Chapter 2
The Anatomy and Function of the Semilunar Valves

Michael G. Bateman, Jason L. Quill, Alexander J. Hill, and Paul A. Iaizzo

2.1 Introduction

2.1.1 Historical Perspective

In the past century, with the advent of high resolution noninvasive imaging, our understanding of the functional internal anatomy of the body has rapidly progressed. New insights greatly extend beyond the classic work of anatomists such as Galen, Vesalius, Leonardo da Vinci, and more recently Hunter, Gray, and Netter. For a more in-depth description of progress in the understanding of the anatomy and morphology of the cardiac valves, the reader is referred to Chap. 1.

M.G. Bateman, PhD (✉)
Departments of Surgery and Biomedical Engineering, University of Minnesota,
420 Delaware St. SE, MMC 195, Minneapolis, MN 55455, USA

J.L. Quill, PhD
Medtronic, Inc., 8200 Coral Sea St. NE, Mounds View, Minneapolis, MN 55112, USA
e-mail: jason.l.quill@medtronic.com

A.J. Hill, PhD
Cardiovascular, Medtronic, Inc., 8200 Coral Sea St. NE, Mounds View,
Minneapolis, MN 55112, USA

Department of Surgery, University of Minnesota, 420 Delaware St. SE,
MMC 195, Minneapolis, MN 55455, USA

P.A. Iaizzo, PhD
Department of Surgery, Institute for Engineering in Medicine, Lillehei Heart Institute,
University of Minnesota, 420 Delaware St. SE, MMC 195, Minneapolis, MN 55455, USA
e-mail: iaizz001@umn.edu

P.A. Iaizzo et al. (eds.), *Heart Valves: From Design to Clinical Implantation*,
DOI 10.1007/978-1-4614-6144-9_2,

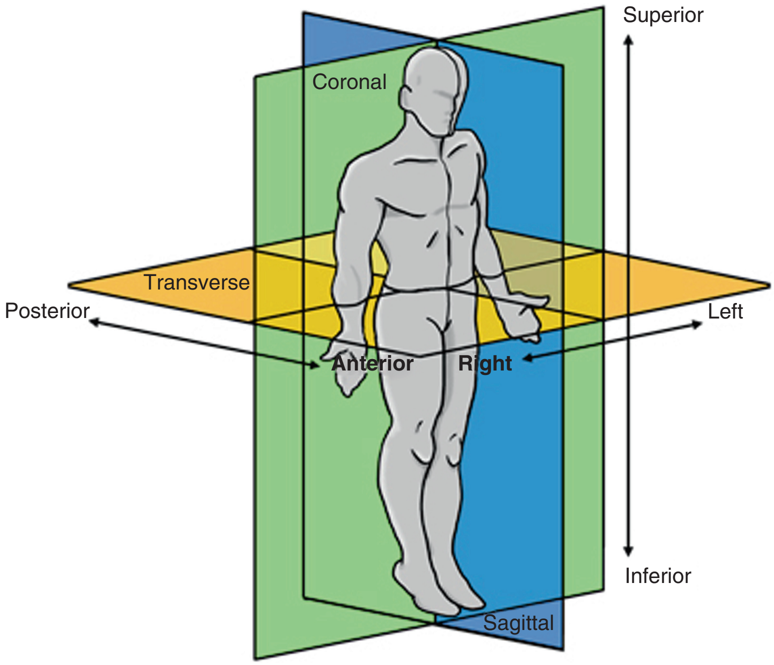

Fig. 2.1 The anatomical planes of the human body (www.vhlab.umn.edu/atlas)

2.1.2 Attitudinally Correct Cardiac Anatomy

As mentioned previously in Chap. 1, the published descriptions of human cardiac anatomy have not adhered to the same fundamental rules of orientation and/or anatomical position as overall gross anatomy. Briefly, the three planes of the body, sagittal, coronal, and transverse (Fig. 2.1), are used to describe the position and nature of almost all other aspects of internal anatomy with respect to the patient's own orientation. Only recently have cardiac anatomy specialists turned away from the traditional labeling of the human heart as though explanted from the body, to now redefine the nomenclature as though the heart was situated within the body (i.e., describe the cardiac anatomical features relative to the body's anatomical planes) [1].

The naming of the cardiac semilunar valves, as seen in Fig. 2.2, has not been directly affected by attitudinally correct nomenclature due to the leaflets of each valve being described by their surrounding anatomies, rather than their position within the heart. For example, the three leaflets of the aortic valve are traditionally named after the coronary arteries that branch from the sinus of Valsalva supplying blood to the left and the right sides of the heart—the left, right, and non-coronary leaflets (Fig. 2.2). More recently due to repeated reports of coronary arteries arising from the posterior sinus, the non-coronary leaflet is referred to as the nonadjacent.

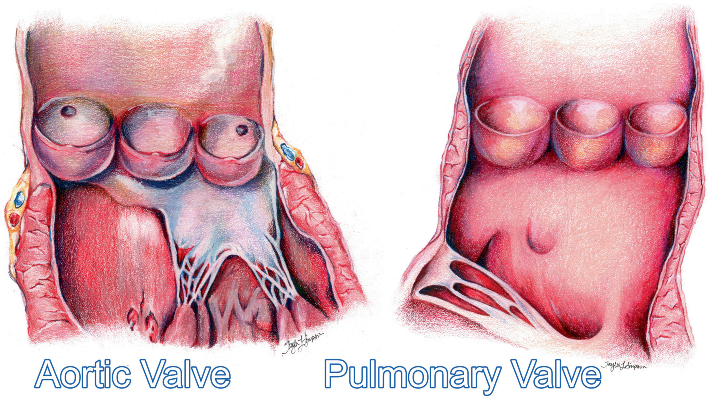

Fig. 2.2 An artist's rendition of the healthy aortic and pulmonary valves clearly showing the leaflets, sinuses, outflow tracts, and arterial trunks

Further, due to its oblique positioning in the body, the pulmonary valve leaflets are not named according to the sagittal, coronal, and axial planes, but have rather been described by their relationships to the aortic valve [2]. In a normal anatomical orientation, the right and left coronary cusps of the aortic valve face the septum between the right and left chambers. These leaflets are usually opposed by two leaflets of the pulmonary valve, hence these two leaflets of the pulmonary valve are labeled the "right and left facing leaflets." The third leaflet of the pulmonary valve is consequently labeled the *nonfacing leaflet* to complete the trifecta. The specific anatomies of each semilunar valve will be described in more detail later in this chapter.

2.2 The Cardiac Skeleton

The cardiac valves are situated in close proximity to each other, shown in Fig. 2.3, and as with the atrioventricular valves, it is important to carefully describe the anatomical framework that holds these valves in position [2].

Understanding the specific anatomies of the arterial valves requires an appreciation of their ventricular supporting structures themselves. Only part of this support is provided by the so-called fibrous skeleton (Fig. 2.4). In the human heart, the components of the skeleton support the aortic-mitral unit, binding it into the roof of the left ventricle. Inconstant cords of fibrous tissue then extend from the margins of the fibrous continuity between the aortic and mitral valve to support the mural (anterior) leaflet of the mitral valve. It has been described previously by the authors that the position of the aortic valve within the cardiac base makes it the centerpiece of the organ [3]. The central fibrous body, the strongest portion of the cardiac skeleton, is formed by the union of the right fibrous trigone with the membranous part of the ventricular septum. The right trigone itself is the rightward end of the area of fibrous

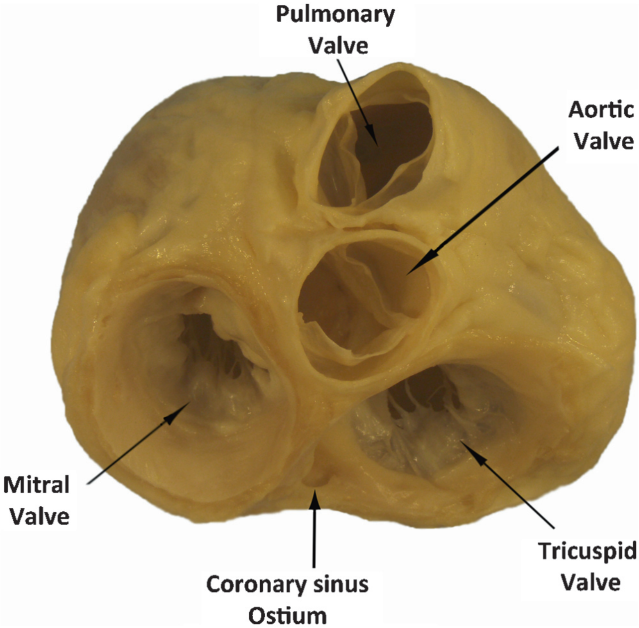

Fig. 2.3 An anatomical plate of a human heart with the atria and great arteries removed showing the relationship between the four valves at the base of the heart

continuity between the leaflets of the aortic and mitral valves. The smaller left fibrous trigone is formed at the leftward end of this zone of fibrous continuity [3].

The leaflets of the pulmonary valve have no direct fibrous support other than that provided by the valvar sinuses. The basal components of each leaflet are supported by the right ventricular infundibulum. It is this unique positioning of the pulmonary root away from the other valvar structures that makes possible its surgical removal during the Ross procedure, while the presence of the supporting skirt of infundibular musculature facilitates its use as an autograft to replace the aortic valve [3].

2.3 Anatomical Features of the Semilunar Valves

In the most basic anatomical sense, a healthy semilunar valve is composed of three valve leaflets, each attached to its respective sinus, as visualized in Fig. 2.2. These valves lie between the ventricular outflow tracts and the arterial trunks, the main arteries carrying blood away from the heart. This elegant structure is much simpler than that of the atrioventricular valves described in Chap. 1, in that the semilunar valve leaflets do not require a tension apparatus to maintain competency. When closed, the three leaflets of each valve co-apt along zones of apposition or *commissures*, which are fibrous zones some distance from the free edge of the leaflets. At the center of the valve where all three leaflets co-apt, a distinct fibrous nodule can be

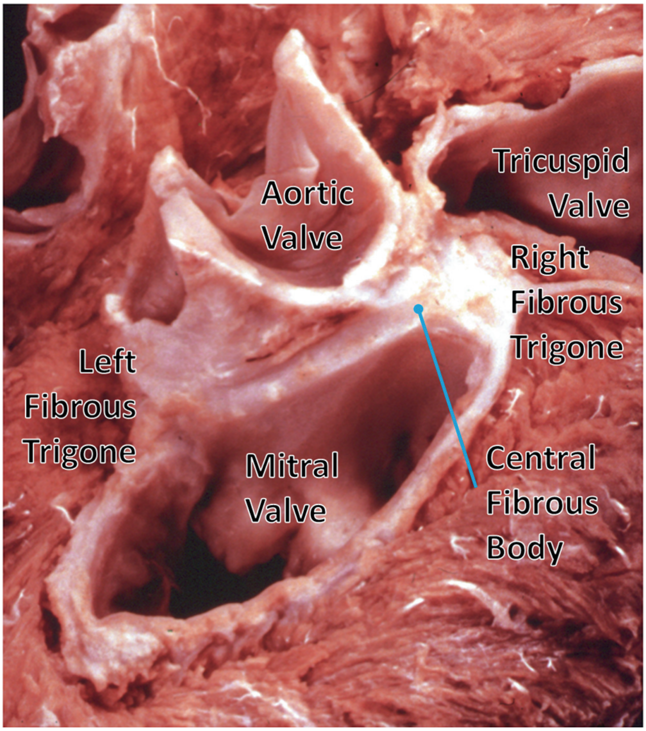

Fig. 2.4 Dissection of the cardiac base with the atrial walls and great vessels removed. It shows the coronet shape of the aortic root and its relationship with the mitral valve. The image is reproduced by kind permission of Professor Robert H. Anderson, and was published initially in "Cardiac Anatomy" [34]. This figure was published in Cardiac Anatomy: An Integrated Text and Colour Atlas, RH Anderson, AE Becker, and SP Allword, page 239, © Elsevier 1980

found in the center. The valve leaflet margins are attached to the arterial wall in the shape of a half-moon, hence the *semilunar* moniker. Normally, the regions of the valves where the commissures meet the arterial wall are considerably higher than the seats of the leaflets, thereby giving the valve a crown-like shape. These three points, particularly in the aortic valve, are used to define the sinutubular junctions (Fig. 2.5). Although we have discussed the positioning of the valves in the heart by referring to their respective annuluses, many anatomists contest the idea that there are single defined annuluses for both the pulmonary and aortic valves [4]. Interestingly, there is a defined annulus where the respective arteries are attached to the ventricular outflow tract; however, due to the crown-like structure of the valve, the hemodynamic junction of the valves spans this annulus. This structural shape results in part of the arterial wall being considered a ventricular structure (in a hemodynamic sense) and part of the ventricular wall (hemodynamically an arterial structure). Just distal to the valves are the *arterial sinuses* that are represented by dilations of the artery positioned above each leaflet and additionally house the coronary artery ostium. The sinus also provides a recess for the valve leaflets to retract into, allowing for

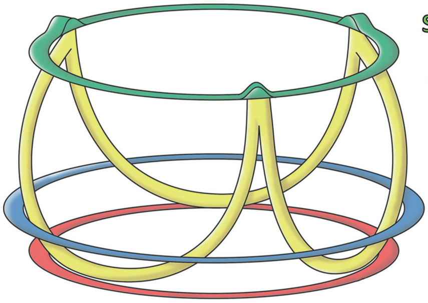

Fig. 2.5 Idealized three-dimensional arrangement of the semilunar valve (this diagram represents an aortic root). The model contains three circular *rings* with the leaflets suspended within the root in crown-like fashion. The cartoon is reproduced by kind permission of Professor Robert H. Anderson, who retains the intellectual copyright in the original image [3]. We acknowledge the excellent artwork created by Gemma Price. This same figure is being published in two Springer publications at the same time (Heart Valves: From Design to Clinical Implantation and The Clinical Anatomy and Pathology of the Human Arterial Valves: Implications for Repair or Replacement, J Cardiovasc Transl Res, MG Bateman, AJ Hill, JL Quill, and PA Iaizzo, 2013 Jan 17 [Epub ahead of print], PMID: 23325456)

unrestricted flow from the ventricle to the artery. Finally, the virtual ring, upon which many annular measurements are based and which defines the basal plane of aortic valve, is defined by the three anatomical anchors at the nadir of each aortic leaflet [5]. These features are illustrated by the diagram in Fig. 2.5. The position and definition of the valve annulus is often contested by different medical specialists and a recent questionnaire highlighted the current lack of consensus between physicians regarding the optimal means of describing the semilunar valve anatomy [6]. As such it is important to be precise in the definition of exactly what is being measured when documenting the size and shape of the semilunar valve annuluses.

2.3.1 The Functioning of the Semilunar Valves

When a semilunar valve is functioning correctly, the leaflets are pushed into the sinus during myocardial contraction (systole) to allow blood to leave the ventricles. As the myocardium relaxes and the pressure within the ventricle drops below the pressure distal to the valve in the arterial system (the aorta or pulmonary artery), the valve snaps shut. This usually happens soon after ventricular systole but before the heart has completely relaxed, so that during diastole, when the chambers are filling through the atrioventricular valves, the leaflets of the semilunar valves remain tightly closed. A positive pressure difference between the aorta and the coronary sinus, which lies within the right atrium, allows for the flow of blood through the coronary vasculature. Thus, it should be noted that the heart muscle is perfused with blood when the semilunar valves are closed and the cardiac myocytes are relaxing.

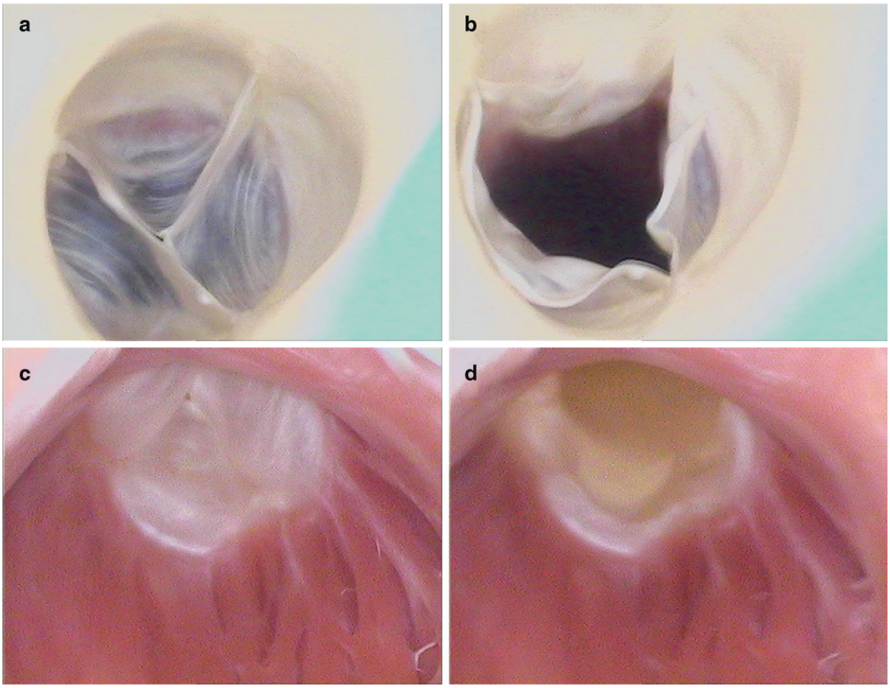

Fig. 2.6 Internal videoscopic images of the pulmonary valve from above (**a**, **b**) and below (**c**, **d**) during systole (**a**, **c**) and diastole (**b**, **d**) obtained employing Visible Heart® methodologies

Figures 2.6 and 2.7 show image sequences of the functional movements of the pulmonary and aortic valves respectively; these images were obtained from reanimated human hearts employing Visible Heart® methodologies [7, 8]. See Chap. 15 for an in-depth description of this technique. The images include views of semilunar valves from above (i.e., from videoscopes within the pulmonary artery and the aorta) and from below (with videoscopes within the right and left ventricular outflow tracts).

In general, dysfunctions of the semilunar valves are usually characterized by one of two symptoms: failure of the valves to successfully close or failure of the valves to successfully open. Such dysfunctions of the valves during systole, i.e., failure of the valve to successfully open, are defined as *stenosis* of the valve. This pathology is characterized by reduction in the effective orifice area of the valve (the size of the opening that allows blood to pass), which in turn forces the ventricles to work harder to move blood to the body or lungs. Dysfunctions of the semilunar valves during diastole, when the ventricles are relaxing, result in *regurgitation*; this occurs when blood is allowed back into the ventricle from the arterial system, overloading the ventricles and potentially causing chronic heart failure. These pathologies are described in more detail in Chap. 6.

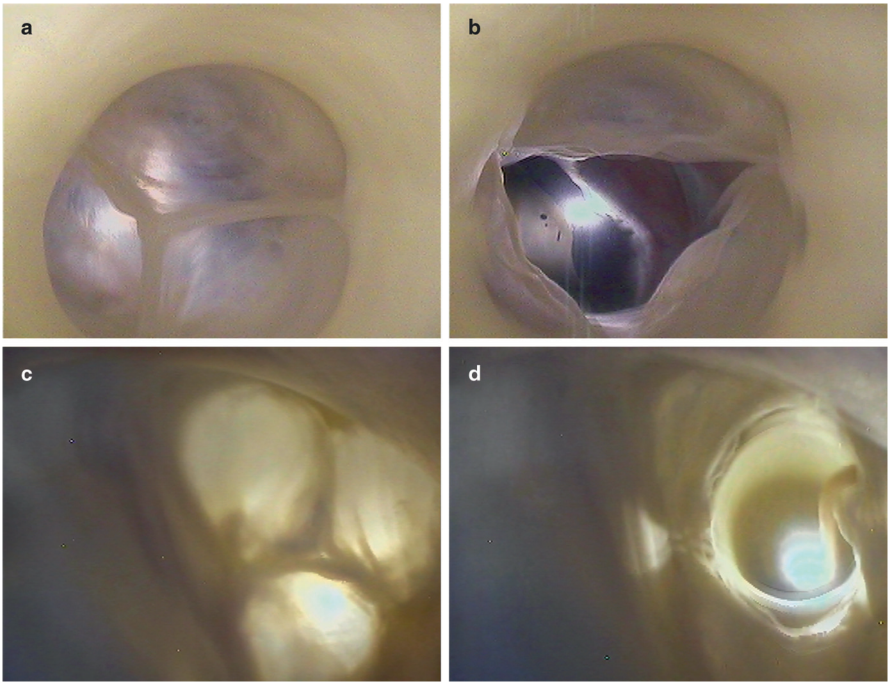

Fig. 2.7 Internal videoscopic images of the aortic valve from above (**a**, **b**) and below (**c**, **d**) during systole (**a**, **c**) and diastole (**b**, **d**) obtained employing Visible Heart® methodologies

2.3.2 Histologic Features of the Semilunar Valves

It was Gross who first drew attention to the specific histological structures of the arterial valves, his account then being endorsed by others such as Misfeld and colleagues [9, 10]. Each leaflet of the semilunar valve has a fibrous core, or *fibrosa*, with an endothelial lining containing delicate sheets of elastin on its arterial and ventricular aspects. This so-called fibrous "backbone" is represented by a dense collagenous layer, which gives way to a much looser structure, or *spongiosa*, toward the ventricular aspects of the leaflet cusps. The zone of apposition of the leaflets consists of an abrupt thickening of the fibrous layer made up of closely packed vertically directed fibers and builds at the central portion of the free edge, creating a node termed the *Nodulus Arantii* [9, 10]. Figure 2.8 displays a cross-section of an aortic valve leaflet displaying the varying tissue types [11].

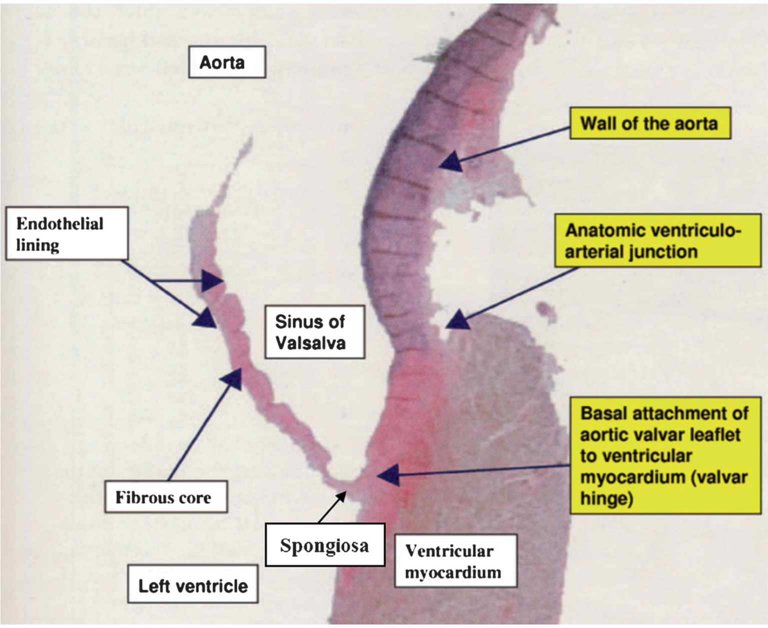

Fig. 2.8 Histologic features of the aortic valvar complex showing the anatomic ventriculoarterial junction. Also note that the basal attachment of the aortic valvar leaflets to the ventricular myocardium is proximal relative to the anatomic junction [11]

2.4 The Aortic Valve

As previously mentioned in the chapter, due to its location in the center of the heart between the mitral valve and the tricuspid valve, the aortic valve is considered as the "centerpiece" of the heart and is often considered the most important cardiac valve with respect to normal cardiac function [11].

2.4.1 The Aortic Root

The aortic root contains three circular rings and one crown-like ring (Fig. 2.5) [4]. The connection of the leaflets to the arterial wall mimics the shape of a crown, whose base forms a virtual ring known as the basal plane of the valve. This plane represents the inlet from the left ventricular outflow tract into the aortic root. The top of the crown can be considered as a true ring, the sinutubular junction, defined by the sinus ridge and the related sites of attachment of the peripheral zones of

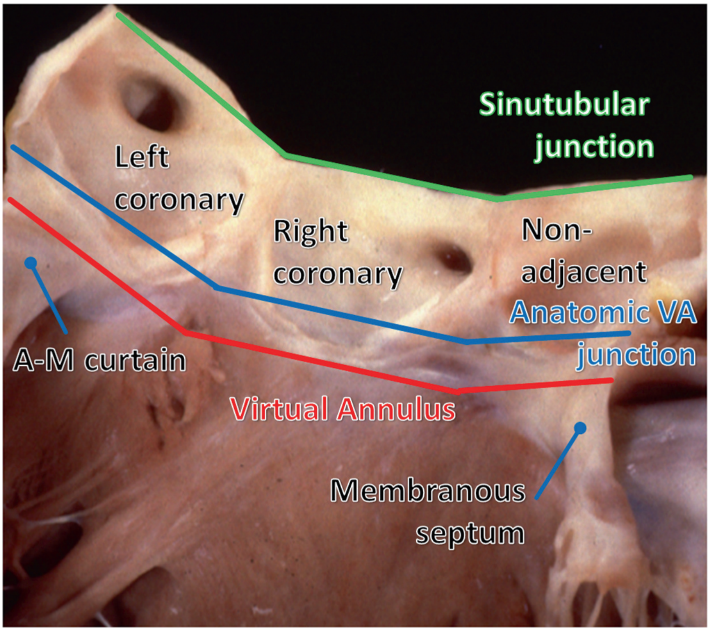

Fig. 2.9 The aortic leaflets have been removed from this human aortic root specimen; one can then observe the locations of the three defined aortic rings, i.e., relative to the crown-like hinges of the leaflets. A-M = aortic-mitral, VA = ventriculoarterial [3]. Image was modified from an original figure provided by Professor Robert H. Anderson; Professor Anderson retains the intellectual copyright of the original image

apposition, between the aortic valve leaflets [11]. Hence the sinutubular junction dictates the transition from the aortic root into the ascending aorta. The semilunar hinges then cross another defined "ring" known as the anatomic *ventriculoarterial* junction. This overall anatomic arrangement is described previously in Fig. 2.5, but can be readily observed when the aortic root is opened linearly as seen in Fig. 2.9.

The normal aortic root elicits a relatively consistent shape between patients, but can vary dramatically in size (Table 2.1). Kunzelman et al. demonstrated a definable mathematical relationship between root diameter and clinically measurable leaflet dimensions [12]. In general, the diameter at the level of the sinutubular junction typically exceeds that at the level of the basal plane by a factor of 1:1.6 [12, 13]. The valvar complex is a dynamic structure with its geometric parameters changing continuously throughout the phases of the cardiac cycle and relative to the associated changes in pressure that will occur within the aortic root [14]. For example, from diastole to systole, the relative changes in diameter at the level of the sinutubular junction and at the *ventriculoarterial* junction has been noted to increase by ~12% and decrease by ~16%, respectively [15–17]. Additionally, the orientation of the left ventricular outflow tract and the aortic root (i.e., the angle between the two) is known to vary from patient to patient. It is also understood that this angle becomes

Table 2.1 Data on the aortic valve annulus, sinus of Valsalva, and sinutubular junction measured using multislice computed tomography

Measured anatomical feature	Data (mm)	Sample size
Maximum aortic annular diameter [5, 27]	26.9 ± 2.8	$N=25$
	26.4 ± 2.8	$N=150$
Minimum aortic annular diameter [5, 27]	21.4 ± 2.8	$N=25$
	24.0 ± 2.6	$N=150$
Sinus of Valsalva mean diameter [27]	32.3 ± 3.9	$N=150$
Sinus of Valsalva height above the basal plane [27]	17.2 ± 2.7	$N=150$
Sinutubular junction mean diameter [27]	28.1 ± 3.1	$N=150$
Sinutubular junction height above basal plane [27]	20.3 ± 3.1	$N=150$

more acute with age. Middelhof et al. reported that hearts from individuals aged >60 years exhibited angles between 90 and 120°, whereas individuals aged <20 years presented with angles between 135 and 180° [18].

It is important to note that one of the most critical functions of the aortic root is to facilitate coronary artery perfusion during ventricular diastole. This is achieved by directing 3–5% of the circulating blood through both the left and right coronary arteries while the aortic valve itself is closed. In general, the orifices of the coronary arteries arise within the two anterior sinuses of Valsalva, usually positioned just below the sinutubular junctions [13, 19, 20]. However, it is not unusual to find these arteries positioned superior relative to the sinutubular junction. Cavalcanti et al. reported the mean distances measured from the orifice of the left coronary artery to the basal attachments of the corresponding leaflets were 12.6 ± 2.61 mm, and for the right coronary artery they were 13.2 ± 2.64 mm in 51 normal postmortem hearts [21]. Variations in coronary arterial origin, nonetheless, can occur with some of these configurations posing as risk factors in sudden cardiac death [22, 23]. It should also be recalled that it is the location of these coronary arteries that dictates the naming of the aortic valve leaflets/cusps—the left coronary, the right coronary, and the non-adjacent (or non-coronary).

2.4.2 The Aortic Leaflets

As noted above, the leaflets of the aortic valve are named for the branching coronary arteries that feed the left and right sides of the heart (Fig. 2.2). More specifically, both the right and left leaflets attach to the aortic root in the predominantly muscular region of the left ventricular outflow tract, whereas the non-adjacent leaflet is chiefly attached to the fibrous region above the membranous septum (Fig. 2.9). This fibrous continuity connects the aortic valve to the anterior (aortic) leaflet of the mitral valve, forming the aortic-mitral curtain. The zone of apposition of the right leaflet to the non-adjacent leaflet is positioned above the membranous part of the ventricular septum. The zone of apposition of the non-adjacent leaflet with the left coronary aortic leaflet is adjacent to the anterior wall of the left atrium. The left leaflet then continues towards the right leaflet, again achieving support from the muscular part of the ventricular septum. As previously mentioned the zones of apposition themselves ascend as they extend to be attached peripherally at the sinutubular junction and below each peripheral attachment there is a fibrous interleaflet triangle that forms part of the ventricular outflow tract [24].

It should be noted that variations may exist in all aspects of the aforementioned dimensions of individual leaflets, including (1) height; (2) width; (3) surface area; and (4) volume of each of their supporting sinuses of Valsalva [11]. Vollebergh et al. reported that the average widths (measured between the peripheral zones of attachment along the sinus ridge) for the right, the non-adjacent, and the left coronary leaflets were 25.9 mm, 25.5 mm, and 25.0 mm, respectively, in an investigation of 200 normal hearts [25]. It was also described that the average heights (measured from the base of the center of the leaflet to their free edges) for the right coronary, non-adjacent, and left coronary cusps were 14.1 mm, 14.1 mm, and 14.2 mm, respectively. Such variations in the leaflet dimensions of healthy valves highlight the need to focus on the anatomy and function of each leaflet when developing prosthesis for either the surgical or transcatheter treatment of aortic valve pathologies.

2.5 The Pulmonary Valve

Due to its relative location within the infundibular musculature (at the distal portion of the right ventricular outflow tract), the pulmonary valve is considered, in an anatomical sense, a more simple valvar structure than the aortic valve. The left and the right leaflets of the aortic valve face lie adjacent to the pulmonary trunk, and this relative anatomic orientation has been used to name the pulmonary valve leaflets: the right and left facing leaflets and the nonfacing leaflet (Fig. 2.10) [2]. Anatomically, the commissure of both the right and left leaflets are supported by the supraventricular crest of the right ventricle, which separates the pulmonary valve from the tricuspid valve. Further, the opposite edge of the valve (i.e., the nonfacing leaflet is supported by the anterior wall of the infundibulum), is in general the most anterior part of the heart [2].

Pulmonary valve replacement is considered by most to be less challenging than aortic valve replacement due to the lower pressure gradient across the valve and the relative ease of access to the valve annulus. The ease of complete valve removal from the cardiac base has led to the use as an autograft replacement for the aortic valve in some congenital heart patients. Even so, information on the valve is less abundant and reports on variations in valve dimensions are less comprehensive. Capps et al. report the mean diameter of the valve as 25.4 ± 3.2 mm in a study comparing the size of the aortic and pulmonary valve to the overall body surface area (Table 2.2). It should be noted that these measurements were taken on valves removed postmortem using a Hegar dilator without annular dilation. By the authors' admission, this

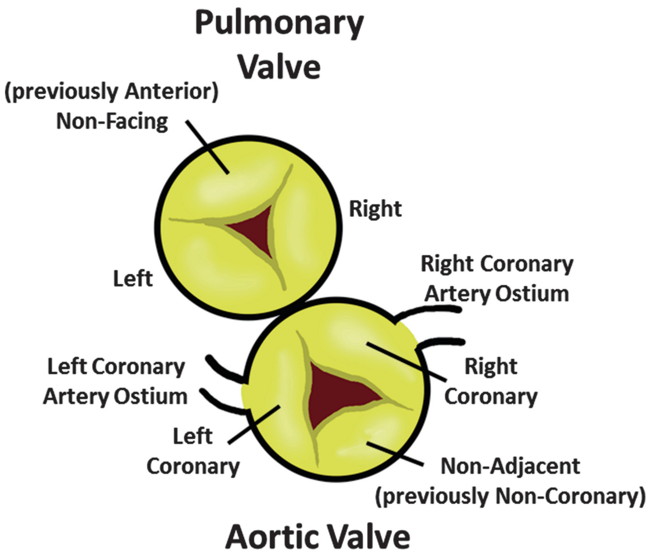

Fig. 2.10 The nomenclature for the individual leaflets of both the aortic and pulmonary valves

Table 2.2 Post mortem mean pulmonary and aortic diameters

Measured anatomical feature	Data (mm)	Sample size
Mean annular diameter [26]	25.4 ± 3.2	*N* = 3997
Mean aortic annular diameter [26]	22.4 ± 2.7	*N* = 3370

sizing presents limitations regarding the material properties of the pulmonary annulus differing significantly from the aortic [26]. As such, these measurements should be used as a rough guideline and the alternate methodology explains the difference in the aortic measurements reported here from those measured at end systole in vivo by Schultz et al. and Tops et al. [5, 27] shown in Table 2.1.

2.6 Semilunar Valve Co-location

When one is considering performing semilunar valve surgeries and/or contemplating novel percutaneous approaches to valvar repairs, it is vital to have strong anatomical appreciation of the associated structures, i.e., those cardiac structures that surround either aortic or pulmonary valves. The important anatomical structure related to the pulmonary root is the first perforating branch of the anterior interventricular artery; this artery is avoided during the Ross procedure. Note should also be taken of anomalous coronary arteries either coursing between the arterial roots or extending across the right ventricular infundibulum. Being located in the most anterior aspect of the

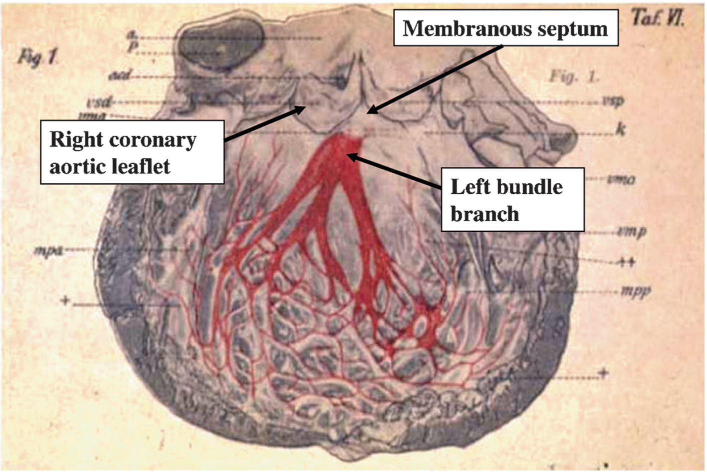

Fig. 2.11 Tawara's anatomical diagram of the left bundle branch showing the conduction system exiting from the base of the aortic valve between the nonadjacent and right coronary leaflets. It then branches out and descends along the septal, endocardial surfaces of the left ventricular myocardium [11, 23]

heart, the pulmonary root is also directly adjacent to the sternum [3]. Additionally, being the most anterior portion of the heart, this valve lies just beneath the patient's sternum, thus sternal compression may alter the performance of any prosthesis placed in the pulmonary annulus.

Nevertheless, the anatomical orientation of the aortic valve is considered much more challenging, thus the remainder of this section will focus on this valve. One of the most important and complex structures in proximity to the aortic valve is the *cardiac conduction system*. Within the right atrium, the atrioventricular node is located within the *triangle of Koch*, a region demarcated by the tendon of Todaro, the attachment of the septal leaflet of the tricuspid valve, and the orifice of the coronary sinus. Within this region the atrioventricular node penetrates the central fibrous body just inferior to the apex of the triangle and adjacent to the membranous septum. This situates the atrioventricular node in close proximity to the subaortic region of the left ventricular outflow tract helping to explain why the treatment of pathologies involving the aortic valve may lead to either a complete heart block or to an intraventricular conduction abnormality [11]. Further, as the atrioventricular conduction axis reaches the crest of the muscular ventricular septum it then branches, with the left bundle branch cascading down the left ventricular septal surface, as illustrated so elegantly by Tawara over a century ago [28] (Fig. 2.11). Thus, it is important that this anatomical relationship be considered when planning the repair and/or replacement of the aortic valve as the interaction of a specific percutaneous prosthesis or the errant placement of sutures during surgical valve implantation can both induce adverse effects on the conduction system and result in the patient requiring cardiac rhythm management.

In addition to the conduction system, an intimate knowledge of the aortic valve's proximity to both the coronary arteries and the mitral valve helps to minimize procedural complications.

In particular, the main stem of the left coronary artery can be remarkably short, bifurcating into the left anterior descending and circumflex arteries in close proximity to the root [3]. In the instance of transcatheter valve deployment, the prosthesis typically will crush the leaflets of the native valve against the aortic wall. Consequently, the combination of a relatively low-lying coronary artery ostium and a large, heavily calcified native aortic leaflet can lead to obstruction of the flow into the coronary arteries [11].

2.7 Common Clinical Imaging of the Semilunar Valves

Echocardiography not only provides anatomic information but also reveals functional aspects, and will continue to be the modality of choice when first assessing the health of the semilunar valves [29]. Briefly, the aortic valve can be readily viewed with echo from the apical, parasternal long-axis, and suprasternal views, whereas the pulmonary valve is usually imaged from the parasternal long-axis view (Fig. 2.12), allowing the echocardiographer to assess the following valve criteria [30]:

- Size and shape of the annulus.
- Number and mobility of the leaflets, in particular whether they show restricted motion. This assessment will also include exclusion of thickening calcifications, fusions along zones of apposition, and/or leaflet damage.
- Whether the functioning of the ventricles is normal, globally deranged, or shows evidence of regional abnormalities of motion of the walls.

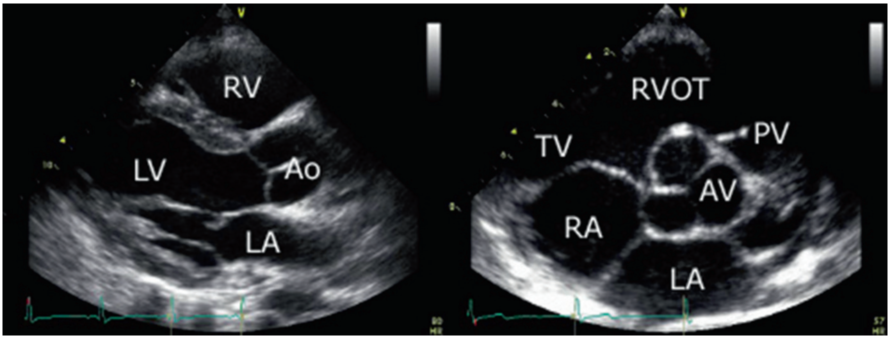

Fig. 2.12 Parasternal long-axis section through the aortic root (*left panel*) shows the closed aortic valve, while the short-axis section shows all three leaflets of the valve. *AO* aorta; *LA* left atrium; *LV* left ventricle; *RA* right atrium; *RV* right ventricle; *RVOT* right ventricular outflow tract; *PV* pulmonary valve; *TV* tricuspid valve

For a comprehensive description of the echocardiographic techniques used to image and assess both healthy and diseased semilunar valves the readers are referred to the *Textbook of Clinical Echocardiography* by Otto [31] and the recommendations for clinical evaluation of stenosis by Baumgartner et al. [32] and regurgitation by Zoghbi et al. [33].

2.8 Conclusions

The pulmonary and aortic (semilunar) valves are highly complex anatomical structures that are composed of supporting structures, leaflets, and their associated arterial vessels. The assessment, imaging, and treatment of these structures are considered an important branch of cardiology due to their importance in dictating the supply of blood to the vital organs. Although the anatomies of each semilunar valve are similar, it should be noted that unique pathological changes can affect each valve resulting in differing approaches to disease assessment and treatment. Ultimately, it is a detailed understanding of the semilunar valve anatomy that will aid physicians and engineers alike in the development and deployment of future clinical therapies for the treatment of congenital and degenerative diseases affecting these valves.

References

1. Cook AC, Anderson RH (2002) Attitudinally correct nomenclature. Heart 87:503–506
2. Wilcox BR, Cook AC, Anderson RH (2005) Surgical anatomy of the valves of the heart. In: Wilcox BR, Cook AC, Anderson RH (eds) Surgical anatomy of the heart. Cambridge University Press, Cambridge UK, pp 45–82
3. Bateman MG, Hill AJ, Quill JL, Iaizzo PA (2013) The clinical anatomy and pathology of the human arterial valves: implications for repair or replacement. J Cardiovasc Transl Res (in press, April 2013). DOI: 10.1007/s12265-012-9438-8
4. Anderson RH, Devine WA, Ho SY et al (1991) The myth of the aortic annulus: the anatomy of the subaortic outflow tract. Ann Thorac Surg 52:640–646
5. Schultz CJ, Moelker A, Piazza N et al (2010) Three dimensional evaluation of the aortic annulus using multislice computer tomography: are manufacturer's guidelines for sizing percutaneous aortic valve replacement helpful? Eur Heart J 31:849–856
6. Sievers HH, Hemmer W, Beversdorf F et al (2012) The everyday used nomenclature of the aortic root components: the tower of Babel? Eur J Cardiothorac Surg 41(3):478–82
7. Hill AJ, Laske TG, Coles JA Jr et al (2005) In vitro studies of human hearts. Ann Thorac Surg 79:168–177
8. www.vhlab.umn.edu/atlas/index. Accessed Mar 22 2012
9. Gross L, Kugel MA (1931) Topographic anatomy and histology of the valves in the human heart. Am J Pathol 7:445–473
10. Misfeld M, Sievers HH (2007) Heart valve macro- and microstructure. Philos Trans R Soc Lond B Biol Sci 362:1421–1436
11. Piazza N, de Jaegere P, Schulz C et al (2008) Anatomy of the aortic valvar complex and its implications for transcatheter implantation of the aortic valve. Circ Cardiovasc Intervent 1:74–81

12. Kunzelman KS, Grande KJ, David TE et al (1994) Aortic root and valve relationships: impact on surgical repair. J Thorac Cardiovasc Surg 107:162–170
13. Reid K (1970) The anatomy of the sinus of Valsalva. Thorax 25:79–85
14. Swanson M, Clark RE (1974) Dimensions and geometric relationships of the human aortic valve as a function of pressure. Cir Res 35:871–882
15. Brewer RJ, Deck JD, Capati B et al (1976) The dynamic aortic root: its role in aortic valve function. J Thorac Cardiovasc Surg 72:413–417
16. Thubrikar MPW, Shaner TW, Nolan SP (1981) The design of the normal aortic valve. Am J Physiol 10:H795–H801
17. Hamdan A, Guetta V, Konen E et al (2012) Deformation dynamics and mechanical properties of the aortic annulus by 4-dimensional computed tomography: insights into the functional anatomy of the aortic valve complex and implications for transcatheter aortic valve therapy. J Am Coll Cardiol 59(2):119–27
18. Middelhof CJFM, Becker AE (1981) Ventricular septal geometry: a spectrum with clinical relevance. In: Wenink ACG et al (eds) The ventricular septum of the heart. Martinus Nijhoff Publishers, The Hague, Netherlands
19. Turner K, Navartnam V (1996) The positions of coronary arterial ostia. Clin Anat 9:376–380
20. Muriago M, Sheppard MN, Ho SY et al (1997) Location of the coronary arterial orifices in the normal heart. Clin Anat 10:297–302
21. Cavalcanti JS, de Melo MN, de Vasconcelos RS (2003) Morphometric and topographic study of coronary ostia. Arq Bras Cardiol 81:359–362
22. Jo Y, Uranaka Y, Iwaki H et al (2011) Sudden cardiac arrest: associated with anomalous origin of the right coronary artery from the left main coronary artery. Tex Heart Inst J 38(5):539–43
23. Roynard JL, Cattan S, Artigou JY et al (1994) Anomalous course of the left anterior descending coronary artery between the aorta and pulmonary trunk: a rare cause of myocardial ischaemia at rest. Br Heart J 72(4):397–9
24. Sutton JP, Ho SY, Anderson RH (1995) The forgotten interleaflet triangles: a review of the surgical anatomy of the aortic valve. Ann Thorac Surg 59(2):419–27
25. Vollebergh FE, Becker AE (1977) Minor congenital variations of cusp size in tricuspid aortic valves: possible link with isolated aortic stenosis. Br Heart J 39:1006–1011
26. Capps SB, Elkins RC, Fronk DM (2000) Body surface area as a predictor of aortic and pulmonary valve diameter. J Thorac Cardiovasc Surg 119:975–982
27. Tops LF, Wood DA, Delgado V et al (2008) Noninvasive evaluation of the aortic root with multi-slice computed tomography: implications for transcatheter aortic valve replacement. J Am Coll Cardiol Img 1:321–330
28. Tawara S (1906) Das reizleitungssystem de saugetierherzens: eine anatomichhisologische studie uber das atrioventricularbundel und die Purkinjeschen faden. Verlag von Gustav Fischer, Jena, Germany
29. Skjaerpe T, Hegrenaes L, Hatle L (1985) Noninvasive estimation of valve area in patients with aortic stenosis by Doppler ultrasound and two-dimensional echocardiography. Circulation 72(4):810–8
30. Asante-Korang A, O'Leary PW, Anderson RH (2006) Anatomy and echocardiography of the normal and abnormal mitral valve. Cardiol Young 16(Suppl 3):27–34
31. Otto CM (2009) Textbook of clinical echocardiography: expert consult, 4th edn. Saunders, Philadelphia, PA
32. Baumgartner H, Hung J, Bermejo J et al (2009) Echocardiographic assessment of valve stenosis: EAE/ASE recommendations for clinical practice. J Am Soc Echocardiogr 22:1–23
33. Zoghbi WA, Enriquez-Sarano M, Foster E et al (2003) Recommendations for evaluation of the severity of native valvar regurgitation with two-dimensional and Doppler echocardiography. J Am Soc Echocardiogr 16:777–802
34. Anderson RH, Becker AE, Allwork SP (1980) Cardiac anatomy: an integrated text and colour atlas, vol xi. Gower Medical Publishing/Churchill Livingstone, London/Edinburgh, p 239

Springer

http://www.springer.com/978-1-4614-6143-2

Heart Valves
From Design to Clinical Implantation
Iaizzo, P.A.; Bianco, R.W.; Hill, A.J.; St. Louis, J.D. (Eds.)
2013, XI, 429 p. 165 illus., 103 illus. in color., Hardcover
ISBN: 978-1-4614-6143-2