Original Article

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Evaluation of Radiation Dose in Computed Tomography Angiography before Transcatheter Aortic Valve Implantation

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Abstract:

Objective: To investigate the effective radiation dose and image quality of computed tomography angiography (CTA) before transcatheter aortic valve implantation (TAVI).

Material and Methods: This study involved 65 participants, diagnosed with aortic valve stenosis and examined with CTA before TAVI. The total mAs, kVp, volume CT dose index (CTDIvol), and dose-length product (DLP) in each scanning phase were recorded. The effective dose was calculated by multiplying the DLP by the conversion coefficient (k=0.015 mSv/[mGy.cm]). For quantitative image analysis, circular regions of interest were placed on six levels of the aorta in the axial images. The CT attenuation value, image noise, signal-to-noise ratio, and contrast-to-noise ratio were measured. For qualitative analysis, two radiologists rated the image quality of the aortic root and aortoiliac pathway.

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Results: The mean CTDIvol and DLP were 23.59±5.19 mGy and 881.01±193.41 mGy.cm., respectively. The mean effective dose was 13.22±2.90 mSv; the whole-aorta CTA phase received the highest dose, followed by the coronary CTA and coronary artery calcium scoring phases (9.62±2.60, 2.44±1.13, and 1.16±0.55 mSv, respectively). Image quality ranged from good to excellent in all segments of the aorta.

Conclusion: The mean effective radiation dose of the pre-TAVI CT examination using 256-multidetector CT was 22.91± 5.03 mSv. The image quality in the aorta was good to excellent. The main factors that affected the radiation dose were: body mass index, total mAs, and kVp.

Keywords: transcatheter aortic valve implantation, computed tomography angiography, radiation dose, computed tomography

Introduction

Aortic stenosis (AS) is one of the most common and serious valve diseases.[1] AS is characterized by obstruction of blood flow across the aortic valve, leading to a deficiency in the body's blood supply. The standard and most effective treatment is a surgical aortic replacement. The alternative treatment is transcatheter aortic valve implantation (TAVI), which is also a highly effective way to treat patients who cannot be treated surgically. Before TAVI, patients were required to undergo computed tomography angiography (CTA) for treatment planning, which provides good visualization in peripheral access route imaging for annular size estimation as well as investigation of aortic valve calcification and vessel abnormalities.[2] Contrast-enhanced computed tomography (CT) and electrocardiography (ECG)-synchronized scanning are required in cardiovascular CT.

There is wide variation in the scanning acquisition parameters, radiation doses, and image quality in the pre-TAVI CT examination. Several protocols can be used; including prospective ECG gating and retrospective protocols, which have different purposes in clinical practice regardless of the patient's condition. The scanning techniques determine the patient dose and image quality. Annoni et al.[3] assessed the image quality and radiation dose using a low contrast volume in third-generation wide-array CT scanners and reported a mean effective dose of 6.50± 2.60 mSv and good image quality. Schicchi et al.[4] evaluated the image quality and patient diagnostic performance of third-generation dual-source CT (DSCT) with a high ultra-pitch acquisition, and found that this technique was feasible for pre-TAVI CT with a mean effective dose of 3.0 mSv. Because of the standard of practice in pre-TAVI CT, little information is available, and reference diagnostic doses are not available when compared with most common CT procedures. Harries et al.[5] collected pre-TAVI CT data in the United Kingdom, and reported that there were variations in practice among United Kingdom cardiac centers in terms of the acquisition and reporting of pre-TAVI CT data. Because this procedure is still uncommon in Thailand, less information is available in this country, and CT is a modality that provides a high patient radiation dose. This high dose should be taken into consideration if patient safety is to be given priority.

Therefore, this study aimed to investi-gate the effective dose and image quality of pre-TAVI CT.

Material and Methods

This retrospective descriptive study involved patients who were diagnosed with AS and examined by CTA before TAVI at Chulabhorn Hospital. Ethical approval was given by the Human Research Ethics Committee at Chulabhorn Research Institute. The study sample comprised

65 participants aged >30 years who were examined at the Department of Diagnostic Radiology of Chulabhorn Hospital, and underwent a pre-TAVI CT examination from January 2019 to April 2021. The exclusion criteria were a previous, severe reaction to an iodinated contrast media agent, an estimated glomerular filtration rate and creatinine concentration outside of the reference range. Images with inadequate image quality or repeated scans were excluded. Patient characteristics such as age, gender, weight, height, and diagnostic history were recorded.

Pre-TAVI CT studies were performed on a 256-detector row CT scanner (Revolution CT; GE Healthcare, Chicago, IL, USA). No premedication with beta-blockers was used before the CT scan. The pre-TAVI CT examinations involved three scanning phases: the coronary artery calcium (CAC) scoring phase, coronary CTA phase, and whole-aorta CTA phase. The scan parameters were as follows. (1) The CAC scoring phase was performed with prospective ECG triggering with 2.5-mm-thick sections, axial scan mode, 120 kVp, and Smart mA (50–370 mAs) beginning at or immediately below the carina and extending inferior to the heart. (2) The coronary CTA phase was performed with ECG gating or triggering, axial scan mode, 100 to 120 kVp, a rotation time of 0.28 s, Smart mA (250–370 mAs), a noise index of 20, and detector coverage of 160 mm. This phase used the test bolus technique, with the ROI placed at the descending aorta and an enhancement threshold of 150 HU. After 5.9 seconds, the scanner was started. (3) CTA of the aorta and iliac arteries was performed at least from the subclavian arteries to the femoral arteries with 120 kVp, helical scan mode, 45 to 200 mAs, a rotation time of 0.28 s, and detector coverage of 80 mm.

The total mAs, kVp, volume CT dose index (CTDIvol), and dose–length product (DLP) in each scanning phase were recorded. The CTDIvol refers to dose quantities measured in a cylindrical acrylic phantom placed at the scanner isocenter. The CTDI is obtained by using a 100-mm-long pencil-shaped ionization chamber in a 32-cm-diameter phantom to calculate the CTDI for body examinations, which is equal to the weighted CTDI divided by pitch. This value approximates the average dose in the phantom during the helical CT scan that covers the phantom. The DLP is the product of the CTDIvol and scan length (in centimeters); and refers to the total amount of radiation in a CT examination.[6] To perform patient dosimetry, the DLP was used to evaluate the effective dose (mSv). The effective dose was calculated by multiplying the DLP with the conversion coefficient (k); as presented in the European Guidelines on Quality Criteria for Computed Tomography. In this study, conversion factors (k=0.026 mSv/[mGy.cm]) were used, derived from the updated k-factor, to estimate the effective radiation dose accurately in CTA.[7]

For quantitative image analysis, circular regions of interest were placed on six levels of the aorta in the axial images: the aortic root, ascending aorta, descending aorta, subrenal aorta, right femoral artery, and left femoral artery. The CT attenuation value and image noise (standard deviation of CT attenuation) were measured. The signal-to-noise ratio (SNR) is defined as the average attenuation of a vessel divided by the image noise of the CT attenuation of the vessel. Moreover, circular regions of interest were placed on the right lobe of the liver with no vascular structures to calculate the contrast-to-noise ratio (CNR). CNR is defined as the difference between the average attenuation of a vessel and the liver tissue attenuation value, divided by the vessel noise [(mean CT number$_{vessel}$ – mean CT number$_{liver}$)/ mean S.D. of the vessel].[3] For qualitative analysis, the image quality of the aortic root and aortoiliac pathway were rated by two radiologists with >10 years of experience on a 4-point scale: 4, excellent (attenuation of the vessel lumen and clear delineation of vessel walls with no artifacts); 3, good image quality (effect of image noise and limitations of low contrast resolution); 2, fair image quality (reduced image quality; either poor vessel wall definition or excessive image noise); and 1, poor image quality (excessive noise or poor vessel wall definition).[3] The agreement between the two observers was tested by using Cohen's Kappa statistic. The mean effective dose of the two groups was compared by using the paired sample t-test. Spearman rank correlation analysis was used to study the relationship among the variables. Univariate analysis was performed to identify the linear relationship between two variables. All data were processed and analyzed using Stata/SE version 12 software (StataCorp LP, College Station, TX, USA). A p-value<0.05 was considered statistically significant.

Results

Patient characteristics are shown in Table 1. The patients who underwent pre-TAVI CT examination at the Diagnostic Radiology Department in Chulabhorn Hospital comprised 31 men and 34 women, with a mean age of 78.85±6.34 (range, 58.00–90.00) years. The patients' mean weight and height were 58.18±12.01 (33.60–90.00) kg and 158.39±8.93 (140.00–177.50) cm, respectively, and their mean body mass index (BMI) was 23.18±3.84 (13.99–34.72) kg/m^2. The patients' mean creatinine concentration and estimated glomerular filtration rate were 1.32±1.37 (0.38–10.67) mg/dL and 59.89±21.82 (4.40–99.70) ml/min/1.73 m^2, respectively. Their mean heart rate was 73.82±13.11 (42–115) beats/min. The contrast injection parameters were 83.19±16.38 (47.04–126.00) mL by volume and a flow rate of 5.00±1.06 (4.50–6.00) mL/s.

Radiation dose and scanning parameters are shown in Table 2. The mean kVp of the pre-TAVI CT examination was 114.87±3.28; the CAC scoring phase and whole-aorta CTA phase were performed at approximately 120 kVp, while the coronary CTA phase was performed at 103.69±7.82 kVp. The total tube current–exposure time product was 348.02±65.35 mAs; the CAC scoring phase was 98.81±12.10 mAs, with that in the whole-aorta CTA phase being 35.40±32.51 mAs. However, the coronary CTA phase used automatic exposure control to adjust doses up or down, to acquire the optimum level for any given point in a scan. The mean CTDIvol was 23.59±5.19 mGy; in

Table 1 Patient characteristics

Patient information	n or percentage (%)	Mean±S.D.	Range
Gender: male/female	31 (47.69) / 34 (52.31)	-	-
Age, years	-	78.75±6.34	58.00–90.00
Weight, kg	-	58.18±12.01	33.60–90.00
Height, cm	-	158.39±8.93	140.00–177.50
BMI, kg/m^2	-	23.18±3.84	13.99–34.72
Creatinine, mg/dL	-	1.32±1.37	0.38–10.67
eGFR, mL/min/1.73 m^2	-	59.89±21.82	4.40–99.70
Heart rate, beats/min	-	73.82±13.11	42.00–115.00
Contrast volume, mL	-	83.19±16.38	47.04–126.00
Flow rate, mL/s	-	5.00±1.06	4.50–6.00
Medical history			
Mild AS	5 (7.69)	-	-
Moderate AS	1 (1.54)	-	-
Severe AS	56 (86.15)	-	-
Coronary artery disease	3 (4.62)	-	-

S.D.=standard deviation, BMI=body mass index, eGFR=estimated glomerular filtration rate, AS=aortic stenosis that the CAC scoring phase was 4.71±0.89 mGy, which was lower than that of the whole-aorta CTA phase and coronary CTA phase (8.75±2.02 and 10.12±4.57 mGy, respectively). The length of radiation output along the long axis of the patient is shown in terms of the DLP, and the mean DLP was 881.01±193.41 mGy.cm. Additionally, the mean DLP increased in the order of the CAC, coronary, and whole-aorta phase (77.12±36.57, 162.68±75.03, and 641.22±173.32 mGy.cm, respectively). The effective dose calculation demonstrated that the mean effective dose was 22.91±5.03 mSv; with the whole-aorta CTA phase receiving the highest dose, followed by the coronary CTA and coronary artery calcium scoring phases (16.67±4.51, 4.23±1.95, and 2.01±0.95 mSv, respectively).

Image quality results are summarized in Table 3, wherein inadequate image quality or repeated scans were excluded. The overall mean attenuation value in the aortic root, ascending aorta, and descending aorta was >500 HU; whereas, that in the subrenal aorta, right common femoral artery, and left common femoral artery was <500 HU. SNR in the aortic root, ascending aorta, and descending aorta was <20, while that of the subrenal aorta, right common femoral artery, and left common femoral artery was >20. CNR in the aortic root, ascending aorta, descending aorta, and subrenal aorta was <20; whereas, that in the left and right common femoral arteries was >20. Qualitatively, the median Likert quality score was 3.5 in the aortic root and 4.0 in the other aortic segments, with fair to substantial agreement (Cohen's kappa score in the range of 0.29–0.65).

Table 2 Radiation dose parameters

	CAC scoring phase Mean±S.D.	**Coronary CTA phase Mean±S.D.**	**Whole-aorta CTA phase Mean±S.D.**
kVp	120.00±0.00	103.69±7.82	120.92±4.23
mAs	98.81±12.10	Smart mA	135.40±32.51
Scan length, mm	152.06±7.35	160.82±26.19	653.30±60.46
CTDIvol, mGy	4.71±0.89	10.12±4.57	8.75±2.02
DLP, mGy.cm	77.12±36.57	162.68±75.03	641.22±173.32
Effective dose, mSv	2.01±0.95	4.23±1.95	16.67±4.51
	Pre-TAVI CT examination		
	Mean±S.D. (range)	**Median**	**Third percentile**
kVp	114.87±3.28 (113.33–126.67)	-	-
Total mAs	348.02±65.35 (213.30–680.39)	-	-
CTDIvol, mGy	23.59±5.19 (15.74–49.99)	22.71	24.53
DLP, mGy.cm	881.01±193.41 (442.69–1699.60)	862.16	967.41
Effective dose, mSv	22.91±5.03 (11.51–44.19)	22.42	25.15

CAC=coronary artery calcium scoring, CTA=computed tomography angiography, S.D.=standard deviation, CTDIvol=volume computed tomography dose index, DLP=dose-length product, TAVI=transcatheter aortic valve implantation, CT=computed tomography

Table 3 Quantitative and qualitative image quality

Vessel segment	HU Mean±S.D.	Noise Mean±S.D.	SNR Mean±S.D.	CNR Mean±S.D.	Image quality score (median)
Aortic root	588.11±106.16	41.23±8.99	14.70±3.23	12.86±3.08	3.50
Ascending aorta	591.08±107.25	40.33±8.70	15.26±3.98	13.40±3.82	4.00
Descending aorta	565.36±98.79	38.27±8.17	15.31±3.61	13.32±3.24	4.00
Subrenal aorta	491.66±125.22	24.42±7.59	21.37±6.92	17.95±6.80	4.00
Right common femoral artery	480.47±115.38	22.63±7.39	23.87±11.23	20.19±10.41	4.00
Left common femoral artery	475.79±111.27	23.57±11.45	23.90±13.47	20.10±12.37	4.00

HU=Hounsfield units, SNR=signal-to-noise ratio, CNR=contrast-to-noise ratio, S.D.=standard deviation

Discussion

This study investigated the radiation dose in addition to image quality among patients undergoing pre-TAVI 256-MDCT examination at Chulabhorn Hospital. Most of the patients were of advanced age (mean age of 78.75 years), and 86.15% had a history of severe AS. The mean effective dose was not significantly different between men and women (15.6±0.83 and 14.34±0.82 mSv, respectively; p-value< 0.05). Spearman rank correlation analysis showed that the three variables; moderate to strong, correlated with an effective dose were BMI, total mAs, and kVp (Spearman's rho=0.51, 0.81 and 0.51). In the univariate analysis, an increase in BMI resulted in an increase in the effective dose; i.e., a 1-kg/m^2 increase in BMI had a probability of resulting in a 0.42-mSv increase in the effective dose of pre-TAVI CT (ß-coefficient=0.42, R^2=0.11, p-value=0.05). The total mAs is a measure of radiation produced (milliamperage) over a set amount of time (seconds) via an X-ray tube[12]. Whereas, a 10-mAs increase had a probability of a 0.4-mSv increase in the patient's effective dose (ß-coefficient=0.04, R^2=0.54, p-value=0.05). With respect to kVp, a 10-kVp increase had a probability of increasing 6.2 mSv in the effective radiation dose (ß-coefficient=0.62, R^2=0.18, p-value=0.05).

In addition to patient factors (BMI) and scanning parameters, the scanning technique in each scanning phase also affects the patient's effective dose and image quality. Calcium score evaluation is a prospective technique involving partial exposure in the R-R interval to achieve a small amount of radiation. The objective of the CAC scoring phase is to investigate coronary calcium. A high calcium score may affect coronary artery interpretation. For coronary assessment, retrospective ECG gating with exposure on is used for the entirety of the R-R interval during imaging with tube current modulation. These techniques reduce the radiation dose in some phases, which is not used in coronary artery reconstruction. Moreover, the retrospective gating technique is used to assess the ejection fraction and adjust exposure in systole and mid-diastole in the diagnosis of coronary artery abnormalities.[8] In the whole-aorta scanning phase, a non-ECG helical scan was used, with a short scanning time. This scanning phase is required to cover a long length of the aorta, from the subclavian artery to the bilateral femoral arteries; resulting in the highest DLP and affecting the effective dose calculation.

The mean effective dose in this study was found to be 22.91±5.03 mSv in pre-TAVI CT, which is higher than that reported by Shnayien et al.[2], Annoni et al.[3], Schicchi et al.[4], and Kok et al.[8] (Table 4). Shnayien et al.[2] used 80-MDCT with prospective ECG gating, which has less scan coverage and requires more scanning rotation. When compared with Annoni et al.[3], which used the same scanner, they used only 100 kV and scanned in two phases;

however, this study used 100-120 kVp and three scanned phases. Schicchi et al.[4] and Kok et al.[8] used DSCT with a single prospective ECG-triggered acquisition and DSCT, with a retrospective ECG-triggered acquisition and a shorter scanning length. The study by Harries et al.[5] collected protocols from many institutes, consisting of many types of scanners and techniques. The report showed a wide range of effective radiation doses in CT-pre TAVI.

Concerning image quality, the quantitative assessment was good when compared with that of Annoni et al.[3] The mean noise, SNR, and CNR were assessed as baseline information. The mean attenuation value was >500 HU in the aortic, ascending, and descending arteries; however, it was <500 HU in the subrenal and common femoral arteries. Due to the use of the CARE bolus technique (Combined Applications to Reduce Exposure technique) in the coronary CTA phase, there was a delay in restarting the whole-aorta scan; resulting in less enhancement of the lower part. Vascular enhancement depends on the contrast media volume, flow rate, kVp, and patient factors (BMI).[9] A contrast media volume, which is calculated from the weight of the patient, results in good aortic enhancement. In this study, the qualitative assessment ranged from good to excellent in all segments of the aorta. The coronary vessels were not included, because the examination focused on aortic valve measurement evaluation in the systole phase, aortic anatomy and assessing the intervention root before TAVI. For this reason, heart rate had a minimal effect on image quality.

For those who have a high surgical risk, TAVI has become the standard treatment for patients with AS. For successful TAVI, CT imaging guidance before treatment is an important factor in evaluating the prosthesis and peripheral route vessels. Pre-TAVI CT can improve the procedure's effectiveness as well as reduce the duration of exposure to ionizing radiation. Throughout the whole procedure, the patient receives radiation from the TAVI examination itself, pre-TAVI CT, and post-procedure intervention, with the majority of the dose arising from the CT examination.[10] As CT is a high-dose modality, dose evaluation and influencing factors should be considered, and based on the "as low as reasonably achievable" (ALARA) concept.[11,12] Both prospective and retrospective techniques, with a small padding window, or DSCT might be a better way to reduce patient dose in the pre-TAVI CT examination, which should be included in future studies.

Table 4 Mean effective dose of pre-TAVI CT in this study compared with other studies

Pre-TAVI CT studies	Number of detector rows	CTDIvol, mGy Mean±S.D.	DLP, mGy.cm Mean±S.D. or median (range)	Effective dose, mSv Mean±S.D. or median (range)
Present study	256-MDCT	23.59±5.19	881.01±193.41	22.91±5.03
Shnayien et al.[2]	80-MDCT	-	790.90±238.15	13.44±4.05
Annoni et al.[3]	256-MDCT	36.90±15.10	479.10±45.70	6.50±2.60
Schicchi et al.[4]	DSCT	-	201.10±22.70	3.00±0.20
Kok et al.[8]	DSCT	38.00±9.00	521.00±124.00	8.00±2.00
Harries et al.[5]	-	-	882 (524–1688)	13.23 (7.76–25.32)

TAVI=transcatheter aortic valve implantation, CT=computed tomography, CTDIvol=volume computed tomography dose index, DLP=dose–length product, S.D.=standard deviation, MDCT=multidetector-row computed tomography, DSCT=dual-source computed tomography

Conclusion

This study showed that the mean effective dose of pre-TAVI CT examination using 256-MDCT was 22.91 ±5.03 mSv. The image quality in the aorta was good to excellent. The main factors that affected the radiation dose were BMI, total mAs, and kVp. In Thailand, there is still minimal information on dose reporting and the diagnostic reference level. Hence, this present study provides baseline data to develop a local diagnostic reference level, and further adjust to the scanning techniques.

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Conflict of interest

The authors declare that there are no conflicts of interest.

References

1. Latsios G, Spyridopoulos TN, Toutouzas K, Synetos A, Trantalis G, Stathogiannis K, et al. Multi-slice CT (MSCT) imaging in pretrans-catheter aortic valve implantation (TAVI) screening. How to perform and how to interpret. Hellenic J Cardiol 2018;59:3-7. doi: 10.1016/j.hjc.2017.09.013.
2. Shnayien S, Bressem KK, Beetz NL, Asbach P, Hamm B, Niehues SM. Radiation dose reduction in preprocedural CT imaging for TAVI/TAVR using a novel 3-phase protocol: a single institution's experience. Rofo 2020;192:1174-82. doi: 10.1055/a-1150-7646.
3. Annoni AD, Andreini D, Pontone G, Mancini ME, Formenti A, Mushtaq S, et al. CT angiography prior to TAVI procedure using third-generation scanner with wide volume coverage: feasibility, renal safety and diagnostic accuracy for coronary tree. Br J Radiol 2018;91:20180196. doi: 10.1259/bjr.20180196.
4. Schicchi N, Fogante M, Pirani PE, Agliata G, Piva T, Tagliati C, et al. Third generation dual source CT with ultra-high pitch protocol for TAVI planning and coronary tree assessment: feasibility, image quality and diagnostic performance. Eur J Radiol 2020;122:108749. doi: 10.1016/j.ejrad.2019.108749.
5. Harries I, Weir-McCall JR, Williams MC, Shambrook J, Roditi G, Bull R, et al. CT imaging prior to transcatheter aortic valve implantation in the UK. Open Heart 2020;7:e001233. doi: 10.1136/openhrt-2019-001233.
6. Huda W, Mettler FA. Volume CT dose index and dose-length product displayed during CT: what good are they? Radiology 2011;258:236-42. doi: 10.1148/radiol.10100297.
7. Trattner S, Halliburton S, Thompson CM, Xu Y, Chelliah A, Jambawalikar SR, et al. Cardiac-specific conversion factors to estimate radiation effective dose from dose-length product in computed tomography. JACC Cardiovasc Imaging 2018;11:64-74. doi: 10.1016/j.jcmg.2017.06.006.
8. Kok M, Turek J, Mihl C, Reinartz SD, Gohmann RF, Nijssen EC, et al. Low contrast media volume in pre-TAVI CT examinations. Eur Radiol 2016;26:2426-35. doi: 10.1007/s00330-015-4080-x.
9. Mayurasakorn S, Siriapisith T, Wasinrat J. Influence of heart rate on image quality to identify the best cardiac phase in 16-slice coronary CT angiography. J Med Assoc Thai 2008;91:1076-81.
10. Villecourt A, Faroux L, Blanpain T, Kinnel M, Mora C, Tassan-Mangina S, et al. Exposure to ionizing radiation in patients undergoing transfemoral transcatheter aortic valve implantation. Am J Cardiol 2020;125:114-9. doi: 10.1016/j.amjcard.2019.09.028.
11. Miller DL, Schauer D. The ALARA principle in medical imaging. Philosophy 1983;44:595-600.
12. Lewis S. Exposure technique factors in digital X-ray imaging systems: demonstrating the effect of mAs. Afr J Health Prof Educ 2020;12:50. doi: 10.7196/AJHPE.2020.v12i2.1261.