A STUDY OF STRUCTURE OF THE HUMAN TRICUSPID VALVE APPARATUS IN 50 AUTOPSY SPECIMENS.

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MCh Cardiothoracic Surgery

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CERTIFICATE

This is to certify that **Dr.B.KASINATHAN** postgraduate student (2003 - 2006) in the Department of cardiothoracic surgery, Government General Hospital Chennai & Madras Medical College, Chennai- 600 003, has done this Dissertation of **''A STUDY OF STRUCTURE OF THE HUMAN TRICUPSID VALVE APPARATUS IN 50 AUTOPSY SPECIMENS''** under my guidance and supervision in partial fulfillment of the regulation laid down by The Tamil Nadu Dr.M.G.R. Medical University, Chennai, for MCh cardiothoracic - Branch II examination to be held in August 2006.

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CONTENTS

INTRODUCTION

The tricuspid valve complex consists of functional units, which include the valve leaflets, chordae tendineae and papillary muscles. The mechanical properties of these functional units depend on the large extent of the link between the muscle and the valve. This link is usually arranged in a branching network of avascular chordae tendineae composed of collagen and elastic fibers, which transmit contractions of the papillary muscle to the valve leaflets.

Although it has been known for many years that the tricuspid valve has 3 leaflets, almost always smaller or larger accessory cusps are to be found at one or all of the angles between the principal cusps. Based on morphological and morphometric criteria, tricuspid valve can be formed by 2 - 6 habitual/supernumerary leaflets besides commissural leaflets. The chordae tendineae, associated with the tricuspid valve, originated from a major anterior papillary muscle, a minor posterior papillary muscle and the septal wall. The anterior and posterior leaflets were the major components of this valve and received their major support from chordae tendineae originating from the anterior papillary muscle and the posterior wall.

Morphometric criteria such as area of leaflet, the basal width and the ratio of commissure depth to leaflet depth can be utilized for characterization of the tricuspid valve leaflets. The great variation in leaflet appearances is probably due to embryological development. Division of the common atrioventricular canal into the right and left channels starts in the embryo of 40 days. These channels, which are surrounded by mesenchymal subendothelial tissue called endocardial cushions that contribute to the future atrioventricular valve, grow and straighten to approximate the margins of these endocardial cushions.

The inferior leaflet is formed from the lateral and inferior wall of the myocardial gully and the anterosuperior leaflet from the supraventricular crest, which develops from the intraventricular part of the muscular outlet septum. This difference could explain the anatomical differences between the anterior and posterior leaflets.

In particular, minor anatomical differences in tricuspid valve anatomy are frequent. The tricuspid valve is not always in the same shape and configuration.

Controversies still exist on the importance of these variations and put the human beings at risk of unexpected deaths.

The left atrioventricular valve and its papillary muscle and chordae tendineae have been largely studied. Victor and Nayak pointed out that the internal morphology of the two cardiac chambers was extremely complicated and remarkably variable.

In particular, the observation of chordae tendineae of the right ventricle showed endless variability in their number, shape and location. The number, size, location and morphology of the right papillary muscle and their correlation to age and race were studied in an attempt to provide a classification. A normal right ventricular cavity has coarse trabeculations, with diffuse and variable chordal attachment to papillary muscles within the body of the ventricle and to the interventricular septum. The cavity of the right ventricle is triangular in shape and contains an identifiable muscular moderator band. It is guarded at its inflow by a tricuspid valve of variable anatomy and is separated from the outflow tract by an infundibular muscular band.

With aging, the tricuspid valve, like other tissues, changes; this changes consist mainly of local fibrous thickening of both the papillary muscle and chordae.

DEVELOPMENT OF TRICUSPID VALVE

Normal embryonic development of the cardiovascular system involves the transition from a primitive single - chambered tube into a highly specialized, four chambered heart. Establishment of basic cell populations and architecture upon which further changes occur. Internal changes which model the heart tube into the four chambered adult configuration. These changes transform the symmetric embryonic vasculature into the asymmetrical adult configuration.

ENDOCARDIAL CUSHION FUSION

Endocardial cushions are areas of mesenchymal proliferation. These represent areas of the fibrous skeleton forming between the atrium and ventricle. Endocardial cushions serve two important functions.

1. They form a partition in the heart tube between the primitive atrium and primitive ventricle, known as the atrio ventricular canal. The resulting two channels represent sites for the future tricuspid and mitral valves.

2. Provide a ‘‘Scaffold’’ in which the interatrial septae and the interventricular septum will grow towards and fuse with.

Defects in endocardial cushions function are associated with trisomies 18 and 21 (Down's syndrome). Since the scaffold for future growth is absent, ventricular septal defects are also common. The resulting condition is referred to as **atrioventricular communis**. This anomaly is seen with varying degrees of severity - the most severe being characterized by four chamber communication.

The proliferation of the fibrous skeleton, combined with the fusion of the endocardial cushions will form the biscuspid (mitral) and tricuspid valves.

BULBOVENTRICULAR LOOPING

BV looping is a consequence of several changes:

Dorsal folding

The first dorsal fold forms an expanded primitive ventricle, referred to as the bulboventricular loop. This loop is subject to further changes, mainly of a hemodynamic nature.

Ventricular growth

Differential growth of the proximal ventricular tissue causes a counter - clockwise rotation of the folded heart tube. The site of ventricular growth marks the future left ventricle.

Abnormal growth of the distal primitive ventricle causes clockwise rotation, an anomaly known as dextrocardia

AV canal partitioning

The Atrio-Ventricular (AV) canal between the primitive atrium and Ventricle has now been partitioned by the **fusing endocardial cushions.** The division serves to direct the blood preferentially through one channel.

Shunting of venous return

The development of the venous system causes an increase in right-sided venous return to the primitive atrium. Combined with the partitioning of the AV canal, the change in blood flow volume and directions assists in the outgrowth of the left ventricle.

Valvular defects can arise if endocardial cushion fusion does not partition the AV canal evenly.

INTERVENTRICULAR SEPTUM FORMATION

The interventricular septum (IVS) serves as the final event in separating aortic and pulmonary outflow from the heart. The division between IVS formation and aortico-pulmonary (AP) septum formation is done in order to highlight important features of each event. In reality, however, the two occur simultaneously. The IVS is characterized by two part, contributed by three separate structures:

A muscular portion

The muscular wall grows upwards towards the fused endocardial cushions, separating the bicuspid and tricuspid valves (and thereby, in-and outflow).

a membranous portion

The membranous portion of the IVS is contributed by the fused endocardial cushions, as well as the descending **bulbar ridges**.

Once the interventricular septum is formed, the tricuspid and bicuspid valves are separated, thereby dividing cardiac outflow into pulmonary and aortic streams. 25% of all **ventricular septal defects** occur in the membranous portion, due to the complexity of fusing three separate components together.

To summarize the origin of the interventricular septum.

AORTICO-PULMONARY SEPTUM FORMATION

The aortico-pulmonary (AP) septum arises within the truncus arteriosus. The septum results from the downward growth and fusion of bulbar ridges, induced by invasion of neural crest cells.

The AP septum serves to divide the ventricular outflow between the pulmonary artery and the ascending aorta.

In addition to dividing cardiac outflow, the AP septum contributes to the formation of the semilunar valves.

The different valves arise over the course of fetal development. Spatial or 'topological' arrangements of developing heart tissue appear to influence how the valves form, and whether two or three leaflets will develop on a particular side of the heart.

The embryology of the heart is incredibly complicated. We don't start out with a four chambered heart. Within the first three weeks of human development a single large vessel undergoes a series of rotations to create the primitive atria which connect to a single ventricle. A 'flap valve' separates the two atria (the foramen ovale, or oval opening). While in the womb, blood is oxygenated within the placenta-a rich nexus of blood vessels where the fetal circulation exchanges oxygen and receives nutrients from the maternal circulation. Exchange occurs in the placenta as the lungs do not function until birth. Thus the heart must shunt blood away from the lungs. It accomplishes this in a variety of ways.

Blood entering the right atrium is shunted to the left atrium across the foramen ovale. In utero, pressures in the right side of the heart are greater than in the left side. Blood readily flows from right to left. Once the lungs fill with air, however, the situation reverses. Pressures on the left side are then greater than on the right. By the time of birth the connections between the right and left side have closed (or so one hopes.), so there is no flow of blood from left to right.

Blood making it into the right ventricle can readily cross into the left ventricle as the interventricular septum has not yet formed to separate the right ventricle from the left ventricle. Blood entering the Pulmonary arteries from the right ventricle can cross directly into the aorta via the ductus arteriosis. This connection normally closes a few days after birth. Aside from having a single ventricle, that nothing separates the atria from the ventricles. They form a continuous canal - the atrioventricular canal. Within this area lie the endocardial cushions, areas of developing tissue that form part of the ventricular walls. Most people believe that they contribute little to no tissue to the actual valve leaflets. However, their position within the atrioventricular canal is of importance. They also fuse during the 4th week of development to form a ring of tissue from which the valves will develop.

'Mesenchymal tissue' near the area of the AV canal will form the valve leaflets. Over time the ventricular tissue is 'hollowed out' so the mesenchymal tissue overhangs the receding myocardium. Receding ventricular muscle forms the chordae tendineae - thick stringy attachments which connect the valve leaflets to the papillary muscles of the ventricular wall. These muscles contract with the rest of the ventricle when blood is being moved into either the aorta or the pulmonary vessels. Without their contraction, the pressure of the blood could force the tricuspid and mitral valve leaflets back into the atrial chamber (a bad thing.)

The position of the endocardial cushions is of importance. The cushion tissue bulges more on the left side of the heart than on the right side. Some studies suggest this bulge becomes incorporated into the mitral valve by fusing two areas of the valvular ring of tissue into a single leaflet. The remaining tissue develops into the second valve leaflet (a bicuspid valve). On the right side of the heart, there is no similar bulge, so the developing valvular tissue splits into three leaflets - the tricuspid valve.

EMBRYOGENESIS OF THE LEAFLETS OF THE

TRICUSPID VALVE

Before septation, the right atrium has access to the right ventricle only via the cavity of the left ventricle. The formation of the tricuspid valve, therefore, occurs in two phases. The first phase involves the development of the connection of the right atrium with the right ventricle, whereas the second phase involves the formation of the valvar leaflets with their tensor apparatus. Leaflets of the tricuspid valve develop more or less equally from two components, namely, the ventricular musculature and the endocardial tissues of the atrioventricular canal and the outflow segment. Furthemore, the valve was found to develop from two building blocks, the so-called tricuspid gully complex and the fused ridges that divide the outflow segment

Tricuspid Gully

The remodeling of the tissues of the right atrioventricular junction produces a myocardial gully that guards the inferior portion of the ventricular inlet and directs atrial blood toward the middle of the right ventricle. Staining with the GIN2 antibody reveals that the precursor of the right bundle branch demarcates the position of the anterior free boundary of this gully, while the simultaneous development of the anterior papillary muscle complex marks it anterolateral free boundary. Wessels et al., (1996). As early as week 6 of development, therefore, the anterior ledge of this tricuspid gully can be identified as the precursor of the septomarginal trabeculation. Two points should be made concerning this configuration. First, the gully originally has only an anterior ventricular orifice pointing toward the developing outflow tracts. A new inferior orifice develops in the floor of the gully during week 7. Interestingly, separate anterior and inferior valvar orifices can persist as characteristic morphological features of the so- called double orifce tricuspid valve Second, when the septomarginal trabeculation becomes prominent with the appearance of the inferior ventricular orifice, it is attached relatively high on the septum. Only gradually does it descend towards the apex to attain its definitive position around week 10.

The inferior and lateral myocardial wall of the gully, together with the right lateral endocardial cushion, form the inferior leaflet, while the septal leaflet is formed from the muscular ventricular septum together with the posterinferior endocardial cushion. From the stance of the myocardial delamination, the formation of these leaflets is a single and continuous process, with the formation of the septal leaflet following temporally on that of the inferior leaflet. The precise mechanism of delamination within the myocardium remains to be established. This may very well be similar to that underscoring the expansion of the ventricular cavity elsewhere, namely, by expansion of preexisting intertrabecular spaces, Such spaces already exist in the stage 15 embryo, not only between the ventricular trabeculations but also between the crest and the stem of the ventricular septum.

Endocardial Ridges of the Outflow Segment

In the early embryonic heart, the myocardium of the lesser curvature (the ventriculoinfundibular fold) separates the inlet and outlet components of the right ventricle superiorly. Toward week 7 of development, these components become additionally separated by a frontally oriented partition that arises as a result of the fusion of the endocardial ridges of the outflow segment. The lower (conal) portion of these ridges, together with the adjacent part of the right lateral cushion, becomes transformed in its greatest part into myocardium. Although the advancement of a dynamic process such as in growth of cardiomyocytes from the surrounding myocardium into endocardial cushion tissue can only be inferred from the analysis of a temporal series of staged embroynic hearts, several facts support the conclusions concerning myocardialization. First, the myocardial tissue separating the subaortic and subpulmonary portions of the outflow segment are derived from the tissues formed by fusion of the endocardial ridges. Second, the myocardialization of the endocardial ridges starts well before their fusion, as shown immunohistochemically by co-localization of slender myocardial cells and endocardial tissue. Third, throughout this period, the endocardial cushion tissue retains a thickness of 0.1mm and decreases in size only relatively as a result of the pronounced growth of the ventricular myocardium. The upper part of this newly formed myocardium is incorporated to form the outlet component of the muscular ventricular septum. The lowermost, intraventricular, part is interposed between the tricuspid gully and the subpulmonary part of the outflow segment and contributes both to the supraventricular crest and to the anterosuperior leaflet of the tricuspid valve.

The anterosuperior leaflet of the tricuspid valve develops from this lower, intraventricular, part of the fused ridges septating the outflow segment. This myocardialized structure carries the tissues of the right lateral cushion, and the anterosuperior cushions are carried on the atrial surface. These conclusions are based on several further facts. First, the lower, intraventricular, part of the endocardial ridges, subsequent to fusion and apical growth, forms the new anterosuperior boundary of the tricuspid funnel. Second, via the right lateral endocardial cushion, the parietal component of the fused ridges is continuous with the anterolateral boundary of the tricuspid gully. Third, the anterolateral boundary of the tricuspid gully is marked by the position of the anterior papillary muscle, which, in turn, marks the junction between the anterosuperior and inferior leaflets.

Temporally, the process of delamination of the anterosuperior leaflet from the developing supraventricular crest follows that of the inferior leaflet, beginning anterolaterally as a superior expansion of the space around the tricuspid gully. The medial papillary muscle develops solely from the medial (septal) margin of the septal component of the fused endocardial ridges and initially has no connection with the developing septal leaflet. The development of this topographical relation (the anteroseptal commissure) depends entirely on the completion of the process of delamination.

Endocardial Cushion Tissue and the formation of the Valvar Leaflets

Although it was initially held that the endocardial cushions contributed markedly to the valvar leaflets, various investigators more recently have stressed the importance of the invagination of the atrioventricular junction in the formation of the inferior and septal leaflets. According to this concept, both the epicardial tissue of the atrioventricular groove and the atrial myocardium make contributions to the valvar leaflets. The atrioventricular endocardial cushions, in contrast, are devoted to a minor role, being held, at best, to form only the free edges of the leaflets and the nodules of Albinus.

The development of the leaflets and their tensor apparatus cannot, therefore, be explained simply on the basis of invagination of the atrioventricular junction together with undermining of the ventricular myocardium. The cushions function mainly as a "glue" between the muscular components of the septal structures during cardiac septation and that their material contribution to the valves is minimal. The contributions of endocardial cushion tissue and myocardium are approximately equal at the time of delamination, the endocardial cushion tissue forming the atrial face of the developing leaflet.

Tricuspid valve - the evolutionary conservation

In birds and in some reptiles, the inferior and anterosuperior leaflets of the tricuspid valve together form a single, sickle-shaped, permanently muscular structure that can be described as the "great mural leaftlet". Its anterosuperior and inferior portions are demarcated by the position of the anterior papillary muscle. In these species, the septal leaflet is hardly developed. This arrangement is remarkably reminiscent of the architecture of the tricuspid gully as it is seen in the mammalian embryos (Lamers, et al., observations 1991). The fact that the formation of the tricuspid valve in higher vertebrates follows an evolutionarily conserved pattern, therefore, further strengthens our earlier conclusion, based on the comparison of cardiac septation, that morphogenetic programs in the heart are basically similar in all higher vertebrates. This is particularly relevant for the use of either mammalian or avian embryos as models in experimental studies.

ANATOMY OF THE TRICUSPID VALVE

The tricuspid orifice is the largest of the four cardiac valves. The three leaflets are supported by a tensor apparatus composed of chordae tendineae (primary, secondary and tertiary) and papillary muscles (usually a single major anterior papillary muscle and several accessory papillary muscles).

There is no tricuspid annulus, but the bases of the leaflets are attached to the heart at the atrioventricular junction. In normal situs and connection, this ‘‘ring’’ is related to the base of the aortic valve, the membranous septum, the central fibrous body, the right coronary artery, the lateral atrioventricular junction, the coronary sinus and the bundle of His (clockwise from medially).

Of the three well defined leaflets the anterior is the largest and the chordae are attached to the dominant papillary muscle. It is separated from the septal leaflet by the anterior septal commissure and from the small posterior leaflet by the posterior commissure.

The base of the septal leaflet harbors the penetrating portion of the conducting system.

The anterior commissure lies adjacent to the atrioventricular septum and the tricuspid valve lies in a plane caudad to the mitral valve.

With right ventricular dilatation, the tricuspid annulus enlarges along the major portion of the attachment of the anterior leaflet, the posterior leaflet and the lateral third of the septal leaflet.

SURGICAL ANATOMY OF TRICUSPID VALVE

Organic tricuspid valve disease is more common in India than in Western Countries,it has been reported to occur in the hearts of more than one third of patients in the rheumatic heart disease studied at autopsy on the subcontinent EWY, G.A. : Tricuspid valve disease. In Chatterjee K., Cheitlin, M.D., Karliner, J. et al., (eds): Cardiology: An illustrated text reference vol.2. Philadelphia, J.B.Lippincott, 1991 p.991 (Braunwald Heart Disease vol.2, 5th edition page:1054).

Primary diseases of the tricuspid valve apparatus which includes the tricuspid annulus, the leaflets, the chordae, the papillary muscle, and the RV wall also cause tricuspid regurgitation (Hurst's

THE HEART 10th Edition vol.2 page.1741). Waller BF, Howard J, Fess S. Pathology of tricuspid valve stenosis and pure tricuspid regurgitation III. Clin cardiol 1995; 18: 225-230.

AIM OF THE STUDY

The aim of this study is to investigate the relationship of valvochordal anatomy of tricuspid valve in autopsy specimen and its surgical application.

MATERIALS AND METHODS

The 50 human hearts were collected between 2003 and 2006 from 50 autopsy cases during a medicolegal autopsy with permission from the Forensic Medicine, MMC.

Morphometric and morphological data were obtained from each valve namely area, basal width, depth of leaflets, depth of commissure, number of chordae tendinease and their relation to the leaflets. These data were correlated for various anatomical variants.

The materials were collected from 50 AUTOPSY cases (25 male and 25 female) during a medicolegal autopsy with permission from the Forensic Medicine, MMC. We studied hearts with macroscopic evidence of normal hearts. There were 2 groups, females 25 and from males 25. The age of the individuals, whose autopsies were performed between 2003 and 2006 in MMC, varied from 25-60 years.

DISSECTION

Each heart was sectioned along its acute margin. The section passed near the anteroposterior commissure of the right atrioventricular valve with an incision from the right atrium to the apex of the right ventricle. After opening each heart was washed under tap water to remove blood clots. Dissection of the myocardium was carried out from the right atrioventricular fibrous ring to the origin of papillary muscles, preserving the integrity of the valve apparatus as a whole. The right atrioventricualr valves were determined and valve was removed with their chordae tendineae and papillary muscles. After examination in the fresh state, the valve of the right ventricle was flattend on glass plates. Morphometric and morphological data were obtained from each valve: area, basal width, depth of leaflets, depth of commissure, number of chordae tendineae and their relation to the leaflets. These data were studied and measured under magnifying lens.

The leaflet surface was impressed on aluminium foil and cut to measure its area and set as an isometric sample. This aluminum foil was placed on a smooth surface without changing the folds made by projection and indentation of the leaflet. The area of the leaflet surface was obtained by orthogonal projection on the paper. Boundaries of the projections were drawn on the paper, and the areas were calculated using the point counting probes. The number of chordae attached to each leaflet, their distribution and arrangement, morphology at the site of their insertion and its attachment to the leaflet were investigated. The length of chordae from origin to insertion and chordal thickness at its midpoint were measured. Measurements were made with a digital caliper, a flexible metric rule and surgical silk thread. The right atrioventricular valves and chordae tendineae were photographed, 48(male-23, female-25) and 4 leaflets in 2 (male only) hearts.

Although chordal abnormalities were extremely rare, most chordae tendineae retained a normal or near - normal appearance, while in four male hearts it was thickened and shortened.

DISCUSSION

The tricuspid orifice is the largest of the four cardiac valves. The valve complex comprises

a. the so called tricuspid atrio-ventricular orifice and the tissue that makeup its associated tricuspid valve annulus.

b. the valve leaflets or cusps and their sub divisions.

c. the chordae tandineae of various types.

d. the papillary muscles.

(Gray's anatomy 36th edition - angiology - page 644-648.)

The possibility of performing surgical interventions on the cardiac valves to treat a variety of diseases involving these structures demand precise knowledge of the valvochordal anatomy of each valve and of their major sub-divisions.

Silver and colleagues found a notch close to the antero septal commissure in 47 of the 50 anterior leaflets they examined. Kirklin and Barrott - Boyes textbook of cardiac surgery 3rd edition page 20.

The relevance of valvochordal variations in AUTOPSY specimen have been discussed in this study. It is important to understand the anatomical characteristics of the right atrioventricular valve and its variation in cardiac surgery

The present dissertation is intended to provide structures of the right valvochordal anatomy and its variations to determine that most frequent morphologic pattern in various autopsy specimen studied.

The annular circumference of the tricuspid valve was a large oval aperture and enough to admit the tips of 4 fingers. It was surrounded by a strong fibrous ring that was covered by the endocardial lining of the heart. That opening was 12.4$\pm$1.1 cm in males and 11.8 $\pm$1.3 cm in females.

TRICUSPID ORIFICE

When viewed from the atrial aspect of the basal attachment of the tricuspid valve, orifice was roughly triangular with anterior, posterior and septal sides.

The tricuspid orifice is the largest of the four cardiac valves.

DIAMETER	**MALE**	***FEMALE***
in cms	12.4 $\pm$ 1.1cms	11.8 $\pm$ 1.3 cms

LEAFLETS

In this study, the number of leaflets varied from 3-4. In 48 hearts (90%) there are 3 leaflets and in 2 (10%) there were 4 leaflets. A commissural leaflet was present in 2 hearts. The number of commissural leaflets varied from 0 to 1 and their preferential localization was between the anterior and septal leaflets and between the posterior and septal leaflets. Commissural leaflets were observed in 74% of the valves analyzed in most specimens and between the posterior and septal leaflets.

MORPHOLOGICAL DATA OF TRICUSPID VALVE

Leaflet	Male	Female	Total	Shape
Anterior	24	24	48	Triangular
Posterior	23	23	46	Triangular
Anterior	1	1	2	Rectangular
Posterior	2	2	4	Rectangular
Septal	22	23	45	Triangular
	3	2	5	Rectangular

LEAFLET ZONES

The surface of the leaflets was divided into 3 zones. Passing from free margin to the inserted margin. All leaflets of tricuspid valves displayed rough, clear and basal zones. The rough zone of the tricuspid leaflets was rough and thick on palpation and semiopaque on transillumination. It was rough at the point where chordae tendineae inserted. The **clear zone** was smooth and translucent, received few chordae tendineae and had a thinner fibrous core. The basal zone was a few millimeters wide and extended from the annulus of the posterior leaflets to the clear zone.

MORPHOLOGICAL DATA OF TRICUSPID VALVE

Leaflets	Male	Female	Total
Three	23	24	47
Four	2	1	3
	25	25	50

ANTERIOR LEAFLET

The anterior leaflet is interposed between the atrioventricular orifice and the anterior wall of the right ventricle. The anterior leaflet was triangular in 46 (95%) and rectrangular in 4 cases (5%). The average area of the anterior leaflet was measured as 292.5mm^2. The relationship between the width of the leaflet and its number demonstrated that the anterior leaflet was larger in valves with 3 leaflets than those with 4.

THE POSTERIOR LEAFLET

The posterior leaflet extended between the anteroposterior and posteroseptal commissures. The average area of the posterior leaflet was measured as 159.3mm^2. The posterior leaflet appeared as rectangular in 5 cases (10%), square in 5(10%) and triangular in 40 (80%).

SCALLOP OF LEAFLETS

The posterior leaflet of 5 hearts had only one scallop, while 40 had 2, 3 hearts had 3, and 2 hearts had 4. The scallops were of equal sizes in 12 leaflets, while the anteroposterior commissural scallop was larger in 22, and the posteroseptal in 16. No relationship was observed in terms of depth, width and number of chordae tendineae in the posterior leaflet when comparing valves with, 3 or 4 leaflets.

SCALLOPS IN ANTERIOR LEAFLET

Number	**Male**	**Female**	**Total**
Single	3	2	5
Two	20	20	40
Three	2	1	3
Four	1	1	2

SCALLOPS IN POSTERIOR LEAFLET

Number	**Male**	**Female**	**Total**
Single	3	2	5
Two	35	2	37
Three	3	3	6
Four	1	1	2

THE SEPTAL LEAFLET

The septal leaflet extended between the interventricular orifice and the right side of the interventricular septal wall. The average area of the septal leaflet was found to be the largest as 342.3mm^2. The septal leaflet appeared rectangular in 5 cases, and triangular in 45. No difference was observed in spetal leaflets when comparing valves with, 3 or 4 leaflets as regards with leaflet width and number of chordae tendineae. Septal leaflet with chordal abnormalities was extremely rare.

The anterior leaflet was the largest component of the tricuspid valve comparing to others. The anterior leaflet was triangular in 48, rectangular in 2.

The sum of the average areas of the anterior leaflet was found to be 221.3mm^2. Some chordae tendineae retained a normal or near-normal appearance, while others were thickened and shortened.

The sum of the average areas of the posterior leaflet was measured as 220.2mm^2. The posterior leaflet appeared as rectangular in 4 cases and triangular in 46. The posterior leaflet had scallops all of which were small and had an approximately equal sizes. No relationship was observed in terms of depth, width and number of chordae tendineae in the posterior leaflet when comparing valves with, 3 or 4 leaflets.

The average areas of the septal leaflet was calculated as 212.7mm^2. The septal leaflet appeared rectangular in 5 and triangular in 45. In the majority of cases with septal leaflet abnormally short cords were observed. Leaflets and cords were also thickened.

CHORDAE TENDINEAE

Based on an extensive quantitative study of mitral valve chordae LAM et al., 1970 proposed a useful classification. This was soon applied with addition by Silver et al., 1971 to the tricuspid valve.

Five types of chordae were attached to the tricuspid valve: these were

1. fan-shaped,
2. rough zone,
3. basal,
4. free edge and

5. deep chordae.

The number was approximately 20 and they were of different lengths and thickness. They originated from a papillary muscle either directly from the apex of the muscle or from small nipples, which were usually on their upper third. The chordae were attached to the ventricular end of the valve leaflets and their apices and margins, and then, anchored to the muscular ventricular wall. The majority of the chorade branched soon after their origin, some branched just before insertion and a few did not branch at all. Those inserted into the lateral margins of the leaflets or into the scallops of the posterior leaflet and passed at an oblique angle from their origin to insertion.

FAN-SHAPED CHORDAE

Fan-shaped chordae had a short stem from which branches radiated to attach to the margin of zones. Fan-shaped chordae were present at the anteroposterior commissure in 20 hearts, at the posteroseptal commissure in 25, and at the anteroseptal 5.

At dissection, thickened leaflets with fused commissures were noted along with thickened and shortened chordae.

Location	**Male**	***Female***	**Total**
Antero posterior commissure	10	10	20
Posteroseptal commissure	15	10	25
Antero septal	3	2	5

ROUGH ZONE CHORDAE

Rough zone chordae was inserted into the rough zone on the ventricular aspect of each leaflet. Each chorda split into 3 cords soon after its origin. One cord was inserted into the upper limit of the rough zone at the line of closure, and the other inserting into the free margin of a leaflet and the other between the two. Rough zone chordae were attached to the anterior leaflet in all 25 hearts, to the posterior leaflet in 20, and to the septal leaflet in 5.

Location	Male	Female	Total
Anterior leaflet	15	10	25
Posterior leaflet	10	10	20
Septal Leaflet	3	2	5

BASAL CHORDAE

Basal chordae were the round ones or flat ribbons, long and slender or short and muscular. They arose from the smooth or trabeculated ventricular wall and attached to the basal component of a leaflet. They arose directly from the myocardium or from small trabeculae carneae. They inserted a zone approximately 2 mm wide extending into the leaflet from the annular region. Basal chordae were found to be attached to 20 anterior, 28 posterior, and 2 septal.

Location	Male	Female	Total
Anterior leaflet	10	10	20
Posterior leaflet	15	13	28
Septal Leaflet	1	1	2

FREE EDGES

Chordae tendineae attached to the free edges and ventricular surfaces of the anterior, posterior and septal leaflets. There was no significant difference between the total numbers of the two sexes. Of the 34 chordae, 12 passed to the anterior leaflet, 7 to the posterior leaflet and 11 to the septal leaflet, and 4 inserted into the commissural areas.

OBSERVATION

Our findings indicated that the average area of the septal leaflet (212.7mm^2) was smaller than the anterior leaflet (221.3 mm^2) and posterior leaflet (220.2mm^2) in all specimen studied. Comparing the data of male and female, anterior leaflets would be considered to be the largest. The sum of average areas of the anterior leaflets would be considered to be the largest. The sum of average areas of the anterior leaflet (221.3mm^2) and posterior leaflet (220.2mm^2) happened to be higher than those of the septal leaflet (212.7mm^2) in all specimen studied.

The results of this anatomical study may explain the increased incidence in wide variations of chordae tendineae. Higher ratio of the abnormal chordae that were too short and too thick is also significant. Short, thick or differing from normal can be easily ruptured. This may exhibit individual differences.

REVIEW OF LITERATURES

Normal pathway dimensions from autopsy specimens

Rowlatt and colleagues provided extensive information about the dimensions (measured as circumference) of cardiac valves in formalin-fixed autopsy specimens from apparently normal children. (Kirklin - Barrott - Boyes Text book of cardiac surgery 3rd edition p.36). Because it is the diameter that is usually measured by echocardiography, angiography, and in the operating room, circumferences have been transformed to diameter, assuming that valve orifices are perfectly circular and using the equation.

$$\text{Diameter} = \frac{\text{Circumference}}{\pi}$$

These dimensions can also be expressed in terms of cross sectional area, using the transformation of the equation

$$\text{Area} = \left(\frac{\text{Diameter}}{2}\right)^2$$

Krovetz and Westaby and colleagues also made measurements in autopsy specimens from adults that are compatible with those of

Rowlatt and colleagues. These investigators added the information that as adults age, the size of the aortic orifce gradually enlarges. Eckner and colleagues measures pressure - fixed autopsy specimens and found dimensions similar to but slightly larger than those of Rowlatt and colleagues.

Scholz and colleagues also present extensive information on cardiac dimensions obtained in autopsy specimens. Their findings and equations are generally similar to those of Rowlatt and colleagues, except that they find the valve dimensions are best normalized to the age and gender of the individual (rather than to body surface area). These investigators believe that the predicted values from their regression equations are applicable to either fresh or fixed specimens, and that they compare well with systolic annular dimensions obtained by imaging techniques in living subjects.

Most of the information relating dimensions in patients to those obtained at autopsy uses equations derived from the work of Rowlatt and colleagues to compute the mean normal valve and standard deviation, based on the patient's body surface area. Dimensions were expressed as circumference and body surface area as cm^2 by Rowlatt colleagues.

BSA (m2)	**Tricuspid**	
	Mean	**± SD**
0.25	13.4	11.8-15.0
0.30	14.9	13.3-16.5
0.35	16.2	14.5-17.8
0.40	17.3	156.18.9
0.45	18.2	16.6-19.9
0.50	19.1	17.5-20.7
0.60	20.6	19.0-22.2
0.70	21.9	20.3-23.5
0.80	23.0	21.4-24.6
0.90	24.0	22.3-25.6
1.00	24.8	23.2-26.5
1.20	26.3	24.7-28.0
1.40	27.6	26.0-29.2
1.60	28.7	27.1-30.3
1.80	29.7	28.131.3
2.00	30.6	28.9-32.3

CONCLUSIONS

The valvochordal anatomy is found to correlate with literature findings in terms of morphologic data.

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