Chest X-Ray to Predict Difficult Right Transradial Cardiac Catheterization Due to Vascular Tortuosity: A Retrospective Study

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Abstract: Tortuous brachiocephalic artery may lead to procedural difficulties among patients undergoing right transradial cardiac catheterization. By prospectively identifying patients with this anatomic barrier, operators may choose an alternate catheterization site to avoid complications from switching midway. To assess brachiocephalic artery tortuosity, 23 patients who underwent challenging diagnostic coronary angiography by right transradial access were compared to a control group of 29 patients who lacked brachiocephalic artery tortuosity. Preprocedural, plain chest x-rays were analyzed for measurable anatomic parameters and assessed for statistical significance between groups. The vertebrocarinal distance—the distance in centimeters between the spinous process of the first thoracic vertebra (T1) and the most caudal point of tracheal bifurcation, measured at and parallel to the midline—was the most reliable and statistically significant

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radiographic predictor of brachiocephalic artery tortuosity. Using this novel concept reduces procedure duration and radiation exposure by decreasing transradial cardiac catheterization failure rates. (Curr Probl Cardiol 2021;46:100471.)

Introduction

Coronary angiography is regarded as the gold-standard tool to detect coronary heart disease.[1] While the transfemoral approach has traditionally been used, right transradial access-site has become increasingly common[2] since Lucien Campeau's groundbreaking trial in 1989.[3,4] Subsequent studies on transradial access have demonstrated clear benefits over transfemoral access, including decreased access-site bleeding, fewer ischemic events, earlier ambulation, shorter hospital stays, and decreased morbidity.[2-9] Furthermore, the radial artery at its puncture site is relatively separate from major veins and nerves, allowing for easier access compared to the compact neurovascular bundle of the groin.[10,11] For these reasons, patients and physicians alike, prefer a transradial cardiac catheterization procedure, over a traditional transfemoral one.[4,12] In performing coronary angiography through the transradial approach, there is a preference for right-radial artery access.[9,13] This is due, in part, to operator experience as well as to the ease of procedural execution with the standard operating table setup.[9,13] However, a key disadvantage of the right transradial approach is the possibility experiencing procedural difficulties secondary to a tortuous brachiocephalic (innominate) artery.[9,12,14] Failure to advance the catheter beyond the point of tortuosity usually forces a switch to the transfemoral access site.[2] This increases the possibility of complications[2] for patients by adding a second, and potentially riskier access site. In considering the recent skepticism with right transradial artery access, this study seeks to predict brachiocephalic artery tortuosity through predictors from precatheterization chest x-rays to better advise access site choice prior to commencing cardiac catheterization.

Methods

This study is a systematic, retrospective review of 56 patients who underwent diagnostic coronary angiography between April 2015 and October 2016 at the University of Tennessee Health Science Center in Memphis, TN. These patients were organized into a dedicated registry, of which a subset of 27 patients was identified as having a tortuous right

brachiocephalic artery on procedural fluoroscopy. When the guidewire or diagnostic catheter either failed to advance or formed a loop due to right brachiocephalic artery kinking, catheter turnability was adversely affected.

Exclusion criteria were either lack of preoperative chest x-ray ($n = 2$), or poor-quality chest films ($n = 2$). The remaining 23 patients comprised the study group. A control group was formed from 29 age- and sex-matched patients who had no tortuosity of the brachiocephalic artery, as evident by ease of steering and straight course of the diagnostic catheter through the brachiocephalic artery. Both the study and the control groups were identified by retrospective analysis of procedural cardiac catheterization imaging with fluoroscopy. Patients in the study and control group were further categorized according to their sex. This was done to account for natural differences in physical and anatomical parameters between males and females.

Through extensive chart review, pertinent clinical data was aggregated on different demographic parameters, including age, height (in inches), weight (in pounds), body mass index, and total body surface area, as shown in Table 1. Anteroposterior or posteroanterior chest x-ray films performed prior to catheterization were analyzed for certain anatomical parameters, as illustrated in Figure 1. Those anatomical parameters measured distances (in centimeters) and angles (in degrees). Measurements were obtained using digital calipers integrated within the institution's Picture Archiving and Communication System software. The anatomic parameters derived from analysis of chest films are summarized in Table 2.

Using R (statistical analysis computing software), demographic, and anatomic parameters for the study- and matched control- groups were analyzed and compared using a student's *t*-test. The results were stratified by sex. Next, a stepwise logistic regression was used to select a variable subset that best predicts transradial cardiac catheterization difficulty. Backward selection with AIC (Akaike Information Criterion) was used to balance model fit and complexity. Finally, histograms and dot plots were created to highlight outliers. A professional statistician consulting within the University of Tennessee Health Science Center performed statistical analysis.

Results

We used *t*-tests to compare 9 parameters in the study and control groups. Five were derived from patient demographic information, namely age, weight, height, body mass index, and body surface area. The other 4 were anatomic parameters measured on preprocedural chest radiography: width of bony thorax at the level of the first rib, width of bony thorax at

TABLE 1. Patient demographics based on sex.

Patient demographics based on sex				
Baseline characteristics	**Male patients**		**Female patients**	
	Study group (n = 9)	**Control group (n = 12)**	**Study group (n = 14)**	**Control group (n = 17)**
Age	51.3 ± 13.6	56.4 ± 10.6	57.5 ± 10.3	57.1 ± 8.2
Height (inches)	68 ± 2.3	70 ± 2.5	63 ± 2.7	64 ± 2.4
Weight (pounds)	226 ± 35.4	227.6 ± 69.1	196.6 ± 35.8	198.4 ± 48.8
Chronic diseases				
Hypertension	8 (88.9%)	11 (91.7%)	11 (78.6%)	15 (88.2%)
Diabetes mellitus	4 (44.4%)	5 (41.7%)	8 (57.1%)	9 (52.9%)
Heart failure	3 (33.3%)	6 (50%)	9 (64.3%)	5 (29.4%)
Peripheral vascular disease	0	1 (8.3%)	2 (14.3%)	1 (5.9%)
Current smokers	4 (44.4%)	7 (58.3%)	5 (35.7%)	6 (35.3%)
History of myocardial infarction	1 (11.1%)	1 (8.3%)	5 (35.7%)	0
History of procedures				
CABG	2 (22.2%)	0	0	0
PCI	4 (44.4%)	3 (25%)	4 (28.6%)	3 (17.6%)
Medications				
Aspirin	9 (100%)	11 (91.7%)	11 (78.6%)	7 (41.2%)
Plavix	3 (33.3%)	3 (25%)	5 (35.7%)	3 (17.6%)
Statins	8 (88.9%)	10 (83.3%)	12 (85.7%)	7 (41.2%)
B-Blockers	8 (88.9%)	11 (91.7%)	14 (100%)	8 (47.1%)
ACEI/ARB*	3 (33.3%)	7 (58.3%)	10 (71.4%)	8 (47.1%)
Nitrates	5 (55.6%)	3 (25%)	3 (21.4%)	3 (17.6%)
Calcium Channel Blockers	2 (22.2%)	7 (58.3%)	1 (7.1%)	6 (35.3%)

CABG, coronary artery bypass graft; PCI, percutaneous coronary intervention; ACEI, angiotensin-converting-enzyme inhibitor); ARB, Angiotensin II receptor blocker.

the level of the carina, vertebrocarinal distance (VCD), and maximum angle of the right first rib to midline. These are shown in Table 2. VCD is defined as the distance in centimeters between the spinous process of the first thoracic vertebra (T1) and the most caudal point of tracheal bifurcation, measured at and parallel to the midline. VCD was found to be the most statistically significant anatomical parameter, with a mean distance of 9.2 cm in the study group of patients with tortuous brachiocephalic artery during right transradial cardiac catheterization, compared to 11.31 cm in the control group ($P < 0.0001$; confidence interval [CI] −2.83 to −1.34). VCD has also been found to vary according to sex, with a mean distance of 9.7 cm in the subset of males in the study group with tortuous brachiocephalic artery, compared to 12 cm in the subset of males in the control group without tortuous brachiocephalic artery ($P < 0.0001$; CI −3.56 to −1.15). The same observation was also found in females in the study group; with mean VCD of 8.97 cm in those with tortuous brachiocephalic artery, compared with a mean VCD of 10.88 cm in female

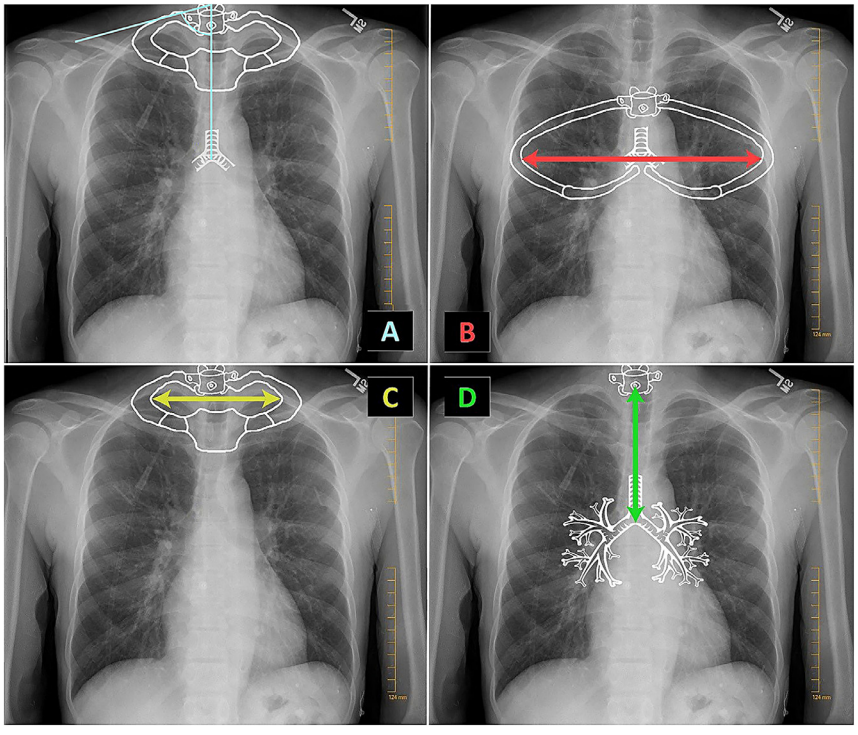

FIG 1. Typical chest x-rays showing the anatomic parameters studied. Anatomical parameters as identified on chest x-ray plain film. (A) Right second rib angle. (B) Width of the thoracic cavity at the level of the Carina. (C) Width of the thoracic cavity at the level of the first rib. (D) Vertebrocarinal Distance (VCD).

patients without brachiocephalic artery tortuosity ($P < 0.0001$; CI −2.82 to −1.01).

Body height was marginally statistically significant demographic parameter as well, with a mean of 163 cm (5'4") in the study group of patients with brachiocephalic artery tortuosity, compared to 168 cm (5'6") in the control group ($P = 0.041$; CI −0.100 to −0.002). When analyzing a subset population based on sex, only the male subset of patients with easy transradial cardiac catheterization remained statistically significant, with a mean body height of 171 cm (5'7") in males with brachiocephalic artery tortuosity, compared to a mean body height of 177 cm (5'10") in males without brachiocephalic artery tortuosity ($P = 0.031$; CI −0.14 to −0.01), as shown in Table 3. There was no statistical significance in the remaining 7 parameters (age, weight, body mass index, body surface area, width of bony thorax at the level of first rib and carina, and maximum angle of the right first rib to midline) (Table 3).

TABLE 2. Anatomical parameters from chest x-ray landmarks and their respective definitions.

Anatomical parameters from chest x-ray landmarks and their respective definitions	
Chest X-ray anatomical parameter	**Definition**
Right second rib angle	Using the T1 vertebral spinous process as the vertex, it is the angle (in degrees) formed between one ray extending down the midline and another ray tangentially touching the outer border of the right first rib.
Width of the thoracic cavity at the level of the carina	Distance (in centimeters) measured between inner borders of bilateral thoracic ribs at the level of the carina, perpendicular to the midline.
Width of the thoracic cavity at the level of first rib	Distance (in centimeters) measured between inner borders of bilateral first ribs, perpendicular to the midline.
Vertebrocarinal distance (VCD)	Distance (in centimeters) between the spinous process of the first thoracic vertebra (T1) to the most caudal point of tracheal bifurcation, measured at and parallel to the midline.

AIC score balanced the model fit and complexity. After inputting all variables with $P < 0.2$, items were removed if they reduced the AIC score. The final model included sex and VCD. The corresponding receiver operating characteristic curve had an area under the curve of 0.88 (95% CI 0.77-0.96), as shown in Figure 2. The confidence intervals were obtained using 2000 stratified bootstrap samples. A model with just VCD had area under the receiver operating characteristic curve of 0.86 (95% CI 0.76-0.95), as shown in Figure 3. The CIs were also obtained using 2000 stratified bootstrap samples. This indicates that it is possible to use VCD alone to identify with reasonable accuracy those patients who will have difficult right transradial catheterization.

Difficulty of transradial cardiac catheterization due to tortuosity in the brachiocephalic artery has also been examined by constructing dot charts. As illustrated in Figures 4 and 5, a VCD of 11 cm in men and 9 cm in women is a reasonably accurate cutoff to distinguish between those with and without brachiocephalic artery tortuosity, hence predicting difficulty of right transradial cardiac catheterization.

Discussion

Coronary angiography is the gold standard test for diagnosing coronary artery disease,[1] and outcomes are tied to patient- and procedure-related factors.[1] The 2 major approaches to cardiac catheterization are femoral access and radial access. With femoral access, complications

TABLE 3. Comparison of results of demographic and anatomic parameters analyzed in the study.

Comparison of results of demographic and anatomic parameters within this study					
Variable		**Study group**	**Control group**	***P* value**	**Confidence intervals [CI]**
Age (years)	All	56.17	56.88	0.80	−6.21 to 4.79
	Male	54.00	56.42	0.67	−14.21 to 9.37
	Female	57.33	57.14	0.95	−5.95 to 6.33
Weight (Kg)	All	92.01	94.82	0.65	−15.35 to 9.73
	Male	96.88	103.23	0.62	−32.52 to 19.80
	Female	89.41	90.01	0.93	−14.35 to 13.15
Height (cm)	All	163	168	**0.04**	−0.1 to −0.002
	Male	171	178	**0.03**	−0.14 to −0.01
	Female	159	163	0.08	−0.08 to 0.01
Body mass index (kg/m^2)	All	34.62	33.60	0.64	−3.25 to 5.27
	Male	33.21	32.57	0.86	−8.60 to 9.87
	Female	35.37	34.20	0.66	−4.21 to 6.55
Body surface area (m^2)	All	1.96	2.71	0.37	−2.40 to 0.90
	Male	2.08	2.19	0.38	−0.36 to 0.14
	Female	1.91	3.01	0.39	−3.72 to 1.50
Vertebrocarinal distance (VCD) (cm)	All	9.22	11.31	<**0.0001**	−2.83 to −1.34
	Male	9.70	12.06	<**0.0001**	−3.56 to −1.15
	Female	8.97	10.88	<**0.0001**	−2.82 to −1.01
Width of thorax at the first rib (cm)	All	15.37	15.67	0.60	−1.44 to 0.84
	Male	15.89	17.03	0.16	−2.78 to .050
	Female	15.10	14.90	0.78	−1.23 to 1.62
Width of thorax at carina (cm)	All	24.76	25.74	0.06	−1.99 to 0.05
	Male	25.94	27.06	0.21	2.95 to 0.70
	Female	24.14	24.98	0.10	1.86 to 0.17
Angle of the right first rib to midline (cm)	All	48.83	46.45	0.10	0.54 to 4.22
	Male	48.75	46.08	0.70	−0.24 to 5.58
	Female	48.87	46.67	0.79	−0.29 to 4.69

occur at a rate of 1.8%-17%.[15] In contrast, the radial approach has been found to be superior by multiple studies, with a reduced rate of postprocedural complications[2-9,16-18]—especially those associated with bleeding.[17,18] However, one new study of 17,000 individuals demonstrated that the transradial approach also continues to have a lower procedural success rate,[16] perhaps partly attributable to brachiocephalic artery tortuosity.[9,12,14] In order to reduce risk of procedure failure, it becomes imperative to determine which patients might have this anatomical barrier prior to starting the cardiac catheterization. Through identifying a surrogate marker for brachiocephalic artery tortuosity, operators can better choose an access site or allocate tools to overcome anatomic boundaries.

Literature review revealed very few articles that used imaging to predict difficulty with radial artery cardiac catheterization, and none were applicable to a broad patient population. This study explored various

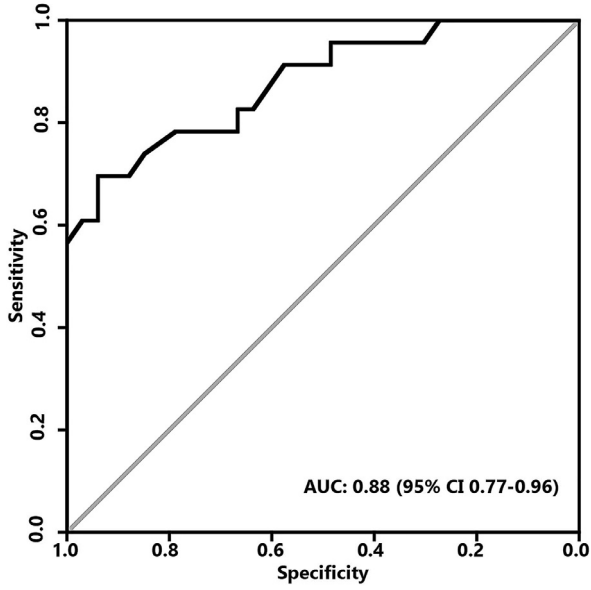

FIG 2. Receiver operating characteristic (ROC) curve illustrating final model including sex and vertebrocarinal distance (VCD). Plot of sensitivity and specificity of a final model composed of sex and VCD in predicting difficult right transradial cardiac catheterization. AUC, area under the curve.

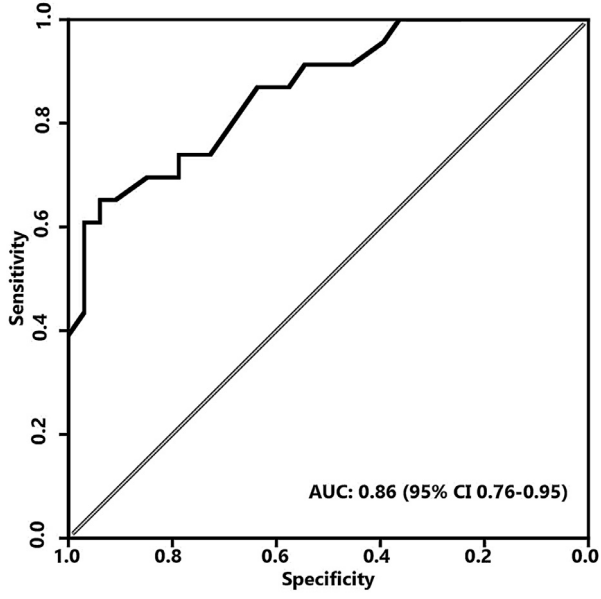

FIG 3. Receiver operating characteristic (ROC) curve illustrating final model of vertebrocarinal distance (VCD) only. Plot of sensitivity and specificity of a final model composed VCD only in predicting difficult right transradial cardiac catheterization. AUC, Area under the Curve.

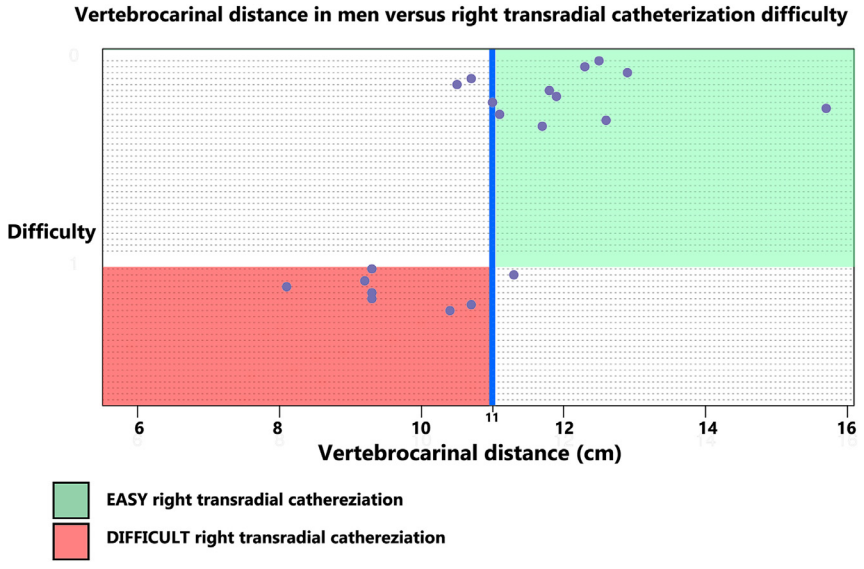

FIG 4. Vertebrocarinal distance (VCD) cutoff in men. Dot plot of VCD measured in men versus difficulty of right transradial cardiac catheterization.

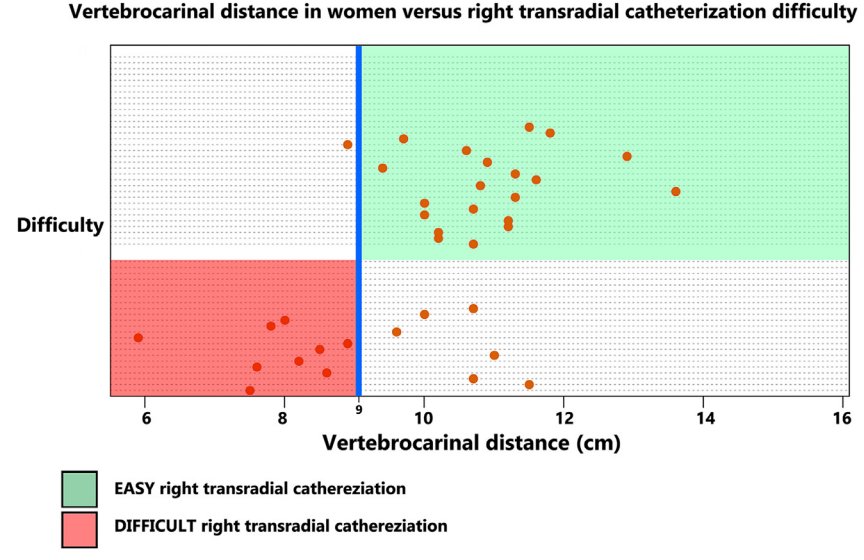

FIG 5. Vertebrocarinal distance (VCD) cutoff in women. Dot Plot of VCD measured in women versus difficulty of right transradial cardiac catheterization.

predictors of tortuosity based on the hypothesis that patients with a crowded thoracic inlet (due to small dimensions or narrow angles of key structural landmarks) would have more tortuosity of the brachiocephalic

artery, hence, more challenging right transradial cardiac catheterization. Of all potential predictors, this study identifies the VCD as the most reliable predictor of brachiocephalic artery tortuosity. Identification requires only a preprocedural chest x-ray with calipers on imaging software. In men, VCD <11 cm. increases the risk of procedural failure due to tortuosity encountered during transradial catheterization, while VCD <9 cm in women increases this risk. Measuring the VCD can reduce the risk of requiring a second needle-stick at a femoral site if tortuosity is too great to overcome, and it can avert the need to switch to a different type of catheter or guidewire midway through the procedure. This might limit fluoroscopic time for both patients and operators, reduce infection risk, and generally better-stream line an age-old procedure.

Over the years, the use of transradial cardiac catheterization has gained popularity, averaging 25% in 2009 and 76% in 2012.[2] Right transradial access failure seems to decrease in incidence with experience,[2] ultimately occurring in <5% of cases.[19] Nevertheless, failure rates might be higher than predicted due to widespread use of right transradial cardiac catheterization, offset by practitioner experience.[10]

The major limitation of this study is the small sample size, having $n = 23$ of study population. Furthermore, this sample was taken from a relatively homogeneous population in Memphis, TN, where majority of patients are African-American males. Matching the cohort for age and sex reduced bias, but the external validity is potentially limited.

Next, retrospective chart review was used to build the study's patient registry. Precatheterization chest x-ray films were usually performed for a different purpose, and not all images were anteroposterior, filmed perfectly perpendicular, or certifiably filmed in full inspiration. Thus, quality of the chest films, themselves, may confound the vertebrocarinal distance measurements. Patient rotation, anteroposterior projection, and those x-rays performed at less than the patient's true inspiratory capacity are all potential confounders. Lack of standardization of chest films among patients may have adversely affected the results of this study.

Conclusions

This study is novel in identifying VCD (distance in centimeters between the spinous process of the first thoracic vertebra [T1] and the most caudal point of tracheal bifurcation, measured at and parallel to the midline) on chest x-ray as a predictive, noninvasive surrogate for difficult right transradial cardiac catheterization due to brachiocephalic artery tortuosity. This can help cardiologists identify this potential procedural

limitation prior to catheterization and perhaps pre-emptively elect a different site (left transradial or right- or left-common femoral).

Future studies should focus on determining a cutoff for VCD among larger and more diverse patient populations to better predict when an operator may have encounter a tortuous brachiocephalic artery and experience difficulty with catheter advancement and turnability. Thus, we recommend that vertebrocarinal distance measurement should be limited to good quality, posteroanterior chest x-ray films with minimal rotation and full inspiratory effort.

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