The aortic valve and its root: the modern Babylonian tower still stands

WP Mistiaen*

Abstract

Introduction
The complexity of the aortic valve and aortic root is appreciated, especially by specialists in medical imaging and by surgeons who devise and perform aortic valve repair. However, the terminology used to describe the components of the valve differs between different specialists and even within one group of specialists. The aim of this review was to discuss the aortic valve and its root.

Discussion
The following structures need proper labelling before the root itself can be described unequivocally: valve leaflets, commissures, sinuses of Valsalva, interleaflet triangles, sinutubular junction and ventriculo-aortic junction. Especially the latter deserves attention since there is an anatomic as well as a haemodynamic junction. The difference between both junctions is the key to understand the aortic valve. Its understanding is also of vital importance for surgeons in performing durable aortic valve reparations.

Conclusion
The differences in terminology of the components of the aortic valve are probably long lasting. Therefore, a clarifying definition of every component described in any scientific manuscript should be provided.

Introduction
The aortic valve connects the left ventricle (LV) with the arterial circulation. Its main function is ensuring a unidirectional flow of blood: it allows its movement distally during systole, while backflow during diastole is prevented. The valve is more than a passive unidirectional gate: a laminar flow with minimal resistance is maintained during systole. Its superiority over biological and mechanical valve prostheses prompted several investigators to develop techniques to repair diseased aortic valves, whenever possible. To understand the physiological effects of these operations and to compare their results, a set of standardised and consistent definitions of every part of the aortic valve is needed. Recently, a survey revealed that differences exist between cardiac surgeons in labelling the components of the aortic root. This is of importance, since the aortic leaflet is the second most frequent area of surgical intervention. There is also a risk of variable agreement among untrained data abstractors. Without consistent standardised definitions, aggregate data in clinical databases should be treated with caution. A description of the aortic root in this manuscript is preceded by the description of its components. The preferable terms and their alternatives are summed up in Table 1. Their orientation must also be expressed in a proper way (Table 1). The parts needing description are the leaflets, the sinuses, the sinutubular junction (STJ), the commissures and the interleaflet triangles. The most controversial part is the aortic annulus with the anatomic and haemodynamic ventriculo-aortic junction (VAJ).

Discussion
The components of the aortic root
The leaflets are thin, centrally located, free moving parts of the valve (Figures 1 and 2). This term is preferable above 'cusps'. They have several components including the semilunar attachment, an almost transparent belly and a crescent-shaped lunula at the full length of the free margin, which is the area of coaptation. These lunula close the LV from the aorta and carry at the centre of the nodule of Arantius. The attachments transmit the stress of the leaflets to the aortic wall through collagen fibres. The length of the free margin and the height of the leaflet are important parameters. The maximal height of the leaflet is less than the height of the sinuses, but considerable variations between individuals have been reported. Pathological retraction of leaflets makes them unsuitable for repair. However, retraction is not easy to define, and poor measurement of the height may lead to its underestimation. There is no consensus of which leaflet is the largest, but the observed differences seem statistically not significant. The non-coronary leaflet is exclusively fibrous, whereas both other leaflets can contain small portions of ventricular muscle. This could play a role in arrhythmias. The right coronary leaflet attaches to the predominantly muscular region of the LV outflow tract (LVOT). The non-coronary leaflet arises exclusively from the area where the left coronary leaflet is continuous (Figure 2) with the mitral valve.
### Critical review

The commissures can be defined as the place of attachment of the lu
nula to the aortic wall3,12, close to the STJ (Figure 1). These commissures separate the leaflets1 and are the most distal parts of a cown-
like structure. Their fibrous tissue suspend the leaflets5. However, some authors consider the commissures only as the peripheral parts where the free edges of the leaflets run parallel and coapt. The majority of surgeons consider both the area of attachment and the coapting parts as commissures3.

The sinuses of Valsalva (Figures 3 and 5) share the name with the corresponding leaflets13. The distal boundary is the STJ and the prox-
imal border is the attachment of the leaflets5.

Within the interior of the right and left coronary (also called anterior), sinuses are the right and left coronary ostia19. The sinuses allow coro-
nary perfusion during diastole and prevent their occlusion during systo-
le6. They also show a cresten of ven-
tricular muscle at the base (Figure 2). The non-coronary sinus has only fibrous tissue1,9,13. The right coronary sinus is the largest and the left one the smallest6,14. The three sinuses are functionally comparable13 and have a stress-sharing mechanism for the leaflets, which contributes to the du-
rability of the native aortic valve14,15. In valve-sparing root replacement surgery, these sinuses can be recon-
structed, which could improve the durability of the repair, but these procedures are not standardised16. There is a relation to the surrounding structures which has its importance in case of rupturing aneurysms6.

The triangles, sometimes unjustly called trigones1, are located between the anatomic VAJ and the semilunar attachment of the leaflets (Figures 2 and 5)5,10,11. The latter give the sides a parabolic shape7. These tri-
angles only contain fibrous tissue and are extensions of the LVOT and reach the STJ19 or the commissures9. There is a proximity between the most distal parts and the pericardial space. The triangles have a specific height, which reduces with dilated annulus. This can be corrected by annuloplasty7.

The sinutobular junction6 forms the distal boundary of the aortic root5,11. This is the location of the distal end of the attachment of the leaflets1. The STJ plays an integral part of the valve mechanism: dilat-
ation of the STJ leads to valve regur-
gitation6,12,13. The shape of the STJ is not perfect circular, but follows the sinuses as a trefoil6. Thickening and calcification of the STJ could serve as a marker of atherosclerotic dis-
ease2,17. The openings of the coro-
nary arteries are closely below the STJ (Figure 2)6.

The cardiac skeleton supports the aortic valve, which is the centrepiece (Figures 3 and 4). The aorto-mitral continuity (AMC) is located into the roof of the LV. Its fibrous tissue

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**Table 1 Names for structures**

<table>
<thead>
<tr>
<th>Preferable</th>
<th>Alternative</th>
</tr>
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<tbody>
<tr>
<td>Aortic annulus3</td>
<td>Virtual or base annulus, VAJ</td>
</tr>
<tr>
<td>Aortic valve3</td>
<td></td>
</tr>
<tr>
<td>Cusps only</td>
<td>Sinuses + triangles + STJ + attachment of the leaflets to the wall</td>
</tr>
<tr>
<td>Aortic root3</td>
<td></td>
</tr>
</tbody>
</table>
| - Sinuses + triangles + STJ + commis-
sures + leaflets | - sinuses + triangles + STJ + commis-
sures without leaflets |
| Leaflets1,9,13 | Semilunar valvules5, cusps2,23 |
| Leaflet orientation5 |  |
| - Non-coronary | Posterior*, non-adjacent9 |
| - Left coronary | Sinistra*, left posterior7 |
| - Right coronary | Dextra* |
| Leaflet attachment | Semilunar ring, hemodynamic VAJ, crown-like ring3 |
| Lunula | Lannula5 |
| Semilunar attachment5 | Hinge-lines6,13 |
| Sinuses5; advantage of alternatives: abnormal coronary ostia |  |
| - Non-coronary | Right posterior, posterior |
| - Left coronary | Left posterior |
| - Right coronary | Anterior |
| Triangles3,6 | Trigones, intercommissural trigones or triangles, interleaflet trigone or triangle, fibrous trigones3,5,64 |

**Orientation terms**

| Proximal5 | Basal10,11,25 |
| Distal5,11 | Ascending3, apical10 |

*British Terminology Anatomical System.
International Terminology Anatomica Nomenclatura.
The risk of confusion with the intervalvular trigones is clearly present. STJ, sinutobular junction; VAJ, ventriculo-aortic junction.
The aortic root is the central piece of the aortic apparatus and is wedged between the mitral and tricuspid orifice and relates to all cardiac cavities. The aortic root contains the commissures, annulus, triangles, sinuses, STJ and leaflets. It is the continuation of the LVOT and is located between the attachment of the leaflets and the STJ. The root supports and surrounds the leaflets.

The aortic valve can be considered as a part of the aortic root. Most surgeons restrict the term aortic valve to the three leaflets, the only parts that are replaced by prosthesis. Other authors also include the sinuses, the STJ and the triangles. This is supported by the view that abnormalities that do not include the leaflets (such as dilation of the STJ) render the valve incompetent. The size of all parts can be measured in a reliable way by CT angiography, which has its importance as preparation for transcatheter implantation. However, a standardised approach to the measurement of the aorta is needed, and features suggestive of an underlying connective tissue disorder should be recognised. Radiologists should be aware of the image limitations and clinical implications of reported measurements.

The aortic root is the centre-piece and is wedged between the mitral and tricuspid orifice and relates to all cardiac cavities. The aortic root contains the commissures, annulus, triangles, sinuses, STJ and leaflets. It is the continuation of the LVOT and is located between the attachment of the leaflets and the STJ. The root supports and surrounds the leaflets.
throughout the cardiac cycle can be detected using CT angiography with high spatial and temporal resolution. An animal experiment has shown a precise chronology: at the end of diastole the aortic root is more as a truncate cone in shape. During systole, the aortic root is more cylindrical because of the changes at commissural level; this facilitates ejection, minimises transvalvular turbulence and reduces stress applied on the leaflets. The size of all levels should be measured in preparation of transcatheter valve replacement. Using echocardiography, the planes of transsection should be chosen carefully.

No single structure mentioned above should be called the aortic annulus. Some state the aortic annulus does not really exist, or do not discern a true fibrous ring. Others call the aortic root ‘well defined’ or describe it on anatomical or on echocardiographic grounds. The term annulus means ring, but there are several rings, which are not all anatomically discrete structures. These rings are from proximal to distal in (i) a virtual ring formed by the line connecting most proximal attachment of the leaflets, the inlet from the LVOT into the root, (ii) the VAJ, which can be considered as a true anatomical ring, fixed firmly at the LV and at the trigones, and (iii) the STJ. The semilunar attachment of the leaflets has the shape of a crown and is located between the first virtual ring and the third ring and crosses the anatomical VAJ. Some authors call this VAJ the annulus which can be measured with a Hegar dilator. Others call the crown-shaped attachment the annulus since it can be reconstructed by placing sutures with pledgets along the curves. It seems reasonable to avoid this discussion by labelling the STJ plus the basal ring as the root. It serves as natural stent and needs correction in case of dilation with valve regurgitation.

and is for two-third connected to the muscular ventricular septum and for one-third connected to the AMC; this includes the non-coronary and a part of the left coronary leaflets. With increasing age, the angle between the root and the body of the LV decreases from 135–180° to 90–120°. A horizontal aortic root may result in difficulties with transcatheter valve implantation and retrieval of delivery systems in some settings.

There are three levels of the root with different diameters (Figure 5): the widest is at the level of the sinuses, giving the root the shape of a truncated cone. The rates of the diameters have been determined and are also related to the size of the leaflets. Echocardiographic measurement can underestimate the diameters of the root by transecting the wrong plane. These three levels are crossed by the crown-like attachment and can be measured preoperatively. However, it is better to mention the size of the three levels. The shape of the aortic root is considered as ideal for the optimal function of the aortic valve. This shape maintains a laminar flow and an optimal coronary perfusion during diastole. Changes of the shape of the sinuses, giving the root the shape of a truncated cone. The rates of the diameters have been determined and are also related to the size of the leaflets. Echocardiographic measurement can underestimate the diameters of the root by transecting the wrong plane. These three levels are crossed by the crown-like attachment and can be measured preoperatively. However, it is better to mention the size of the three levels. The shape of the aortic root is considered as ideal for the optimal function of the aortic valve. This shape maintains a laminar flow and an optimal coronary perfusion during diastole.

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**Figure 3:** The so-called skeleton of an unfixated heart in cranial view. The aortic valve is the centrepiece with top right clearly visible one of the sinuses of Valsalva. At the lower left side is the mitral annular ring and at the right lower side is the tricuspid annular ring. The leaflets and some tendinous chords are visible. At the top is the pulmonary valve, which is located most anterior.
Mathematical models allow the construction of the complex 3D geometry of the root with a small margin of error. It could serve as an alternative for difficult 3D imaging in preparation for surgical repair. Individual variability as well as changes during the cardiac cycle have to be taken into account. However, application of geometric formula seems less important than surgical skills in restoring the valve-sparing aortic root. Moreover, preoperative measuring of the various components with subsequent tailoring of the graft seems more accurate. ECG-triggered MRI and CT imaging also might offer 3D constructions which take the motion during the cardiac cycle into account. There must be sufficiently high temporal and spatial resolution. This has profound implications for reparative surgery of the aortic valve, since the dynamic behaviour of the root after reparation affects the movements of the leaflets.

Conclusion

The differences in terminology and hence the potential for confusion are probably to stay. For this reason, each author should define every structure mentioned in scientific manuscripts. Some etymological differences such as ‘cusp – leaflet’ do cause serious difficulties. Defining the aortic annulus is much more problematic and has much more implications.

Abbreviations list

AMC, aorto-mitral continuity; LV, left ventricle; LVOT, LV outflow tract; STJ, sinotubular junction; VAJ, ventriculo-aortic junction

References


Figure 4: The so-called skeleton of the heart. Centrally located is the aortic valve with the sinuses removed. The leaflets are almost in a closed position. The full length of the attachment of the leaflets is clearly visible. Their most distal end is fixed by needles. The other valves are oriented as in Figure 3.

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