

Original Article

Description of the aortic root anatomy in relation to transcatheter aortic valve implantation



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ABSTRACT

Introduction: Transcatheter aortic valve implantation (TAVI) has emerged as a less invasive treatment than surgical aortic valve replacement in patients with aortic stenosis. Understanding the anatomy of aortic valve complex may help in optimal positioning of prosthetic valve and circumvent complications that can arise during its implantation. **Material and methods:** The anatomy of aortic root was studied in 30 formalin-fixed cadavers. Aortic root and left ventricular cavity was opened to measure the diameter at the base of aortic root and sinotubular junction (STJ); distance of coronary ostia from base of aortic root and STJ; height and width of aortic valve leaflets; length and thickness of membranous septum (MS).

Results: The diameter of aorta at the base of aortic root and STJ was 22.4 ± 2.1 mm and 21.8 ± 2.4 mm, respectively. The height of aortic leaflets was smaller than the width. The right and left coronary ostia were 10.7 ± 1.9 mm and 10.5 ± 1.9 mm above the base of aortic root. Membranous septum was 4.7 ± 1.23 mm (range 2.9–6.1 mm) long and formed part of the wall of aortic root in 40% (12/30) cases.

Conclusions: Low lying coronary ostia speculate the use of a small prosthesis size to avoid or reduce the degree of coronary compression. Length of MS may help in deciding the extent of devise penetration into left ventricular outflow tract to avoid conduction block. Membranous septum forming wall of aortic root increases the risk of aortic root rupture and iatrogenic membranous defect during TAVI.

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1. Introduction

Transcatheter aortic valve implantation (TAVI) is increasingly being used to treat severe aortic stenosis in high surgical risk patients [1]. Despite its many advantages, TAVI is associated with some procedure related complications. The anatomic proximity of the aortic valve to the conducting system carries the risk of mechanical trauma to atrioventricular node and bundle of His, which may necessitate placement of permanent pacemaker [2,3]. Coronary flow impairment due to obstruction of coronary ostia is another major issue encountered in TAVI. Coronary ostia may be obstructed either due to direct blocking by the implanted aortic valve stent or the sewing cuff; from the native aortic leaflets immobilized against the ostia; or by the displacement of the calcified native aortic leaflets toward the coronary ostia [4–6]. Moreover the stentless bioprosthetic

valves are potentially prone to coronary occlusion during the procedure as the space between the transcatheter heart valve stent and the sinuses of aortic valve is not protected by the struts [7]. Modern TAVI prosthesis are provided in a limited number of sizes, therefore prosthesis size – annulus mismatch, or underestimated prosthesis size, has been related to paravalvular aortic regurgitation, valve migration and aortic root rupture [8–10]. Assessment of the dimensions and anatomy of aortic root with respect to the coronary arteries and the conducting system is mandatory to choose a suitable size for the prosthetic aortic valve and avoid prosthesis related complications of TAVI [9]. Thus, the purpose of this study is to provide a detailed morphometric description of the aortic root.

2. Material and methods

The present study was conducted on 30 human hearts obtained from adult Northwest Indian individuals of both sexes (14 male, 16 female) aged 20–55 years. (mean 31.6 ± 13.1 years). Hearts with any gross abnormalities, pathological changes of aortic valves and/or history of any other cardiac disease were excluded from the study. The aortic root and the cavity of left ventricle were opened longitudinally. The aortic root extends from the aortic annulus to the sinotubular junction and is an ensemble of the aortic valve leaflets, the leaflet attachments, the sinuses of Valsalva, the interleaflet trigones, the sinotubular junction (STJ) and

SUMMARY: Assessment of the dimensions and anatomy of aortic root with respect to the coronary arteries and the conducting system may help in optimal positioning for the prosthetic valve and circumvent complications that can arise during its implantation.

Authors declare that they have no conflict of interest.

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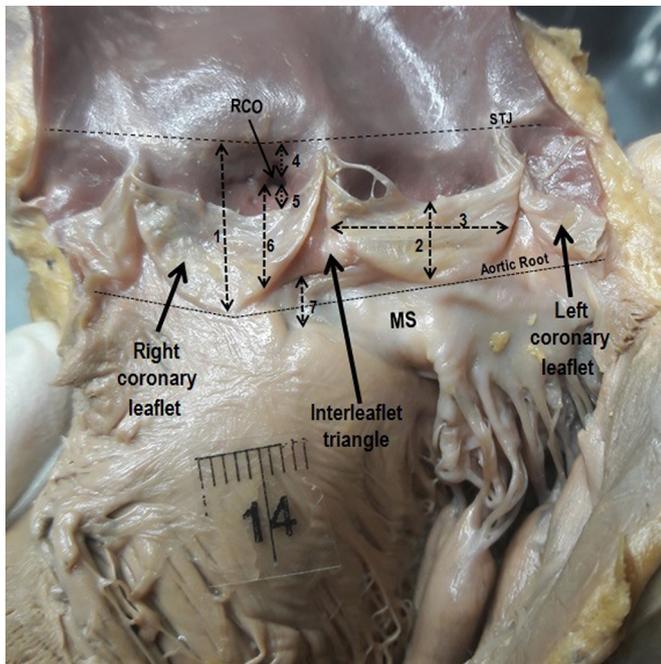


Fig. 1. Opened aortic root and the cavity of left ventricle showing measurements of (a) distance between aortic root and STJ, 1; (b) height of aortic valve leaflet, 2; (c) width of aortic valve leaflet, 3; (d) distance of coronary ostia from the STJ, 4; (e) distance of coronary ostia from aortic leaflet, 5; (f) distance of coronary ostia from aortic root, 6; (g) length of MS, 7. STJ, Sinotubular Junction; MS, Membranous septum.

the annulus. The aortic annulus forms the base of the aortic root and is defined at the level of the basal attachment of the aortic valve leaflets. The STJ is the interface between the aortic root and the tubular ascending aorta. The structures forming the aortic root complex and membranous septum (MS) were identified. We used transillumination to define the boundaries and extent of MS. The circumference of the base of the aortic root and STJ was measured using a thread. Linear measurements were taken with the help of digital Vernier caliper.

Following measurements were made (Fig. 1):

- (i) Circumference at the base of aortic root and STJ (The diameter was calculated using the mathematical formula: circumference / π)
- (ii) Distance between aortic root and STJ
- (iii) Distance of coronary ostia from the base of aortic root, STJ and free margin of the aortic leaflet
- (iv) Height and width of aortic valve leaflets
- (v) Length and thickness of MS

The data was presented as mean values with their corresponding standard deviations (SD) or as number and percentages.

3. Results

The diameter of the aorta at the base of aortic root was 22.4 ± 2.1 mm (range 17.5–24.2 mm), and at the STJ was 21.8 ± 2.4 mm (range 15.2–22.4 mm). The vertical separation between the base of the aortic root and the STJ was 15.5 ± 2.0 mm (range 14.4–20.7 mm). The maximum average height of right coronary, non-coronary, and left coronary aortic leaflet was 10.0 ± 1.8 mm, 10.9 ± 1.3 mm and 9.9 ± 1.1 mm, respectively. The maximum average width of right coronary, non-coronary, and left coronary aortic leaflet was 19.6 ± 3.6 mm, 18.4 ± 3.6 mm and 17.8 ± 2.7 mm, respectively.

The right coronary ostia and left coronary ostia were 10.7 ± 1.9 mm (8.3–15.1 mm) and 10.5 ± 1.9 mm (7.9–13.6 mm) above the base of aortic root. The right coronary ostia was at the level of STJ in 33.3% (10/30) cases and 2.0 ± 1.8 mm below STJ in the remaining 66.7% (20/30) of cases, the left coronary ostia was at the level of STJ in 56.7% (17/30) cases and 1.5 ± 0.9 mm below STJ in the remaining 43.3% (13/30) of cases (Fig. 2). The aortic leaflet partly overlapped the right and left coronary ostia in 26.7% (8/30) cases, and 33.3% (10/30) cases, respectively (Fig. 2a). In the remaining 73.3% (22/30) of cases and 66.6% (20/30) cases, the right and left coronary ostia were 3.05 ± 2.15 mm and 1.84 ± 0.86 mm above the free margin of the aortic leaflet, respectively (Fig. 2b).

The length and thickness of the MS was 4.7 ± 1.23 mm (range 2.9–6.1 mm) and 0.88 ± 0.18 mm, respectively. The membranous septum had variable relationship with the components of aortic root. In 60% (18/30) cases, MS did not extend into the aortic root and was located below aortic annulus (Fig. 3a). It crossed the annulus, forming

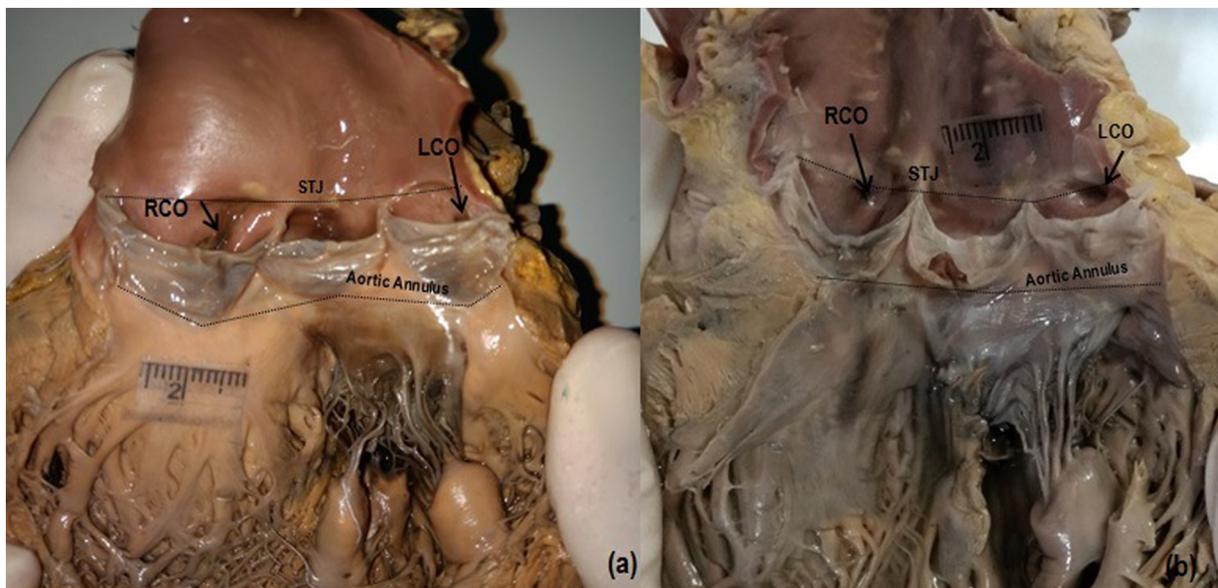


Fig. 2. The right coronary ostia and left coronary ostia located (a) below STJ and partly overlapped by the aortic leaflet; (b) at the level of STJ and above the free margin of the aortic leaflet. STJ, Sinotubular Junction.

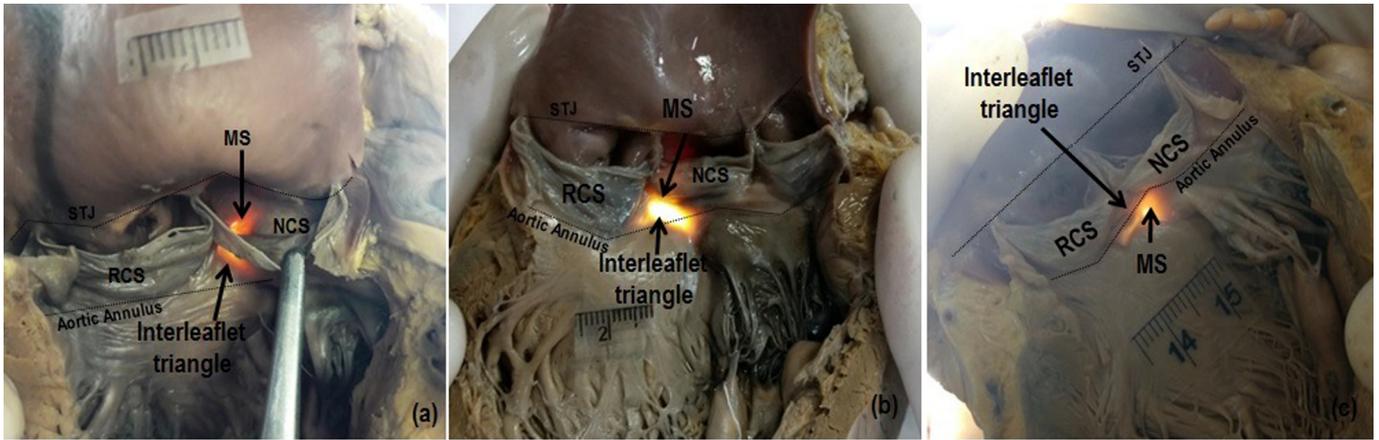


Fig. 3. Membranous septum (MS) (a) located below the aortic annulus(b) projected into the interleaflet triangle between right coronary and noncoronary sinus; (c) projected into the noncoronary sinus deep to the aortic leaflet.

part of the wall of aortic root by projecting into the interleaflet triangle between right coronary and noncoronary sinus in 13.3% (4/30) cases; and projected into the noncoronary sinus deep to the aortic leaflet in the remaining 26.6% (8/30) of cases (Fig. 3b, c). (See Fig. 4.)

4. Discussion

The aortic root dimensions are the most relevant anatomical structure for the appropriate prosthesis selection in patients undergoing TAVI [9]. Migration of the device, when the prosthesis size is too small, or rupture of the aortic valve annulus with large prosthesis size are two potential procedural complications that can be avoided by selecting the best possible size and type of the valve [8,11]. A cadaveric study reported the diameter of aortic annulus to be 20.6 ± 2.2 mm [12]. Another MDCT study on Japanese population reported the diameter of the aorta at the STJ and basal ring to be 22.1 ± 1 mm and 22.6 ± 2.7 mm, respectively [6]. The diameter of aortic annulus (22.4 ± 2.1 mm) and STJ (21.8 ± 2.4 mm) reported in the present study is in concordance with the values of these earlier studies. According to the current sizing information, the annulus measuring between 18 mm and 27 mm are appropriate for the Edwards Sapien valve and Core Valve devices [11]. In the present study the diameter of the basal ring

is about 22 mm which indicates the suitability of the currently available implant devices for TAVI in Northwest Indian population.

Inappropriate height of the transcatheter aortic valve device might lead to suboptimal positioning which could lead to paravalvular regurgitation, embolization into the aorta, perforation of MS or even conduction block [13]. The vertical separation between the basal ring and STJ represents the height of the aortic root complex, and according to our data 1.5 to 2 cm high implant would be suitable for successful TAVI implantation in our population. The height of the aortic root observed in our study (15.5 ± 2.0 mm.) is lower than reported by a cadaveric study (22.6 mm) and another MDCT study (18 mm) [6,14].

Ventricular septal defect is a rare peri-procedural complication of TAVI [1]. In the present study the membranous septum was 0.88 ± 0.18 mm thick and formed the wall of aortic root by projecting above the level of aortic annulus into the interleaflet triangle and noncoronary aortic sinus in 40% of cases. This may form a potentially weak point in the aortic wall in these cases, resulting in aortic root rupture and iatrogenic membranous defect during TAVI.

Low lying coronary ostia in relation to the aortic annulus may be occluded by the displacement of the native aortic cusps during TAVI. There have also been reports of coronary artery obstruction following TAVI due to displacement of previously deployed and degenerated aortic prosthetic valve [15,16]. Pre-procedural evaluation of position of



Fig. 4. Cases depicting (a) maximum, 6.1 mm and (b) minimum, 2.9 mm length of the MS. MS, Membranous septum.

coronary ostia relative to the aortic annulus and aortic leaflet may avoid this fatal complication [6]. The currently recommended minimum height of the coronary ostia from the aortic annulus is 10 mm to proceed safely with the TAVI procedure [17]. A MDCT study on Japanese population reported the incidence of low take off coronary arteries, and observed that the distance of coronary orifice from aortic annulus was ≤ 10 mm in 9.8% of cases and < 5 mm in 1.3% of cases [6].

In the present study, the height of right and left coronary ostia from the aortic annulus was 9 mm in 13.3% of cases and 30% of cases, and 8 mm in 6.67% and 10% of cases, respectively, and may bear the risk of coronary obstruction by the implant device. The distance of the right and left coronary ostia from the basal ring was ≥ 10 mm in 80% and 60% of cases, respectively, and would not suffer from the complication of the post-TAVI coronary obstruction. Okuyama et al. (2013) reported a case of coronary occlusion in which coronary ostium was located sufficiently high from aortic annulus, but had a long leaflet compared to the height of aortic sinus. The ratio between the aortic leaflet length and height of aortic sinus may be a novel predictor of coronary artery obstruction [4]. In the present study, the ratio between the height of aortic leaflet and aortic sinus was less than 1 in all the cases, which indicates smaller height of aortic leaflets than height of aortic sinus and no risk of coronary occlusion by the aortic valve leaflet during TAVI. Muriago et al. (1997) in a cadaveric study described the location of coronary arterial orifices in relation to the aortic valve in 23 cases. They observed the ostium of right and left coronary artery below the STJ in 78% of cases and 69% of cases; above or at the level of STJ in 22% of cases and 31% of cases, respectively [18]. In the present study the coronary ostia were located either below the STJ (right coronary ostia, 66.7% of cases; left coronary ostia, 43.3% of cases) or at the level of STJ (right coronary ostia, 33.3% of cases; left coronary ostia, 56.7% of cases).

Bundle of His running between the lower margin of MS and the summit of muscular interventricular septum, may get damaged during aortic valve implantation which may result in conduction injury, requiring permanent pacemaker implantation [3,19]. Due to the proximity of the aortic root to the left bundle branch and the atrioventricular node, these structures are subjected to direct pressure during the deployment of the bioprosthetic valve over the usually heavily calcified native valve, resulting in significant damage to the conduction system. Injury to left bundle branch along with the previously present right bundle branch block, may favor the development of complete bundle branch block [20]. The left bundle branch block is the most common (10.5%) conduction defect following TAVI [21]. TAVI device implantation within the length of the aortic root, with little penetration beyond the hinge lines of the aortic leaflets into the left ventricle outflow tract is associated with a lower incidence of conduction abnormality [22]. High degree atrioventricular block was seen in 13 cases in which implantation depth of TAVI was greater than the length of MS. A longer MS length indicates a greater separation of aortic annulus from the His bundle, which may allow safe device penetration without any conduction abnormality [3]. In a CT study, the average length of MS was 7.5 mm in patients undergoing transcatheter aortic valve replacement, which is higher than the value observed in the present cadaveric study (4.7 ± 1.23 mm). Valve deployment at a depth of ≤ 6 mm below the aortic annulus is associated with a lower rate of permanent pacemaker implantation after TAVI [23]. We noted that the bundle of His was located at a safe distance (≥ 6 mm) from the aortic root in 30% of cases, and does not bear the risk of injury to the conducting system. The length of MS ranged between 3–5.9 mm in 50% of cases, and was < 3 mm in the remaining 20% of cases, which should undergo lesser penetration of the implant device to avoid any conduction abnormality.

In our population the diameter of the aorta was similar to the Japanese population while the height of the aortic root was found to be less than that of Japanese and Caucasian population. The present study found a high (40%) incidence of low take off left coronary arteries, with less than 9 mm distance between the coronary orifice and aortic annulus [6,14].

5. Conclusions

Preoperative radiological assessment of each case is essential. Despite the availability of individual data by modern radiological methods, the knowledge of base line data for the dimensions of the aortic root would be helpful in TAVI planning and decreasing the number of undersized prosthesis implantations. Ventricular septal defect may be a periprocedural complication of TAVI in 40% of cases, in which membranous septum formed the wall of aortic root; 70% of cases have MS length < 6 mm, and bear the risk of conduction disturbance by greater penetration of the implant device. Low lying right and left coronary ostia in relation to aortic annulus in 20% of cases and 30% of cases, respectively, may bear the risk of coronary occlusion during TAVI.

6. Limitations

The shrinkage effects of formalin fixation may result in underestimating the dimensions of aortic root observed in the present study. This fact further increases the safety margin available to the surgeon. We have not analyzed our data age wise because the sample size is small for that purpose. Due to non-availability of the hearts with aortic stenosis, the authors could not include them in the present study to assess anatomic remodeling induced by aging and abnormal aorta flow.

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