Chapter 3 REVIEW OF LITERATURE

3.1 Valves of Heart

Primarily the valves of heart are atrioventricular valves and semilunar valves. Atrioventricular valves are tricuspid (right atriovetricular valve) and bicuspid (left atrioventricular) forming inflow part of the heart. Aortic and pulmonary valves are semilunar valves forming outflow part of the heart.

3.1.1 Morphometry & Morphology of Valves of Heart

The atrioventricular valvular complex, in both ventricles, consists of the orifice and its associated annulus, the leaflets, the supporting chordae tendineae of various types and the papillary muscles. The harmoniousinterplay of all of these, together with the myocardial mass, depends on the conduction tissues and mechanical cohesion provided by the Cardiac skeleton. All parts change substantially in position, shape, angulation and dimensions during the cardiac cycle.

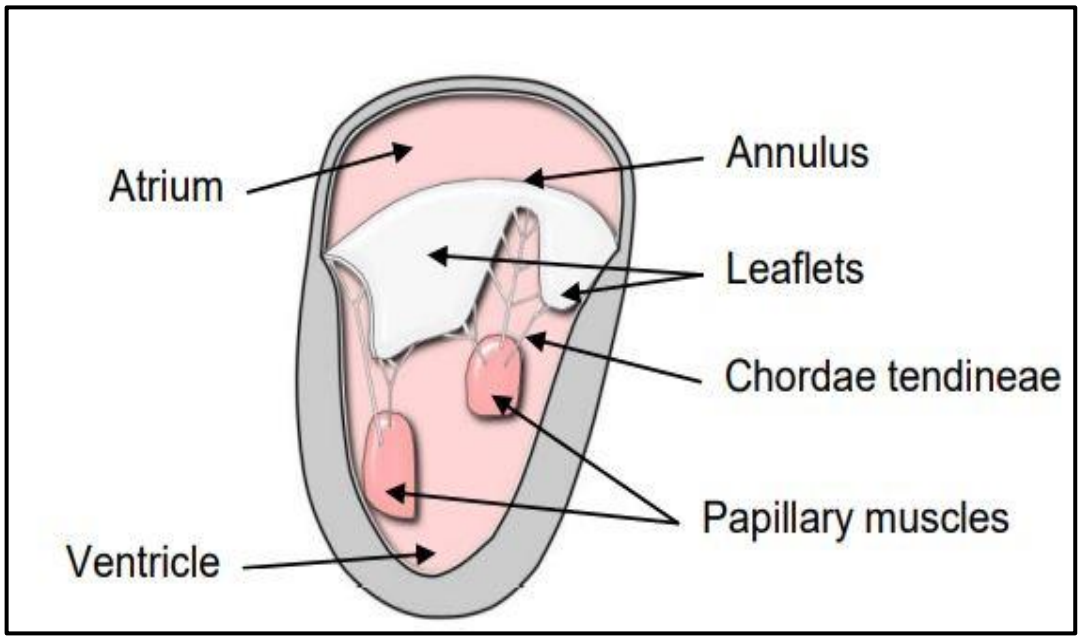


Figure 3.1: Schematic Presentation of Atrioventricular Valvular Complex

- **Tricuspid Valve(Figure No.3.1)**

Tricuspid valvular orifice

The tricuspid valve orifice is best seen from the atrial aspect. It measures, on average, 11.4 cm in circumference in males and 10.8 cm in females. There is a clear line of transition from the atrial wall or septum to the lines of attachment of the valvular leaflets. Its margins are not precisely in a single plane. It is almost vertical but at 45° to the sagittal plane and slightly inclined to the vertical, such that it 'faces' (on its ventricular aspect) anterolaterally to the left and somewhat inferiorly. Roughly triangular, its margins are described as anterosuperior, inferior and septal, corresponding to the lines of attachment of the valvular leaflets. The connective tissues around the orifice of the atrioventricular valves separate the atrial and ventricular myocardial masses completely, except at the point of penetration of the atrioventricular bundle; they vary in density and disposition around the valvular circumference. Extending from the right fibrous trigone component of the central fibrous body is a pair of curved, tapered, subendocardial tendons, or 'prongs' (fila coronaria), which partly encircle the circumference. The Latter is completed by more tenuous, deformable fibroblastic sulcal areolar tissue. Although the extent of fibrous tissue varies with sex and age, the tissue within the atrioventricular junction around the tricuspid Orifice is always less robust than similar elements found at the attachments of the mitral valve. The topographical 'attachment' of the free valvular leaflets in the tricuspid valve does not wholly correspond to the internal level of attachment of the fibrous core of the valve to the junctional atrioventricular connective tissue. The line of attachment of the leaflet is best appreciated in the heart when examined grossly, this feature is more readily discerned clinically.

Tricuspid valve leaflets

The tricuspid valve is made of three thin but strong flaps of tissue. They're called leaflets or cusps. The leaflets are named by their positions: anterior (anterosuperior), inferior(posterior) and septal.When they are closed, it is usually possible to distinguish the three leaflets in the tricuspid valve based on the zones of apposition between them: hence the name. The leaflets are located anterosuperior, septally and inferiorly, corresponding to the marginal sectors of the atrioventricular orifice named in conjunction. The inferior leaflet is often described as being posterior, but when assessed in the attitudinally correct anatomical position, the leaflet is positioned

inferiorly. Each leaflet is a reduplication of endocardium enclosing a collagenous core, continuous marginally and on its ventricular aspect with diverging fascicles of chordae tendineae and basally confluent with the annular connective tissue. In passing from the free margin to the inserted margin, all leaflets of the tricuspid valve display rough, clear and basal zones. The rough zone is relatively thick, opaque and uneven on its ventricular aspect where most chordae tendineae are attached; its atrial aspect makes contact with the comparable surface of the adjacent leaflets during full valve closure. The clear zone is smooth and translucent, and receives few chordae tendinae and has a thinner, fibrous core. The basal zone, extending 2–3 mm from the circumferential attachment of the leaflets, is thicker from increased connective tissue, vascularised and innervated. It contains the insertions of the atrial myocardium. The anterosuperior leaflet is the largest component of the tricuspid valve, attached chiefly to the atrioventricular junction on the posterolateral aspect of the supraventricular crest, and extending along its septal limb to the membranous septum ending at the anteroseptal commissure. One or more notches often indent its free margin. The attachment of the septal leaflet passes from the inferoseptal commissure on the inferior ventricular wall across the muscular septum, then angling across the membranous septum to the anteroseptal commissure. The septal leaflet defines one of the borders of the triangle of Koch, thereby aiding location of the atrioventricular node at the apex of this triangle, and ensuring avoidance during tricuspid valve surgery. The inferior leaflet is wholly mural in attachment and guards the diaphragmatic surface of the atrioventricular junction, its limits being the inferoseptal and anteroinferior commissures. The zone of apposition between the inferior and the anterosuperior leaflets is supported by the septal papillary muscle of the conus.

Opening of the tricuspid valve

Despite its name, the tricuspid valve acts more like a bicuspid valve because its smallest septal leaflet is fixed between the atrial and ventricular septa. The remainder of the tricuspid anulus is muscular. During diastole, the anulus dilates with right ventricular relaxation and the large anterior and posterior leaflets move away from the plane of the anulus into the right ventricle. During systole, the anulus constricts as the right ventricle contracts and the two major leaflets move like sails about a relatively immobile septal leaflet and the septum itself.

- **Bicuspid Valve(Grays Anatomy 41st Edition)**

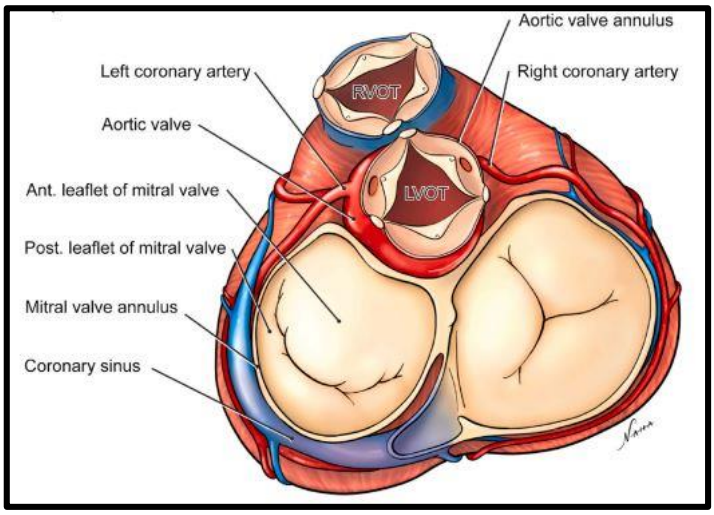


Figure 3.2: Surface View Of Bicuspid Valve Of Heart

Bicuspid ValveOrifice

The Bicuspid valve orifice is a well-defined transitional zone between the atrial wall and the leaflet bases, being smaller than the tricuspid orifice (mean circumference is 9.0 cm in males and 7.2 cm in females). The approximately circular orifice is almost vertical and at 45° to the sagittal plane in diastole, but with a slight anterior tilt. Its ventricular aspect faces anterolaterally to the left and a little inferiorly towards the left ventricular apex. It is almost co-planar with the tricuspid orifice but posterosuperior to it, whereas it is posteroinferior and slightly to the left of the aortic orifice. The mitral, tricuspid and aortic orifices are intimately connected at their central fibrous body. When the mitral valve leaflets close, they form a single zone of coaptation, termed the commissure. The anulus of the valve is not a simple fibrous ring but is made up of fibrocollagenous elements of varying consistency, from which the fibrous leaflet cores take origin; the variable consistency is essential to allow the major changes in anular shape and dimensions during the cardiac cycle that are needed for optimal valvular efficiency. The area of Hypertrophic cardiomyopathy is characterized by myocardial wall thickening, particularly a disproportionate thickening of the interventricular septum in comparison with the posterior wall. Echocardiography accurately assesses the degree of thickening and its effect on systolic function, such as dynamic left ventricular outflow obstruction, systolic anterior motion of the aortic mitral valve leaflet and mid-systolic closure of the aortic valve. There may also be a degree of diastolic dysfunction. Serial short-axis gradient echo MRI allows accurate measurement of wall thickness and is particularly useful in assessing apically

confined hypertrophy. A number of histological changes are observed, including cardiomyocytic disarray with replacement fibrosis and collagenous component expansion. Treatment is usually medical, except for refractory cases and those in whom the left ventricular outflow tract obstruction has a gradient of greater than 50 mmHg. Ventricular septal myotomy and myectomy are performed in such cases. Catheter alcohol septal ablation has been introduced as a non-surgical alternative. A number of patients may also require implantation of cardiac defibrillators to prevent sudden cardiac death. An athlete's heart may physiologically hypertrophy but in a uniform fashion; the left ventricle cavity is usually less than 55 mm in size, and thickness decreases on deconditioning. In contrast, hypertrophic cardiomyopathy reveals asymmetric patterns of left ventricular hypertrophy, often with sharp segmental transitions, left atrial enlargement and bizarre electrocardiographic patterns. Furthermore, there is an autosomal dominant inheritance pattern of abnormalities in genes coding for myocardial proteins associated with hypertrophic cardiomyopathy. Individuals with mutations of the β-MHC (major histocompatibility complex) gene usually develop the classic form of hypertrophy, whereas those with cardiac troponin T gene mutations generally have only mild or clinically undetectable hypertrophy. Rare forms of hypertrophy include localized left ventricular apical hypertrophy as a result of cardiac troponin I mutations, and isolated midcavity hypertrophy caused by cardiac actin and MLC (myosin light chain) gene mutations. the anulus increases linearly with body surface area in children and young adults . The anulus is strongest at the internal aspects of the left and right fibrous trigones. Extending from these structures, the anterior and posterior coronary prongs (tapering,fibrous, subendocardial tendons) partly encircle the orifice at the atrioventricular junction. Between the prong tips, the atrial and ventricular myocardial masses are separated by a more tenuous sheet of deformable fibroelastic connective tissue. Spanning anteriorly between the trigones, the fibrous core of the central part of the aortic leaflet of the mitral valve is a continuation of the fibrous subaortic curtain that descends from the adjacent halves of the left and adjacent (non-coronary) valve leaflets.

Bicuspid Valve leaflets(Grays Anatomy 39th Edition,1003-1005) The mitral valvular leaflets have long been described as paired structures. (The name 'bicuspid valve' is explicit but erroneous because the leaflets are not cuspid, or

'peaked', in form). Small accessory leaflets are almost always found between the two major leaflets and so the mitral valve should be described as a continuous veil that is attached around the entire circumference of the mitral orifice. Its free edge bears several indentations, of which two are sufficiently deep and regular to be nominated as the ends of a solitary and oblique zone of apposition or commissure. These anteromedial (inferoseptal) and posterolateral (superoposterior) extremities may be regarded as two independent commissures, each positionally named as indicated in brackets. Although simple, the official names for these leaflets – anterior and posterior, respectively – are somewhat misleading because of the obliquity of the valve.

When the valve is laid open, the anterior leaflet (aortic, septal, 'greater' or anteromedial) is seen to guard one-third of the circumference of the orifice and to be semicircular or triangular, with few or no marginal indentations. Its fibrous core (lamina fibrosa) is continuous on the outflow aspect, beyond the margins of the fibrous subaortic curtain, with the right and left fibrous trigones. Between the trigones, it is continuous with the fibrous curtain itself and, beyond the trigones, with the roots of the anular fibrous prongs. The leaflet has a deep crescentic rough zone that receives various chordae tendineae. The ridge limiting the outer margin of the rough zone indicates the maximal extent of surface contact with the mural leaflet in full closure. A clear zone is seen between the rough zone and the valvular anulus; it is devoid of attachments of chordae, although its fibrous core carries extensions from chordae attached in the rough zone. The anterior leaflet has no basal zone and continues into the valvular curtain. Hinging on its anular attachment, and continuous with the subaortic curtain, it is critically placed between the inlet and the outlet of the ventricle. During passive ventricular filling and atrial systole, its smooth atrial surface is important in directing a smooth flow of blood towards the body and apex of the ventricle. After the onset of ventricular systole and closure of the mitral valve, the ventricular aspect of its clear zone merges into the smooth surface of the subaortic curtain, which, with the remaining fibrous walls of the subvalvular aortic vestibule, forms the smooth boundaries of the ventricular outlet.

The posterior leaflet (mural, ventricular, 'smaller' or posterolateral) usually has two or more minor indentations. Lack of definition of the major intervalvular commissures has led to disagreement and confusion concerning the territorial extent of this leaflet

and the possible existence of accessory scallops. Examination of the valve in the closed position reveals that the posterior leaflet may conveniently be regarded as comprising all the valvular tissue posterior to the anterolateral (inferoseptal) and posteromedial (supero-posterior) ends of the major zone of apposition with the aortic leaflet. Thus defined, it has a wider attachment to the anulus than does the anterior leaflet, guarding two-thirds of the circumferential attachments. Further indentations usually divide the mural leaflet into a relatively large middle scallop and smaller lateral and septal commissural scallops. Each scallop has a crescentic opaque rough zone, receiving on its ventricular aspect the attachments of the chordae that define the area of valvular apposition in full closure. From the rough zone to within 2–3 mm of its anular attachment, there is a membranous clear zone devoid of chordae. The basal 2–3 mm is thick and vascular, and receives basal chordae. The ratio of rough to clear zone in the anterior leaflet is 0.6 and in the middle scallop of the posterior leaflet is 1.4. Much more of the mural leaflet is in apposition with the aortic leaflet during closure of the mitral valve.

Opening of the mitral valve

At the onset of diastole, opening is passive but rapid, the leaflets parting and projecting into the ventricle as left atrial pressure exceeds left ventricular diastolic pressure. Passive ventricular filling proceeds as atrial blood pours to the apex, directed by the pendant aortic valvular leaflet. The leaflets begin to float passively together, hinging on their anular attachments and partially occluding the ventricular inlet. Atrial systole now occurs, jetting blood apically and causing re-opening of the leaflets. As maximal filling is achieved, the leaflets again float rapidly together. Closure is followed by ventricular systole, which starts in the papillary muscles and continues rapidly as a general contraction of the walls and septum. Coordinated contraction of the papillary muscles increases the tension in the chordae and promotes joining of the corresponding points on opposing leaflets, preventing their eversion. With general mural and septal excitation and contraction, left ventricular pressure increases rapidly. The leaflets ‘balloon’ towards the atrial cavity, and the atrial aspects of the rough zones come into maximal contact. Precise papillary contraction, and increasing tension in the chordae, continue to prevent valvular eversion and maintain valvular competence.

The orifices and the leaflets of both atrioventricular valves undergo considerable changes in position, form and area during a cardiac cycle. Both valves move anteriorly and to the left during systole, and reverse their motion in diastole. The mitral valve reduces its orificial (anular) area by as much as 40% in systole; its shape changes from circular to crescentic at the height of systole, the anular attachment of its aortic leaflet being the concavity of the crescent. The attachment of its mural leaflet, although remaining convex, contracts towards the anterior cardiac wall.

- **Aortic Valve**

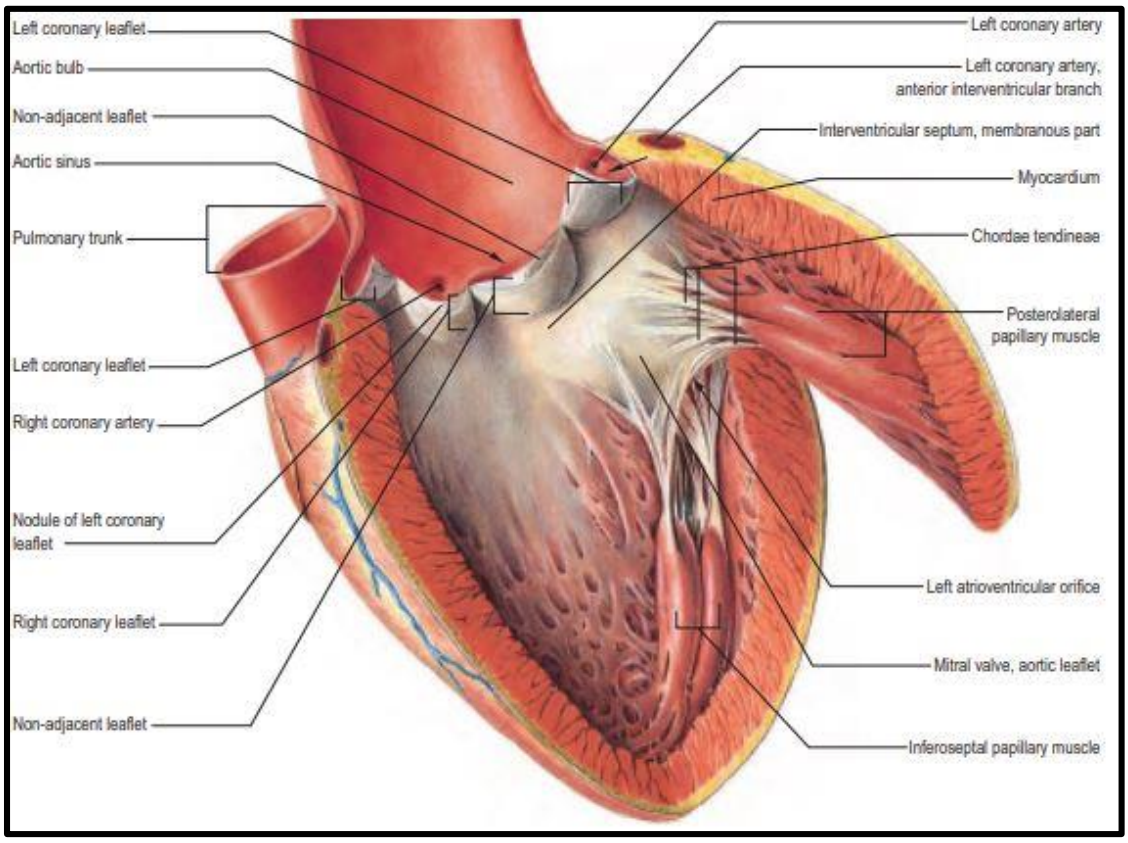


Figure 3.3:Aortic Valve cut open

The anatomical bridge between the left ventricle and the ascending aorta, consists of the aortic valvular leaflets and the inter-leaflet triangles interposed between their basal attachments. As such, it possesses significant length, but because of the semilunar attachment of the leaflets, it has no discrete proximal border. It is limited distally by the sinutubular junction. The essential feature is the semilunar attachments of the valve leaflets; their hinge lines cross the anatomical ventriculoarterial junction, marking a transition from the myocardium of the left ventricle to the fibroelastic tissue of the valve sinuses. The muscular portion of the aortic root is roughly two-

thirds of its widest circumference. Descriptions of the aortic root over the years have been bedevilled by accounts of a valve anulus. Although echocardiographers used to describe this proximal border in terms of an ‘annulus’, examination of cross-sections of the left ventricular outflow tract has never found any circular anatomical boundary or a distinct boundary of any kind. There are at least two rings within the root; neither serves to support the valve leaflets, which are attached in semilunar fashion from the sinutubular junction at basal ventricular attachment. Two leaflets are supported by muscle, and the third has an exclusively fibrous attachment. The root acts as a bridging structure not only anatomically, separating the myocardial and arterial components of the left ventricular pathway, but also functionally because its proximal and distal components can withstand considerable changes in ventricular and arterial pressures.

Aortic valve leaflets(Figure 3.3)

The aortic valve leaflets are attached in part to the aortic wall and in part to the supporting ventricular structures. The situation is more complicated than in the pulmonary valve because parts of the leaflets also take origin from the fibrous subaortic curtain, and are continuous with the aortic leaflet of the mitral valve. This area of continuity is thickened at its two ends to form the right and left fibrous trigones. As with the pulmonary valve, the semilunar attachments incorporate segments of ventricular tissue within the bases of two of the aortic sinuses. The sinuses and leaflets are conveniently named as right, left and non-coronary, according to the origins of the coronary arteries. However, the so-called non-coronary leaflet is better termed the non-adjacent leaflet because it rarely gives rise to a coronary artery. The semilunar attachments incorporate three triangular areas (trigones) of aortic wall within the apex of the left ventricular outflow tract. They are interposed between the bulbous aortic sinuses and separate the cavity of the left ventricle from the pericardial space. Removal of the trigones in an otherwise intact heart is instructive in demonstrating the relationships of the aortic valve, which, justifiably, may be considered as the keystone of the heart.

The first triangle, between the non-coronary and left coronary leaflets, has a base continuous inferiorly with the fibrous aortic–mitral curtain. The second triangle, between right and non-coronary leaflets, has the membranous components of the interventricular septum as its base and thus ‘faces’ the right ventricle, whereas its

apex 'points' towards the transverse pericardial space behind the origin of the right coronary artery. The third triangle, between the two coronary leaflets, has its base on the muscular interventricular septum and its apex 'points' to the plane of space found between the aortic wall and the free-standing sleeve of right ventricular infundibular musculature that supports the leaflets of the pulmonary valve. Although the basal attachments of each aortic valvular leaflet are thickened and collagenous at their ventricular origins, the leaflets lack a continuous collagenous circular skeletal support; valvular function depends primarily upon the semilunar attachments of the leaflets. The leaflets are endocardial folds with a central fibrous core. With the valve half-open, each equals slightly more than a quarter of a sphere, an approximate hemisphere being completed by the corresponding sinus. Each leaflet has a thick basal border, deeply concave on its aortic aspect, and a horizontal free margin that is only slightly thickened, except at its midpoint, where there is an aggregation of fibrous tissue, the valvular nodule of the semilunar leaflet. The fibrous core that flanks each nodule is tenuous, forming the lunules of translucent and occasionally fenestrated valvular tissue; fenestrations are of no functional significance. The aortic surface of each leaflet is rougher than its ventricular aspect. Confusingly, three sets of names are used to describe the aortic leaflets. Posterior, right and left refer to their fetal positions before full cardiac rotation has occurred. Corresponding terms based on their approximate positions in maturity are anterior, left and right posterior. Widespread clinical terminology, which links both leaflets and sinuses to the origins of the coronary arteries, has replaced anterior, left and right leaflets with right and left coronary and non-adjacent leaflets, respectively; these clinical terms are preferable in the normal heart because they are simple and unambiguous.

Aortic sinuses (of Valsalva)

The aortic sinuses are more prominent than those in the pulmonary trunk. The upper limit of each sinus reaches considerably beyond the level of the free border of the leaflet and forms a well-defined circumferential sinutubular ridge on the aortic inner surface, just above the aortic valvular leaflets. Coronary arteries usually open near this ridge within the upper part of the sinus but are markedly variable in their origin. The walls of the sinuses are largely collagenous near the attachment of the leaflets but the amount of lamellated elastic tissue increases with distance from the zone of attachment. At the midlevel of each sinus, its wall is about half the thickness of the

supravalvular aortic wall and less than one-quarter of the thickness of the sinutubular ridge. At this level, the mean luminal diameter at the commencement of the aortic root is much larger than that of the ascending aorta; these details are functionally significant in the mechanism of valvular motion. A linear relationship between the diameter of the aortic sinus and the square root of body surface area has been described in children.

Opening of the aortic valve

During diastole, the closed aortic valve supports an aortic column of blood at high but slowly diminishing pressure. Each sinus and its leaflet form a hemispherical chamber. The three nodules are apposed and the margins and lunular parts of adjacent leaflets are tightly apposed on their ventricular aspects. From the aortic aspect, the closed valve is triradiate, three pairs of closely compressed lunules radiating from their nodules to their peripheral commissural attachments at the sinutubular junction. As ventricular systolic pressure increases, it exceeds aortic pressure and the valve is passively opened. The fibrous wall of the sinuses nearest the aortic vestibule is almost inextensible but, more superiorly, the wall is fibroelastic. Under left ventricular ejection pressure, the radius here increases 16% in systole, as the commissures move apart to form a fully open triangular orifice. The free margins of the leaflets then become almost straight lines between peripheral attachments. However, they do not flatten against the sinus walls, even at maximal systolic pressure, which is probably an important factor in their subsequent closure. During ejection, most blood enters the ascending aorta but some enters the sinuses, forming vortices that help to maintain the triangular ‘mid position’ of the leaflet during ventricular systole and also probably initiate their approximation at the end of systole. Tight and full closure ensues with the rapid decrease in ventricular pressure in diastole. Commissures narrow, nodules aggregate and the valve reassumes its triradiate form. Experiments indicate that 4% of ejected blood regurgitates through a valve with normal sinuses, whereas 23% regurgitates through a valve without them. The normal structure of the aortic sinuses also promotes nonturbulent flow into the coronary arteries.

- **Pulmonary Valve**

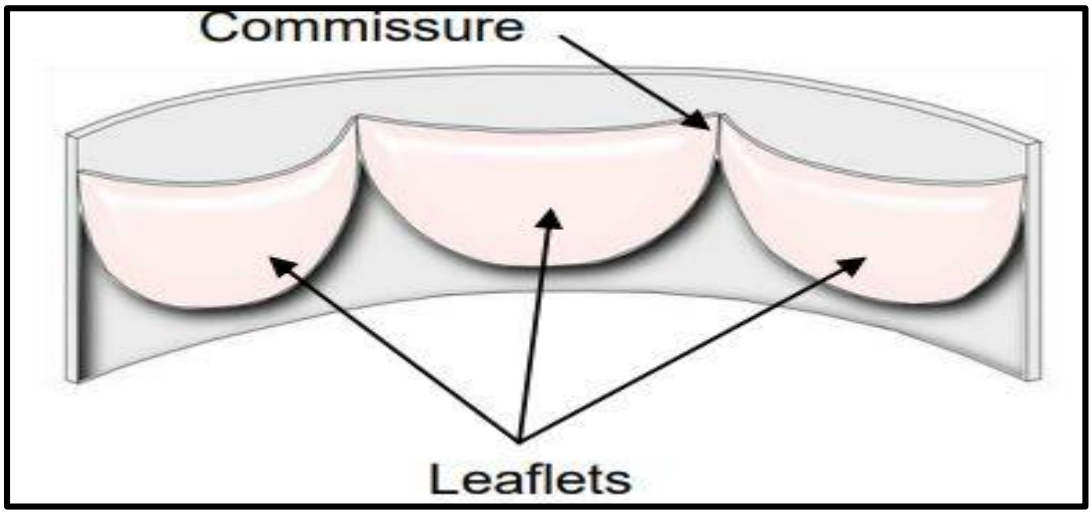


Figure 3.4: Schematic Diagram To Show Leaflet Of Pulmonary Valve

The pulmonary valve, guarding the outflow from the right ventricle, surmounts the infundibulum and is situated at some distance from the other three cardiac valves .Its general plane faces superiorly to the left and slightly posteriorly. It has three semilunar leaflets, attached by convex edges partly to the infundibular wall of the right ventricle and partly to the origin of the pulmonary trunk. The line of attachments is curved, rising at the periphery of each leaflet near their zones of apposition (the commissures) and reaching the sinutubular ridge of the pulmonary trunk. Removal of the leaflets reveals that the fibrous semilunar attachments enclose three crescents of infundibular musculature within the pulmonary sinuses, whereas three roughly triangular segments of arterial wall are incorporated within the ventricular outflow tract beneath the apex of each commissural attachment. Thus there is no proper circular 'anulus' supporting the leaflets of the valve, and the fibrous semilunar attachment is an essential requisite for snug closure of the nodules and lunules of the leaflets during ventricular diastole. It is difficult to name the leaflets and corresponding sinuses of the pulmonary valve and trunk precisely according to the coordinates of the body because the valvular orifice is obliquely positioned.

Pulmonary Valve Leaflets: Terminologia Anatomica (2011) refers to anterior, posterior and septal leaflets on the basis of their fetal position but this changes with development, becoming anterior, right and left, respectively, in the adult. Each leaflet is an endocardial fold with a variably developed intervening substantial fibrous core that traverses both the free edge and the semilunar attached border. The latter is particularly thickened at its deepest central part (nadir) of the base of each leaflet, and therefore never forms a simple complete fibrous ring. The free margin of each leaflet contains a central localized

collagenous thickening, the nodule of Arantius. Perforations within the leaflets close to the free margin and near the commissures are frequently present and are of no functional significance. Each semilunar leaflet is contained within one of the three sinuses of the pulmonary trunk.

Opening of the pulmonary valve: During diastole, all three leaflets of the pulmonary valve are tightly apposed. The pulmonary valve is difficult to visualize at echocardiography and usually only the posterior leaflet is visible when the valve is closed; atrial systole may cause a slight posterior movement of the valve leaflets. The pulmonary valve opens passively during ventricular systole and then closes rapidly at the end of systole.

3.1.2 Functions of Valves of Heart

The heart pumps blood in a specific route through four chambers (two atria and two ventricles). Every time heart beats, the atria receive oxygen-poor blood from the body. And the ventricles contract (squeeze) to pump blood out. As the heart pumps, valves open and close to allow blood to move from one area of the heart to another.The valves ensure that blood flows at the right time and in the correct direction.

- **Functions of Tricuspid Valve**

The tricuspid valve ensures that blood flows from the right atrium to the right ventricle. It also prevents blood from flowing backwards between those two chambers. When the right atrium fills, the tricuspid valve opens, letting blood into the right ventricle. Then the right ventricle contracts to send blood to the lungs. The tricuspid valve closes tightly so that blood does not go back into the right atrium.

- **Function of Bicuspid valve**

The bicuspid valve ensures that blood flows from the left atrium to the left ventricle. It also prevents blood from flowing backwards between these two chambers. When the left atrium fills, the bicuspid valve opens, letting blood into the left ventricle.

Thus valve play a crucial role in ensuring the unidirectional flow of blood from the atrium to the ventricles.

- **Functions Of Aortic Valve**

With the contraction of left ventricle (systole), pressure rises in the left ventricle. When the pressure in the left ventricle rises above the pressure in the aorta, the aortic valve opens, allowing blood to exit the left ventricle into the aorta. When ventricular

systole ends, pressure in the left ventricle rapidly drops. When the pressure in the left ventricle decreases, the momentum of the vortex at the outlet of the valve forces the aortic valve to close. The closure of the aortic valve contributes the A_2 component of the second heart sound (S_2).

- **Functions Of Pulmonary Valve**

The function of the pulmonary valve is to prevent blood that is leaving the heart via the right ventricle (into the pulmonary trunk - of the pulmonary artery), from flowing backwards and so re-entering the heart.

3.1.3 Development of Valves of Heart

- **Development of Atrioventricular Valve**

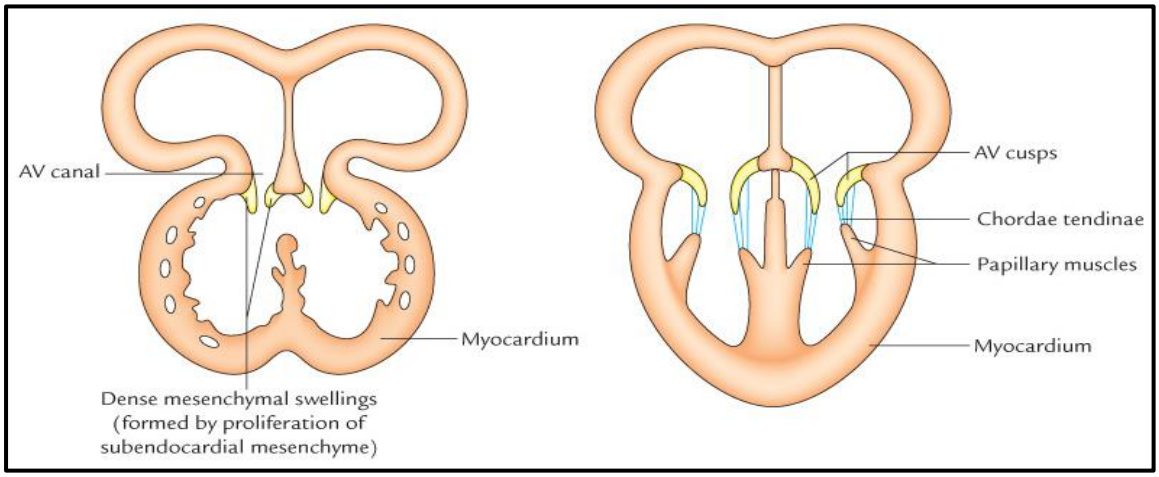


Figure 3.5: Development Of Tricuspid and Bicuspid Valve

Tricuspid Valve:

It is present between the right atrium and right ventricle, and guards the right AV canal. In the AV canal, subendocardial mesenchyme proliferates and forms three swellings (anterior, posterior, and septal) that project in the AV canal. The swellings enlarge and meet each other in the lumen. But the free margins of these swellings do not fuse with each other. When the blood stream starts flowing, the mesenchymal tissue degenerates and is replaced by connective tissue. The ventricular surface of these swellings is hollowed and cusps are formed. There are three cusps: the anterior, posterior, and septal, and consists of connective tissue covered by endocardium. The free margin ventricular surfaces of these valves are connected to thick trabeculae in the wall of the ventricle (the papillary muscles) by thin tendinous cords (the chordae tendinae) much like the cords attaching to a parachute.

Mitral Valve: It is present between the left atrium and left ventricle, and guards the left AV canal. It develops by the proliferation of subendocardial mesenchyme forming due swellings: anterior and posterior in the same way as the tricuspid valve. There are only two cusps in left AV valve (anterior and posterior) that are obliquely placed. It is also called bicuspid valve. The left AV valve is called mitral valve due to valve's resemblance to a bishop's miter (headdress).

- **Development Of Semilunar Valve**

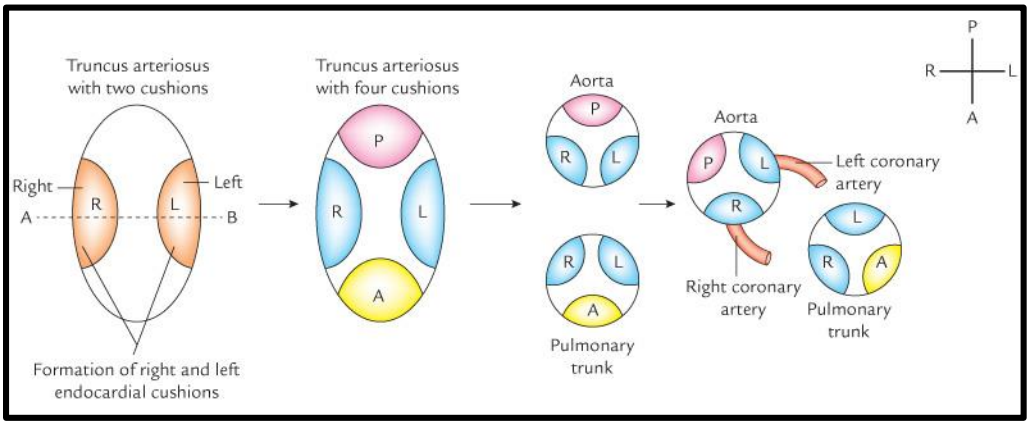


Figure3.6: Development of Aortic and Pulmonary Valve

They develop from endocardial cushions that are formed at the junction of truncus arteriosus and conus. The two endocardial cushions develop in the right and left wall. Simultaneously two more cushions, anterior and posterior, appear. The truncus arteriosus now has four cushions: anterior (A), posterior (P), right (R), and left (L). With the separation of aortic and pulmonary openings by aorticopulmonary septum, the right and left cushions divide into two parts. The one part goes to aortic opening and other part goes to pulmonary opening. Now each opening has three cushions from which three cusps of the corresponding opening develop. The pulmonary opening is first ventral to the aortic opening. Now the heart undergoes partial rotation to the left. As a result, the pulmonary opening comes to lie anterior and to the left of the aortic opening; and cusps acquire their definitive relationship, i.e., pulmonary trunk has one posterior and two anterior (right and left) cusps; and aorta has one anterior (right and left) and two posterior cusps.

Embryologically, the pulmonary valve has right, left, and anterior cusps, whereas the aortic valve has right, left, and posterior cusps. This terminology is in accordance with the origin of coronary arteries as the right coronary artery arises from the right aortic sinus, superior to the right cusp of the aortic valve, and the left coronary artery arises from the left aortic sinus superior to the left cusp of the aortic valve. The posterior

cusp and sinus do not give rise to the coronary artery, hence it referred as noncoronary cusp.

3.1.4 Variations of valves of Heart

- **Variation of Tricuspid Valve**

Wafae et al. (1990) described that normally the tricuspid valve is having three leaflets.There may be supernumerary leaflets either by duplication or subdivision.He reported in 72% of 50 hearts the valve was formed by less (two) or more (four, five or six) leaflets. With four being the most common (52%), this was termed the anterolateral leaflet due to its favored position between the anterior and posterior leaflets. They also reported commissural leaflets in 64% with a range of one to four leaflets, with one being the most common (78.1%). The commissural leaflets were located between the anterior and septal or the posterior and septal leaflets. There does not appear to be a correlation between supernumerary leaflets and the presence or number of commissural leaflets.

- **Variation of Bicuspid Valve**

Nwaejike N et al (2012) stated that The double orifice mitral valve is associated with a number of congenital abnormalities and comprises two mitral orifices separated by an accessory bridge of fibrous tissue and surrounded by a single fibrous annulus. We present our management of a case of a double orifice mitral valve associated with a papillary fibroelastoma.

- **Variation of Aortic Valve**

Aure´lien Seemann et al (2011): In a 58-year-old man, transthoracic echocardiography showed a severe aortic regurgitation. Two and three-dimensional transoesophageal echocardiography revealed a quadricuspid asymmetric aortic valve and a severe aortic regurgitation due to the absence of coaptation. The patient underwent an aortic valve replacement with an associated coronary artery bypass graft. Surgery confirmed the diagnosis of quadricuspid asymmetric aortic valve. Quadricuspid aortic valve is a very uncommon congenital malformation, occurring separately or associated with other congenital disorders. It is responsible for regurgitation more often than stenosis. Transoesophageal echocardiography is helpful for the diagnosis and the precise description of the mechanism of the regurgitation.

- **Variation of Pulmonary Valve**

The pulmonary valve displays a very similar anatomy as the aortic valve, but does not have any vessels branching from it. The leaflets are positioned in different orientations to the aortic (Loukas et al. 2014). The leaflet size of the pulmonary valve shows inequality among the different leaflets (Vollebergh and Becker 1977). It has been noted that the pulmonary valve may exhibit two cusps instead of the usual three.

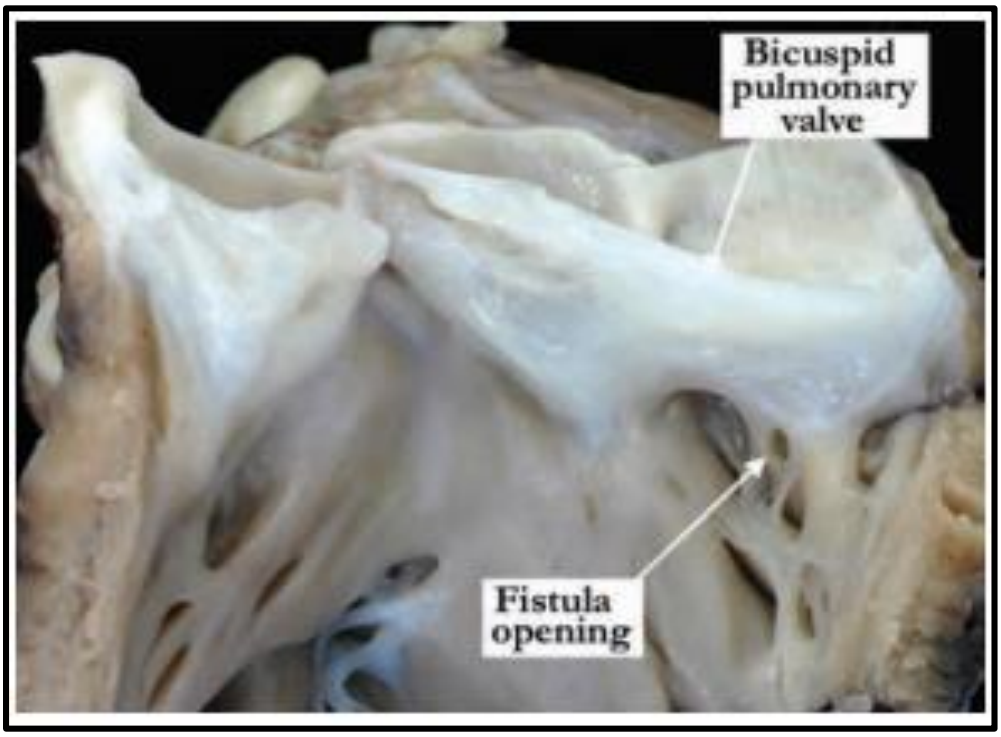


Figure 3.7: Bicuspid Pulmonary Valve

Bergman's Comprehensive Encyclopedia of Human Anatomic Variation noted bicuspid pulmonary valve as shown in figure (Figure 3.7)

Ashalatha P R et al (2017): Pulmonary valves from hearts dissected during autopsy were washed thoroughly and fixed in formalin. Each specimen was numbered systematically. Circumference was measured. Age, sex, height, weight, weight of the heart and other cardiac anomalies, if any, were recorded.Out of 213 cases, 211 valves had 3 cusps (99.06%), one valve had two cusps (0.46%) and one had four cusps (0.46%). Fenestrations were seen in 103 valves (48.35%).Cusps were asymmetrical in 15 valves (7.04%).Circumference of the valve had a significant relation to age and sex of the individual.The anatomical variations occurring in the pulmonary valve have significant clinical relevance in the diagnosis, management and prevention of valve diseases, valve repair and valve replacement surgeries.

3.1.5 Clinical Terms & Cardiac Procedure related to valves

- **Clinical Terms & Procedure related to Tricuspid valve**

Several factors can cause problems with the tricuspid valve are including:Cardiac tumor or radiation to the chest to treat cancer, congenital defect (a structural problem present at birth, such as the valve having only two leaflets or having more than three leaflets),disorders that affect your body's connective tissue, such as marfan syndrome, enlarged right ventricle,infection that causes swelling in the heart muscle, such as endocarditis or rheumatic fever.These underlying cause may lead to-

Tricuspid atresia is a form of congenital heart disease whereby there is a complete absence of the tricuspid valve. Therefore, there is an absence of right atrioventricular connection. This leads to a hypoplastic (undersized) or absent right ventricle.This defect is contracted during prenatal development, when the heart does not finish developing. It causes the systemic circulation to be filled with relatively deoxygenated blood. The causes of tricuspid atresia are unknown.[3]

In most cases of tricuspid atresia, additional defects exist to allow exchange of blood between the loops of systematic circulation and pulmonary circulation, filling in the role of the missing atrioventricular connection. An atrial septal defect (ASD) must be present to fill the left atrium and the left ventricle with blood.[4] Since there is a lack of a right ventricle, there must also be a way to pump blood into the pulmonary artery. This can be accomplished by a ventricular septal defect (VSD) connecting the left ventricle to the pulmonary artery or by a patent ductus arteriosus (PDA) connecting the aorta to the pulmonary artery. In the latter case, prostaglandin E1 is used to maintain the PDA connection until emergency corrective surgery can be completed. As oxygenated blood is mixed with deoxygenated blood in both cases, there is a reduction in the oxygen-carrying capacity. It is also possible for tricuspid atresia to appear without the life-saving defects. In this case, the systemic and pulmonary circulations would be cut off from each other and no useful breathing can occur. An experimental procedure called fetal balloon atrial septostomy can be used to artificially create the required defect in utero.

Tricuspid regurgitation (TR): This condition means blood is leaking backward through the tricuspid valve. The carcinoid syndrome and use of ergot-related drugs

more frequently produce TR, which if severe contributes to a gradient across the tricuspid valve.

Tricuspid Stenosis (TS) : In this condition, the tricuspid valve opening is too narrow, restricting blood flow between the two chambers. Tricuspid Stenosis is almost always rheumatic in origin, although rheumatic valve disease more frequently affects left-sided valves. This is more often are associated with tricuspid regurgitation (TR), but can become looped and fused to the tricuspid valve apparatus and, particularly if multiple, cause obstruction. Dysfunction, including thrombosis, of a tricuspid mechanical or bioprosthetic valve can result in stenosis.Most patients with rheumatic tricuspid valve disease have TR or a combination of TS and TR. Isolated rheumatic tricuspid valve disease is uncommon, and this lesion generally accompanies mitral valve disease, which dominates the presentation. In many patients with TS, the aortic valve also is involved. TS is found at autopsy in approximately 15% of patients with rheumatic heart disease but is of clinical significance in only approximately 5%. Organic tricuspid valve disease is more common in India, Pakistan, and other developing nations near the equator than in North America or Western Europe. The anatomic changes of rheumatic TS shows fusion and shortening of the chordae tendineae and fusion of the leaflets at their edges, producing a diaphragm with a fixed central aperture. However, valvular calcification is rare. TS is more common in women. The right atrium often is greatly dilated in TS, and its walls are thickened.

Various corrective surgical procedure available are-

Tricuspid valve repair: A surgeon can reshape, widen or tighten the leaflets in the tricuspid valve. Surgery can also strengthen or tighten the tricuspid valve by implanting an artificial ring.

Tricuspid valve replacement: A surgeon can replace the tricuspid valve with an artificial mechanical valve or a biological valve from an animal.

Transcatheter valve repair: In severe and symptomatic tricuspid valve regurgitation, an interventional cardiologist may repair the valve through the skin (percutaneous repair).

Transcatheter valve replacement: Percutaneous valve replacement can be done in severe and symptomatic tricuspid valve regurgitation.

- **Clinical Terms & Procedure related to Bicuspid Valve**

Bicuspid(Mitral) Valve Stenosis(MS)

The predominant cause of bicuspid valve stenosis is rheumatic fever.With rheumatic changes present in 99% of stenotic mitral valves excised at the time of mitral valve replacement. Approximately 25% of all patients with rheumatic heart disease have isolated MS, and approximately 40% have combined MS and mitral regurgitation (MR). Multivalve involvement is seen in 38% of patients with MS, with the aortic valve affected in approximately 35% and the tricuspid valve in approximately 6%. The pulmonic valve is rarely affected. Two thirds of all patients with rheumatic MS are female. The interval between the initial episode of rheumatic fever and clinical evidence of mitral valve obstruction is variable, ranging from a few years to more than 20 years. Rheumatic fever results in characteristic changes of the mitral valve; diagnostic features are thickening at the leaflet edges, fusion of the commissures, and chordal shortening and fusion. With acute rheumatic fever, the changes include inflammation and edema of the leaflets, with small fibrin-platelet thrombi along the leaflet contact zones. Subsequent scarring leads to the characteristic valve deformity, with obliteration of the normal leaflet architecture by fibrosis, neovascularization, and increased collagen and tissue cellularity. Aschoff bodies,the pathologic hallmark of rheumatic disease, are seen most frequently in the myocardium, not the valve tissue, with aschoff bodies identified in only 2% of autopsied patients with chronic valve disease.These anatomic changes lead to a typical functional appearance of the rheumatic mitral valve. In earlier stages of the disease, the relatively flexible leaflets snap open in diastole into a curved shape because of restriction of motion at the leaflet tips . This sudden restriction of leaflet opening in diastole is responsible for the characteristic opening snap (OS) on auscultation, and the interval between the second heart sound (S2) and OS bears an inverse relationship with left atrial (LA) pressure. This “diastolic doming” is most evident in the motion of the anterior leaflet and becomes less prominent as the leaflets become more fibrotic and calcified, which also muffles the OS. The symmetric fusion of the commissures results in a small, central oval orifice in diastole that on pathologic specimens is shaped like a fish mouth or buttonhole because the anterior leaflet is not in the physiologic open position. With end-stage disease, the thickened leaflets may be so adherent and rigid that they cannot open or shut, with consequent reduction in or, rarely, even abolition of the first heart

sound (S1), and leading to combined MS and MR. When rheumatic fever results exclusively or predominantly in contraction and fusion of the chordae tendineae, with little fusion of the valvular commissures, dominant MR results. Debate continues about whether the anatomic changes of severe MS result from recurrent episodes of rheumatic fever or from a chronic autoimmune process caused by cross-reactivity between a streptococcal.

Cardiac Procedure Related to Bicuspid Valve

Surgical Valvotomy

Three operative approaches are available for the treatment of rheumatic MS:

1. closed mitral valvotomy (CMV) using a transatrial or transventricular approach
2. open valvotomy (i.e.valvotomy done under direct vision with the aid of cardiopulmonary bypass [CPB]), which may be combined with other repair techniques, such as leaflet resection or augmentation, chordal procedures, and annuloplasty when MR is present.
3. mitral valve replacement

Surgical intervention for MS is recommended for patients with severe MS and significant symptoms (NYHA Class III or IV) when Balloon Mitral Valvuloplasty(BMV) is not available, when BMV is contraindicated because of persistent LA thrombus or moderate to severe MR, or when the valve is calcified and surgical risk is acceptable. The preferred surgical approach is valve repair (open valvotomy, with or without additional procedures) whenever possible, although since patients referred for surgery often have poor morphology for BMV, valve replacement is often the best choice. Surgery also is reasonable for patients with severe MS and severe pulmonary hypertension when BMV is not possible and may be considered for patients with moderate to severe MS with recurrent embolic events despite anticoagulation. Closed Mitral Valvotomy(CMV) is rarely used now, having been replaced by BMV, which is more effective in patients who are CMV candidates. CMV is more popular in developing nations, where the expense of open heart surgery and even of balloon catheters for BMV is an important factor, and where patients with MS are younger and therefore have more pliable valves. However, even in these nations, CMV is being replaced by BMV, with balloon resterilization to keep the

procedure economical. CMV is performed without CPB but with the aid of a transventricular dilator. It is an effective operation, provided that MR, atrial thrombosis, or valvular calcification is not serious and that chordal fusion and shortening are not severe.

Abnormalities of Valve Leaflets. MR caused by primary abnormalities of the valve leaflets occurs in many situations.In the developed world, myxomatous degeneration is the leading cause of organic MR. Intensive work in the past decade has demonstrated the mitral valve to be a dynamic structure with protein turnover and remodeling continuing throughout life. The normal mitral valve is a thin (<3 mm) endotheliumlined bileaflet structure with dense collagen on the ventricular side (fibrosa), a less stiff layer of collagen and elastin on the atrial side (atrialis), and in between a loose connective tissue layer with abundant glycosaminoglycans (spongiosa). Interspersed among the spongiosa are valvular interstitial cells (VICs), derived from endocardial endothelium, which normally are inactive. .In myxomatous degeneration, these VICs can be transformed to myofibroblasts, which secrete excess glycosaminoglycans and matrix metalloproteinases, leading to fragmentation of the fibrosa and atrialis and thickening of the spongiosa. In turn, this reduces the tensile strength of the MV, making it prone to prolapse into the left atrium with repetitive application of ventricular pressure. A minority of myxomatous degeneration cases have a clear genetic component, with MVP frequently seen in connective tissue disorders such as Marfan, Loeys-Dietz, and Ehlers-Danlos syndromes and pseudoxanthoma elasticum. A common thread in these syndromes appears to be excessive transforming growth factor beta (TGF-β) stimulation.

- **Clinical Terms & Procedure related to Aortic Valve**

Aortic regurgitation (**AR**), also known as **aortic insufficiency** (**AI**), is the leaking of the aortic valve of the heart that causes blood to flow in the reverse direction during ventricular diastole, from the aorta into the left ventricle. As a consequence, the cardiac muscle is forced to work harder than normal.

Aortic stenosis (**AS** or **AoS**) is the narrowing of the exit of the left ventricle of the heart (where the aorta begins), such that problems result. It may occur at the aortic valve as well as above and below this level. It typically gets worse over time. Symptoms often come on gradually with a decreased ability to exercise often

occurring first. If heart failure, loss of consciousness, or heart related chest pain occur due to AS the outcomes are worse.Loss of consciousness typically occurs with standing or exercising.Signs of heart failure include shortness of breath especially when lying down, at night, or with exercise, and swelling of the legs.Thickening of the valve without narrowing is known as aortic sclerosis.

- **Clinical Terms & Procedure related to Pulmonary Valve**

Pulmonary stenosis

Congenital pulmonary valve stenosis with intact ventricular septum is by far the commonest cause of obstruction to the RV outflow and is a relatively common lesion. Supravalvular pulmonary stenosis can also lead to RV outflow obstruction. In isolated pulmonary stenosis, the valve is usually acommissural unicuspid with a central stenotic orifice (Roberts et al., 1973; Polansky et al., 1985; Freedom, 1983). The anatomy of tetralogy of Fallot with pulmonary stenosis was studied by Anderson and Jacobs (2008). A narrowing of the RV outflow tract occurred at the pulmonary valve (valvular stenosis) or just below the pulmonary valve (infundibular stenosis). The later was produced by the 'squeeze' between the anterocephalad misalignments of the outlet septum and the abnormal situated hypertrophied septoparietal trabeculations which extend onto the ventricular free wall. Cases were also found of stenosis more proximal within the ventricle, produced either by hypertrophy of the moderator band or by prominent apical trabeculations, giving a 'two-chambered RV'. Abnormal pulmonary valves may be classified as acommissural with a prominent systolic doming of the valve cusps and an eccentric orifice, unicommissural with a single asymmetric commissure, bicuspid with fused commissures, or dysplastic with severely thickened and deformed valve cusps (Kirshenbaum, 1987).

A distinctive type of pulmonary valvular stenosis, termed "pulmonary valvular dysplasia", is a deformity characterized by the presence of three distinct cusps and commissures and composed of disorganized myxomatous tissue with little, if any, fusion. The obstructive mechanism is related to the markedly thickened, immobile cusps (Koretzky et al., 1969).

Pulmonary atresia

The extreme of pulmonary valve stenosis is pulmonary atresia with or without VSD. Cases of pulmonary atresia have been reported, usually accompanied by some other

cardiac abnormality like tricuspid atresia or dysplasia of the RV free wall (Kasahara et al., 2010; L'Ecuyer et al., 2001).

Percutaneous pulmonary valve implantation (**PPVI**), also known as **transcatheter pulmonary valve replacement (TPVR)**, is the replacement of the pulmonary valve via catheterization through a vein. It is a significantly less invasive procedure in comparison to open heart surgery and is commonly used to treat conditions such as pulmonary atresia.

3.1.6 Studies Related To Valves of Heart

- **Studies Related To Tricuspid Valve**

Silver MD et al (1971): stated that the annular circumference of the valve in 27 hearts from men was 11.4 ± 1.1 cm and in the 23 female hearts was 10.8 ± 1.3 cm.The morphology of 50 normal tricuspid valves was studied. Five types of chordae were distinguished by their morphology and mode of insertion: fan-shaped, rough zone, basal, free edge, and deep chordae. The last two types are unique to the tricuspid valve. If fan-shaped chordae, used to define the commissures between the leaflets, are absent, other landmarks may be used for commissural definition. Once defined, all tissue between the commissures was regarded as part of the anterior, posterior, or septal leaflet. The recognition that the free edges of the anterior and septal leaflets contain notches, that rough zone chordae insert into them, and that the posterior leaflet has scallops further aids identification of a leaflet's components. Thus, structures formerly regarded as accessory leaflets were incorporated into one of the three leaflets.

Keith L .Moore (1980): Stated that the oval right atrioventricular orifice is large enough to admit the tips of three average sized.

R .Wayne Alexander et al (1998): Quoted that tricuspid annulus is nearly a circular fibrous structure. He also mentioned that tricuspid valve is larger in circumference and measures 10cm to 12.5cm.

Kocak A et al (2004): Study was conducted on 400 human hearts of autopsy cases during a medicolegal autopsy with permission from the Council of Forensic Medicine, Izmir, Turkey. Morphometric and morphological data from each tricuspid valve namely area, basal width, depth of leaflets, depth of commissure, number of chordae tendineae and their relation to the leaflets was obtained. In 40 hearts 2 leaflets (20%),

in 140 (70%) 3 leaflets and in 20 hearts there were 4 leaflets (10%) in deaths of noncardiac origin.Also 2 leaflets in 36 hearts (18%), 3 leaflets in 130 hearts (65%) and there were 4 leaflets in 34 hearts (17%) in deaths of cardiac origin. Although chordal abnormalities were extremely rare in cardiac death cases, some chordae tendineae retained a normal or near-normal appearance, while others were thickened and shortened in cardiac death cases. He also reported that in non cardiac death cases the anterior leaflet was triangular in 100 case (95%), rectangular in 10 cases. The posterior leaflet was the smallest and it appeared as rectangular in 20 case (10%), square in 20 (10%) , triangular in 160 (80%) cases. The septal leaflet appeared rectangular in 32 cases (16%), square in 12 (6%) and triangular in 156 (78%) cases. In cardiac death cases the anterior leaflet was the largest component of the tricuspid valve and was triangular in 82 cases (91%), rectangular in 11 (5.5%) and square in 7 (3.5%) cases. The posterior leaflet appeared as rectangular in 16 cases (8%), square in 14 (7%) and triangular in 170(85%)cases.The septal leaflet appeared rectangular in 28 cases (14%), square in 21 (10.5%) and triangular in 151 (75.5%) cases.

Susan Standring (2005) stated that the tricuspid valve orifice is best seen from atrial aspect and roughly triangular.

Mohamed A.B.Motabagani (2006) stated that total annular length of the human tricuspid valve ranges between 11.3 cm to 13.9 cm. He reported that three commissures were observed to intervene between the three leaflets of the human tricuspid valve: anteroposterior , posteroseptal and anteroseptal. The clefts and commissures were grossly identified by the attachment of the fan shaped chordae tendineae. The anteroposterior and posteroseptal commissures received commissural chordae originating from the medial most apex of the anterior and posterior papillary muscles respectively. The anteroseptal commissure received chordae that arose from one of the masses of the septal papillary muscle or directly from the septal wall of the right ventricle.

Chummy S. Sinnatamby (2006) stated that tricuspid valve guards the right atrioventicular orifice and has three cusps .The three cusps are called anterior , posterior and septal.

Christine H. Attenhofer Jost et al(2007): A case of Ebstein's anomaly .It is a rare congenital heart disorder occurring in 1 per 200 000 live births and accounting for 1%

of all cases of congenital heart disease.This anomaly was described by Wilhelm Ebstein in 1866 in a report titled, "Concerning a very rare case of insufficiency of the tricuspid valve caused by a congenital malformation.".The patient was a 19-year-old cyanotic man with dyspnea, palpitations, jugular venous distension, and cardiomegaly. At autopsy, Ebstein described an enlarged and fenestrated anterior leaflet of the tricuspid valve. The posterior and septal leaflets were hypoplastic, thickened, and adherent to the right ventricle. There was also a thinned and dilated atrialized portion of the right ventricle, an enlarged right atrium, and a patent foramen ovale.By 1950, only 3 cases of this anomaly had been published.

R Kalyani et al (2012): The study was carried out on 100 formalin fixed hearts without any pathology from patients who had died of non-vascular causes and whose age ranged from 8 to 85 yrs. The hearts were grouped into three cohorts corresponding to age, 54 hearts aged between 8 to 40 yrs, 42 hearts aged between 41 to 64 yrs and 4 hearts aged 65 yrs and above. The statistically significant increase in tricuspid valve measurements was observed with advancing age both in men and women. In younger hearts the tricuspid valve resembled a triangle and with advancing age the tricuspid valve became more elliptical in shape.

Yan Topilsky (2014):- The study involved 353 patients with isolated TR (age 70 years; 33% male; ejection fraction, 63%; all with right ventricular systolic pressure <50 mm Hg). Severe isolated TR was diagnosed in 76 patients (21.5%) qualitatively and 68 patients (19.3%) by quantitative criteria (effective regurgitant orifice).

Krunal R.Chauhan et al (2014):- This study was performed on a 100 human cadaveric hearts to assess the incidence of abnormal tricuspid valve and the number of main and accessory cusps. The hearts were non-macerated and preserved by immersion in 4% neutral formalin solution. The incidence of 4 cuspidal tricuspid valve was 10%(10/100hearts) and bicuspidal valve is 1%(1/100hearts) and the incidence of normal tricuspidal valve is 89%.

Aarti Rohilla (2015):- Research performed on One hundred cadaveric human hearts were studied by dissection method for the correlation among various morphometric parameters of the heart and tricuspid valve. From the total hearts only 86 hearts were studied and 14 hearts have been excluded because of the one or the other anatomical variation in the structure of leaflets. A strong and direct correlation was observed

between the circumference of tricuspid valve with the weight of heart, attachment length of leaflets and the three commissures and height of leaflets. Thus the present study tried to provide the normal data on morphometric parameters of heart and tricuspid valve which will help the cardiac surgeons and forensic experts. Possibly, it can also be used as an important tool in the anthropological studies, for better understanding of surgical anatomy of heart and designing of tissue-engineered cardiac valves.

Sunita Athavale et al (2017): Thirty-six embalmed cadaveric hearts were utilized for the present study. Leaflet morphology was studied using newly defined criteria. Commissural zones were identified and leaflets were delineated. Presence of scallops was also recorded. Single leaflet was observed in six cases, double in 26 cases, and triple in four cases. The anterior leaflet is large with multiple scallops and frequently accrues portion of inferior leaflet. The septal leaflet is in the form of a plateau and also frequently accrues parts of inferior leaflet. The inferior leaflet rarely occurs as independent leaflet.

P. Preethi et al (2020):- They performed a descriptive work on 45 cadaveric human hearts by conventional dissection technique and a detailed morphometry of the tricuspid valve was studied, and observed The mean total annular length of the tricuspid valve orifice was 10.91 ±1.00cm. The mean annular length of each leaflets were 4.55 ± 0.51cm; 3.37 ± 0.76cm and 2.70 ± 0.69cm. The mean height of each leaflets were 1.82 ± 0.36cm; 1.60 ±0.31cm and 1.20 ± 0.43cm. The mean height of each commissures were 1.06 ±0.30cm; 0.74 ±0.28cm and 1.04 ±0.32cm.

- **Studies Related To Bicuspid Valve**

F. W. Mohr et al (1998):- Study on 56 heart in which the mitral valve was either repaired (*n* 28) or replaced (*n* 23) in 51 patients by means of a minimally invasive approach through a right lateral mini-thoracotomy and under video-scopic guidance. *Observed the* mean length of incision was 5.4 6 1.8 cm (range 3.8 to 8 cm). Mean duration of operation, cardiopulmonary bypass, and cross-clamp time was 196 6 53, 133 6 52, and 72 6 27 minutes, respectively. Median intubation time was 25.5 hours (range 5 to 264 hours). Median duration of intensive care and hospital stay was 2 days (range 1 to 36 days) and 13 days (10 to 36 days), respectively. Hospital mortality was 9.8% (5/51). Overall morbidity was relatively high. In two patients acute retrograde

aortic dissection led to conversion of the procedure. At follow-up (261 ±13 days), three patients required reoperation for paravalvular leakage. Baseline mean duke activity index score was 19.3 6 11.3 before the operation and increased to 23.2 ± 10 at 6 weeks' and 24.2±10.3 at 12 weeks' follow-up.

Tetsuro Sakai et al (1999):- Study in 57 normal cadaveric hearts, the distance from the tip of the papillary muscle to its corresponding mitral anulus was directly measured, andobserved.The distance from the tip of the anterolateral papillary muscle to the left trigone (10-o'clock position: D10) and to the point between the anterior and the middle scallops of the mural leaflet (8- o'clock position: D8) was 23.5 ± 3.7 mm and 23.2 ± 3.6 mm, respectively. The distance from the tip of the posteromedial papillary muscle to the right trigone (2-o'clock position: D2) and to the point between the middle and the posterior scallops of the mural leaflet (4-o'clock position: D4) was 23.5 ± 4.0 mm and 23.5 ± 3.9 mm, respectively. There was no statistically significant difference among the 4 distances (P = .96). Each distance was significantly longer than the corresponding chordae tendineae (D10 vs the anterior main chorda: 17.2 ± 3.9 mm, D8 vs the anterior cleft chorda: 14.5 ± 3.2 mm, D2 vs the posterior main chorda: 17.9 ± 4.3 mm, and D4 vs the posterior cleft chorda: 14.9 ± 3.2 mm, respectively; P = .0001). The mean distance had a significant correlation with the mitral annular diameter (r = 0.31, P = .019). In normal hearts,the annulo–papillary muscle distances of the mitral apparatus are similar in 2-, 4-, 8-, and 10-o'clock positions and correlate with the mitral annular diameter.

D.Patil et al (2008): A total of 50 adult hearts procured from cadavers of dissection hall from Department of Anatomy, were used for study irrespective of sex and age above 50 years. The heart were meticulously dissected for mitral leaflets with the annulus, chordae and papillary muscles were removed as described by Louis a. Du Plessis and Paul Marchand (1964) with some modification. The overall prevalence of mean annular circumference was found to be 8.248cm, Length of free edge of valve curtain7.362 cm, maximum length of leaflet anterior1.924cm and posterior 1.104cm. In our study we get lower circumference of mitral valve as compared to others with similarities in other findings. As heart is procured from cadavers of Indian origin we try to correlate racial difference in morphology.

Rakesh M. Suri et al (2009):- We obtained real-time, three-dimensional (3D) transesophageal echocardiographic images of the MV in 44 patients: 29 patients

scheduled to undergo MV repair for severe MR due to leaflet prolapse (MV disease group) and 15 normal outpatients undergoing evaluation for various reasons (control group). Mitral valve repair was performed by median sternotomy or minimally invasively using thoracoscopic or robotic assistance. All patients underwent implantation of a standard-length flexible 63-mm posterior annuloplasty band at the time of mitral repair and we obtained postoperative 3D images for 11 patients after separation from bypass. Mitral annular dimensions were measured throughout the cardiac cycle using reconstructive analysis software (QLAB MVQ Version 6.0; Phillips, Bothell, WA).The mean patient age was 60 years; 30 were men. The mean ejection fraction was 0.61 and was similar between the two groups (p 0.16). In patients with MR due to leaflet prolapse, posterior annular length and total annular circumference were significantly larger than in control patients ($p < 0.001$). In contrast, there was no detectable difference in the anterior intertrigonal distance between patients with MR and normal controls. After mitral valve leaflet repair and posterior annuloplasty there was a significant decrease in both the total annular circumference and posterior annular length ($p < 0.0001$) while cyclic annular contraction was preserved.

Amgain K et al (2013): This study was carried out on 50 cadaveric adult human hearts. Left atrium was opened along the left border of heart so as to expose the mitral orifi ce. Then, the diameter of the valve was measured by using cardiac sizer, whereas circumference was calculated manually. Number of mitral valve cusps and papillary muscles were observed.The mean annular circumference and diameter of the mitral valve was found to be 8.03 ± 0.82 cm and 2.56 ± 0.32 cm, respectively. Majority (72%) of the mitral valves had the circumference ranging from 7.53 to 8.47 cm and the diameter ranging from 2.4 to 2.7 cm. The size of mitral valve in the North Karnataka region was found to be less as compared to the other studies. This study might help cardio-thoracic surgeon as well the prosthetic valve manufacturing companies for the rough estimation of the mitral valve size.

Gupta C. et al (2013): In human heart left atrioventricular orifice is guarded by mitral valve, which lies at the junction of the left atrium and the left ventricle of the heart controlling and directing unidirectional blood flow during ventricular diastole. Irrepairable damage to the mitral valve calls for its replacement using either a valve made up of biological tissue or metal, pyrolytic carbon, vulcanised silicon rubber and

similar materials. Prostheses of these synthetic valve needs detailed knowledge of mitral orifice and valve dimensions. In the study an attempt was made to study the dimensions of mitral orifice and mitral valve in formalin fixed adult human heart specimens Mitral orifice was cut opened in these specimens and photographed with a scale. This image was used for Scion image analysis for measurement of (i) Length of free margin and area of each leaflet, (ii). Inner circumference of the mitral valve and (iii) Surface area of the mitral valve leaflets. It was found that circumference of annulus of mitral valve was 8-10 cm, length of free margin of anterior leaflet was 5-7 cm, length of free margin of posterior leaflet was 7-9 cm, area of anterior leaflet was 1-3 cm^2, and area of posterior leaflet was 2-4 cm^2 .

Tamas Ruttkay et al (2014):- In this study ,compared the aortic, left atrial, and apical approaches to visualize the mitral valve with the goal to investigate the endoscopic anatomy and give exact step-by-step descriptions of these views.study In 30 cases after the removal of the hearts, the endoscopes were introduced directly into the aortic root through an aortotomy, left atrium through a standard atriotomy, and apex of the heart through a transmural incision. In 10 cases, the in situ visualization was performed using standard surgical approaches, such as partial upper ministernotomy, right and left minithoracotomy. The investigation was performed first with the mitral valve open, then the left ventricle was filled with saline, and the valve was closed by clamping the aorta For the visualization of ventricular surfaces of the mitral leaflets and the sub-valvular apparatus, the apical approach was most optimal. The aortic approach had limitations at the posterior leaflet. Using the atrial approach, we did not obtain any direct visual information about the subvalvular apparatus with the valve closed. The atrial surfaces of the leaflets were best visible using both the atrial and apical approaches with the mitral valve open. In the case of a closed valve, the apical approach did not allow for an investigation of the atrial surfaces. The aortic approach was useful to visualize the atrial surface of the posterior leaflet with an opened valve.

Dr. S. Ilankathir et al (2015): Human heart valve is a vital structure and knowledge about the normal anatomy of heart valve circumference is important for assessing the valve pathologies and also in valve replacement surgery for a deceased valve. Thus the present study was done to assess the exact dimension of the annular circumference of bicuspid valves in formalin fixed 50 human hearts. Annular Circumferences of

bicuspid valves were measured in all the specimens. The Average annular circumference of the mitral valve was 8.285 cm. This study had provided the necessary data on the dimensions of circumference of bicuspid valve of the heart, which will be helpful for surgeons to carry out valve repair and to manufacture prosthetic valves of appropriate dimension.

Agata Krawczyk-Oz og et al (2017): A study on 200 autopsied human hearts from white individuals without any valvar diseases was conducted. Parameters measured were the intercommissural and aorto-mural diameters of the mitral annulus and identified the leaflets and their scallops.Also noted the base and the height of the inferoseptal commissure, superolateral commissure, anterior mitral leaflet, and posterior mitral leaflet with their scallops. Variations in posterior mitral leaflet were found in 55 specimens (27.5%), and variations in anterior mitral leaflet were found in 5 hearts (2.5%). The most common variations included valves with 1 accessory scallop between P3 and inferoseptal commissure (7%), accessory scallop between P1 and superolateral commissure (4%), connections of P2 and P3 scallops (4%), connections of P1 and P2 scallops (3%), and accessory scallop in anterior mitral leaflet (2.5%).In all cases, the mitral valve was built by 2 main leaflets with possible variants in scallops (29.5%). The variations were largely associated with posterior mitral leaflet and were mostly related to the presence of accessory scallop. Anatomically, the anterior mitral leaflet is not divided into scallops, but could have an accessory scallop (2.5%). Understanding the anatomy of the mitral valve leaflets helps with the planning and performing of mitral valve repair procedures. Variations in scallops may affect repair procedures, but unfortunately cannot be predicted by any of the annular sizes.

Dr.Prasenjit Bose et al (2017): Dilated cardiomyopathy is a heart muscle disorder defined by the presence of a dilated and poorly functioning left ventricle in the absence of abnormal loading conditions (hypertension, valve disease) or ischaemic heart disease sufficient to cause global systolic impairment. The main objective of our study is to evaluate the changes of heart wall by gross morphometric measurements in DCM patient's heart samples and compare these with the control heart samples and this study is mainly focused in the regions of North India. Previous studies do not sufficiently reveal the anatomical variation of the heart musculature wall in DCM patients from North India. Dilated Cardio Myopathy(DCM) is the most common

cardiomyopathy, occurring primarily due to genetic defects or secondarily as a consequence of multiple factors, including long-standing hypertension, ischaemic heart disease, infection and sarcoidosis.

Abdallah El Sabbagh et al (2018):- Mitral valve regurgitation (MR) is the most common valvular heart disease. Primary MR is a disease of the mitral valve apparatus, whereas secondary MR is a disease of the left ventricle. Diagnosing and managing MR is often challenging and requires a structured approach, integrating findings on history, physical examination, and imaging. Decisions regarding treatment depend on knowledge of the etiology, natural history, and outcome of interventions for these patients with mitral valve disease. The optimal timing of intervention requires a comprehensive 2-dimensional and Doppler echocardiogram in each patient to determine the cause of the mitral valve disease, the severity of the regurgitation, and the effect of the volume overload on the left ventricle, as well as determining if a durable valve repair can be performed. Advances in both surgical and catheter-based therapies have resulted in recommendations for lower thresholds for operation and extension of interventional treatments to the older, sicker population of patients with MR. The current review discusses the pathophysiological rationale for current diagnostic and management strategies in MR.

Alborto Pozzoli et al (2018) Transcatheter valve therapies deeply changed the treatment of heart valve disease over the last decade. Shifting from aortic valve interventions (TAVI), more reproducible and with less anatomical variables, toward the AV valves entails increasing complexity and deeper knowledge of these two valves. The development of transcatheter mitral valve (MV) therapies was much more slower, mainly due to the structure and complexity of the MV apparatus and its pathology. With the development of transcatheter tricuspid valve (TV) therapies, interventionists are dealing with an even more stimulating anatomical scenario.

Dr. Shruthi B. N et al (2019): Out of 60 cadaveric hearts studied,80% of the hearts(48) had 2 cusps,18.3% of the hearts(11) had 3 cusps,1.7% of the hearts(1)had 4 cusps. Mean circumference of the annulus was 7.68cm. Mean length of anterior cusp; posterior cusp, accessory cusp-1 and accessory cusp-2 were 2.26cm,2.16cm,1.31cm,1.2cm respectively. Mean breadth of anterior cusp, posterior cusp, accessory cusp-1 and accessory cusp-2 were 2.97cm, 3.02cm, 1.39cm, 1.4cm respectively. Mean height of anterior cusp, posterior cusp, accessory cusp-1and

accessory cusp-2 were 1.72cm, 1.68cm, 1.3cm, 1cm respectively. Conclusion: Mitral valve is the commonly affected valve of the heart. The morphometric analysis of the mitral annulus with its cusps is important in assessing various pathological conditions like mitral stenosis and regurgitation. It is evident that the number of cusps varies greatly and this morphometric analysis is useful for determining the size of the prosthetic valve. Hence, it is of immense importance to cardiologists and cardiothoracic surgeons who perform valvotomy, valve repair and prostatic valve replacements to be aware of these variations as an increase in the number of the cusp and their improper approximation causes various valvular disorders.

- **Studies Related To Aortic Valve**

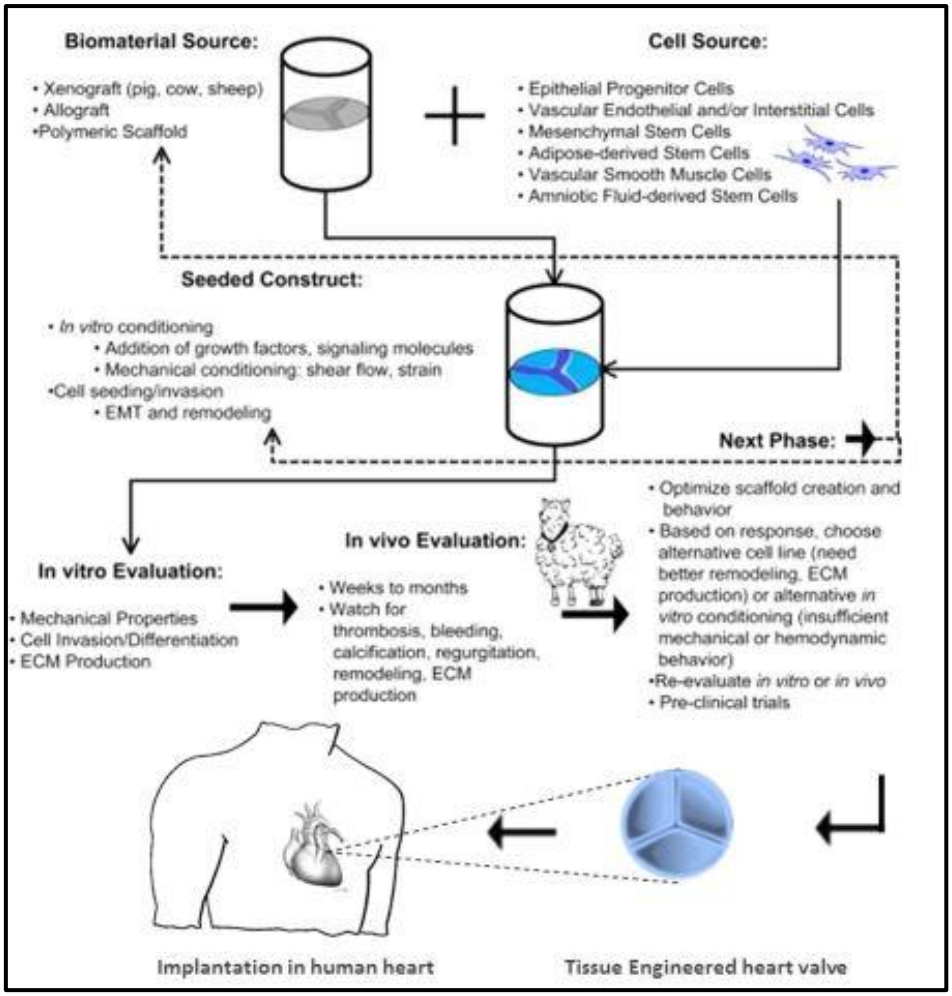
Marcelo Biscegli Jatene et al (1999): Analyzed 100 healthy fixed human hearts; 84% of them obtained from males, 61% of them from Caucasian individuals. The ages of the individuals ranged from 9 to 86 years (mean 30±15.5 years).All hearts assessed had a tricuspidal aortic valve. In regard to the height of the cusps and size of the lunula, the left coronary cusp was larger, followed by the right coronary cusp and the noncoronary cusp. The internal and external intercommissural distances had mean values of 24.6±5.7mm and 19.7±7mm, respectively.
In regard to the position of the coronary ostia, in one heart two ostia emerged from the left coronary sinus, and in another, the ostium was supracommissural. The mean diameter of the aorta was 21.8±3.6mm, and there were no significant sexual or racial differences, but the diameter increased progressively with the increase in age. The thickness of the cusps did not show any significant difference in the 3 points assessed.

Joseph Knight et al (2009): Assessed the distribution of coronary ostial locations in patients using cardiac dual-source computed tomography (CT) and compare those values to those of human cadaveric specimens. Measurements of the coronary ostia location were performed in 150 patients undergoing dual-source CT and in 75 cadavers using open measurement techniques. This study provided data of normal coronary ostial origins and demonstrated significant differences between in vivo and ex vivo measurements regarding the right coronary ostium. The observed large variations of coronary ostia origins emphasized the importance of considering such anatomic variations in the development of treatments.

Krishnaiah M et al (2012): This study was done in 25 cadavers and in 50 living people of both sexes and different age groups and an attempt was made to compare the measurements of area and circumference of aortic valve with that of previous studies for standardization which can help in prosthetic valve manufacturing. In this study, in cadavers the measurement was done using the calipers and for living cases 2D echocardiography (ECHO) was chosen as a tool for measuring valvular areas, as it is a safe, painless noninvasive means. Most of the parameters of present study were correlating with previous studies which were done in western countries. In the cadavers the values were little higher than the normal range may be because of postmortem changes of myocardium and papillary muscles.

Anwarul Hasan et al(2014): Due to the increasing number of heart valve diseases, there is an urgent clinical need for off-the-shelf tissue engineered heart valves. While significant progress has been made toward improving the design and performance of both mechanical and tissue engineered heart valves (TEHVs), a human implantable, functional, and viable TEHV has remained elusive.Common approaches for tissue engineering of heart valves were adopted. Scaffolds prepared from various natural or synthetic biomaterials were seeded with desired cell types. The cell seeded constructs were conditioned in vitro using various chemical and mechanical cues for tissue formation and improvement of mechanical and hemodynamic properties. The preconditioned engineered tissue constructs were evaluated in animal models. After optimization of the constructs in animal models, the intended step is to implant the constructs in human subjects.

Schematic illustration was modified and reprinted by Loftin et al. (2011), with permission from Springer Science as per below.



Dr. S. Ilankathir et al (2015): Human heart valve is a vital structure and knowledge about the normal anatomy of heart valve circumference is important for assessing the valve pathologies and also in valve replacement surgery for a deceased valve. Thus the study was done to assess the exact dimension of the annular circumference of aortic valve in 50 formalin fixed human hearts. Circumferences of aortic valve was measured in all the specimens. The Average annular circumference of aortic valve was found to be 7.542 cm. The present study provided the necessary data on the dimensions of circumference of all the valves of the heart, which would be helpful for surgeons to carry out valve repair and to manufacture prosthetic valves of appropriate dimension.

Dr. R.D.Virupaxi et al (2016): The present study was carried out on 40 adult cadaveric hearts (30 males and 10 females). Left ventricle was dissected according to the Cunningham's dissection manual. The aortic orifices and valves were exposed. The circumference of the orifice was measured by the cardiac sizer. The diameter was measured by Vernier caliper. The size of the aortic valve in the North Karnataka

region was found to be less as compared to other studies. The present study might help cardio-thoracic surgeon as well the prosthetic valve manufacturing companies for the rough estimation of the aortic valve size.

Kumar A et al (2017): In this study, total sixty formalin fixed cadaveric heart specimens irrespective of age, sex, and race were collected for the purpose of teaching undergraduate students were utilized. The Aortic valve of heart was opened and dissected. Fusion of the right and left valve cushions at the beginning of valvulogenesis appears to be a key factor in Bicuspid Aortic Valve (BAV) formation. The fewer the number of cusps, the greater is the chance that the valve is stenotic from birth. In the present study, BAV had been noticed in a 3(5%) specimen out of 60 hearts studied. Bicuspid aortic valve is the commonest etiology of aortic stenosis between the ages of 60 and 75 years (59% of cases); it was also the cause in 40% of those aged under 60 years and 32% of those aged more than 75 years . The incidence of aortic stenosis complicating BAV in an autopsy series ranges from 15% to 75%. The anatomy of the bicuspid valve may also influence the propensity for obstruction: Stenosis is more rapid if the aortic cusps are asymmetrical or in the antero-posterior position. Progression of BAV stenosis is age related, with fibrosis beginning in the second decade and calcification progressing significantly after the fourth decade.

Dr. Khushnuda Perween et al (2021):25 post-mortem human hearts 15 from male and 10 from female cadaver had been utilized in the study. Circumference of valve orifice, diameter of valve orifice, length spread and thickness of each cusp, thickness and position of nodulus, thickness of lunula and position of each coronary orifice were calculated. In this study showed that the various measurements of aortic valve of the hearts of the males were more than the findings of female. In this study all dimensions were less than that of found by previous studies. The morphometric measurement of this study might help the prosthetic valve manufacturing companies to make the valves of the exact size.

Damian Dudkiewicz et al (2022): Aortic valve fenestrations were defined as a loss of aortic valve leaflet tissue. They were a common but overlooked finding with unclear significance. The aim of this study was to investigate the varied functional anatomies of aortic valve fenestrations. A total of 400 formalin-fixed autopsied human hearts were macroscopically assessed and the function of the aortic valve of 16 reanimated human hearts were imaged using visible heart methodologies. Aortic valve leaflet

fenestrations were present in 43.0% of autopsied hearts (in one leaflet in 24.0%, in two leaflets 16.0%, in all leaflets 3.0%). Fenestrations were mostly present in left (25.5%) followed by right (23.3%) and noncoronary leaflet (16.3%). In 93.8% of cases, the fenestrations form clusters and were mainly located at the free edge of the leaflet in the commissural area (95.4%). Hearts with aortic valve fenestrations had significantly larger aortic valve diameters and aortic valve areas ($p < 0.001$). The average surface area sizes of fenestrations were 23.8 ± 16.6 mm^2, and the areas were largest for left followed by right and noncoronary leaflet fenestrations ($p < 0.001$). The fenestration areas positively correlated with donor age ($r = 0.31$; $p = 0.02$). Significant hypermobility and subjective weakening of the leaflet adhesion levels of the fenestrated regions were observed. In conclusion, fenestrations of the aortic leaflets are frequent, and their sizes may be significant. They occur in all age groups, yet their size increase with aging. Fragments of leaflets with fenestrations show different behaviors during the cardiac cycle versus unchanged areas.

- **Studies Related To Pulmonary Valve**

Srijit Das et al(2001): They examined the gross anatomical features of pulmonary valve in human cadavers. One hundred human cadaveric heart were dissected over the period of three years. The diameters and other dimensions of pulmonary valve were recorded. Valve was also examined for the presence of any anomalies. Out of 100 specimen one specimen had bicuspid pulmonary valve. Bicuspid pulmonary valve may remain undetected during life. It may be incidental finding during routine doppler echocardiography. Cardiologist and pathologist may need to aware about the fact that not all cases with bicuspid pulmonary valve present with symptoms, unless it is complicated by superimposed cardiac or extra cardiac disease.

Arkalgud Sampath Kumar et al (2003): The purpose of this study was to assess the mid-term results of aortic valve replacement with the pulmonary autograft. From October 1993 through September 2003, 153 patients with aortic valve disease (81 rheumatic and 72 non-rheumatic), with a mean age of 28 $\pm$ 14.2 years underwent the Ross procedure with root replacement technique and right ventricular outflow tract reconstruction using a homograft. Associated procedures included mitral valve repair (n=19), open mitral commissurotomy (n=15), tricuspid valve repair (n=2), homograft mitral valve replacement (n=2), and subaortic membrane resection (n=1).Early mortality was 6.5% (10 patients). Mean follow-up was 77$\pm$ 42 months (range, 7 to

132 months; median, 90 months). One hundred, twenty-one survivors (84.6%) had no significant aortic regurgitation. Reoperation was required in 10 patients for autograft dysfunction alone (n=3), infective endocarditis (n=2), autograft dysfunction with failed mitral valve repair (n=3), and failed mitral valve repair alone (n=2). No reoperations were required for the pulmonary homograft. There were 8 late deaths. Actuarial and reoperation-free survival at 90 months were 91.% ±3.5%, 95.3% ±2.7%, in nonrheumatics and 86.1±3.9%, 90.5±3.7% in rheumatics, respectively. Freedom from significant aortic stenosis or regurgitation was 91.5%±2.8% in non-rheumatics and 80.6% ± 4.8% in rheumatics. Event-free survival was 86.2%±4.9% in non-rheumatics and only 68.9%± 5.3% in rheumatics.The Ross procedure is not recommended for young patients (< 30 years) with rheumatic heart disease. It provides satisfactory hemodynamic and clinical results in properly selected patients. Important autograft dilatation was not observed in patients.

Theodoros Xanthos et al (2011): For the pulmonary valve, the number of cusps was variable. Except from its normal tricuspid morphology, 2 to 5 cusps had been described (usually with no clinical significance). Congenital pulmonary valve stenosis is the most common cause of obstruction to the RV outflow, with pulmonary atresia representing the worst case scenario (with or without VSD). Pulmonary atresia (or even absent pulmonary valve) can be found in patients with congenital cardiac anomalies (e.g. Fallot's tetralogy), associated with VSD and absence of direct communication between the RV and the pulmonary trunk.

Garg S et al (2013): The knowledge of anatomy of the heart has evolved over the ages and has contributed to the applications of cardio thoracic surgery and in understanding physiology of the various heart related diseases. In this study the anatomy of pulmonary valve in human cadaveric heart was studied by gross examination and dissection of hearts. The range of various parameters along with mean value and standard deviation was calculated. The annular length of the pulmonary valve was in the range of 5.4-7.8 cm with mean of 6.5±0.59cm.The width of right anterior, left anterior and of posterior leaflet was in the range of 1.9- 3.1cm with mean of 2.4±0.35, 1.8-3.4cm with mean of 2.5±0.45 and 2.1-3.5 cm with mean of 2.7±0.4 respectively. As a result of such studies, current notions may be so changed and extended so as to understand the better morphologic structures of the heart and to provide a scientific basis for its function.

Dr. S.Ilankathir et al (2015):A total of 50 adult cadaveric human hearts were taken up for the study from the Department of Anatomy. Only the specimens which retains its morphological features and in good condition after removal from the cadavers and the reason for undertaking was to explore the accurate dimension of the annular circumference of pulmonary valve of the heart. Specimens with gross morphological changes and having calcified valves were excluded. The Average annular circumference of the pulmonary valve was 6.823 cm. The circumference of the pulmonary valve ranged from 6.0-6.5 cm in 16 specimens and 6.6-7.0 cm in 24 specimens and 7.1-7.5 cm in 6 specimens and 7.6-8.0 cm in 4 specimens. The circumference of the pulmonary valve orifice ranged from 6.0-8.0 cm. The average circumference of the pulmonary valve orifice is 6.823 cm. Annular circumference is maximum in range of 6.6-7.0 cm (48%) followed by 6.0-6.5 cm (32%), 7.1-7.5 cm (12%) and lowest in range of 7.6-8.0 cm (8%).

Ashalatha P R et al (2017): The human pulmonary valve is an important structure and knowledge about its normal anatomy is essential in detecting valve diseases and in valve replacement surgeries. The normal pulmonary valve has three semilunar cusps or leaflets. The valve is known to present anatomical variations with respect to number of cusps, circumference and presence of fenestrations. The aim of the study is to detect and record such variations. A prospective observational type of study on 213 randomly selected autopsy cases with age ranging from 2 ½ to 89 years was conducted at Government Medical College. Out of 213 cases, 211 valves had 3 cusps (99.06%), one valve had two cusps (0.46%) and one had four cusps (0.46%). Fenestrations were seen in 103 valves (48.35%).Cusps were asymmetrical in 15 valves (7.04%).Circumference of the valve had a significant relation to age and sex of the individual.

Wilke M. C. Koenraadt et al (2018): Data on pulmonary valve morphology are scarce. This study was aimed to determine pulmonary valve morphology in hearts with Bicuspid Aortic Valve (BAV) associated with CHD. In 83 post-mortem heart specimens with BAV and associated CHD, pulmonary valve morphology was studied and related to BAV morphology. In 14/83 (17%) hearts, the pulmonary valve was affected, bicuspid in 8/83 (10%), dome-shaped in 3/83 (4%) and atretic in 3/83 (4%). In specimens with a bicuspid pulmonary valve, 2/3 hearts (67%) with dome-shaped pulmonary valves and 2/3 hearts (67%) with atretic pulmonary valves had BAV without raphe. Six out of eight (75%) specimens with a bicuspid pulmonary valve had

a perimembranous ventricular septal defect (VSD). 4/8 (50%) specimens with a bicuspid pulmonary valve were associated with chromosomal abnormalities: 3 (38%) had trisomy 18 and 1 (13%) had trisomy 13. In BAV with associated CHD, abnormal pulmonary valve morphology was observed in 17% of the hearts. The majority of hearts with abnormal pulmonary valve morphology had a Type B bicuspid aortic valve (without raphe). Bilateral semilunar valvular disease is associated with Type B BAVs and in many cases related to chromosomal abnormalities. As this study was performed in post-mortem specimens with high frequency of associated CHD, caution is warranted with application of these results to the general BAV population.

3.2 Papillary Muscle and Chordae Tendinae

3.2.1 Morphometry & Morphology of Papillary Muscle and Chordae Tendinae

- **Papillary Muscle In Right Ventricle: (Grays Anatomy 41st Edition)**

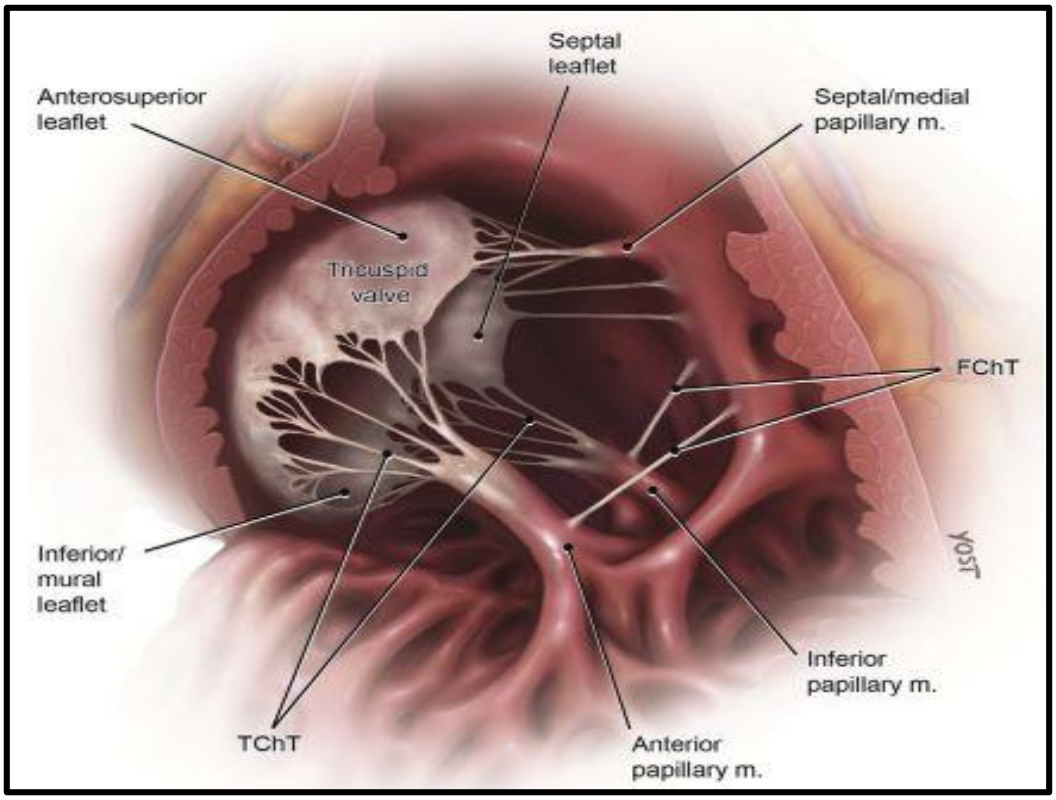


Figure 3.8:Papillary Muscle and Chordie in Right Ventricle (TChT-True Chordae Tendinae,FChT-False Chordae Tendinae)

The two major papillary muscles in the right ventricle are located in anterior and inferior positions. A third, smaller muscle lies medially, together with several smaller, variable muscles attached to the ventricular septum. The anterior papillary muscle is the largest, its base arising from the right anterolateral ventricular wall inferior to the

anteroinferior commissure of the inferior leaflet, also blending with the right end of the septomarginal trabecula. The inferior, papillary muscle, often bifid or trifid, arises from the myocardium inferior to the inferoseptal commissure. The septal (medial) papillary muscle of the conus, the muscle of Lancisi, is almost always present and is the most superior and largest of the small septal papillary muscles. It arises from the posterior septal limb of the septomarginal trabeculation and locates the right bundle branch within the right ventricle. All the major papillary muscles supply chordae to adjacent components of the leaflets they support. A feature of the right ventricle is that the septal leaflet is tethered by individual chordae tendineae directly to the ventricular septum; such septal insertions are never seen in the left ventricle. When closed, the three leaflets fit snugly together, the pattern of the zones of apposition confirming the trifoliate arrangement of the tricuspid valve.

- **Chordae Tendinae In Right Ventricle:**

The chordae tendineae are fibrous collagenous structures that support the leaflets of the atrioventricular valves. Sometimes, false chordae connect the papillary muscles to each other or to the ventricular wall or septum, or pass directly between points on the wall or septum, or both. Their numbers and dimensions vary in the right ventricle; approximately 40% of these false cords contain conduction cardiomyocytes. The true chordae usually arise from small projections on the tips or margins of the apical third of papillary muscles, although they sometimes arise from the papillary muscle bases or directly from the ventricular walls and septum. They attach to various parts of the ventricular aspects or the free margins of the leaflets. True chordae are classified into first, second- and third-order types, according to the distance of the attachment from the margins of the leaflets; the scheme has little functional or morphological merit. Fan-shaped chordae have a short stem from which branches radiate to attach to the margins (or the ventricular aspect) of the zones of apposition between leaflets and to the ends of adjacent leaflets. Rough-zone chordae arise from a single stem that usually splits into three components that attach to the free margin, the ventricular aspect of the rough zone and to some intermediate point on the leaflet, respectively. Free-edge chordae are single, thread-like and often long, passing from either the apex or the base of a papillary muscle into a marginal attachment, usually near the midpoint of a leaflet or one of its scallops. Deep chordae pass beyond the margins and branching to various extents, reach the more peripheral rough zone or even the clear zone. Basal chordae

are round or ribbon like, long and slender, or short and muscular; they arise from the smooth or trabeculated ventricular wall and attach to the basal component of a leaflet.

- **Papillary Muscle In Left Ventricle:**

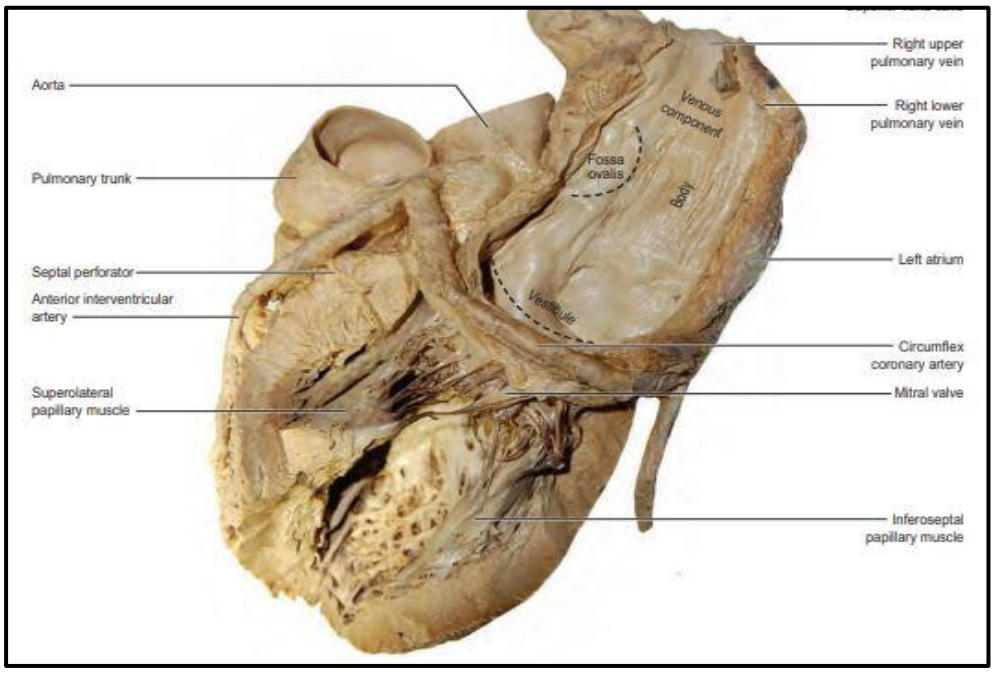


Figure 3.9: Papillary Muscle of Left Ventricle

Above figure is from grays anatomy 41st edition.The two muscles supporting the leaflets of the mitral valve vary in length and breadth, and may be bifid. The anterolateral (superolateral) muscle arises from the sternocostal mural myocardium, and the posteromedial (inferoseptal) from the diaphragmatic region. Chordae tendineae arise mostly from the tip and apical third of each muscle but sometimes take origin near their base. The chordae from each papillary muscle diverge and are attached to corresponding areas of closure on both valvular leaflets.

- **Chordae Tendinae In Left Ventricle:**

Mitral chordae tendineae resemble those supporting the tricuspid valve. False chordae are also irregularly distributed as in the right ventricle. They are single or multiple, thin, fibrous or fibromuscular structures that traverse the cavity of the left ventricle and have no connection with the valvular leaflets. They occur commonly in human left ventricles and often cross the sub aortic outflow. Histologically, false chordae sometimes contain extensions from the ventricular conducting tissues; these left ventricular bands are often identified on echocardiography. It has been suggested that false chordae produce premature ventricular contractions and be the possible cause of

functional heart murmurs or innocent murmurs in children and young adults. True mitral valve chordae may be divided into four types: interleaflet (commissural), rough zone (including the special strut chordae), 'cleft' and basal chordae. Most true chordae divide into branches from a single stem soon after their origin from the apical third of a papillary muscle, or proceed as single chordae that divide into several branches near their attachment. Basal chordae, in contrast, are solitary structures passing from the ventricular wall to the mural leaflet. There is such marked variation between the arrangement of the chordae that any detailed classification loses much of its clinical significance. Suffice it to say that, in the majority of hearts, the chordae support the entire free edges of the valvular leaflets, together with varying degrees of their ventricular aspects and bases, and there is some evidence to suggest that those valves with unsupported free edges become prone to prolapse in later life.

3.2.2 Functions of Papillary Muscle and Chordae Tendinae

The papillary muscles of both the right and left ventricles begin to contract shortly before ventricular systole and maintain tension throughout. This prevents regurgitation—backward flow of ventricular blood into the atrial cavities—by bracing the atrioventricular valves against prolapse—being forced back into the atria by the high pressure in the ventricles.

The chordae tendinae is the important component of atrioventricular (AV) valve complex. Chordae plays an important role in ventricular contraction by maintaining the continuity in between the different components of atrioventricular valve complex with proper tension.Chordie prevent the cusps from swinging back into the atrial cavity during systole. Commissural chordae plays an important role in approximation of the two adjacent cusps in ventricular contraction.

The Subvalvular Apparatus

The atrioventricular valve is connected to the ventricular cavity by a suspension system—the subvalvular apparatus—that has the following two functions: one function is to limit the extent of the upward displacement of the leaflets during systole; the other is to facilitate the opening of these leaflets during diastole ("active opening valve") .To achieve these two goals, the suspension system consists of the following two structures that have different physical characteristics: the papillary muscles, with contractile properties, and the chordae tendineae, with elastic properties.

3.2.3 Variation of Papillary Muscle and Chordae Tendinae

The papillary muscles and their tendinous cords vary greatly in terms of number, shape, and location (Loukas et al. 2008a). The chorda tendinae are classified based on their length, or the distance between the papillary muscle and leaflet. Further classifications are single, free-edge, deep, and basal (Standring 2009) and false when they do not attach to leaflets at all. Right ventricular papillary muscles were classified by based on their position: posterior (posterolateral or posteromedial); anterior; or septal (infundibular or septal inferior)

3.2.4 Clinical Terms and Cardiac Procedure Related to Papillary Muscle and Chordae Tendinae

Papillary muscle rupture can be caused by a myocardial infarctand dysfunction can be caused by ischemia. Both complications may lead to worsening of mitral regurgitation.

3.2.5 Studies Related To Papillary Muscle and Chordae Tendinae

G.R. Nigri et al(2000) A series of 79 normal human hearts was studied focusing on the morphological characteristics of the papillary muscles of the right ventricle and their tendinous cords (chordae tendineae). The number, incidence, length and shape of the anterior, septal and posterior papillary muscles were observed. The tendinous cords attached to each papillary muscle were counted at their origin. The papillary muscles and the tendinous cords were measured in situ and after the removal of the right atrioventricular valve (tricuspid valve). The anterior and posterior papillary muscles (apm, ppm) were present in 100% of the cases. The septal papillary muscle (spm) was absent in 21.5% of the hearts. The apm presented 1 head in 81% and 2 heads in 19% it was 19.16 mm in length. The spm was one-headed in 41.7% and presented two heads in 16.5% the presence of a 3 and 4 heads appeared in 12.7% and 7.6% respectively the spm was 5.59 mm in length. The ppm had 1 head in 25.4%, 2 heads in 46.8%, 3 heads in 21.5% and 4 heads in 6.3% of the cases it was 11.53 mm in length. Tendinous cords (TC) varied as follows from 1 to 11 TC originated in the apm (mean 4.74) from 1 to 8 TC originated in the ppm (mean 2.67) and from 1 to 5 TC originated in the spm (mean 1.77).

Hideki Uemura et al (2008) The tension apparatus was straddling to the morphologic right ventricle in 2. Another 34 hearts had a bifoliate valve and the papillary muscles

abnormally oriented; a solitary papillary muscle in 3, two papillary muscles but deviated in 5, one of two papillary muscles being dysmorphic in 9, and three or more papillary muscles in 17. The origin of these papillary muscles was frequently deviated. In 5 hearts with a trifoliate or quadrifoliate valve, multiple papillary muscles were also the case. One of these had thick leaflets, a part of which was adherent to a membranous flap around the ventricular septal defect as well as to subpulmonary fibrous tissue tags. Eventually, the valve was comparable with the mitral valve seen in the normally structured heart in only 7 hearts (15%). There was no obvious correlation noted between the presence of abnormality in the mitral valve and that in the tricuspid valve.Architectural abnormalities are not rare in the morphologic mitral valve in this setting. The valvar structure needs precise recognition.

Harsha B. R et al (2015) In the present study, number of papillary muscles was present with a frequency of 2-10. Maximum numbers of papillary muscles were 10 seen in only one heart (1%) and minimum numbers of papillary muscles were 2 seen in 3 hearts (3.1%). Anterior papillary muscles were present in all 96 (100%) hearts. Maximum numbers of muscles observed were 3 seen in 6 hearts (6.3%) and minimum number muscle was 1 seen in 66 (68.8%) hearts, which was normal. Two papillary muscles were seen in remaining 24 hearts (25%). Posterior papillary muscles were present in 95 (98.95%) hearts. Seven papillary muscles were observed in only 1 (1%) heart and only 1 papillary muscle was seen in 27 (28.1%) hearts. In measurements of papillary muscles, anterior papillary muscle mean height was 1.49±0.44 cm; mean width was 0.82±0.21 cm and mean thickness was 0.64±0.15 cm respectively and posterior papillary muscle mean height was 1.05±0.37 cm, mean width was 0.63±0.17 cm and mean thickness was 0.5±0.11 cm respectively.

Manisha B Sinha(2020) In the right ventricle, authors observed 31.42% anterior, 34.3% posterior and 34.3% septal papillary muscles, and in the left ventricle, 41.7% anterior and 58.3% posterior papillary muscles. Classical papillary muscles were observed in 64.3% heart specimens in right ventricle and 55% in left ventricle. Authors found conical, pyramidal and broad apexed papillary muscles in 44.3%, 51.4% and 4.3% heart specimens respectively in right ventricle, whereas in left ventricle the corresponding values were 33.3%, 30% and 36.7%. Separate bases and fused apex pattern was observed in 24.3%, single base and divided apex in 55.7% heart specimens in right ventricle and in left ventricle in 45% and 43.3% heart specimens respectively. The length of anterior, posterior and septal papillary muscle

in right ventricle was 1.27±0.45, 1.36±0.52, 0.92±0.54 cm respectively whereas in left ventricle, the mean length of anterior and posterior papillary muscles was 2.13±0.44 and 1.76±0.46 cm. In right ventricle mean thickness was 1.17±0.31cm whereas in left ventricle it was 2.16±0.32 cm.

3.3 Coronary Sinus and Thebesian Valve

3.3.1 Morphometry & Morphology of Coronary Sinus and Thebesian Valve

The coronary sinus originates at the right atrial orifice and ends at the "site of origin of the valve of Vieussens" that is, at the junction of the great cardiac vein and the oblique vein of the left atrium (vein of Marshall) and terminates at the right atrial orifice . Once formed, the coronary sinus traverses the posterior (according to attitudinal correct nomenclature this is inferior instead of posterior) coronary sulcus (Loukas et al., 2016 ; Mazur et al., 2019). The coronary sinus is technically part of the right atrium; however, it is often seen with a myocardial coat in the posteroinferior aspect of the left atrium . The ostium of the coronary sinus is located between the inferior vena cava ostium and the inferior right atrioventricular annulus. This opening is often demarcated by a fold of endocardial tissue. This fold is termed the coronary sinus valve or Thebesian valve; this flap is the embryological remnant of the right sinus valve. It is a semicircular flap of endocardial tissue, sometimes called the gatekeeper to the coronary sinus . Obstruction of the valve was only determined if 100% of the coronary sinus ostium was covered, this was the case in only 2.6% of cases. It was observed that in the absence of the thebesian valve, coronary sinus ostium was larger in diameter. A larger diameter was also associated with a lower hebesian valve height. The coronary sinus is the receptacle for the majority of the epicardial veins, including the oblique vein, the inferior vein of the left ventricle, the great cardiac vein, the left marginal vein, anterior interventricular vein, and the inferior interventricular vein [Mazur et al., 2019]. As such, it is responsible for returning the bulk of the deoxygenated blood from the left side of the heart. The drainage of blood from the aforementioned tributaries into the coronary sinus occurs during myocardial systole and is subsequently drained into the right atrium.

3.3.2 Development Of Coronary Sinus and Thebesian Valve

In previous studies, the development of the coronary vessels was thought to have arisen from the proepicardium [13], however other studies on mice and myocardial organ cultures have revealed that the coronary vessels actually develop from angiogenic buds from the sinus venosus, the primary drainage vessel for the developing embryo.These, angiogenic sprouts or endothelial buds emanating from the sinus venosus result in the development of the coronary vessels, through aggressive migration and invasion into the myocardium. Furthermore, as some of the angiogenic sprouts invade the myocardium, they differentiate into arteries; while some remain on the epicardial surface and differentiate into the coronary venous system in the developing embryo. As the veins begin to develop in the growing embryo, the union of the anterior cardinal vein and the inferior posterior cardinal vein form the left and right common cardinal veins, also known as the ducts of Cuvier, which will ultimately drain into the sinus venosus. The right horn of the sinus venosus develops into the posterior wall of the right atrium, while the right common cardinal vein leads to the development of the superior vena cava. The left horn of the sinus venosus, or the systemic venous sinus, along with the degenerating left common cardinal vein leads to development of the coronary sinus as well as the vein of Marshall. The majority of the cardiac veins will terminate in the coronary sinus . The symmetrical tributaries that drain into the systemic venous sinus begin bilaterally and will empty into the atrial section of the heart tube via the sinus horns. In the initial stages of the embryo, the venous sinus develops under asymmetrical growth with the right side growing larger compared to the left. Although the embryology of the coronary venous system is not as well studied as the embryology of the coronary arteries; it is believed that the great cardiac veins originate from the cardinal veins. The left superior caval vein will eventually become the coronary sinus. When the horizontal component of the left superior caval vein converts into the coronary sinus, the portion of the caval that descends becomes the oblique vein of the left atrium .

3.3.3 Variation of Coronary Sinus and Thebesian Valve

M.W. Kassem et al. (2021) The coronary sinus is the most constant structure in the cardiac venous system in man [10]. However, there have been reported cases of variations. Sinus coronarius duplex or duplication of the coronary sinus has been reported. One case report identified the last portion of the inferior interventricular

vein in the area of the crux cordis, just beneath the opening to the inferior vena cava, the diameter was found to be almost as large as the coronary sinus and was found to be covered in myocardial fibers similar to the coronary sinus. This finding was therefore considered a duplicated coronary sinus [10]. There have been cases in the past where there has been a total absence of the coronary sinus. Such cases have identified the cardiac veins draining individually into the right and left atria [39]. An absence of the coronary sinus is seldomly an isolated anomaly, and is almost always associated with a co-anomaly, in particular, a persistent left superior vena cava [39,40].

3.3.4 Clinical Terms and Cardiac Procedure Related to Coronary Sinus and Thebesian Valve

Transesophageal Echocardiography (TEE): One of the major uses of echocardiography is detection of objects in and around the heart. With increasing intraoperative use of transesophageal echocardiography (TEE) by anesthesiologists, the potential exists that detection of an object that is in reality a rare, yet normal, variant may lead to unnecessary surgical intervention.

Coronary sinus and tachyarrhythmias : A significant interatrial myocardial connection is related to the coronary sinus as myocardial extensions from both atria arise to traverse the coronary sinus posteroinferiorly. It is this muscular sleeve which is responsible for the generation of a number of arrhythmias. However, with regards to atrial fibrillation the majority of the cases demonstrated the origin in the sleeve's connection with the left atrium rather than the right.

3.3.5 Studies Related To Coronary Sinus and Thebesian Valve

Hołda et al.in (2015) The Thebesian valve was present in 82.1% of cases and varied in morphology and size. Semilunar was the most common morphology identified, followed by remnant, fold, cord, mesh and fenestrated types.

Wiesława Klimek-Piotrowska et al (2016) The coronary venous system is an increasingly frequent target of minimally invasive cardiac procedures. The purpose of this paper is to assess the anatomical barriers in the right atrium to coronary sinus cannulation.

Arlene Sirajuddin et al (2020) The CS has two valves: the Thebesian valve and the valve of Vieussens, which are shown in Fig. 2. 1 The Thebesian valve, present up to 86% of the time, is located at the junction of the coronary sinus and the right atrium.

It is visualized on CT in approximately 72% of individuals as a thin, hypodense linear structure at the junction of the CS and the right atrium. Image noise and heart failure can make it difficult to visualize the Thebesian valve the remainder of the time.1,11 Thebesian valve morphology varies.3 Typically it is a thin semilunar fold with fenestrations and a height of 2–9 mm.1,6,12,18 In approximately 16% of people the Thebesian valve has features that make cannulation of the CS during cardiac procedures difficult. These features include: fibromuscular or muscular composition, covering over 75% of the ostium, and lack of fenestrations. Of these features, CT can detect when the Thebesian valve covers more than 75% of the CS ostium.1,19 The valve of Vieussens is located at the junction of the CS and the great cardiac vein, adjacent to where the oblique vein of Marshall enters the CS. It is present up to 87% of the time. When visible on CT, it may appear as a slight indentation at the junction of the great cardiac vein and the CS. A prominent valve of Vieussens can make it difficult to advance a catheter into the great cardiac vein.

Sirajuddin et al. (2020) Journal of Cardiovascular Computed Tomography play a part in the planning various procedures such as left ventricular pacing. Analysis of the coronary venous anatomy on CT can detect coronary venous anomalies causing right to left shunts with risk of stroke, left to right shunts, and arrhythmias.

3.4 Eustachian Valve, Chiari Network and Left Venous Valve Remnant

3.4.1 Morphometry & Morpholgy of Eustachian Valve,Chiari Network and Left Venous valve Remnant

The Chiari network is the result of incomplete resorption of the right and left venous valves.11 During involution of the embryonic valves, the tissue undergoes fenestration so that a network may be formed from remnants that eventually disappear. Incomplete resorption leaves a meshwork of thread-like strands connecting the edges of the Eustachian and Thebesian valves to the terminal crest, with occasional attachment to the wall of the right atrium or the interatrial septum. On echocardiography, the Chiari network often appears as a web-like structure with a characteristic undulating motion within the right atrium. The prevalence of Chiari network on transesophageal echocardiography is 2%.12 These structures may create diagnostic confusion, difficulty during interventional procedures,11,13 and

complications including thromboembolic events and are therefore important to recognize and document.

3.4.2 Functions of Eustachian Valve,Chiari Network and Left Venous valve Remnant

The right and left venous valves are prominent structures in the fetal heart that direct inferior vena caval flow towards the foramen ovale.

3.4.3 Variation of Eustachian Valve,Chiari Network and Left Venous valve Remnant

Dr. Ashita Kaoreet al (2021) The remnants of left venous valve of sinus venosus are rarely noticed in the interior of right atrium. The remnants can be seen attached to the floor of fossa ovalis. The incidence of remnants of left venous valve was studied in 50 cadaveric hearts utilised for undergraduate teaching programme. The right atrium was opened and the interior was studied for the presence of these embryological remnants. The incidence of remnants of left venous valve is 12% in the present study. It was seen either inform of membranous structure or fibrous strands attached to the fossa ovalis. This anomaly may give rise to complications like thromboembolism or difficulty during important surgical procedures of the interatrial septum. So knowledge regarding the incidence, morphology and complications of this embryological remnant is mandatory.

3.4.4 Clinical Terms and Cardiac Procedure Related to Eustachian Valve, Chiari Network and Left Venous valve Remnant

Transesophageal Echocardiography (TEE): Two structures found rarely within the right atrium that may mimic pathology are the eustachian valve and the Chiari network . The eustachian valve was initially described by Eustachius in 1563 and is located at the opening of the inferior vena cava into the right atrium . Although of no functional significance in the adult, the eustachian valve functions in the fetus to direct blood flow preferentially from the inferior vena cava through the foramen ovale into the left atrium. A eustachian valve is found in up to 86% of autopsy examinations , yet it is visualized in only 0.20% of routine echocardiographic examinations as a mobile, curvilinear structure in the right atria1 cavity It is not surprising, therefore, that a prominent eustachian valve may mimic pathology. The Chiari network was initially described by Chiari in 1897 and consists of a network of fine or course fibers

in the right atrium. It represents the filamentous remnant of the valve of the coronary sinus, and its exact function is unknown. The Chiari network is found in only 2%-3% of autopsy examinations and is visualized in only 1.5% of routine echocardiographic examinations as a delicate, highly mobile, serpentine structure in the right atria1 cavity.

In Right atrium catheterization, the operator may encounter a number of anatomical barriers that are mainly embryological remnants of the right venous valve (Sadler & Langman, 2011), including: the Eustachian valve (valve of the IVC ostium) and ridge, Chiari's network, Thebesian valve (valve of the CSO), muscle bridges within right atrium, overdeveloped tendon of Todaro, and other networks and structures in the right atrium and ostia of main veins. The purpose of this study is to assess the anatomical barriers to CS cannulation through main veins and right atrium.

Fetal Flow Pattern and Abnormal Imaging Patterns on Echocardiography and Contrast Computed Tomography: In the setting of a persistent fetal flow pattern and PRVV, the inferior caval vein flow is preferentially directed towards the interatrial septum. In such situations where the caval flow remains as 2 distinct columns of flow (dual caval flow), there is minimal mixing of superior and inferior caval vein flow in the right atrium, resulting in minimal to absent contribution of superior vena caval flow to any right-left shunt.

3.4.5 Studies Related To Eustachian Valve, Chiari Network And Left Venous Valve Remnant

S.D. Joshi et al (2016) This study was conducted in 50 apparently normal hearts available in Department of Anatomy.After opening of right atrium,the presence of fibrous strands of left venous valve remnant was observed in one of the specimen studied. This unique feature of fibrous strands has not been reported in the literature reviewed. The strands present in the FOv do not resemble Chiari network described in the literature. In such cases, difficulty may be encountered in transcatheteric closure of PFO.

Sevinc Bayer Erdogan et al (2017) The Chiari network is described as a reticulated network of fibers connected to the Eustachian valve identified as the embryological remnant of the right valve of the sinus venosus. It is an incidental finding without any significant pathophysiological consequences. However, the presence of the Chiari network in the right atrium obliges the physician to differentiate from other right atrial

pathologies. In a study it showed a presence of a case of a large Chiari network mimicking a right atrial thrombus with incidental finding in a 76-year-old man undergoing coronary artery bypass surgery.

Alejandro Jiménez Restrepo et al (2021) The anatomy of the eustachian valve (EV) is of relevance to the interventional cardiologist, cardiac electrophysiologist, and cardiothoracic surgeon, as this anatomical structure (along with its variants) may hinder procedures in the right atrium (RA) and right ventricle from an inferior approach.

3.5 Development Of Venous Valve

- In the fetus, right atrium serves as a conduit for oxygenated blood to be delivered to the left heart bypassing the right ventricle and the nonfunctional lungs. The anatomy in the fetal right atrium is designed for such purposeful circulation. The right and left venous valves are prominent structures in the fetal heart that direct inferior vena caval flow towards the foramen ovale. These anatomic structures typically regress and the foramen ovale closes after birth. However, the venous valves can persist leading to a range of anatomic, physiological, and pathological consequences in the adult.
- Right and left venous valves are embryonic structures in the right atrium of the developing heart, where they play a vital role in fetal circulation. In the adult heart, these valves regress for the most part, saving the Eustachian valve and terminal crest, generally considered benign structures. The embryonic right venous valve during development may disappear completely or may persist in varying degrees causing diagnostic challenges to the cardiac imager.
- In the embryonic heart, the right and left sinus horns form the sinus venosus, which eventually is incorporated into the right atrium. Each sinus horn receives blood from the vitelline vein (yolk sac), umbilical vein, and the cardinal veins. The umbilical veins deliver the oxygenated blood from the chorionic villi, whereas the anterior and posterior cardinal veins drain from the cranial and caudal portions of the embryo. By the eighth week of development, the enlarged right sinus horn is incorporated into the primitive atrium to form the smooth part of the right atrium, whereas the left sinus horn disappears. The junction of the sinus venosus and the right atrium is flanked by 2 muscular folds referred to as the right and left venous valves. The right and left venous valves play an important role in

fetal circulation, facilitating the flow of oxygenated blood from the umbilical vein into the left atrium, allowing the oxygenated blood to bypass the right ventricle and the developing lungs. Thus, the oxygenated blood is preferentially delivered to the head and neck vessels . These valves regress after birth when the fetal circulatory pattern is no longer necessary. In the adult heart, the cranial portion of the right venous valve regresses with its remnant being the terminal crest (Crista terminalis), and the caudal portion regresses with its remnants being the Eustachian valve and the Thebesian valve . The Eustachian valve helps prevent regurgitation of blood into the inferior caval vein, whereas the Thebesian valve presumably helps prevent regurgitation of blood into the coronary sinus during atrial systole. The left venous valve is generally absorbed into the right side of the interatrial septum. When the venous valves do not regress normally there can be clinical consequences.In the setting of persistent venous valves, a variety of physiological, anatomic, and clinical complications may occur.