to ascending aorta ratio; PAd, pulmonary artery diameter; PR, prevalence ratio.

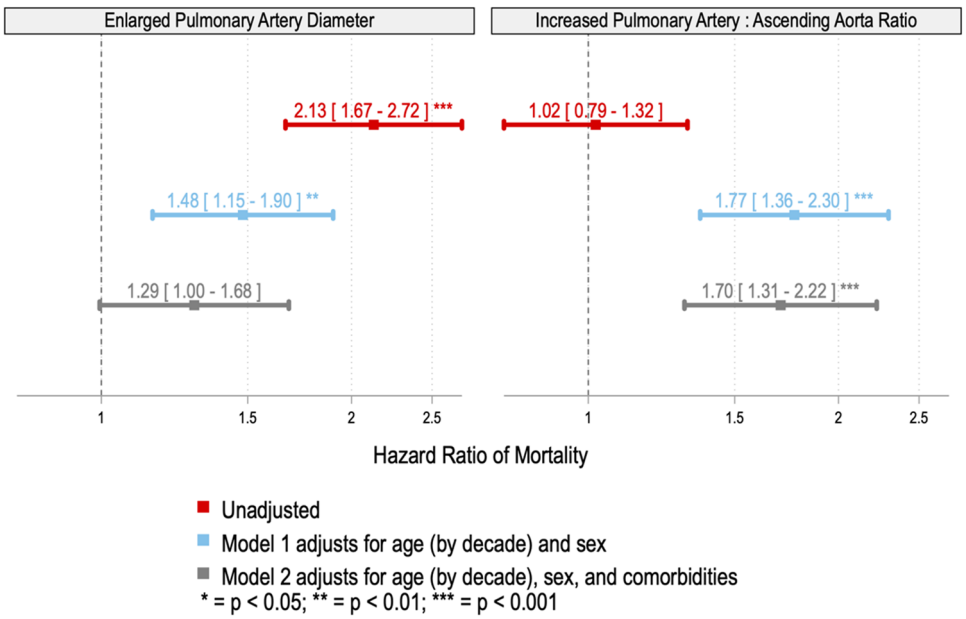

FIGURE 3 Unadjusted and adjusted hazard ratios of the association between increased pulmonary artery measurements and mortality. An enlarged pulmonary artery diameter is defined as greater than 27 mm in females and greater than 29 mm in males. An increased pulmonary artery to ascending aorta ratio is >0.9 in both sexes. In Model 2, the comorbidities included in the proportional hazards model are obesity, diabetes, renal failure, peripheral vascular disease, heart failure, pulmonary vascular disease (defined in Supporting Information: Table 2), and pulmonary disease.

DISCUSSION

In this study, we show that both an enlarged PAd and increased PA:AA ratio are common incidental observations in a population of patients who underwent CTPA in the ED, and that patients with these findings are at increased mortality risk compared with patients of similar age and sex with normal PA size. We find that increased PAd occurs more commonly in patients who are older and have more comorbidities, while increased PA:AA selects a group of younger individuals. Prior studies have demonstrated an association between PA

enlargement and mortality risk among patients with specific cardiopulmonary comorbidities, including COPD,[1] IPF,[4] PAH,[6,7] and systolic heart failure,[9] but have failed to identify an association between PA enlargement and mortality risk in other populations.[2] Our study is the first to report on the long-term prognosis of PA enlargement detected incidentally in an ED population undergoing CTPA and suggests that an enlarged PA by either criterion is a relevant finding that identifies a population at increased risk of death.

This study was designed to consider both PAd and PA:AA ratio separately, as we did not know a priori which would be a more important indicator of outcome. In the assessment of healthy individuals in the Framingham cohort that formed the basis for the current normative ranges, PAd did not increase with age. However, in that study, age was associated with increasing PAd in individuals with comorbidities.[25] Thus, PAd may function as an indicator of cumulative comorbidity. We also find that age and all of the comorbidities included in our analysis are associated with higher likelihood of increased PAd. However, the increased risk of death among those with enlarged PAd persisted even after comorbidity adjustment, which suggests that the finding of an enlarged PAd adds prognostic information beyond the comorbidities known at the time of assessment.

Using a ratio of 0.9 to define an abnormal PA:AA ratio was initially suggested by Truong and colleagues based on an investigation of healthy patients in the Framingham cohort, and has gained widespread use.[25] However, in both the initial Framingham cohort and a separate investigation in Korea,[31] PA:AA decreased with age due to a greater increase in AA diameter as individuals age. If the normal PA:AA declines with age and a fixed cutoff is used, one would expect younger individuals to be classified as abnormal more frequently. In support of this theory, we found that patients with increased PA:AA were younger than patients with normal PA:AA and younger than patients with increased PAd. Therefore, age-specific normal values for PA:AA might improve classification accuracy.

Consistent with age confounding the relationship between PA:AA and mortality, an increased PA:AA was not associated with increased mortality in the unadjusted analysis but was strongly associated with increased mortality after adjusting for age, with or without additional adjustment for the presence of comorbidities. We demonstrate that PAd increases with the presence of multiple comorbid conditions, and others have previously shown that the same is true of the diameter of the ascending aorta.[32–35] Because the PA:AA ratio accounts for enlargement of both the PAd and AA, the net effect is that comorbidities have much less of an effect on PA:AA ratio than on either PAd or AA diameter in isolation. Thus, patients with enlarged PAd versus patients with increased PA:AA have different patterns of comorbid conditions, with far fewer comorbidities seen in those with increased PA:AA. A key finding of this study, however, is that both increased PAd and elevated PA:AA are independently associated with risk of death, despite identifying patients who differ significantly in terms of age and comorbid conditions.

We postulate that increased pulmonary artery size by either metric is likely an indirect indicator of disease rather than a direct cause of death because pulmonary artery dissection or myocardial infarction due to compression of a coronary artery by an enlarged pulmonary artery are rare. Therefore, a finding of an enlarged PAd or PA:AA might have at least two different uses. First, PA size might be useful to predict the risk of death as a surrogate for disease duration and severity in those with known conditions that increase PA size, such as pulmonary hypertension. Second, an incidental finding might be useful to identify patients who have undiagnosed diseases that cause pulmonary artery enlargement. While prior cohorts with systematic assessment of patient comorbidities have suggested PA size indices are helpful in the first case, one strength of the current study is that the presence or absence of comorbidities reflects whether clinicians have identified these conditions in routine care. Thus, the continued association with risk of death after adjustment for recognized comorbidities suggests this measurement can add predictive value to the diagnoses a patient has received.

The frequencies of increased PAd and PA:AA that we report in our cohort are significantly higher than what had previously been reported in the Framingham cohort;[25] however, several important differences in our patient population likely contribute to this difference. First, our cohort had more baseline comorbidities than those described in the Framingham cohort, and the presence of any of the comorbidities that we analyzed was associated with enlarged PAd. Second, our cohort was drawn from an ED population. Although we excluded patients with PE present on CTPA, this population is likely highly enriched for patients with cardiorespiratory symptoms. Third, the hospitals in which the CTPAs for our study were performed are situated at approximately 4300 feet above sea level. While it is unknown how altitude influences PA diameter, it is conceivable that PA enlargement may be more common at higher elevation due to pulmonary hypertension caused by alveolar hypoxia.

In summary, we find that increased PAd and increased PA:AA are common incidental findings on CTPAs of ED patients. Enlarged PAd and increased

PA:AA have prognostic significance for ED patients undergoing CTPA that has not been described previously. These findings extend the results of prior investigations in other care settings and suggest that patients with enlarged pulmonary arteries may benefit from systematic outpatient assessment for relevant comorbidities.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS STATEMENT

The Intermountain Medical Center Institutional Review Board approved this study under a waiver of informed consent. The paper reflects the authors' research and analysis with appropriate credit attributed to co-authors.

ORCID

Brittany M. Scarpato http://orcid.org/0000-0001-6671-221X
Gregory J. Stoddard http://orcid.org/0000-0002-6292-276X
Mark W. Dodson http://orcid.org/0000-0002-4709-1048

REFERENCES

1. LaFon DC, Bhatt SP, Labaki WW, Rahaghi FN, Moll M, Bowler RP, Regan EA, Make BJ, Crapo JD, San Jose Estepar R, Diaz AA, Silverman EK, Han MK, Hobbs B, Cho MH, Washko GR, Dransfield MT, Wells JM. Pulmonary artery enlargement and mortality risk in moderate to severe COPD: results from COPDGene. Eur Respir J. 2020;55(2):1901812.
2. Terzikhan N, Bos D, Lahousse L, Wolff L, Verhamme KMC, Leening MJG, Felix JF, Gall H, Ghofrani HA, Franco OH, Ikram MA, Stricker BH, van der Lugt A, Brusselle G. Pulmonary artery to aorta ratio and risk of all-cause mortality in the general population: the Rotterdam Study. Eur Respir J. 2017;49(6):1602168.
3. Choi JS, Lee SH, Leem AY, Song JH, Chung KS, Jung JY, Kang YA, Park MS, Kim YS, Chang J, Kim SY. Prognostic impact of the ratio of the main pulmonary artery to that of the aorta on chest computed tomography in patients with idiopathic pulmonary fibrosis. BMC Pulm Med. 2019;19(1):81.
4. Shin S, King CS, Puri N, Shlobin OA, Brown AW, Ahmad S, Weir NA, Nathan SD. Pulmonary artery size as a predictor of outcomes in idiopathic pulmonary fibrosis. Eur Respir J. 2016;47(5):1445–51.
5. Kogo M, Otsuka K, Morimoto T, Nagata K, Nakagawa A, Tomii K. Pulmonary artery enlargement predicts poor outcome during acute exacerbations of fibrotic interstitial lung disease. Respirology. 2019;24:777–82.
6. Truong QA, Bhatia HS, Szymonifka J, Zhou Q, Lavender Z, Waxman AB, Semigran MJ, Malhotra R. A four-tier classification system of pulmonary artery metrics on computed tomography for the diagnosis and prognosis of pulmonary hypertension. J Cardiovasc Comput Tomogr. 2018;12(1):60–6.
7. Żyłkowska J, Kurzyna M, Florczyk M, Burakowska B, Grzegorczyk F, Burakowski J, Wieteska M, Oniszh K, Biederman A, Wawrzyńska L, Szturmowicz M, Fijałkowska A, Torbicki A. Pulmonary artery dilatation correlates with the risk of unexpected death in chronic arterial or thromboembolic pulmonary. Chest. 2012;142(6):1406–16.
8. Ema R, Sugiura T, Kawata N, Tanabe N, Kasai H, Nishimura R, Jujo T, Shigeta A, Sakao S, Tatsumi K. The dilatation of main pulmonary artery and right ventricle observed by enhanced chest computed tomography predict poor outcome in inoperable chronic thromboembolic pulmonary hypertension. Eur J Radiol. 2017;94:70–7.
9. Colin GC, Gerber BL, de Meester de Ravenstein C, Byl D, Dietz A, Kamga M, Pasquet A, Vancraeynest D, Vanoverschelde JL, D'Hondt AM, Ghaye B, Pouleur AC. Pulmonary hypertension due to left heart disease: diagnostic and prognostic value of CT in chronic systolic heart failure. Eur Radiol. 2018;28(11):4643–53.
10. Zhu QQ, Gong T, Huang GQ, Niu ZF, Yue T, Xu FY, Chen C, Wang GB. Pulmonary artery trunk enlargement on admission as a predictor of mortality in in-hospital patients with COVID-19. Jpn J Radiol. 2021;39(6):589–97.
11. Ng CS, Wells AU, Padley SPG. A CT sign of chronic pulmonary arterial hypertension: the ratio of main pulmonary artery to aortic diameter. J Thorac Imaging. 1999;14:270–8.
12. Iyer AS, Wells JM, Vishin S, Bhatt SP, Wille KM, Dransfield MT. CT scan-measured pulmonary artery to aorta ratio and echocardiography for detecting pulmonary hypertension in severe COPD. Chest. 2014;145(4):824–32.
13. Mahammedi A, Oshmyansky A, Hassoun PM, Thiemann DR, Siegelman SS. Pulmonary artery measurements in pulmonary hypertension. J Thorac Imaging. 2013;28(2):96–103.
14. Raymond TE, Khabbaza JE, Yadav R, Tonelli AR. Significance of main pulmonary artery dilation on imaging studies. Ann Am Thorac Soc. 2014;11(10):1623–32.
15. Tan RT, Kuzo R, Goodman LR, Siegel R, Haasler GR, Presberg KW. Utility of CT scan evaluation for predicting pulmonary hypertension in patients with parenchymal lung disease. Chest. 1998;113(5):1250–6.
16. Kuriyama K, Gamsu G, Stern RG, Cann CE, Herfkens RJ, Brundage BH. CT-determined pulmonary artery diameters in predicting pulmonary hypertension. Invest Radiol. 1984;19(1):16–22.
17. Terpenning S, Deng M, Hong-Zohlman SN, Lin CT, Kligerman SJ, Jeudy J, Ketai LH. CT measurement of central pulmonary arteries to diagnose pulmonary hypertension (PHTN): more reliable than valid? Clin Imaging. 2016;40(4):821–7.
18. Lewis G, Hoey ET, Reynolds JH, Ganeshan A, Ment J. Multidetector CT assessment in pulmonary hypertension: techniques, systematic approach to interpretation and key findings. Quant Imaging Med Surg. 2015;5(3):423–32.
19. Remy-Jardin M, Ryerson CJ, Schiebler ML, Leung ANC, Wild JM, Hoeper MM, Alderson PO, Goodman LR, Mayo J,

Haramati LB, Ohno Y, Thistlethwaite P, van Beek EJR, Knight SL, Lynch DA, Rubin GD, Humbert M. Imaging of pulmonary hypertension in adults: a position paper from the Fleischner Society. Eur Respir J. 2021;57(1):2004455.
20. Lam CSP, Roger VL, Rodeheffer RJ, Borlaug BA, Enders FT, Redfield MM. Pulmonary hypertension in heart failure with preserved ejection fraction. J Am Coll Cardiol. 2009;53(13):1119–26.
21. Gredic M, Blanco I, Kovacs G, Helyes Z, Ferdinandy P, Olschewski H, Barberà JA, Weissmann N. Pulmonary hypertension in chronic obstructive pulmonary disease. Br J Pharmacol. 2021;178(1):132–51.
22. Mise J, Moriyama K, Itagaki S. Clinical course and prognosis of chronic pulmonary emphysema with special reference to pulmonary circulatory disturbance. Jpn Heart J. 1966;7(1):45–55.
23. Alhamad EH, Cal JG, Alrajhi NN, Alharbi WM. Predictors of mortality in patients with interstitial lung disease-associated pulmonary hypertension. J Clin Med. 2020;9(12):3828.
24. Adams DM, Stevens SM, Woller SC, Evans RS, Lloyd JF, Snow GL, Allen TL, Bledsoe JR, Brown LM, Blagev DP, Lovelace TD, Shill TL, Conner KE, Aston VT, Elliott CG. Adherence to PIOPED II investigators' recommendations for computed tomography pulmonary angiography. Am J Med. 2013;126(1):36–42.
25. Truong QA, Massaro JM, Rogers IS, Mahabadi AA, Kriegel MF, Fox CS, O'Donnell CJ, Hoffmann U. Reference values for normal pulmonary artery dimensions by noncontrast cardiac computed tomography. Circ Cardiovasc imaging. 2012;5(1):147–54.
26. Quan H, Sundararajan V, Halfon P, Fong A, Burnand B, Luthi JC, Saunders LD, Beck CA, Feasby TE, Ghali WA. Coding algorithms for defining comorbidities in ICD-9-CM and ICD-10 administrative data. Med Care. 2005;43(11):1130–9.
27. Zou G. A modified poisson regression approach to prospective studies with binary data. Am J Epidemiol. 2004;159(7):702–6.
28. Chowdhury MZI, Turin TC. Variable selection strategies and its importance in clinical prediction modelling. Fam Med Community Health. 2020;8(1):e000262.
29. Maldonado G, Greenland S. Simulation study of confounder-selection strategies. Am J Epidemiol. 1993;138(11):923–36.
30. Greenland S. Modeling and variable selection in epidemiologic analysis. Am J Public Health. 1989;79(3):340–9.
31. Lee SH, Kim YJ, Lee HJ, Kim HY, Kang YA, Park MS, Kim YS, Kim SK, Chang J, Jung JY. Comparison of CT-determined pulmonary artery diameter, aortic diameter, and their ratio in healthy and diverse clinical conditions. PLoS One. 2015;10(5):e0126646.
32. Sawabe M, Hamamatsu A, Chida K, Naka Mieno M, Ozawa T. Age is a major pathobiological determinant of aortic dilatation: a large autopsy study of community deaths. J Atheroscler Thromb. 2011;18(2):157–65.
33. Komutrattananont P, Mahakkanukrauh P, Das S. Morphology of the human aorta and age-related changes: anatomical facts. Anat Cell Biol. 2019;52(2):109–14.
34. Martin C, Sun W, Primiano C, McKay R, Elefteriades J. Age-dependent ascending aorta mechanics assessed through multiphase CT. Ann Biomed Eng. 2013;41(12):2565–74.
35. Hager A, Kaemmerer H, Rapp-Bernhardt U, Blücher S, Rapp K, Bernhardt TM, Galanski M, Hess J. Diameters of the thoracic aorta throughout life as measured with helical computed tomography. J Thorac Cardiovasc Surg. 2002;123(6):1060–6.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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