Artificial intelligence-powered solutions for automated aortic diameter measurement in computed tomography: a narrative review

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Background and Objective: Patients with thoracic aortic aneurysm and dissection (TAAD) are often asymptomatic but present acutely with life threatening complications that necessitate emergency intervention. Aortic diameter measurement using computed tomography (CT) is considered the gold standard for diagnosis, surgical planning, and monitoring. However, manual measurement can create challenges in clinical workflows due to its time-consuming, labour-intensive nature and susceptibility to human error. With advancements in artificial intelligence (AI), several models have emerged in recent years for automated aortic diameter measurement. This article aims to review the performance and clinical relevance of these models in relation to clinical workflows.

Methods: We performed literature searches in PubMed, Scopus, and Web of Science to identify relevant studies published between 2014 and 2024, with the focus on AI and deep learning aortic diameter measurements in screening and diagnosis of TAAD.

Key Content and Findings: Twenty-four studies were retrieved in the past ten years, highlighting a significant knowledge gap in the field of translational medicine. The discussion included an overview of AI-powered models for aortic diameter measurement, as well as current clinical guidelines and workflows.

Conclusions: This article provides a thorough overview of AI and deep learning models designed for automatic aortic diameter measurement in the screening and diagnosis of thoracic aortic aneurysms (TAAs). We emphasize not only the performance of these technologies but also their clinical significance in enabling timely interventions for high-risk patients. Looking ahead, we envision a future where AI and deep learning-powered automatic aortic diameter measurement models will streamline TAAD clinical management.

Keywords: Artificial intelligence (AI); deep learning; aortic diameter measurement; thoracic aortic aneurysm (TAA); thoracic aortic dissection (TAD)

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Introduction

Thoracic aortic aneurysm and dissection (TAAD) is a group of life-threatening conditions that demand prompt diagnosis and urgent surgical intervention. Thoracic aortic aneurysm (TAA) can be asymptomatic which may lead to dissection and rupture, and an increase in its size may necessitate surgical repair (1). A recent study indicated that the prevalence of thoracic aortic dissection (TAD) may be significantly underestimated, potentially up to 40 times higher than previously believed (2). This could result in an increased demand for imaging studies.

In risk assessment of aneurysm detection and dissection evaluation, aortic diameter measurement serves as a gold standard. Aortic diameters exceeding 60 mm in the ascending aorta and 70 mm in the descending aorta significantly elevate the risk of dissection or rupture (3). Regarding the treatment decision, the 2022 American College of Cardiology and American Heart Association (ACC/AHA) Guideline recommended a primary criterion of an aortic diameter ≥5.5 cm for elective surgical intervention in cases of aneurysms involving the aortic root or ascending thoracic aorta (4). Aortic diameter plays a critical role in surgical planning for thoracic endovascular aortic repair (TEVAR) by guiding the selection of appropriate endograft size and landing zones (5). Annual follow-up is advised for ascending aortic diameters larger than 45mm to monitor progression (3).

An accurate and timely aortic diameter measurement promotes early diagnosis of TAAD. Computed tomography (CT), with its high sensitivity and specificity, is widely employed for diagnosing acute aortic syndromes, particularly for TAD. The entire aorta along with branches can be imaged with high spatial resolution and fast acquisition (4). CT is advised for the initial diagnosis (6), with aortic diameter measurement serving as a key indicator for TAAD. However, this task is generally considered as time-consuming, labour-intensive and prone to inter-observer discrepancy. With the advancement of artificial intelligence (AI), multiple models have emerged for automatic measurement. This review summarises the existing publications on AI-powered aortic diameter measurements in diagnosis and surgical planning, highlighting the alignment of these models with clinical guidelines.

Segmentation is a necessary step prior to aortic diameter measurement, as it accurately delineates the aortic structures essential for precise assessment. However, this review primarily focuses on the advancements in AI-powered diameter measurement techniques. While segmentation is critical, its detailed discussion is beyond the scope of this paper, which aims to highlight the latest developments and applications specifically related to the measurement process itself. Also, genetically triggered TAAD is not addressed in this narrative review due to the limited literature identified through the selected search strategy. We present this article in accordance with the Narrative Review reporting checklist (available at https://atm.amegroups.com/article/view/10.21037/atm-24-171/rc).

Methods

A comprehensive literature search was conducted using PubMed, Scopus, and Web of Science to identify relevant studies published between 2014 and 2024. The search utilized keywords such as [(aortic diameter) AND (artificial intelligence OR machine learning OR deep learning) OR (automated OR automation OR automatically)] AND (CT OR computed tomography) AND (thoracic aorta OR aortic aneurysm OR aortic dissection). Inclusion criteria focused on peer-reviewed full articles and clinical trials addressing automated aortic diameter measurement using CT imaging. Exclusion criteria were non-English studies (*Table 1*).

Overview of CT application in TAAD

Chest pain is the most common complaint of TAAD patients, especially in type A TAD patients. In current emergency department setting, computed tomography angiography (CTA) is the preferred imaging modality for the assessment of acute TAD extension and branch involvement (3). Plain CT, contrast-enhanced CT in early and late phases are typically performed in sequence for a comprehensive blood vessels visualization (7). Upon hospital presentation, plain CT scans are utilized to differentiate intramural hematoma (IMH) from other factors of aortic wall thickening, followed by contrast-enhanced CT. A complete aortic reconstruction can be achieved through a series of thin-slice arterial phase contrast-enhanced CT scans to assess the full extent An entire aortic reconstruction can be achieved through a series of thin-slice arterial phase contrast-enhanced CT scans to assess the full extent of any dissection and thus inform treatment decisions (4).

Although contrast enhanced CT is the gold standard to diagnose aortic dissection, plain CT must also be included as IMH and aortic atherosclerosis sometimes is indistinguishable by contrast enhanced CT. Plain CT also provide accurate outer to outer wall diameter assessment,

Table 1 Search strategy summary

Items	Specification
Date of search	26 Sep 2024
Databases searched	PubMed, Scopus, Web of Science
Search terms used	((aortic diameter) AND (artificial intelligence OR machine learning OR deep learning) OR (automated OR automation OR automatically)) AND (CT OR computed tomography) AND (thoracic aorta OR aortic aneurysm OR aortic dissection)
Timeframe	Sep 2014 to Sep 2024
Inclusion and exclusion criteria	Inclusion: peer-reviewed full articles and clinical trials
	Exclusion: non-English
Selection process	Search and selection conducted by E.M.K.L.

CT, computed tomography.

making it a good diagnostic tool for TAA (6). Both acute and chronic TAD can be distinguished on plain CT as fresh thrombus within the false lumen is detectable in acute TAD (6). However, plain CT may not reliably detect intimal flap and aortic wall changes caused by atherosclerosis and thrombosis (4). Contrast-enhanced CT is essential for comprehensive TAD diagnosis, bridging this diagnostic gap. A limitation of contrast-enhanced CT is its potential harmful effects to patients with compromised renal function or contrast allergy due to the utilization of iodinated contrast (4). In clinical workflow, plain and contrast-enhanced CT are usually performed for comprehensive TAAD diagnosis.

Upon diagnosing a TAAD, a comprehensive assessment of aortic valve and the entire aorta is recommended in operative planning. The use of electrocardiography (ECG) gating in CT is recommended to minimize motion artifact stemmed from heart-beat, particularly for detecting TAD and intimal tear in the ascending aorta to assess the type and extend of surgery (6). By combining ECG gating with contrast-enhanced CT, the radiation dose of contrast can be minimized without compromising diagnostic image quality (8). However, in emergency setting, ECG-gated CT is typically not conducted due to additional time and manpower required for setting up ECG leads and ensuring proper synchronization. A recent study conducted a dedicated ECG-gated CTA immediately following hyperacute stroke and reported a median increase in scan time of 6 minutes (9). Only 30% of CT scans in 6 nationally leading clinical centers in the United States are ECG-gated for managing aortic diseases (10).

Within the spectrum of CT modalities, CTA with ECG gating is recognized as the most comprehensive technique and regarded as the 'gold standard' for aortic imaging. CTA enables three-dimensional reconstruction of aorta, with dynamics images aiding in surgical planning or endovascular interventions (11). Nevertheless, its widespread implementation in practical hospital environments is impeded by constraints related to time and staffing resources (12). The emergence of AI-driven models for aortic diameter measurement presents a promising avenue for addressing these challenges. By leveraging AI algorithms, the process of aortic dimension assessment can potentially be optimized, offering a pathway to enhance the efficiency and accuracy of this advanced imaging modality.

Overview of the consensus on aortic diameter measurement

Numerous guidelines from global medical organizations delineate the methods for measuring aortic diameters and establish thresholds for screening, diagnosis, surgical intervention, and post-treatment monitoring. These standards exhibit variability across different aortic segments, pathological conditions, patient characteristics, and familial backgrounds. Ensuring alignment with these protocols is crucial in evaluating the efficacy of AI models.

Locations and angles

Accurate detection and identification of reproducible anatomical reference points are essential for standardizing and determining aortic dilation in diameter measurements. The 2014 ESC Guideline suggests 10 landmarks (3), while

Table 2 Aortic landmarks suggested for aortic diameter measurement

Landmarks	Aortic segments	Guidelines from organizations	
		ESC [2014]	ACCF/AHA/AATS/ACR/ASA/SCA/SCAI/SIR/STS/SVM [2010]
Root	Aortic sinuses of Valsalva	√	√
	Sinotubular junction	√	√
Ascending	Mid ascending aorta (midpoint in length between sinotubular junction and proximal aortic arch)	√	√
Arch	Proximal aortic arch (aorta at the origin of the brachiocephalic trunk)	√	√
	Mid aortic arch (between left common carotid and subclavian arteries)	√	√
Descending	Proximal descending thoracic aorta (2 cm distal to left subclavian artery)	√	√
	Mid descending aorta (pulmonary arteries)	√	√
	Aorta at diaphragm	√	√
	Abdominal aorta at the celiac axis origin	√	√
	Abdominal aorta right before aortic bifurcation	√	×

ESC, European Society of Cardiology; ACCF, American College of Cardiology Foundation; AHA, American Heart Association; AATS, American Association for Thoracic Surgery; ACR, American College of Radiology; ASA, American Stroke Association; SCA, Society of Cardiovascular Anesthesiologists; SCAI, Society for Cardiovascular Angiography and Interventions; SIR, Society of Interventional Radiology; STS, Society of Thoracic Surgeons; SVM, Society for Vascular Medicine.

the 2010 ACCF/AHA/AATS/ACR/ASA/SCAI/SIR/STS Guidelines identify 9 landmarks (13). *Table 2* summarizes the details of landmarks mentioned in each guideline. The 2022 ACC/AHA and 2024 EACTS/STS Guidelines recommend 11 and 12 landing zones respectively (4,14). These guidelines indicate that multiplanar measurements should be taken perpendicular to the longitudinal axis of the aorta and blood flow at each level, provided a 3D dataset has been acquired. ESC Guideline mentions that it is more desirable to measure maximum diameter perpendicular to the centerline of the vessel using 3D reconstructed CT images, if available, to provide more accurate and reproducible true aortic dimensions compared to axial cross-section diameters (3).

Aortic root measurement

Aortic root is considered to be the most complex segment in aorta. Due to its asymmetric and non-circular cross-section (15), and often degraded images from motion artifacts in non-ECG gated images, aortic root measurement is always subject to inter-reader variability. The ACC/AHA and EACTS/STS guidelines suggested that aortic root diameter can be measured either from the commissure to the opposite sinus or from sinus to sinus, with the latter method yielding larger dimensions (4,14).

Start and end-point

Aortic dimensions can be measured between the external (outer-to-outer wall) or internal (inner-to-inner wall) surfaces of the aortic wall, allowing for the inclusion or exclusion of the wall thickness (16). Aortic wall abnormality is a discrete thickening of aortic wall from atherosclerosis, aortitis, IMH, or other pathological processes (4). In the past, if wall changes were absent, inner-edge to inner-edge approach should be deployed. However, wall changes are now more prevalent, maximum diameter should be measured using the outer-to-outer method to include aortic wall (14). In TAA monitoring, outer-to-outer wall measurements can depict partial false lumen thrombosis which are associated with rupture and TAD. An increasing maximum aortic diameter, coupled with new or worsening partial false lumen thrombosis, are crucial factors in distinguishing between TAA and TAD, as well as in monitoring the disease (17). Therefore, outer-to-outer wall measurements are recommended for comprehensive longitudinal disease assessment.

Comparisons on the performances of different measurement methods with manual measurement

Findings from recent literature comparing the performances of various measurement methods are summarized in *Table 3*.

Comparison on performance metrics of AI models

Timely and accurate diagnosis of TAAD is essential in a clinical setting to facilitate early intervention. A number of automatic models driven by AI and deep learning have emerged to expedite this task while providing reliable outcomes. Given that aortic diameter measurement using landmarks or reference points is crucial for TAAD classification and diagnosis, it is important to examine the performance of these models across various aortic segments.

Reproducibility and reliability in aortic measurement

When evaluating a model's reproducibility and reliability, the intraclass correlation coefficient (ICC) is commonly used to indicate how closely the values align across different groups of data (18). Based on the 16 literature sources, ICC is often used to imply the inter-reader agreement between manual and automatic measurement, as well as among two or more readers. Intra-reader agreement is also compared to assess the measurement differences from the same reader. Bratt *et al.* found a higher ICC in inter-reader agreement for the ascending aorta compared to the descending aorta (0.80 *vs.* 0.70) (19). The study by Fink *et al.* echoed this finding. The manual and automated measurements were significantly different in the descending aortas, when comparing to that in ascending aortas. This may be attributed to the relatively tubular and straight structure of the ascending aorta, which facilitates segmentation compared to the more curved descending aorta, ultimately impacting the reproducibility of measurements taken perpendicular to the centerline (20). Moreover, the increased reproducibility of measurement in the ascending aorta over time might be due to its more stable aortic size, compared to the aortic arch and descending aorta (19).

Classification of TAAD based on aortic diameter

After aortic diameter measurement, classification of TAAD could be done by screening whether the measured diameter exceed the defined thresholds. In Macruz *et al.*'s study, the maximum diameter measurements are employed to determine the presence of an aneurysm using predefined thresholds (≥4 cm for the ascending aorta and ≥3 cm for the descending aorta). The model demonstrates greater overall classification accuracy compared to manual measurements by readers rather than radiological reports (21).

Sensitivity and specificity in TAAD diagnosis

Apart from accuracy, sensitivity and specificity are the standard measures to report the classification performance in cases where the outcome is binary, denoting the true positive and false positive cases respectively (22). In Graby *et al.*'s study, the AI model notably identified new aortic dilation in 27% of patients using routine non-ECG-gated CTA, achieving a specificity of 99% and sensitivity of 77% (23). These results highlight the diagnostic accuracy for TAAD when utilizing non-ECG-gated scans, addressing motion artifacts that frequently cause inaccurate diameter measurements at the aortic root and proximal ascending aorta. Currently, the TAAD diagnostic workflow heavily relies on contrast-enhanced CT, with AI-powered automatic measurement and diagnostic models typically trained and validated using these contrast-enhanced scans. However, a study by Lo Piccolo *et al.* compared the performance of a re-trained AI model across plain and contrast-enhanced CT subgroups, finding that specificity and accuracy were higher in the plain CT subgroup (24). Additionally, another study evaluated the model's performance using plain, non-ECG-gated, low-dose CT and found no significant differences in aortic diameter between manual and automatic measurements, indicating no systematic bias and a repeatability coefficient of 4.0 mm for the AI model (25). Therefore, the current AI models demonstrate promising classification results. To facilitate better comparison and evaluation of different measurement models, it is possible to establish thresholds for sensitivity and specificity, provided that there is adequate diversity and size among studies (26).

Challenges in aortic root measurement

Aortic root measurement is regarded as the most difficult yet important since most aneurysms are located at the aortic root and ascending aorta. However, some studies omit aortic root measurement as ECG gating was not used (27). In Pradella *et al.*'s study in 2021, about one-third of the aortic

Table 3 AI-driven studies on aortic diameter measurement

Author	Publication date	Study population	Research objective	Method	Highlights
Macruz *et al.*	2022	1,400 plain and contrast-enhanced routine CT for validation of the model	Predict largest ascending and descending aortic diameters via automated segmentation and identify aneurysms	(I) Manual outer wall annotations. (II) Centerline determination. Fitting ellipses around the mask to calculate diameters	- MAE between the automatic and reader-measured diameters: ≤0.27 cm - ICC for ascending aorta: ≥0.80 - ICC for descending aorta: ≥0.80 - Aneurysm detection: 88% ascending, 81% descending *vs.* reader 1; 90% ascending, 82% descending *vs.* reader 2
Fink *et al.*	2024	200 plain and contrast-enhanced CT from 100 patients	Evaluate DNN for measuring thoracic aortic diameter and detecting TAD in non-contrast and contrast-enhanced CTs	(I) DNN for landmark detection. (II) Centerline extraction. (III) Max. aortic diameter calculation. (IV) SVM to predict TAD likelihood	- TAD detection: 92.1% accuracy, 88.1% sensitivity, 95.7% specificity - Subgroup analysis: ascending, descending aorta, obesity, prior repair, and dissection - COR: 0.89; ICC: 0.94 - Outer-to-outer wall measurement
Bratt *et al.*	2021	3,051 CTA from 2,835 patients with normal aorta or TAAD or other aortic conditions	Access accuracy of automated model in measuring aortic dimensions, specifically diameter and volume	(I) Volume of the ascending aorta measurement. (II) Max. double-oblique diameter at distal ascending aorta	- Aortic volume measurement also assessed - High mean CV in ascending aortic volume and diameter in automated method. - Narrower limits of agreement in automated method, better reproducibility - Outer-to-outer wall measurement.
Graby *et al.*	2023	436 plain and contrast-enhanced CT according to three study cohorts, some were ECG gated	Assess diagnostic accuracy and clinical impact of AI measurement of thoracic aorta diameter on chest CT	(I) Centerline extraction. (II) Max. CSDM at 9 landmarks	- AI-Rad companion chest CT - Cohort 1: diagnostic accuracy - Cohort 2: repeated measures - Cohort 3: clinical impact; to identify undiagnosed aortic dilatation - 27% of routine scans revealed previously undiagnosed aortic dilatation - 99% specificity; 77% sensitivity
Lo Piccolo *et al.*	2023	995 plain and contrast-enhanced CT, followed by another 250 plain and contrast-enhanced CT to retrain the model	Explore re-training impact on a DL tool for aortic measurements in non-ECG gated exams	(I) Centerline extraction. (II) Max. CSDM at 9 landmarks. (III) 1st model training by 1st CT cohort, 2nd model training by 2nd CT cohort	- AI-Rad companion chest CT - 95.5% accuracy; 49.8% of the cases were correctly measured and 318 measurements were newly found in retrained model - Assessment of TAD: sensitivity: 83.2%; Specificity: 79.5%; accuracy: 80.6% - Sensitivity for CE and non-CE subgroup was 90% and 75% respectively
Hamelink *et al.*	2023	240 plain, non-ECG gated, lose dose chest CTs	Evaluate AI software for automatic thoracic aortic diameter assessment in low-dose, non-contrast chest CT	(I) Centerline extraction. (II) Max. CSDM at 9 landmarks. (III) Subgroup analysis by ages and thoracic aortic diameter ≥40 mm	- AI-Rad companion chest CT - Processing rate: 95.4% - MAD between AI and manual: ~1.3 mm - Slightly higher MAD with aortic diameters ≥40 mm than other subgroups - COR: 4.0 mm
Sedghi Gamechi *et al.*	2019	1,334 plain, non-ECG gated CT scans from 742 participants.	Evaluate automatic measurement of ascending and descending aortic diameter	(I) Centerline computation. (II) CSDM at each 13 slices	- Between manual and automatic segmentations—overall ICC: 0.9; Level-wise ICC: 0.87 to 0.94. - Repeatability—overall ICC: 0.98; Level-wise ICC: 0.91 to 0.96
Pradella *et al.*	2021	405 ECG-gated CTA exams from 371 patients suspected of aortic dilatation	Evaluate AI-Rad companion chest CT in comparison to those of radiologists and evaluated measurement times	(I) Centerline extraction. (II) Max. CSDM at 9 landmarks	- Processing rate: >97% (excluding 6 cases) - 87% of the measurements were coherent as manual measurement - Processing time: ~2:19 min, shorter than that of human readers (~4:48 min)

Table 3 *(continued)*

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Author	Publication date	Study population	Research objective	Method	Highlights
Boninsegna *et al.*	2024	50 contrast enhanced, ECG-gated CT from patients prior to TAVI	Assess AI-algorithm accuracy at CT prior to TAVI with an attention on aortic root analysis.	(I) Centerline extraction. (II) Max. CSDM at 9 landmarks	- AI-Rad companion chest CT - P value ≥0.249 at every aortic landmark among measurement done by AI algorithm and manual measurements - Reduce measurement time from 1:47 to 5:41 minutes.
Rueckel *et al.*	2021	36 ECG gated baseline and FU CT scans from 18 patients with ascending AA	Evaluate AI-Rad companion chest CT model in follow-up assessments for TAAs	(I) Centerline extraction. (II) Max. CSDM at 9 landmarks	- AI-Rad companion chest CT - Processing time: 4:46 min; reduced by 63% - Inter-reader variability: reduced by 42.5%
Saitta *et al.*	2023	479 contrast enhanced, ECG gated CT from patients with severe aortic stenosis	Develop and validate a fully automated deep learning-based pipeline for assessing aortic root morphology to enhance the efficiency and accuracy of pre-procedural planning for TAVI	(I) Aortic root region detection. (II) Automatic segmentation. (III) Aortic surface, annulus and STJ processing. (IV) Aortic root analysis	- Aortic area, perimeter and diameter are computed - Automatic measurements differed by 0.52 mm from manual measurements - Greatly reduce the processing time from 30 minutes to 45 seconds
Lou *et al.*	2015	110 contrast enhanced, ECG gated CT from patients subject to high-risk severe aortic stenosis	To assess the accuracy and reliability of the automated analysis software, particularly in the context of challenges posed by calcification in the aortic annulus, and to determine how these methods affect valve size recommendations for TAVR procedures	(I) Automatic reconstruction of aortic annulus plane. (II) Automatic luminal planimetry at the valve leaflets. (III) Automatic measurements at aortic annulus	- Manual, semiautomated analysis and automated analysis were used - Minor corrections were needed in 95.5% of cases with calcification - Semiautomated analysis improved valve size recommendation agreement from 60% to 82.4%
Gao *et al.*	2019	58 mostly ECG-gated CTA from 29 patients with 2 years of FU	Evaluate semi-automatic measurement of thoracic aorta diameters using CT scans	(I) Centerline computation. (II) Max. CSDM at 7 landmarks	- Between manual and automatic segmentations—overall ICC: ≥0.91 - Processing time: 13 min; reduced by 40%
Artzner *et al.*	2022	122 plain CTs from 62 patients; 9 were ECG-gated for suspected TAAD	Evaluate AI-Rad companion chest CT for automated segmentation and diameter measurement of thoracic aorta in CT images	(I) Centerline extraction. (II) Max. CSDM at 9 landmarks	- Success rate in measurement: 99.2% - ICC between algorithm and readers: ≥0.961 - Processing time: potentially up to 63% faster compared to traditional methods
Koo *et al.*	2024	704 contrast enhanced chest CT from healthy Korean adults	Establish reference values for aortic size by zone, highlighting age and sex influence	(I) Aortic zone segmentation per SVS and STS guidelines. (II) Measurements: Aortic volume, length, area, and diameter per zone (III) Subgroup analysis: sex, age, HTN and DM	- Computed zone-specific reference values in TAAD diagnosis - Adjustments for BSA accounted for body size differences in aortic dimensions - Correlations between HTN and DM, with aortic diameters and sizes - Diameter measurements: COR: 0.81–0.99
Pepe *et al.*	2023	162 CTA from 147 TAAD patients	Develop an uncertainty-aware convolutional neural network for the automated selection of cross-sectional views in CT angiography of aortic dissections, improving measurement reproducibility and efficiency compared to manual methods	(I) Landmark detection. (II) Uncertainty quantification of CNN. (III) Employment of INS and MCDbS to assess model's uncertainty and improve measurement reliability	- Significantly reduce measurement time to 4 ms per sample, comparing to centerline method (10 to 25 minutes) - Reduce 27% MAE compared to centerline approach
Adam *et al.*	2021	551 non-ECG gated CTAs from 345 patients, including pre- and post-operative scans	Evaluate ARVA in automatic aortic diameter measurement	(I) Centerline extraction. (II) Max. diameter measurement perpendicular to the centerline	- ARVA algorithm - Overall MAD: 1.2 mm; lowest in healthy aortas and highest in aortas with stents - Processing time: ~10 min - Outer-to-outer wall measurement
Postiglione *et al.*	2024	350 CTA scans from 216 patients	Evaluate ARVA for aortic segmentation and diameter and volume measurements	(I) Centerline extraction. (II) Aortic segment classification. (III) Diameter measurements for each segment. (IV) Volume measurement	- Multicenter study - Diameter measurement: Same median absolute diameter difference between ARVA and clinicians - Volume measurement: errors: 0.93–0.95 in the main trunk

Table 3 *(continued)*

Table 3 *(continued)*

Author	Publication date	Study population	Research objective	Method	Highlights
Pradella *et al.*	2022	18,243 plain and contrast-enhanced CT scans, some were ECG-gated	Evaluate AI-Rad's accuracy in detecting TAD in chest CTs and identify predictive factors and false positive rates	(I) Centerline extraction. (II) Max. CSDM at 9 landmarks. (III) Radiologist review. (IV) Multivariable logistic regression models	- AI-Rad companion chest CT - 97.0% cases were classified correctly - 5.5% of cases as TAD by the model - TP: 45.0%; FP: 55.0% - Subgroup analysis by sex, contrast type, aortic location, BMI
Monti *et al.*	2022	233 plain CT from 233 patients with healthy aorta and other aorta pathology. Some were ECG-gated	Access CNN for automatically measuring thoracic aortic diameters in a heterogeneous population, utilizing multi-vendor CT datasets	(I) Centerline extraction. (II) Max. CSDM at 9 landmarks	- AI-Rad companion chest CT - Measurement: inner-to-inner on contrast-enhanced CT; outer-to-outer on plain CT - 80% accurate positioning - Bias between automatic and manual measurements: −1.5 mm - COR: 8.0 mm
Martínez-Mera *et al.*	2015	6,599 contrast enhanced CT from 15 healthy patients and patients with aortic conditions	Develop an automatic method for accurately measuring the diameter of the thoracic aorta from CT images to enhance the characterization of thoracic aortic aneurysms	(I) Centerline extraction. (II) Computation of cross section. (III) Diameter calculation by PCA	- 0.2 mm difference in diameter measurement, comparing automatic method with commercial software (gold standard) - Greatly reduce measurement time to less than 8 minutes
Sieren *et al.*	2022	191 non-ECG-gated CTA from patients with normal aorta or TAAD or other aortic conditions	Develop and validate a deep learning algorithm for accurately segmenting and quantifying the physiological and diseased aorta in CTAs	(I) Landmark detection (8 landmarks). (II) Centerline extraction. (III) Diameter quantification	- Segmentation time greatly reduced from 32 minutes to 60 seconds - Overall ICC: ≥0.9
Yu *et al.*	2023	200 CTA from patients without severe deformation of aorta	Develop models for predicting descending thoracic aortic diameters and to offer evidence for selecting the appropriate size of stent grafts for patients with TBAD	(I) Centerline extraction. (II) Landmark detection. (III) Determination of 15 measurement points. (IV) Six measurements obtained from each cross-section	- ~90% of predicted diameters had errors less than 2 mm in the test dataset - Older age and patients with hypertension are correlated with larger descending aortic diameters
Zanfardino *et al.*	2024	1,170 ECG-gated CT from patients with suspected CAD	Identify subgroups of normal ascending aorta and ranges of aortic dimensions that could represent distinct clinical profiles by applying a ML method on CT data blended with clinical characteristics and cardiovascular risk factors data	(I) Selection of measurement planes. (II) Diameter measurements perpendicular to vessel axis	- Inner to inner measurement - Measurements indicated that a diameter greater than 40 mm at the STJ was associated with a 70% increased risk of aortic dissection in high-risk patients - Lower inter-observer variability of less than 5%

AI, artificial intelligence; CT, computed tomography; CTA, computed tomography angiography; TAAD, thoracic aortic aneurysm and dissection; ECG, electrocardiography; TAVI, transcatheter aortic valve implantation; FU, follow-up; AA, aortic aneurysm; CAD, coronary artery disease; DNN, deep neural network; TAD, thoracic aortic dilatation; DL, deep learning; ARVA, augmented radiology for vascular aneurysm; CNN, convolutional neural network; TBAD, type B aortic dissection; ML, machine learning; Max., maximum; SVM, Society for Vascular Medicine; CSDM, cross-sectional diameter measurement; STS, Society of Thoracic Surgeons; STJ, sinotubular junction; SVS, Society for Vascular Surgery; BSA, body surface area; HTN, hypertension; DM, diabetes mellitus; INS, Iterative Neighbor Sampling; MCDbS, Monte Carlo DropBlock Sampling; PCA, principal component analysis; MAE, mean absolute error; ICC, intra-class correlation; COR, coefficient of repeatability; CV, coefficient of variation; CE, contrast-enhanced; MAD, mean absolute difference; TP, true positive; FP, false positive; BMI, body mass index.

root needs to be re-measured caused by tilted measurement plane, generating by the AI-Rad model (28). Boninsegna *et al.* place attention on aortic root measurement and compare the results with other aortic segments. Unsurprisingly, the measurement accuracy at aortic root is less favourable than other aortic segments (29). Rueckel *et al.* propose that the poorer analysis at the sinotubular junction is caused by the geometrically complicated shape of the proximal aorta, which is altered by respiration, blood pressure and bio-elasticity of the aorta (30). High curvature of aortic root and presence of an abundant of calcium deposits may contribute to compromised measurement at aortic root (31). Fortunately, in the subsequent study done by Lo Piccolo *et al.* in 2023, measurements at aortic root (aortic sinus and sinotubular junction) are greatly improved by enhancing the centerline placement. Lou *et al.* observed that calcification affects aortic annulus measurements. They found that measurement results improved after applying interpolation in areas with calcification, suggesting that calcification may reduce measurement accuracy (32). This demonstrates the importance of accurate centerline deployment and continuous model re-training (24).

Difficulties in aortic arch measurement

Measuring the aortic arch is particularly challenging due to the presence of branching arteries. The average diameter differences are most pronounced at the aortic arch, primarily resulting from segmentation errors. Slightly larger diameters are often recorded at the locations of the supra-aortic branches, as indicated by absolute differences between automated and manual measurements at the aortic arch, which range from 1.15 to 1.24 mm—representing the highest errors among the 13 predefined cross-sectional planes (27). Additionally, Pradella *et al.* and Rueckel *et al.* emphasize that the complex three-dimensional structure of the aortic arch, with its curvature and branching vessels, compromises the ability to consistently identify precise measurement points (28,30).

Improvement in reporting efficiency with AI

The accuracy of automated measurements generated by AI models, as well as the agreement between these models and human readers, has been discussed previously. A significant barrier to timely diagnosis is the prolonged duration required for manual measurements. For instance, the semi-automatic tool reported in the Gao *et al.*'s study decreased processing time by 40%, from 22 to 13 minutes. However, human effort remains a critical component, as physicians must manually annotate landmarks to indicate where automatic measurements should be performed (33). Studies by Rueckel *et al.* and Artzner demonstrated a remarkable reduction in reporting time by 63% using the AI-Rad model (30,34). Additionally, Koo *et al.* found that the computation time for each case using a different algorithm was approximately 5 to 10 minutes (35). Pepe *et al.* comes up with a significant reduction in reporting time with estimation of uncertainty done. The suggested approaches only require 4 milliseconds to 0.48 seconds, while the extraction of smooth centerlines requires 11 to 23 minutes per patient (36). With the ongoing development of automatic measurement models, the time required for promising diameter assessments is steadily decreasing. Furthermore, a study by Adam *et al.* noted that processing time after image acquisition has been reduced to around 10 minutes. This ARVA algorithm enables aortic diameter comparisons with previous CT examinations, facilitating efficient aneurysm monitoring (37). While the methodology of this algorithm is not covered in this review, the extended application of automated aortic diameter measurement for disease monitoring represents a promising direction for future treatment advancements.

Comparison on the study design

Importance of multicenter and prospective study designs

The EACTS guidelines recommend a rating system to assess the quality of data derived from clinical trials and research studies. Data collected from multiple randomized clinical trials or meta-analyses are considered to provide a higher level of confidence, while information obtained from retrospective studies and registries is classified as the lowest level of evidence (14). Notably, all the literature identified in this search consisted of retrospective studies, with some conducted at multiple centres. Given that the primary objectives of most studies are to evaluate patient outcomes and clinician workflows, a prospective evaluation of AI models is preferable, particularly in vascular surgery, where patients frequently undergo high-risk and urgent interventions (22). The generalizability of results is limited when conducting retrospective data analysis within a single institution, constraining its applicability to specific clinical scenarios or populations (20). Among the studies reviewed, Postiglione *et al.* is the sole one that analyzed CT scans from two reference aortic centres (38).

Challenges of dataset shift and ongoing evaluation of AI models

An essential challenge to model performance is data-set shift, referring to the temporal modifications in clinical practice or patient characteristic distributions that differ from those initially used to train the algorithm (22). Ongoing evaluation of AI model is necessary to continuously monitor and improve performance. Among the 16 studies reviewed, eight further evaluated the performance of the AI-Rad companion chest CT developed by Siemens Healthineers. This model was initially trained on over 10,000 datasets for the detection of aortic landmarks using deep reinforcement learning, incorporating various imaging manufacturers to enhance its generalization capabilities (34).

Impacts of patient populations and sample diversity on model accuracy

Eight clinical trials involving the AI-Rad model were conducted between 2021 and 2023, featuring diverse study populations and patient demographics. Over time, there has been a notable increase in both sample size and diversity, which are crucial for evaluating the model's effectiveness. Specifically, a total of 18,243 plain and contrast-enhanced CT scans were analyzed by Pradella *et al.* in 2022, thereby enhancing the reliability of their findings (39). In contrast, Rueckel *et al.* included only 36 scans, potentially undermining the statistical robustness of the model and introducing significant measurement variability, particularly in the presence of outliers (30).

In terms of sample diversity, only patients with ascending TAA were included in Rueckel *et al.*'s study, resulting in a statistical overestimation of systemic discrepancies between AI and radiological measurements. In the study by Bratt *et al.* in 2021, 3,051 CT angiograms were obtained from 2,835 patients, encompassing a wide array of pathological states and anatomical variants beyond normal aortic conditions, including thoracic aortic TAA, TAD, right-sided aortic arch, endovascular and open aortic repairs, and severe atherosclerosis (19). However, this study did not delve into how the performance of the model would be affected or improved by including various clinical implications. In Hamelink *et al.* study in 2023, subgroup analysis by ages and thoracic aortic diameter ≥40 mm was performed in order to assess whether the results of the AI system would be significantly influenced by ageing on thoracic aorta, including calcifications, elongation and dilation (25).

ICC is often being used to assess model reliability. Koo and Li proposed a range of ICC values to indicate reliability: values below 0.5 suggest poor reliability, those between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 signify good reliability, and values above 0.90 reflect excellent reliability. However, in situations involving limited sample diversity, small sample sizes, and few raters, ICC values cannot be used as a standard to dictate an acceptable threshold of reliability (40). Therefore, in view of the sample size and diversity in the literatures, a threshold of ICC cannot be proposed but ICC values can be compared to assess model performance. In terms of model evaluation, a large sample size can help establish performance metric thresholds, such as the ICC, enabling more objective evaluation and comparison of different AI models.

Continuous improvement through ongoing research

Subsequent studies can validate meaningful findings explored in earlier research. Fink *et al.* discovered that aortic pathologies limit the accuracy of automated aortic diameter measurements, which is in line with the results of Monti *et al.* (20,41). Lo Piccolo *et al.* reported that the overall diameter measurements was improved after re-training the AI-Rad model by refining centerline fitting and cross-sectional plane placement (24), comparing to the initial version reported by 3 literatures (28,39,41). Continuously incorporating diverse study population in model re-training can enhance model performance, for example, sensitivity and specificity along with clinical practice and process evolvement.

Comparison on clinical relevance

Variability of landmarks across studies: defined vs. undefined

The eight studies evaluating the performance of the AI-Rad model utilized nine recommended landmarks from the 2010 ACCF/AHA/AATS/ACR/ASA/SCAI/SIR/STS Guidelines (23-25,27,29,33,38,39). The pulmonary artery bifurcation level was designated as the landmark level, with 13 cross-sectional slices defined at 1 cm intervals in the study by Sedghi Gamechi *et al.* (27). In contrast, the study by Gao *et al.* identified seven landmarks, while Postiglione *et al.* analyzed seven aortic segments, and Koo *et al.* included eight zones in their assessment (33,35,38).

Fink *et al.* proposed that the maximum aortic diameter may not precisely correspond with these predefined measurements, suggesting that the full extent of the disease could remain obscured if assessments are limited to these specific landmarks. Although this study established predefined landmarks, detailed discussions regarding their application were not provided (20). By comparing the landmarks used in most studies, all landmarks recommended by the 2010 ACCF/AHA/AATS/ACR/ASA/SCAI/SIR/STS guidelines are included. These AI models demonstrate favorable results. The study by Hamelink *et al.* reported that the mean absolute discrepancy between AI and manual measurements across all landmarks is 1.3 mm, which is slightly better than the measurement differences observed among various human readers (1.4 mm) (25). Similarly, the study by Monti *et al.* reported a −1.5 mm bias between automatic and manual measurements (41).

Notably, landmarks were not defined in the studies conducted by Martínez-Mera *et al.*, Adam *et al.*, Macruz *et al.*, and Bratt *et al.* (19,21,37,42). Martínez-Mera *et al.* point out that different regions of the aorta are only approximations of the clinical boundaries established. Therefore, the location of the aneurysm in terms of clinical regions of the aorta could be slightly displaced (42). Furthermore, Bratt *et al.* and Pepe *et al.* are the only two studies that did not employ a centerline approach in measurement of the entire aorta (19,36). Instead, direct measurements from the segmented aorta were made based on the radiologist's judgment in selecting the appropriate measurement plane in Bratt *et al.*'s study (19). Pepe *et al.* revealed that centerline-based approaches are not reliable in patients with chronic aortic dissection due to asymmetric flow channels, differences in contrast opacification and formation of mural thrombus (36).

Standards for aortic measurements: outer-to-outer approach

As mentioned, assessing changes in the aortic wall is essential for identifying the presence of a partially thrombosed false lumen, particularly if a rupture or dissection has occurred following a TAA. To obtain the maximum aortic diameter along the entire aorta, outer-to-outer wall measurement should be employed and several studies support this approach. In the study by Fink *et al.*, both plain and contrast-enhanced CT scans were obtained for each patient and there is a consistent tendency for automated measurements to "overestimate" diameters when using plain scans only, which can be attributed to the limited ability to distinguish between the vessel lumen and the surrounding pathological structures, leading the algorithm to primarily measure the external aortic diameters (20). To reduce variability and enhance reproducibility, it is crucial to standardize the inclusion or exclusion of the aortic wall in measurements (43). Since the most recent EACTS guidelines suggest physicians to utilize outer edge to outer edge aortic diameter measurements during CT scans, this standardized method should be employed for both plain and contrast-enhanced scans (14). Moreover, in the study by Monti *et al.*, although inner-to-inner measurements were utilized, it is also advisable to take the outer vessel diameter into account in contrast-enhanced studies (41).

Importance of ECG and contrast agents in imaging

Most studies have utilized ECG-gated, contrast-enhanced CT for model training and validation, yielding excellent results. However, in clinical practice, ECG gating is not always available, and the use of contrast agents can be risky for patients with impaired renal function, as mentioned before. The automated method proposed by Sedghi Gamechi *et al.* demonstrates promising results in accurately and reproducibly assessing subtle signs of aortic dilation in non-ECG-gated, non-contrast CT scans. However, the limitation of this study is the assessment of the aortic root is excluded (27). Plonek *et al.* emphasized that ECG gating is essential for proper evaluation of the aortic root, as artifacts present in non-ECG-gated CT scans hinder accurate measurement of aortic root dimensions, which is particularly significant in patients with Marfan syndrome, who may present with isolated aortic root aneurysms (34). Therefore, ECG-gated examinations remain an indispensable component of accurate aortic root assessment.

Limitations and challenges

All models under discussion in this review were assessed retrospectively. Li *et al.* suggested that model's impact on patient outcomes and clinician workflow should be prospectively assessed, especially in vascular surgery where patients always undergo high-risk and urgent interventions (44). Machine-learned tools may exhibit varying performance on real-world data that is not aligned with the algorithm compared to their performance during internal validation. Therefore, prospective studies comparing predictions from machine-learned algorithms with those from clinicians are essential for assessing their effectiveness in a clinical setting (22). Moreover, a single-centre evaluation limits the generalizability of model's results to diverse clinical scenarios or populations.

For fully automated models, "silent deployment" can be employed for clinical validation prior to formal implementation. This approach allows the model to operate in parallel with daily clinical workflows, enabling that the generated results can be comparable with real patient outcomes (45). Testing the model in real time without direct communication with end-users ensures uninterrupted routine clinical services, facilitating the assessment of the algorithm's performance in a real-world setting (22).

Model training and validation often require substantial amount of privacy-sensitive data. Federated learning was a decentralized alternative to leave the training data distributed on mobile devices and learns a shared model by aggregating locally computed updates. Each user computes an update to the current global model maintained by the server without uploading a local training dataset to the server (46). Sieren *et al.* applied the concept of such as shared model by annotating CTAs in the software, for example, fine-tuning vascular pathologies and the degree of degeneration of the vessels. Datasets for specific scientific questions can be curated in the future to facilitate AI-powered research (47).

Future directions

Applications of non-ECG-gated and non-contrast imaging

Low dose, plain and non-ECG gated CT is a worth considering modality to be trained and validated in ongoing research. The studies by Sedghi Gamechi *et al.* and Hamelink *et al.* have already demonstrated the potential for further utilization of less invasive and simplified CT modalities (25,27). Multiple studies suggests that non-enhanced CT exhibits comparable efficacy to contrast-enhanced CT, indicating its potential to replace current role of contrast-enhanced CT in clinical practice (48-50). More prospective, multi-centre studies are necessary to enhance and validate the model's generalizability in real-time clinical settings.

Aortic volume and length: better predictors than diameter alone

A limitation of measuring the maximum aortic diameter is its inability to fully capture the three-dimensional processes, such as elongation and cylindrical deformation, involved in aortic growth. Assessing aortic volume and length may provide additional insights into aneurysm progression beyond diameter measurements. In recent years, several AI models have emerged for the longitudinal monitoring of aortic growth. The latest automatic measurement models identified in the literature incorporate both volume and length assessments (35,38). Longitudinal monitoring of aneurysmal volume at different levels has been proposed to provide a better prediction of growth rates and show a more robust correlation with rupture risk than diameter measurements alone (38). Koo *et al.* proposed making adjustments for body surface area to account for individual variations in body size when evaluating aortic dimensions (35).

AI in TEVAR planning and risk factors correlations

Several studies have explored predictive models using machines learning for pre-operative planning of TEVAR, focusing on stent graft size selection and deployment (5,51,52). Numerous studies have identified correlations between risk factors such as age, hypertension, and diabetes mellitus with TAAD. Yu *et al.* integrated risk factors such as age and hypertension in the TEVAR planning model targeting descending aorta (51). Additionally, personalized reference values for each aortic zone have been established (35). Integrating risk factors and clinical parameters into an AI-driven diagnostic model for TAAD can significantly enhance screening and diagnostic efficiency, potentially improving patient survival rates through timely interventions.

Conclusions

This article offers a comprehensive overview of current AI and deep learning-assisted models for automatic aortic diameter measurement in TAAD screening and diagnosis (*Figure 1*). We extensively explored the application of these technologies in the screening and diagnosis of TAAs. Performance metrics were assessed to compare measurement accuracy and classification performance. Measurement results by aortic regions and model processing time were discussed. In addition to evaluating model performance, challenges and limitations in study designs were addressed. We also emphasized the clinical relevance of these applications, focusing on whether these models adhere to guidelines and can be generalized in

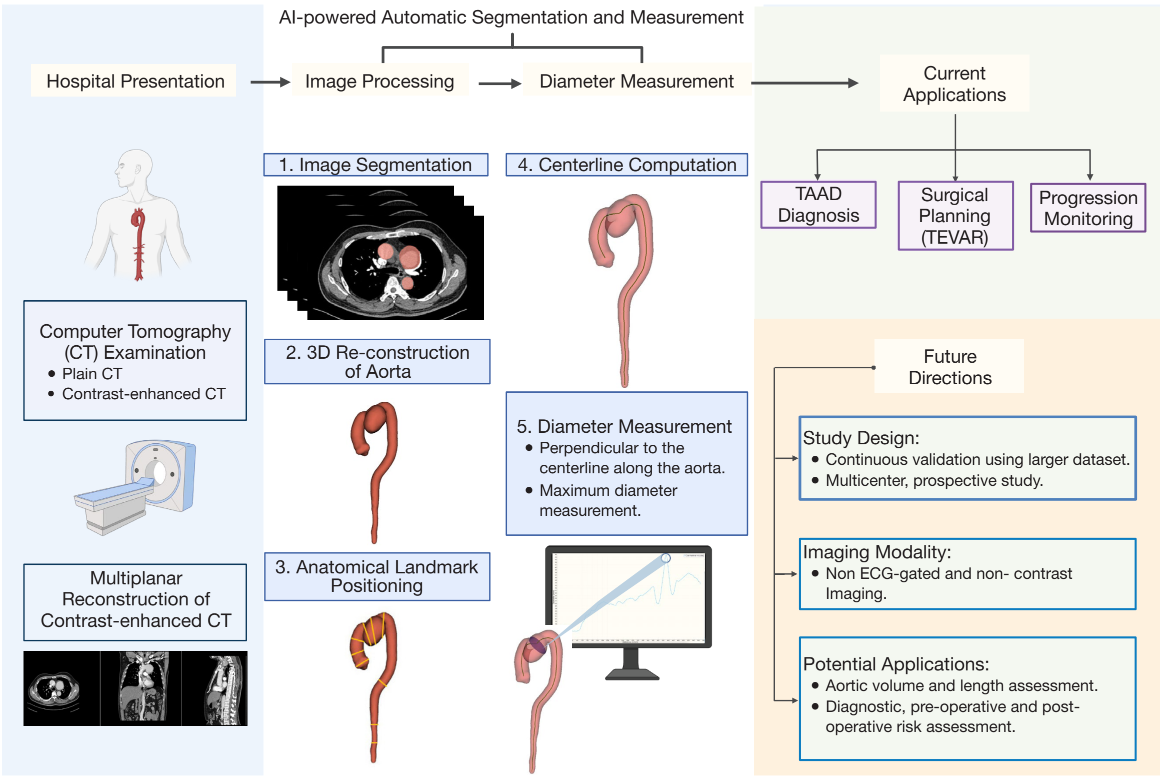

Figure 1 Overview of literature search results on measurement application in the assessment and management of TAAD. This figure summarizes the literature search results related to the assessment and management of TAAD. It begins with the "Hospital presentation" section, detailing the patient pathway, where individuals suspected of having TAAD undergo CT examinations, including both plain and contrast-enhanced scans, followed by multiplanar reconstruction of the contrast-enhanced images. The "Image processing" part outlines critical steps such as image segmentation, 3D reconstruction of the aorta, and precise anatomical landmark positioning. Subsequently, the figure illustrates the processes of "Centerline computation and diameter measurement" which are essential for evaluating aortic conditions. The "Current applications" highlight the use of these methodologies in TAAD diagnosis, surgical planning (e.g., TEVAR), and ongoing disease progression monitoring. Finally, the "Future directions" propose potential advancements in study design, including continuous validation with larger datasets and multicenter, prospective studies, alongside innovative imaging modalities such as non-ECG-gated and non-contrast imaging. Additionally, it suggests exploring potential applications like aortic volume and length assessments and the development of risk assessment. CT, computed tomography; 3D, three-dimensional; TAAD, thoracic aortic aneurysm and dissection; TEVAR, thoracic endovascular aortic repair; ECG, electrocardiogram.

clinical settings. This includes aspects such as landmark definition, outer-to-outer wall measurement, and the use of ECG and contrast agents.

To address the challenges outlined, we suggest several strategies to enhance the generalizability of models across diverse clinical scenarios. For model training and clinical validation, techniques such as silent deployment and federated learning can be utilized in the context of fast-paced clinical environments and limited data availability.

In conclusion, AI and deep learning-assisted models enhance clinical outcomes by improving reporting efficiency and reducing rates of undiagnosed or misdiagnosed cases of TAAD. We foresee a future where a risk prediction score integrates automated imaging analysis, clinical parameters, and patient demographics to offer dependable predictions. Our review underscores the potential of employing AI and deep learning methods to streamline the diagnosis of TAAs and dissections.

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Footnote

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References

1. Salameh MJ, Black JH 3rd, Ratchford EV. Thoracic aortic aneurysm. Vasc Med 2018;23:573-8.
2. Babu A, Meng Z, Oji O, et al. How common is aortic dilatation? Eur Heart J - Cardiovasc Imaging 2021;22:jeaa356.016.
3. Erbel R, Aboyans V, Boileau C, et al. 2014 ESC Guidelines on the diagnosis and treatment of aortic diseases: Document covering acute and chronic aortic diseases of the thoracic and abdominal aorta of the adult. The Task Force for the Diagnosis and Treatment of Aortic Diseases of the European Society of Cardiology (ESC). Eur Heart J 2014;35:2873-926.Erratum in: Eur Heart J 2015;36:2779.
4. Isselbacher EM, Preventza O, Hamilton Black J 3rd, et al. 2022 ACC/AHA Guideline for the Diagnosis and Management of Aortic Disease: A Report of the American Heart Association/American College of Cardiology Joint Committee on Clinical Practice Guidelines. Circulation 2022;146:e334-e482.
5. Saitta S, Sturla F, Caimi A, et al. A Deep Learning-Based and Fully Automated Pipeline for Thoracic Aorta Geometric Analysis and Planning for Endovascular Repair from Computed Tomography. J Digit Imaging 2022;35:226-39.
6. Tanaka R, Yoshioka K, Abiko A. Updates on Computed Tomography Imaging in Aortic Aneurysms and Dissection. Ann Vasc Dis 2020;13:23-7.
7. Baliyan V, Shaqdan K, Hedgire S, et al. Vascular computed tomography angiography technique and indications. Cardiovasc Diagn Ther 2019;9:S14-27.
8. Hou QR, Gao W, Sun AM, et al. A prospective evaluation of contrast and radiation dose and image quality in cardiac CT in children with complex congenital heart disease using low-concentration iodinated contrast agent and low tube voltage and current. Br J Radiol 2017;90:20160669.
9. Rinkel LA, Guglielmi V, Beemsterboer CFP, et al. Diagnostic Yield of ECG-Gated Cardiac CT in theAcute Phase of Ischemic Stroke vsTransthoracic Echocardiography. Neurology 2022;99:e1456-e1464.
10. Asch FM, Yuriditsky E, Prakash SK, et al. The Need for Standardized Methods for Measuring the Aorta: Multimodality Core Lab Experience From the GenTAC Registry. JACC Cardiovasc Imaging 2016;9:219-26.
11. Riambau V, Böckler D, Brunkwall J, et al. Editor's Choice - Management of Descending Thoracic Aorta Diseases: Clinical Practice Guidelines of the European Society for Vascular Surgery (ESVS). Eur J Vasc Endovasc Surg 2017;53:4-52.
12. Lee P, Dhillon G, Pourafkari M, et al. Non-ECG-gated cardiac CT angiography in acute stroke is feasible and detects sources of embolism. Int J Stroke 2024;19:189-98.
13. Hiratzka LF, Bakris GL, Beckman JA, et al. 2010 ACCF/AHA/AATS/ACR/ASA/SCA/SCAI/SIR/STS/SVM guidelines for the diagnosis and management of patients with Thoracic Aortic Disease: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines, American Association for Thoracic Surgery, American College of Radiology, American Stroke Association, Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, Society of Interventional Radiology, Society of Thoracic Surgeons, and Society for Vascular Medicine.

Circulation 2010;121:e266-369. Erratum in: Circulation 2010;122:e410.
14. Czerny M, Grabenwöger M, Berger T, et al. EACTS/STS Guidelines for diagnosing and treating acute and chronic syndromes of the aortic organ. Eur J Cardiothorac Surg 2024;65:ezad426.
15. Plonek T, Berezowski M, Bochenek M, et al. A comparison of aortic root measurements by echocardiography and computed tomography. J Thorac Cardiovasc Surg 2019;157:479-86.
16. Kesävuori R, Kaseva T, Salli E, et al. Deep learning-aided extraction of outer aortic surface from CT angiography scans of patients with Stanford type B aortic dissection. Eur Radiol Exp 2023;7:35.
17. Higashigaito K, Sailer AM, van Kuijk SMJ, et al. Aortic growth and development of partial false lumen thrombosis are associated with late adverse events in type B aortic dissection. J Thorac Cardiovasc Surg 2021;161:1184-1190.e2.
18. Bunting KV, Steeds RP, Slater K, et al. A Practical Guide to Assess the Reproducibility of Echocardiographic Measurements. J Am Soc Echocardiogr 2019;32:1505-15.
19. Bratt A, Blezek DJ, Ryan WJ, et al. Deep Learning Improves the Temporal Reproducibility of Aortic Measurement. J Digit Imaging 2021;34:1183-9.
20. Fink N, Yacoub B, Schoepf UJ, et al. Artificial Intelligence Provides Accurate Quantification of Thoracic Aortic Enlargement and Dissection in Chest CT. Diagnostics (Basel) 2024;14:866.
21. Macruz FBC, Lu C, Strout J, et al. Quantification of the Thoracic Aorta and Detection of Aneurysm at CT: Development and Validation of a Fully Automatic Methodology. Radiol Artif Intell 2022;4:e210076.
22. Antoniou T, Mamdani M. Evaluation of machine learning solutions in medicine. CMAJ 2021;193:E1425-9.
23. Graby J, Harris M, Jones C, et al. Assessing the role of an artificial intelligence assessment tool for thoracic aorta diameter on routine chest CT. Br J Radiol 2023;96:20220853.
24. Lo Piccolo F, Hinck D, Segeroth M, et al. Impact of retraining a deep learning algorithm for improving guideline-compliant aortic diameter measurements on non-gated chest CT. Eur J Radiol 2023;168:111093.
25. Hamelink II, de Heide EEJ, Pelgrim GJGJ, et al. Validation of an AI-based algorithm for measurement of the thoracic aortic diameter in low-dose chest CT. Eur J Radiol 2023;167:111067.
26. Alba AC, Agoritsas T, Walsh M, et al. Discrimination and Calibration of Clinical Prediction Models: Users' Guides to the Medical Literature. JAMA 2017;318:1377-84.
27. Sedghi Gamechi Z, Bons LR, Giordano M, et al. Automated 3D segmentation and diameter measurement of the thoracic aorta on non-contrast enhanced CT. Eur Radiol 2019;29:4613-23.
28. Pradella M, Weikert T, Sperl JI, et al. Fully automated guideline-compliant diameter measurements of the thoracic aorta on ECG-gated CT angiography using deep learning. Quant Imaging Med Surg 2021;11:4245-57.
29. Boninsegna E, Piffer S, Simonini E, et al. CT angiography prior to endovascular procedures: can artificial intelligence improve reporting? Phys Eng Sci Med 2024;47:643-9.
30. Rueckel J, Reidler P, Fink N, et al. Artificial intelligence assistance improves reporting efficiency of thoracic aortic aneurysm CT follow-up. Eur J Radiol 2021;134:109424.
31. Saitta S, Sturla F, Gorla R, et al. A CT-based deep learning system for automatic assessment of aortic root morphology for TAVI planning. Comput Biol Med 2023;163:107147.
32. Lou J, Obuchowski NA, Krishnaswamy A, et al. Manual, semiautomated, and fully automated measurement of the aortic annulus for planning of transcatheter aortic valve replacement (TAVR/TAVI): analysis of interchangeability. J Cardiovasc Comput Tomogr 2015;9:42-9.
33. Gao X, Boccalini S, Kitslaar PH, et al. A novel software tool for semi-automatic quantification of thoracic aorta dilatation on baseline and follow-up computed tomography angiography. Int J Cardiovasc Imaging 2019;35:711-23.
34. Artzner C, Bongers MN, Kärgel R, et al. Assessing the Accuracy of an Artificial Intelligence-Based Segmentation Algorithm for the Thoracic Aorta in Computed Tomography Applications. Diagnostics (Basel) 2022;12:1790.
35. Koo HJ, Lee JG, Lee JB, et al. Deep Learning Based Automatic Segmentation of the Thoracic Aorta from Chest Computed Tomography in Healthy Korean Adults. Eur J Vasc Endovasc Surg 2024;S1078-5884(24)00642-7.
36. Pepe A, Egger J, Codari M, et al. Automated cross-sectional view selection in CT angiography of aortic dissections with uncertainty awareness and retrospective clinical annotations. Comput Biol Med 2023;165:107365.
37. Adam C, Fabre D, Mougin J, et al. Pre-surgical and Post-surgical Aortic Aneurysm Maximum Diameter Measurement: Full Automation by Artificial Intelligence. Eur J Vasc Endovasc Surg 2021;62:869-77.
38. Postiglione TJ, Guillo E, Heraud A, et al. Multicentric clinical evaluation of a computed tomography-based fully automated deep neural network for aortic maximum

diameter and volumetric measurements. J Vasc Surg 2024;79:1390-1400.e8.
39. Pradella M, Achermann R, Sperl JI, et al. Performance of a deep learning tool to detect missed aortic dilatation in a large chest CT cohort. Front Cardiovasc Med 2022;9:972512.
40. Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. J Chiropr Med 2016;15:155-63.
41. Monti CB, van Assen M, Stillman AE, et al. Evaluating the Performance of a Convolutional Neural Network Algorithm for Measuring Thoracic Aortic Diameters in a Heterogeneous Population. Radiol Artif Intell 2022;4:e210196.
42. Martínez-Mera JA, Tahoces PG, Carreira JM, et al. Automatic characterization of thoracic aortic aneurysms from CT images. Comput Biol Med 2015;57:74-83.
43. Díaz-Peláez E, Barreiro-Pérez M, Martín-García A, et al. Measuring the aorta in the era of multimodality imaging: still to be agreed. J Thorac Dis 2017;9:S445-7.
44. Li B, Feridooni T, Cuen-Ojeda C, et al. Machine learning in vascular surgery: a systematic review and critical appraisal. NPJ Digit Med 2022;5:7.
45. Verma AA, Murray J, Greiner R, et al. Implementing machine learning in medicine. CMAJ 2021;193:E1351-7.
46. McMahan HB, Moore E, Ramage D, Hampson S, Arcas BA y. Communication-Efficient Learning of Deep Networks from Decentralized Data. arXiv; 2023 [cited 2024 Sep 26]. Available online: http://arxiv.org/abs/1602.05629
47. Sieren MM, Widmann C, Weiss N, et al. Automated segmentation and quantification of the healthy and diseased aorta in CT angiographies using a dedicated deep learning approach. Eur Radiol 2022;32:690-701.
48. Jacob AJ, Abdelkarim O, Zook S, et al. AI-based, automated chamber volumetry from gated, non-contrast CT. J Cardiovasc Comput Tomogr 2023;17:336-40.
49. Lyu J, Fu Y, Yang M, et al. Generative Adversarial Network-based Noncontrast CT Angiography for Aorta and Carotid Arteries. Radiology 2023;309:e230681.
50. Olive-Gadea M, Crespo C, Granes C, et al. Deep Learning Based Software to Identify Large Vessel Occlusion on Noncontrast Computed Tomography. Stroke 2020;51:3133-7.
51. Yu R, Jin M, Wang Y, et al. A machine learning approach for predicting descending thoracic aortic diameter. Front Cardiovasc Med 2023;10:1097116.
52. Zanfardino M, Punzo B, Maffei E, et al. Unsupervised machine learning for risk stratification and identification of relevant subgroups of ascending aorta dimensions using cardiac CT and clinical data. Comput Struct Biotechnol J 2024;23:287-94.

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