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Clinical Research

Distribution of Calcium in the Ascending Aorta in Patients Undergoing Transcatheter Aortic Valve Implantation and Its Relevance to the Transaortic Approach

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Objectives This study sought to identify how many patients suitable for transcatheter aortic valve implantation (TAVI) would have a contraindication for the transaortic (TAo) approach due to ascending aortic calcification.

Background TAo is an emerging approach for implantation of the Sapien valve through the ascending aorta. A "porcelain aorta" is often considered a contraindication for the TAo approach. This may not always be true, as the TAo procedure requires a small calcium-free area for the purse-string suture, usually in the upper outer quadrant of the distal ascending aorta, identified as the "TAo zone."

Methods A total of 237 patients underwent TAVI between February 2008 and June 2011. Multislice computed tomography scans (MSCT) were analyzed for distribution of calcium with special attention to the TAo zone. Each MSCT was interrogated in cross section and three dimensional (3D) reconstructions. Correlation between the calcium distribution on MSCT and the 3D reconstruction with the clinical findings was sought in patients undergoing the TAo procedure.

Results The vast majority of patients had calcification in the aortic arch (n = 154, 64.9%) and aortic root (n = 220, 92.8%). Of the 237 patients, only 1 patient had diffuse calcification in the ascending aorta, including the TAo zone, thus precluding a TAo procedure. MSCT and 3D reconstruction data in the 33 patients who underwent a TAo procedure, including 6 who were identified as having porcelain aorta preoperatively, correlated very well with the absence of calcium in the TAo zone during surgery. There were no post-procedure neurological events in this group.

Conclusions Conventionally defined porcelain aorta should not be considered a contraindication for performing TAVI by the TAo approach. (J Am Coll Cardiol Intv 2012;5:470–6) © 2012 by the American College of Cardiology Foundation

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Aortic calcification is present in various degrees in almost all patients with atherosclerotic plaques. The incidence varies with the diagnostic method used but lies between 14% and 29% (1). The main risk during cardiac surgery is the occurrence of stroke due to embolization of atheromatous material caused by manipulation of the ascending aorta. Porcelain aorta is at the extreme end of this spectrum and is defined as near-circumferential calcification of the aorta. Although rare (1% to 2%), it poses a unique problem for the surgeons (1,2). The distribution of calcium in the ascending aorta can prevent clamping, cannulation, aortotomy, and/or construction of the proximal anastomosis and is associated with a higher incidence of stroke (3).

For isolated coronary disease, if surgery is the only option, then an "off-pump," no-touch strategy can be employed (3). However, no such options exist for valve surgery other than performing aortic valve and/or ascending aortic replacement under circulatory arrest or performing an apicoaortic conduit (1,3). These options carry a higher surgical and stroke risk (3). Transcatheter aortic valve implantation (TAVI) has emerged as an excellent option for these patients, and successful implantations have been reported using both the conventional approaches, that is, the transapical (TA) and the transfemoral (TF) (4,5).

We have described earlier an alternative approach, that is, the transaortic route (TAo) for TAVI (6,7). This procedure involves performing the procedure through a purse-string suture on the ascending aorta. As it is devoid of clamping and cutting the aorta, the traditional definition of porcelain aorta may not be a contraindication for this procedure. This paper aims to examine the distribution of calcium in the ascending aorta in patients undergoing TAVI using multislice computed tomography (MSCT) and 3-dimensional (3D) reconstruction with special reference to the subset of patients who were identified as having a porcelain aorta, to identify the percentage of patients who have a true contraindication for the TAo technique of TAVI and to determine the accuracy of 3D computed tomography (CT) scan by correlating these with the clinical findings during the procedure.

Methods

All consecutive patients undergoing TAVI at our institute over a 3-year period (February 2008 to June 2011) were included and analyzed. The multidisciplinary heart valve team assessed all referred patients. Pre-operative assessment includes full clinical and laboratory assessment, transthoracic echocardiography, chest x-ray, coronary angiography, carotid Doppler ultrasound, and noncontrast MSCT. Identification of porcelain aorta in a patient was based on fluoroscopy and cross-sectional MSCT images.

Calcium mapping. The ascending aorta was divided into 3 segments, proximal third—from the aortic annulus to the sinotubular junction, middle third—from the sinotubular junction to 5 cm from annulus, and distal third—from 5 cm to origin of the innominate artery. Each segment was further divided into 4 quadrants—anterior, medial, posterior, and lateral (Fig. 1), thus dividing the ascending aorta into 12 zones. The "TAo zone" corresponds to the lateral quadrant and part of the anterior quadrant of the distal third of the ascending aorta. Calcification in the aortic arch (region of the aorta where the 3 head and neck vessels originate) was also documented. All MSCT scans were transferred to and analyzed in detail using the OsiriX MD software (OsiriX, San Antonio, Texas). Mapping of ascending aortic calcification was carried out with aortic segmentation on MSCT for all patients. Two-dimensional scans were reviewed on coronal and sagittal projections on a slice-by-slice basis to determine the exact location and quantity of calcium in the aortic wall (Figs. 2A and 2B). This included maximum intensity projection and multiplanar reconstructions (Figs. 2C and 2D). The availability of volumetric data allowed further processing and generation of 3D volume-rendered reconstructions to assess the absence of calcification in the TAo zone (Figs. 3A and 3B). A

Abbreviations and Acronyms

3D = 3-dimensional
MSCT = multislice computed tomography
TA = transapical
TAo = transaortic
TAVI = transcatheter aortic valve implantation
TF = transfemoral

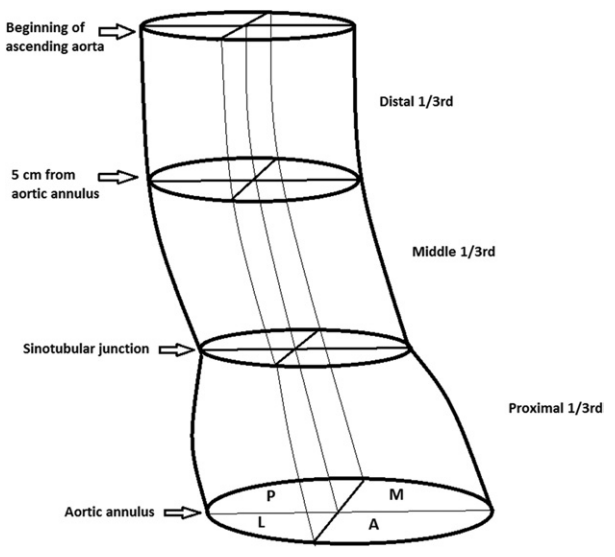

Figure 1. Zones of Ascending Aorta Used for Calcium Mapping

A schematic representation of 3 segments of the ascending aorta (proximal, middle, and distal), which are further divided into 4 quadrants (A = anterior; L = lateral; M = medial; P = posterior), thus resulting in 12 zones.

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Figure 2. MSCT Interrogation for Calcium Mapping

(A) Transverse section of computed tomography (CT) scan through the ascending aorta. **(B)** Sagittal section of the CT scan through the ascending aorta. **(C and D)** Maximum intensity projection and multiplanar reconstructions of the aorta used for the calcium mapping. MSCT = multislice computed tomography.

calcium score could also be calculated, if required, to quantify the amount of calcium. We were interested in mapping the region and surface area covered by calcium but not to quantify the degree of calcification, as the presence of any calcium would preclude that site being used for aortic cannulation. MSCT and 3D reconstructions were used in selecting cases suitable for the TAo approach, that is, when the TAo zone was free of calcium. This was confirmed during the operation with digital palpation.

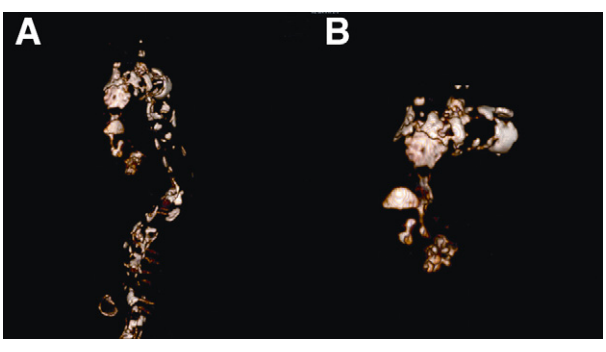

Figure 3. 3D Volume Rendering of MSCT Data

The 3-dimensional (3D) volume-rendered reconstructions to allow the mapping of ascending aortic calcification and to determine absence of calcium in the transaortic zone. **(A)** Extensive calcification of the entire aorta. **(B)** Calcification in the aortic root, part of the ascending aorta and arch. MSCT = multislice computed tomography.

TAo TAVI. The detailed description of the TAo approach is beyond the scope of this paper and has been previously published (6,7). In relation to aortic anatomy, TAo TAVI is performed through a purse-string suture on the aorta, which is placed in an area of the ascending aorta that: 1) is free of calcification; 2) allows the operator to direct the sheath in a straight line to deploy the device; and 3) leaves enough room between the tip of the sheath and the native aortic valve annulus to allow the balloon to expand fully during deployment of the device (Fig. 4). When using the Edwards Sapien device (Edwards Lifesciences, Irvine, California), this is usually a point that is 5 cm from the aortic annulus along the greater curvature of the upper outer quadrant of the aorta, a region that we refer to as the TAo zone (Fig. 4). Thus, the TAo zone is defined as a zone in the anterior and lateral quadrant of the ascending aorta beyond 5 cm from the annulus. When using the CoreValve (Medtronic, Minneapolis, Minnesota), one needs to puncture the aorta 6 to 7 cm from the aortic annulus. This is because the height of a crimped CoreValve is 6.5 cm, but as the valve is deployed, the stent shortens to its final height, which is 5.2 to 5.5 cm, depending on the size of the device chosen.

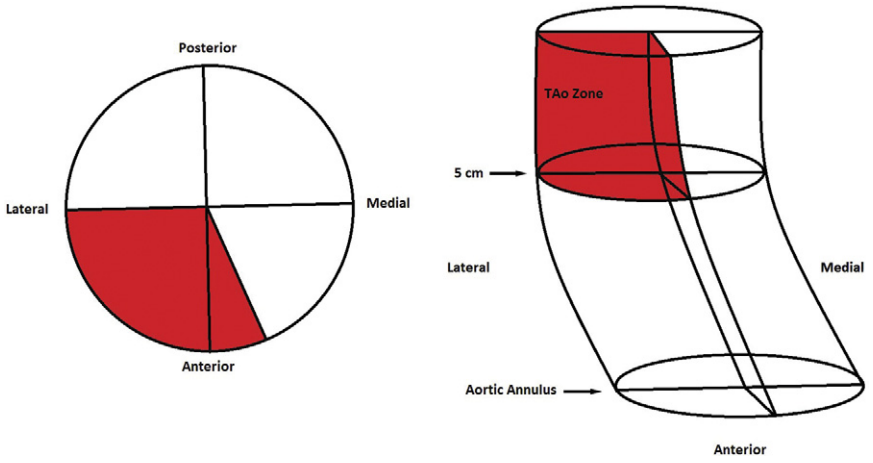

Figure 4. The TAo Zone

A schematic representation of the transaortic (TAo) zone of the ascending aorta (in **red**).

Statistics. Statistical analysis was carried out using the SPSS statistics software version 10.0 (IBM, Armonk, New York). Data are presented as mean ± SD, and confidence intervals for patient variables.

Results

Baseline characteristics. There were 237 patients, of whom 103 (43.4%) had TF, 101 (42.6%) had TA, and 33 (14%) had the TAo approach for TAVI. The mean age at procedure was 82 ± 8.7 years, and the female-to-male ratio was 2:1. All the baseline demographic parameters are outlined in Table 1.

Calcium mapping. The vast majority of patients had calcification in the aortic arch (Table 2). Porcelain aorta patients had more calcium burden than the nonporcelain aorta patients in all 12 segments of the ascending aorta and the aortic arch (Table 2). None of the nonporcelain aorta patients (n = 220) had calcification in the TAo zone of the ascending aorta, which would prevent a safe TAo approach for TAVI. Of the 17 patients with porcelain aorta (TA = 10, TF = 1, TAo = 6), only 1 patient was found to have diffuse calcification in the ascending aorta including the TAo zone, thus precluding a TAo procedure (Fig. 5). This patient had undergone a TF procedure without any neurolog-

Table 1. Demographics and Comorbidities (N = 237)

	TF (n = 103)	TA (n = 101)	TAo (n = 33)	Total
Mean age, yrs	82.3	82.1	81.7	82.0
Age range, yrs	57–96	29–94	44–94	29–96
Female/male	1.86:1	2:1	2:1	1.95:1
COPD	9 (8.7%)	14 (13.8%)	12 (36.3%)	35 (14.7%)
Severe extracardiac arteriopathy	3 (1.65%)	12 (11.8%)	7 (18.7%)	22 (7.3%)
Carotid arteriopathy >50%	12 (11.6%)	25 (24.7%)	12 (34.3%)	49 (20.6%)
Previous CABG	24 (23.3%)	34 (33.6%)	7 (21.2%)	65 (27.4%)
Pulmonary hypertension (moderate–severe)	6 (5.8%)	12 (11.8%)	5 (15.1%)	23 (9.7%)
NYHA functional class III to IV	51 (49.5%)	73 (72.2)%	33 (100%)	157 (66.2%)
CCS class III to IV	2 (1.9%)	7 (6.8%)	5 (15.1%)	14 (5.9%)
Serum creatinine, mg/dl	109.8 ± 10.7	121 ± 16.4	130 ± 25.5	120.2 ± 17.5
Mean LVEF, %	48	48	49	48
Logistic EuroSCORE	19.4	24.8	34.4	26.2

Values are mean, range, n (%) or mean ± SD.

CABG = coronary artery bypass grafting; CCS = Canadian Cardiac Society; COPD = chronic obstructive pulmonary disease; LVEF = left ventricular ejection fraction; NYHA = New York Heart Association; TA = transapical; TAo = transaortic; TF = transfemoral.

Table 2. Calcium Distribution in 12 Zones of the Ascending Aorta I

Anatomical Aortic Segment	Quadrant	Calcification (%)	
		Nonporcelain Aorta (n = 220)	Porcelain Aorta (n = 17)
Proximal third	Anteriomedial	70	88.2
	Posteriomedial	57.2	82.3
	Posteriolateral	62.7	83.3
	Anteriolateral	43.6	88.2
Middle third	Anteriomedial	1	47
	Posteriomedial	3.6	41
	Posteriolateral	0.4	6
	Anteriolateral	0.4	23.5
Distal third	Anteriomedial	33.6	53
	Posteriomedial	19	82.3
	Posteriolateral	30	70.5
	Anteriolateral	0	5.8
Aortic arch		54.5	70.5

ical sequelae. Absence of calcium in the TAo zone in all 33 patients who underwent a TAo procedure, including 6 of 17 with porcelain aorta, correlated very well with the operative findings. None of the patients who underwent TAo TAVI had post-operative neurological events.

Discussion

In the presence of a porcelain aorta, conventional aortic valve surgery can be technically demanding and is associated with a heavy burden of morbidity and mortality

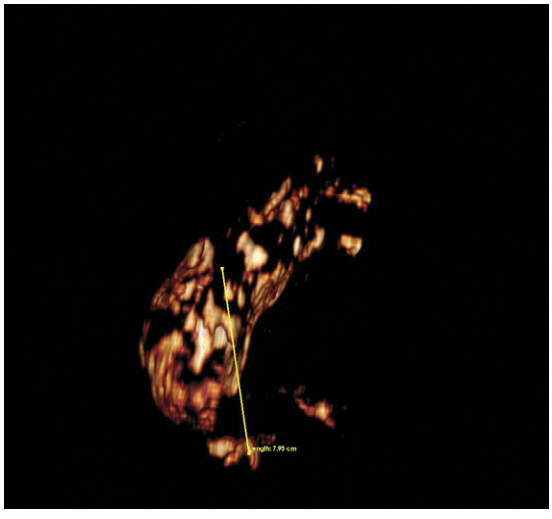

Figure 5. Case Study to Demonstrate Contraindication for TAo TAVI

A 3D reconstruction of MSCT demonstrating diffuse calcification in the entire ascending aorta, including the TAo zone, thus unsuitability for the TAo approach. TAVI = transcatheter aortic valve implantation; other abbreviations as in Figures 3 and 4.

Table 3. Early Patient Outcome After TAVI

	TF (n = 103)	TA (n = 101)	TAo (n = 33)	Overall
Early mortality	7 (6.7%)	7 (6.9%)	2 (6.0%)	16 (6.7%)
New neurological dysfunction	4 (3.8%)	6 (5.9%)	0 (0%)	10 (4.2%)
PPM	2 (1.9%)	3 (2.9%)	0 (0%)	5 (2.55)
Renal failure	6 (5.8%)	13 (12.8%)	4 (12.1%)	23 (9.7%)
Major vascular bleeding	7 (6.7%)	3 (2.9%)	1 (3.0%)	11 (4.6%)
Chest sepsis	7 (6.7%)	5 (5.9%)	2 (6.0%)	14 (5.9%)
ICU stay, days	1	1	0	1

Values are n (%) or median.

ICU = intensive care unit; PPM = prosthesis-patient mismatch; TAVI = transcatheter aortic valve implantation; other abbreviations as in Table 1.

(8). It may be technically impossible for the surgeon to cannulate the aorta for cardiopulmonary bypass safely and/or to cross clamp the aorta. In addition, it may be impossible to perform an aortotomy to access the aortic valve. Hence, for conventional aortic valve replacement, the options are either replacement of the aortic valve and, if necessary, the ascending aorta under deep hypothermic circulatory arrest or an apicoaortic conduit to bypass the aortic stenosis (9–11). This also explains the higher risk of complications, including stroke (8,9).

Patients with porcelain aorta have benefited from TAVI technology. TAVI has been performed through the TF, TA, and subclavian routes in these patients (12–15). The incidence of stroke varies from 4% to 10% (12–15). Kempfert et al. (16) have published their experience with TA in 29 patients who were identified as having a porcelain aorta, using the Edwards Sapien valve. The 30-day mortality was 17.2% with a stroke rate of 3.5%. Buz et al. (17) also evaluated the TA-TAVI in 46 patients with severe aortic calcification. In this series, there was no reported 30-day mortality, with 6- and 12-month survival at 88% and 85.2%, respectively. Brain CT demonstrated new cerebral ischemia in 6.2% of patients, with 1 patient (2.1%) experiencing a stroke. Both the reports, however, do not comment on the distribution and the burden of calcium in the ascending aorta, and hence, it is unclear how many of these would be unsuitable for the TAo approach. In our series, none of our TAo patients (n = 33), including those with a porcelain aorta, (6 of 33), had calcification in the TAo zone; they underwent TAo TAVI without neurological sequelae (Table 3).

The incidence of significant atherosclerotic aorta varies widely from 1.2% to 25% of the population, where, at the severe end of the spectrum, porcelain aorta affects 1% to 5% of patients (1,2). However, identification of a porcelain aorta is largely subjective and hence probably explains the high incidence reported in the TAVI literature (ranging from 10% to 35%) (13–15,17). Fluoroscopy can

Figure 6. Case Study to Demonstrate Inaccuracy of Fluoroscopy in Detecting Calcification

(A) Fluoroscopy demonstrating absence of porcelain aorta. **(B)** Previous noncontrast MSCT demonstrated the heavily calcified ascending aorta. **(C)** Absence of calcium in the anterior wall and TAo zone of the ascending aorta. Abbreviations as in Figures 3 and 4.

be inaccurate in diagnosing a porcelain aorta and at times may fail to show important areas of calcification. This was demonstrated in a clinical case in our series. A 63-year-old patient in our cohort was due for a conventional aortic valve replacement. Fluoroscopy demonstrated some calcification near the left main but no hint of a porcelain aorta (Fig. 6A). On sternotomy, it was discovered that the patient had severe ascending aortic calcification, which made aortic cross-clamping impossible. There was, however, absence of calcium in the anterior wall, especially in the TAo zone. This is demonstrated very well using 3D reconstruction of his MSCT scan (Figs. 6B and 6C). Hence, the patient underwent an immediate conversion to TAo TAVI with an excellent post-procedure result.

MSCT scans have been shown to accurately identify calcification easily. A 3D reconstruction of the MSCT using OsiriX MD software allows an objective assessment of calcium distribution in the ascending aorta and allows measurement of the distance between the aortic annulus and the proposed site of cannulation, that is, the TAo zone (Fig. 7). It has been shown to correlate accurately with the clinical findings (18). Hence, we routinely use MSCT and its 3D reconstruction in selecting patients for the TAo approach. In the vast majority of our patients, this constitutes a noncontrast MSCT that has no impact on the renal system. This was especially evident in the 6 patients who were identified as having a porcelain aorta on fluoroscopy and cross-sectional CT but had a calcium-free TAo zone on 3D reconstruction and hence underwent TAo without neurological events (Fig. 7).

Epiaortic scanning has also been used to detect calcification and plaques in the aorta during open-heart surgery. Van der Linden et al. (19) conducted a very elegant study to correlate the location and extent of calcium in the ascending aorta with post-operative stroke during/after cardiac surgery. Epiaortic scanning of the ascending aorta was performed in 921 consecutive patients who underwent cardiac surgery. The aorta was divided into 12 segments in total. The presence of aortic atheroma (intimal thickening ≥0.5

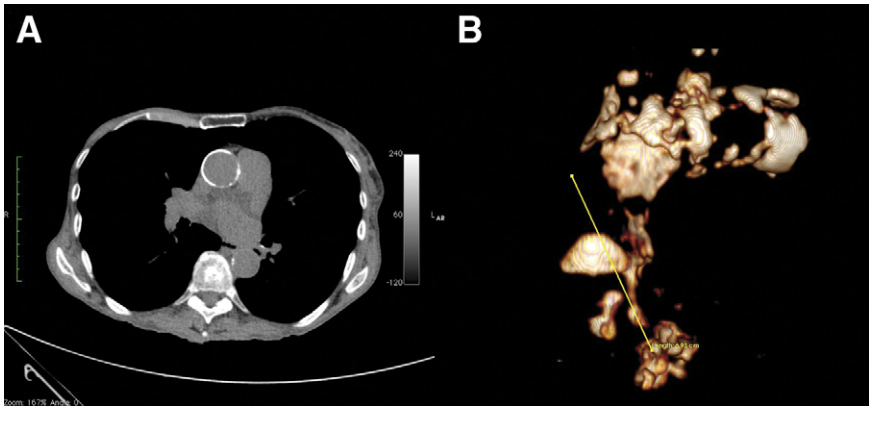

Figure 7. Case Study to Demonstrate That Traditional Definition of Porcelain Aorta Is Not a Contraindication for TAo TAVI

(A) Cross-sectional computed tomography scan shows concentric calcification in the ascending aorta. **(B)** 3D reconstructions demonstrates calcium-free TAo zone hence suitability for the TAo approach. Abbreviations as in Figures 3 and 4.

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mm) and calcification were recorded for each segment. Extent of disease was defined as the number of segments concomitantly involved. A total of 26.2% of the patients had atherosclerosis of the ascending aorta, and in 44% of these, more than 1 of 12 possible segments were involved. The incidence of stroke was 1.8% in patients without atherosclerotic disease of the ascending aorta, and 8.7% in patients with the disease ($p < 0.0001$). Of interest was the lower incidence and intensity of atheroma in the middle and distal lateral segments (which correspond to the TAo zone) when compared with other segments (9.4% and 15.7%, respectively) (19). A few other groups also advocate the routine use of epiaortic scanning to choose the site of aortic cannulation during open-heart surgery to reduce the incidence of stroke (20,21). However, most of this literature predates the widespread use of MSCT that is now a routine investigation in the assessment of patients undergoing TAVI. There is also the easy ability to reconstruct the images to map the aorta in 3D. This allows the clinician to plan the procedure in advance and anticipate problems.

The analysis of MSCT data in our patients indicates that TAo is not necessarily contraindicated in patients with extensive aortic calcification if the TAo-zone is free of plaques and the absence of calcification on MSCT correlates accurately with clinical findings during surgery.

Conclusions

Distribution of calcium in the ascending aorta should be analyzed with MSCT in every patient undergoing TAVI. A 3D reconstruction allows accurate identification and distribution of calcium in the ascending aorta, especially the TAo zone. Conventional definition of porcelain aorta should not be considered a contraindication for performing a TAo procedure if the TAo zone is free of calcium.

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Key Words: aortic calcification ■ aortic stenosis ■ porcelain aorta ■ transaortic ■ transcatheter valve ■ valve replacement.