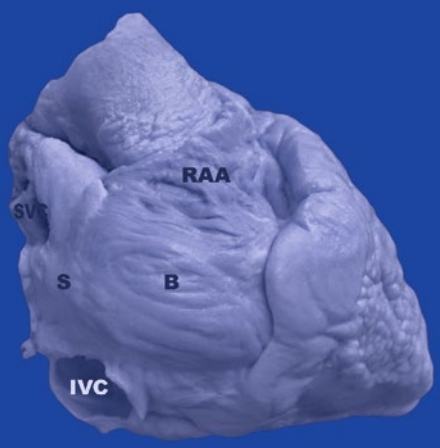
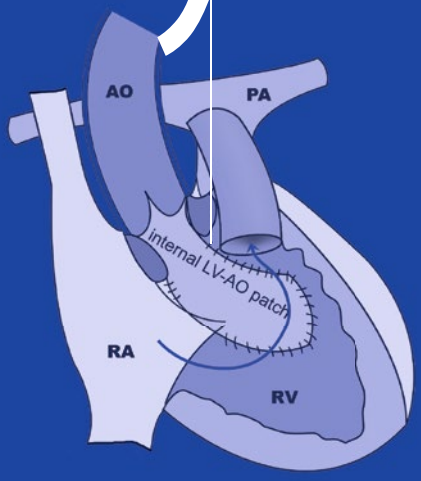
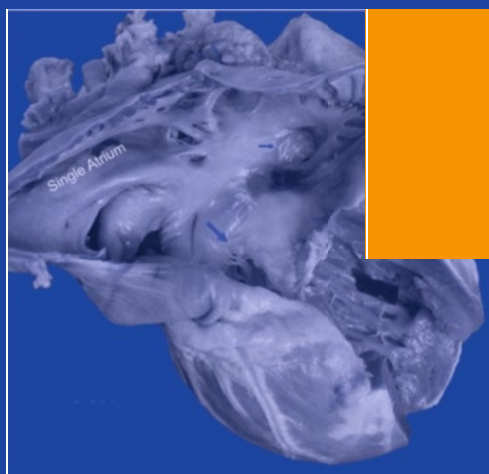
Xiaodong Zhu
Editor

Surgical Atlas of Cardiac Anatomy







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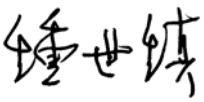
Foreword

Patients with congenital heart defects begin a life of suffering the moment they are born into the world. For years, cardiac surgeons have been trying hard to find ways to make up for and correct such defects using various means. Through such efforts, these surgeons have alleviated the patients' sufferings and brought happiness back to the patients and their families, much like Angel *Nüwa* in the ancient Chinese folktale who benefits mankind by repairing the wall of heaven. Dr. Xiaodong Zhu, an expert in cardiac surgery who has been engaged in clinical works for more than half a century and was named Famous Doctor of the Chinese Academy of Medical Sciences and PUMC in 1993, is such an angel. Dr. Zhu is particularly skillful at hemodynamics and cardiac anatomy. In this book, *Surgical Atlas of Cardiac Anatomy*, pathological features of heart malformations are explained with Dr. Zhu's clinical experiences covering decades.

The book is based primarily on real images in cardiac surgical anatomy with a focus on congenital heart defects. Anatomy is one of the most fundamental disciplines on which clinical practices in surgical departments are based, and it is of great significance particularly for the understanding and treatment of congenital heart defects. In such disciplines, practical experiences are much more important than are theoretic knowledge and instruments. My hope is that this unique book, which analyzes different kinds of cardiac malformation specimens in depth, will inspire colleagues to further develop novel methods in the diagnosis and treatment of congenital heart defects.

Another feature of this book is that it contains massive amounts of precious medical records. Practice makes perfect. This saying is particularly true for surgeons. However, the current autopsy rate in hospitals in China is still far from ideal. This book contains invaluable images of more than 200 well-preserved specimens of heart malformations including some postsurgery specimens collected by the Fuwai Cardiovascular Hospital over the years.

There is no royal road to learning, and cardiac anatomy and surgery are no exceptions. I would like to thank Dr. Zhu for opening a new horizon for the diagnosis and treatment of congenital heart defects with his new book, and I encourage all cardiac experts, scholars, and ambitious young surgeons who are interested in making strides in these areas to read this book and make a difference in this field.



Shizhen Zhong,
Senior Academician of Chinese Academy of Engineering,
Professor of Institute of Clinical Anatomy,
Southern Medical University

Preface

Cardiac anatomy is the foundation for cardiac surgery and the prerequisite for modern cardiac imaging. Gaining a thorough understanding of actual pathological specimens of the heart cannot be achieved simply by studying anatomical models or by observing operations. The author wrote *The Basics of Cardiac Surgery*: *An Illustrated Guide* in the 1980s. It covered both cardiac anatomy and surgeries, aiming to integrate anatomical concepts with surgical techniques. Although the book was recommended and highly valued by colleagues, it was able to describe typical lesions and their surgical significance only by schematic diagrams rather than images of actual specimens due to the technical limitations that then prevailed.

In recent years, the rapid development of technologies for cardiac surgeries in China has enabled us to gain a considerably more insightful understanding of pathological specimens through which we have accumulated a wealth of clinical experiences. Familiarity with actual heart specimens is absolutely necessary for the cardiac surgeon to fully recognize the different types of heart malformations and to identify pathological changes quickly and accurately during surgery. To facilitate the cardiac surgeon's achievement of these goals, this book provides hundreds of three-dimensional images of actual heart specimens taken from multiple perspectives, many also accompanied by schematic illustrations. All specimens come from a collection established over the course of more than 50 years by the Department of Pathology, Fuwai Hospital, and the National Center for Cardiovascular Disease, Beijing.

Specimens of the same disease acquired from different people at different times and places can be quite diverse. The emphasis of this book is on the understanding of this pathology rather than the evaluation of the constantly evolving surgical techniques. All anatomical images of hearts in this book are of actual specimens, and the legends have been written to be as clinically practical as possible.

The book includes 28 chapters, with the first half concentrated on the normal heart structures and the second on congenital heart defects. Because the contents of the book were written according to the various numbers of available specimens, the lengths of the chapters vary accordingly. For example, we have numerous specimens of certain diseases such as Tetralogy of Fallot but only a few of other diseases such as tricuspid valve disease. Nonetheless, we had a sufficient store and variety of samples to provide substantial information on most of the common congenital heart defects in the book.

The majority of the book is composed of images. Each chapter begins with a text overview followed by images numbered by the pathological specimens. Most of the specimens are displayed from their anatomy perspective and some from the surgical perspective. In all images, *S* (*superior*) denotes the head side of the patient, *I* (*inferior*) the foot side, *L* (*left*) the left side, *R* (*right*) the right side, *A* (*anterior*) the front side, and *P* (*posterior*) the back side. As noted in the first chapter, common terms for the anatomy are shortened after their first use to acronyms, which are used in their place in subsequent chapters. The reader is advised to refer to the chart of acronyms for reference.

We would like to thank all the pathology experts, particularly Prof. Hong Zhao, who have worked diligently for many years to collect, store, and organize all the heart specimens used in the book. Also, we would like to express our highest respect and gratitude to the donors of these specimens, without whom our knowledge of cardiac anatomy and our surgical techniques

would not have been advanced. We are grateful for the encouragement and support from colleagues in the National Center for Cardiovascular Disease, the Department of Pathology, and the Department of Cardiac Surgery, Fuwai Hospital. Moreover, we are indebted to Prof. Shizhen Zhong from the Chinese Academy of Engineering, who is a master in anatomy, has been supportive and helpful, and has provided photos of six specimens used in the book.

The images in this book have been inspected and proofread many times. However, mistakes may still occur. The readers are invited to inform us in such case. Until now, only a few books on cardiac anatomy have been available in China, and even fewer provide clinical specimens for illustration. It would be the greatest delight for us if the book could benefit doctors, colleagues, and medical students in cardiac surgery and related fields.

Beijing, China Xiaodong Zhu

Translator's Word

As one of the founders of cardiac surgery in China, Dr Zhu Xiaodong has made great contributions to the establishment and development of cardiac surgery. With more than 50 years of experience in this area, on the occasion of his approaching 80th birthday, Dr Zhu began to compile this book with the intention of sharing information that he thought would improve patients' outcomes after cardiac surgery.

Specimens shown in this book cover normal heart, various cardiac malformations, and malformations that received surgical treatment. In addition to filling a gap in the knowledge of cardiac surgery in China, this book also has significant value for the field of cardiac surgery around the world. Therefore, Dr Zhu authorized its conversion into English in order to share his expertise with peers around the world.

Zheng Zhe

About the Author

Dr. Xiaodong Zhu was born in Kaifeng, Henan. He graduated from the Medical Department of Harbin Medical University in 1956 and then worked in the Chest Hospital of the Chinese People's Liberation Army. His life as a cardiac surgeon started as a resident in the Fuwai Cardiovascular Hospital, Chinese Academy of Medical Sciences, in 1958. He then pursued his M.D. in the Department of Cardiac Surgery, PUMC, in 1962. He visited the United Kingdom and Australia during the mid-1970s and early 1980s, respectively, to advance his education in cardiac surgery. Dr. Zhu was the Director of Fuwai Cardiovascular Hospital and the Director of the Cardiovascular Disease Research Institute from 1992 to 1996. He was the Chairman for the fourth and fifth sessions of the Chinese Society for Thoracic and Cardiovascular Surgery from 1996 to 2006. Currently, he is the Chief Expert in the Department of Cardiac Surgery, Fuwai Cardiovascular Hospital.

Dr. Zhu has long devoted his life to clinical cardiac surgery as well as to carrying out diverse research projects in cardiac catheterization technology, hemodynamics, cardiac anatomy, and biomedical engineering including artificial heart valves and heart assistance devices. He developed the biological valves (pericardial valve) and successfully performed its clinical use first in 1976 for which he received honors and awards from the state, the Ministry of Health, the Academy of Medical Sciences, and the Government of Beijing. He won the Young Medical Science and Technology Expert award by the Ministry of Personnel in 1988 due to his prominent contributions, was named Famous Doctor of the Chinese Academy of Medical Sciences and PUMC in 1993, and was elected as Academician of the Chinese Academy of Engineering in 1996.

In his more than 50 years as a physician, Dr. Zhu has completed as chief surgeon more than 4,000 cardiac surgeries including operations for congenital heart defects, coronary artery diseases, valvular heart diseases, and aortic artery surgeries. In 1990, he led a medical team to aid Tibet, successfully performing open-heart surgery using cardiopulmonary bypass at the altitude of 3,600 m. Dr. Zhu values the training of both the team members and leaders. Under his leadership, the Department of Cardiac Surgery, Fuwai Cardiovascular Hospital, was designated by the State Education Commission in 1990 as the only nationwide key cardiac surgery department. Dr. Zhu also actively participates in the establishment of national technical

collaborations promoting new advancements in cardiac surgery techniques across the nation. In the 1980s, he promoted heart valve surgeries in China. In the 1990s, he helped many domestic hospitals establish and develop the Departments of Surgery for Coronary Artery Disease. In more recent years, he served as the founding member for several hospitals specializing in cardiovascular disease in China.

Dr. Zhu was accepted as a member in the International Society of Surgery in 1988. He has been invited to academic conferences abroad many times, visiting Manila in 1980, Switzerland in 1985, and Indonesia, Iran, Azerbaijan, Japan, the USA, and Australia in the 1990s. During these visits, he demonstrated the advancements and achievements of cardiac surgery that were being accomplished in China, which were highly appreciated by colleagues from all over the world.

Dr. Zhu has published more than 130 papers in academic journals. He was the main author of ***The Basics of Cardiac Surgery***: ***An Illustrated Guide*** (1st and 2nd editions), ***A Guide for Cardiac Surgery***, and ***Cardiac Surgery***. The book ***Cardiac Surgery*** won an award from the General Administration of Press and Publication in 2008 for its originality. Dr. Zhu was also the chief translator of ***Surgery for Congenital Heart Defects***. In addition, he participated in the writing of several academic monographs.

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Cardiac Anatomy: Nomenclature and Abbreviations

1

1.1 Nomenclature of Cardiac Anatomy

1.1.1 Right Atrium (RA)

The right atrium (RA) is the right upper chamber of the heart. It normally receives systemic venous drainage from the superior vena cava (SVC) and the inferior vena cava (IVC) (the two largest veins in the body collectively known as the *venae cavae*) and coronary venous drainage from the coronary sinus (Fig. 1.1). The RA can be divided into the body part, called the *auricula*, and the sinus part, called the *sinus venarum*. The auricula forms the front part of the RA and includes the right atrial appendage (RAA) and lateral wall, with numerous muscle bundles inside that form a network of hills and furrows, giving it a trabeculated surface. Located between the superior and inferior venae cavae, with an internodal tract passing through it, is a special muscle bundle called the *crista terminalis*. The sinus venarum is located just behind the crista terminalis and contains the orifices of the vena cava and coronary sinus.

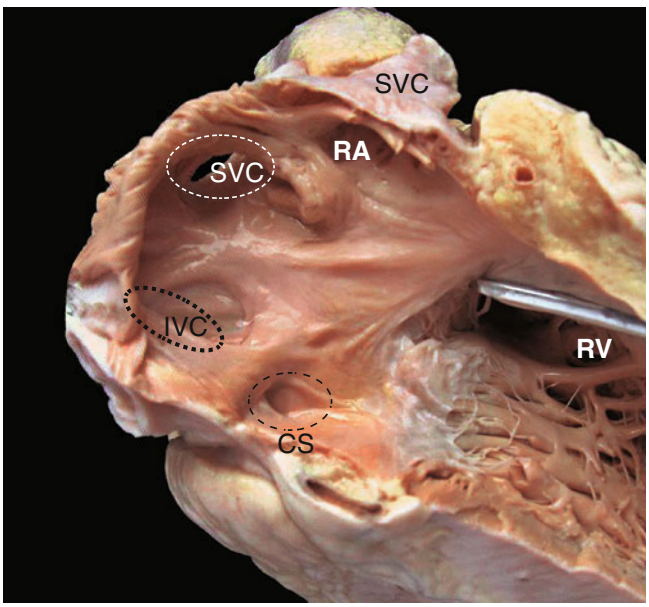

Fig. 1.1 The characteristics of the right ventricle (*RV*). The RV is a cardiac cavity directly connected with the SVC, the IVC, and the coronary sinus. *CS* coronary sinus, *IVC* inferior vena cava, *RA* right atrium, *RV* right ventricle, *SVC* superior vena cava

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1.1.2 Right Atrial Appendage (RAA)

The RAA is a small conical, triangle-shaped muscular pouch. It is attached to the right atrium of the heart and often is short and blunt (Fig. 1.2).

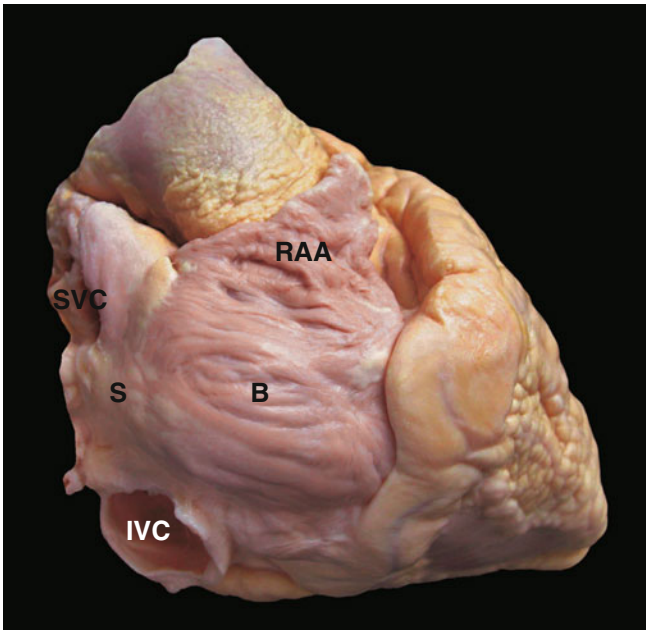

Fig. 1.2 The characteristics of the right atrial appendage (*RAA*). The RAA is short, blunt, wide-based, and triangle-shaped, with numerous muscle bundles inside that give it, like the RA, a trabeculated surface. *B* the body part of RA, *RAA* right atrial appendage, *S* the sinus venarum of RA, *SVC* superior vena cava, *IVC* inferior vena cava

1.1.3 Left Atrium (LA)

The term "left" when used for the left atrium (LA) is a morphological concept, rather than a simple direction. The LA is the cardiac chamber that receives drainage from the pulmonary veins through four ostia in its posterior wall. The LA has a smooth inner wall, whereas in the left atrial appendage (LAA), muscle bundles form a network of hills and furrows (Fig. 1.3). A crescent reductus can be seen in the interatrial septum, the wall of tissue separating the right and left atria, when looking through the LA, in contrast to the fossa ovalis, which can be seen when looking through the RA.

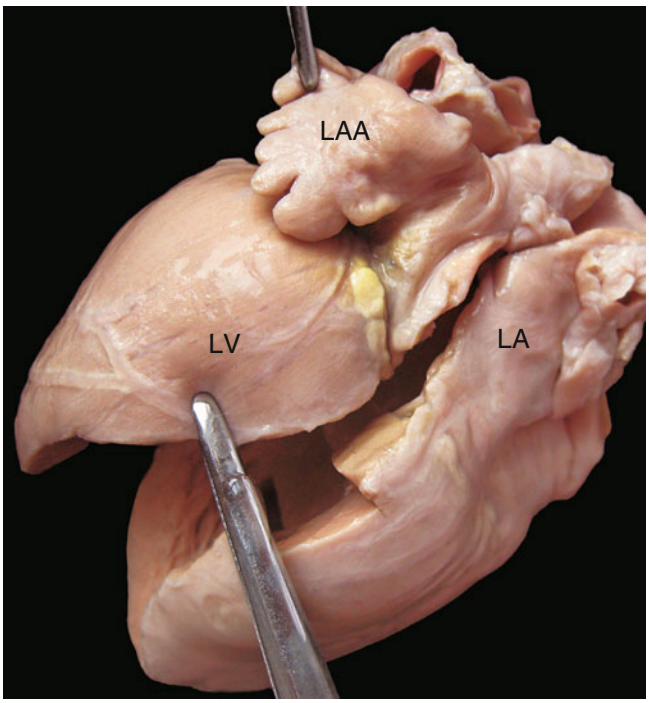

Fig. 1.3 Some muscle bundles form a network of hills and furrows in the LAA. This network is different from the inner wall of other parts of the LA

1.1.4 Left Atrial Appendage (LAA)

The left atrial appendage (LAA) is a small pouch located high in the LA. It pumps oxygenated blood from the lungs into the left ventricle. In contrast to the short and blunt RAA, the LAA has a long, narrow, and tubular shape and an obvious indentation; it usually is multilobed (Fig. 1.4).

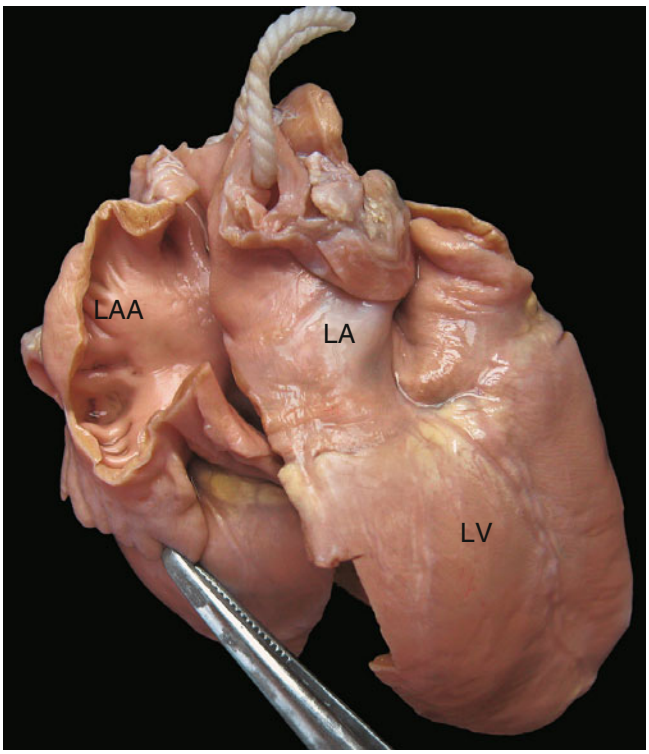

Fig. 1.4 In contrast to the RAA, the LAA has an obvious indentation that is just like the neck of the LAA. *LAA* left atrial appendage, *LA* left atrium, *LV* left ventricle

1.1.5 Right Ventricle (RV)

The right ventricle (RV) is a cardiac chamber located in the front side of the heart. It contains numerous muscle bundles and looks coarsely trabeculated. The term "right" is also a morphological concept. The morphological characteristic is that crista supraventricularis muscles widely separate the atrioventricular (tricuspid) valve from the semilunar (pulmonary) valve in the normal heart (Fig. 1.5). The inner surface of the RV consists of three parts, the orifice portion, the trabecular portion, and the outlet portion.

The outlet portion of the RV is composed of muscles of the infundibulum. The muscle of the inferior border of the infundibular septum is called *crista supraventricularis*, or *trabecula septomarginalis*. It contains several different muscle bundles, the parietal band, the moderator band, and the septal band (Fig. 1.6). The septal band often extends apically to be continuous with the moderator band, which is an important trabeculation located among the septum, anterior papillary muscle of the tricuspid valve (TV), and the free wall. The crista supraventricularis is found between the TV and the pulmonary valve (PV).

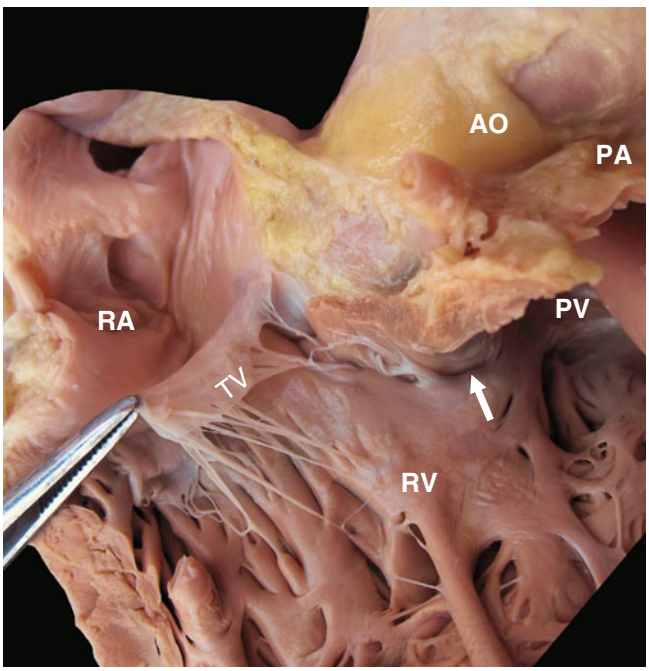

Fig. 1.5 The characteristics of the right ventricle (*RV*). The RV has numerous muscle bundles inside with coarse trabeculae. The atrioventricular or TV, with some chordae tendineae attached to the interventricular septum. The tricuspid valve is separated from the PF by the *crista supraventricularis muscles*. *AO* aorta, *PV* pulmonary valve, *RA* right atrium, *RV* right ventricle, *TV* tricuspid valve, *SVC* the *white arrow* show the muscle that separate pulmonary valve and tricuspid valve

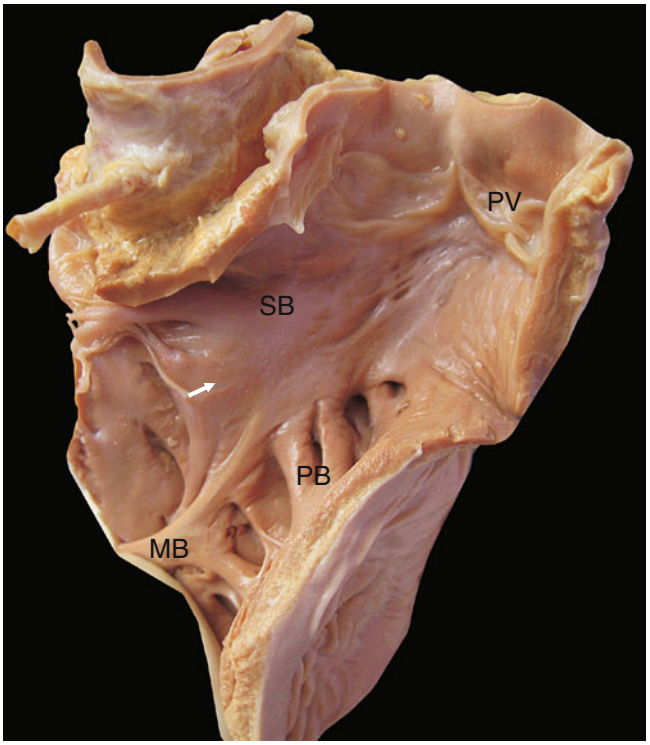

Fig. 1.6 The muscle bundles between the TV and the PV. *MB* moderator band, *PB* parietal band, *PV* pulmonary valve, *SB* septal band

1.1.6 Tricuspid Valve (TV)

The TV is the atrioventricular valve of the RV and has three leaflets: the anterior, posterior, and septal leaflets. The anterior leaflet is usually the largest one, with a strong anterior papillary muscle; the septal leaflet is usually smaller than the anterior leaflet but often larger than the posterior leaflet; it has a small chorda that mostly connects with the interventricular septum.

1.1.7 Left Ventricle (LV)

The left ventricle (LV) is a cardiac chamber that is divided into the orifice portion, the trabecular portion, and the outlet portion. The term "left" is also a morphological concept with regard to the LV. The mitral valve (MV) is the atrioventricular valve of the LV. In a normal heart, the MV is separated from the aortic valve (AV) by fibrous tissue instead of muscles.

1.1.8 Mitral Valve (MV)

The mitral valve (MV) is the atrioventricular valve of the LV and has two leaflets: anterior and posterior. These two leaflets connect with the anterior and posterior papillary muscles, respectively, by chordae. Normally, no chordae are attached to the interventricular septum.

1.1.9 The Posterior Cross of the Heart

The *posterior cross of the heart* refers to the cross in the posterior aspect of the heart, located at the connection of the interatrial groove and the interventricular groove. The coronary sinus runs from the left to the right of the atrioventricular groove, forming the transverse line of the cross (Figs. 1.7 and 1.8). The posterior margins of the interatrial septum and the interventricular septum compose the upright line. The posterior margin of the interventricular septum is the same line as the posterior interventricular groove, with the posterior descending branch of the coronary artery passing through it.

1.1.10 Interatrial Septum (Atrial Septum)

The interatrial septum is the wall of tissue separating the left and right atria of the heart (the upper chambers of the heart). As noted previously, the fossa ovalis (FO) in the interatrial septum can be seen when looking through the RA cavity, whereas a crescent can be seen when looking through the LA. When the interatrial septum does not develop normally, a hole in the septum, called an *atrial septal defect* (ASD), results.

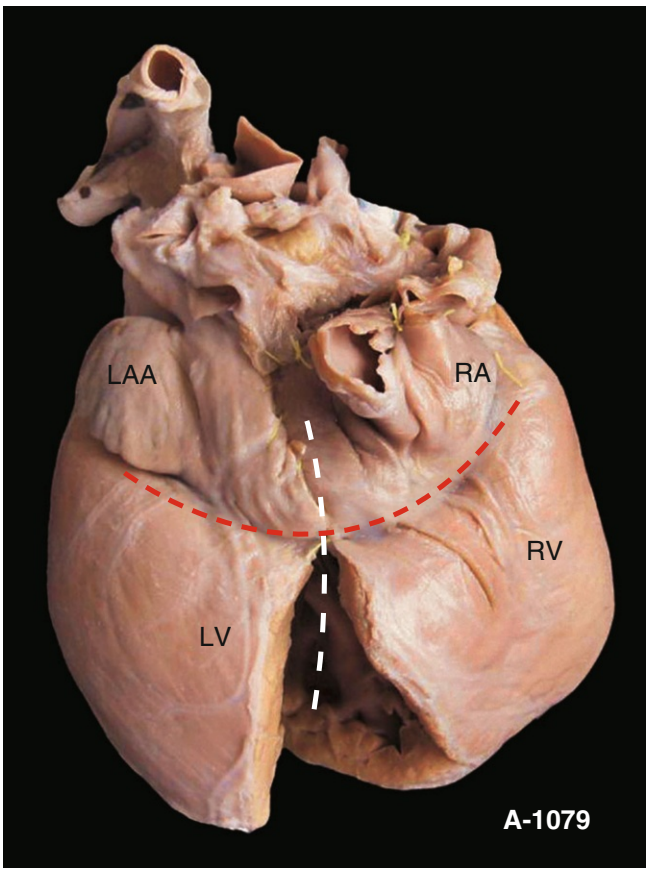

Fig. 1.7 The transverse axis refers to the left and right atrioventricular groove; the longitudinal axis refers to the interatrial groove and the interventricular groove. *LAA* left atrial appendage, *LV* left ventricle, *RA* right atrium, *RV* right ventricle

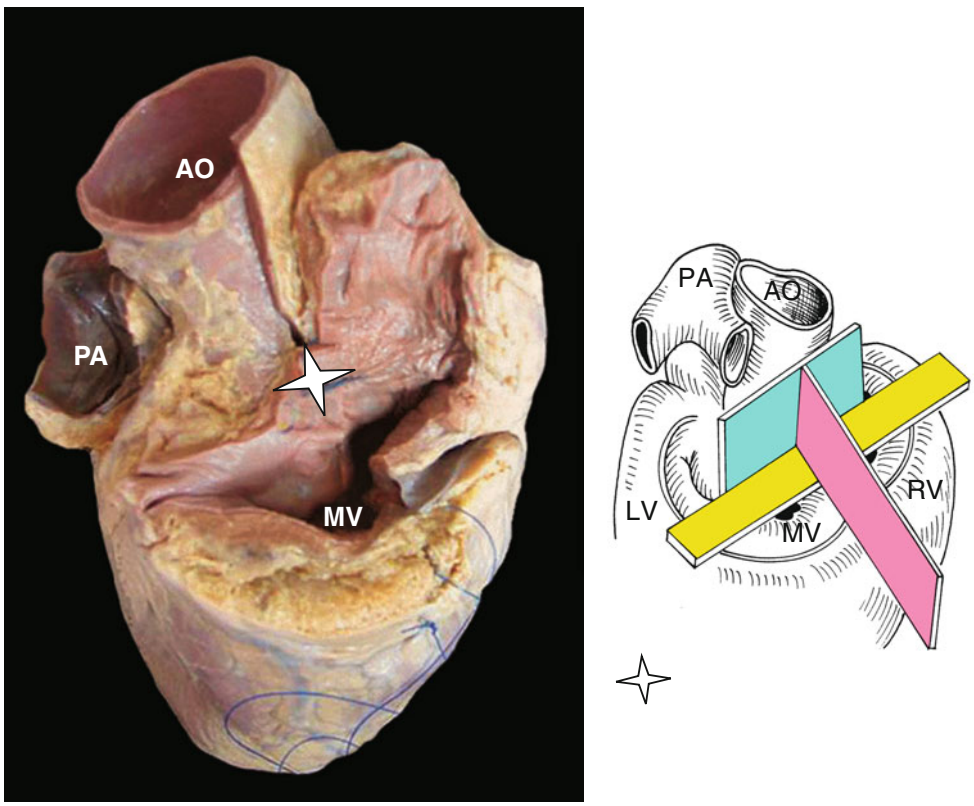

Fig. 1.8 3-D cross section of the heart. *AO* aorta, *PA* pulmonary artery, *MV* mitral valve

1.1.11 Interventricular Septum (Ventricular Septum)

The interventricular septum is another wall just like the interatrial septum but thicker. It separates the left and right ventricles of the hearts (the lower chambers of the heart). Two atrioventricular valves, the MV and the tricuspid valve (TV), are located at its two sides, respectively (Fig. 1.9). The interventricular septum can be divided into the muscular ventricular septum and the membranous ventricular septum (Fig. 1.10). The muscular ventricular septum is thick and is located at the anterior and lower part of the septum. The membranous ventricular septum is thin and fibrous and is located at the posterior and upper part of the septum.

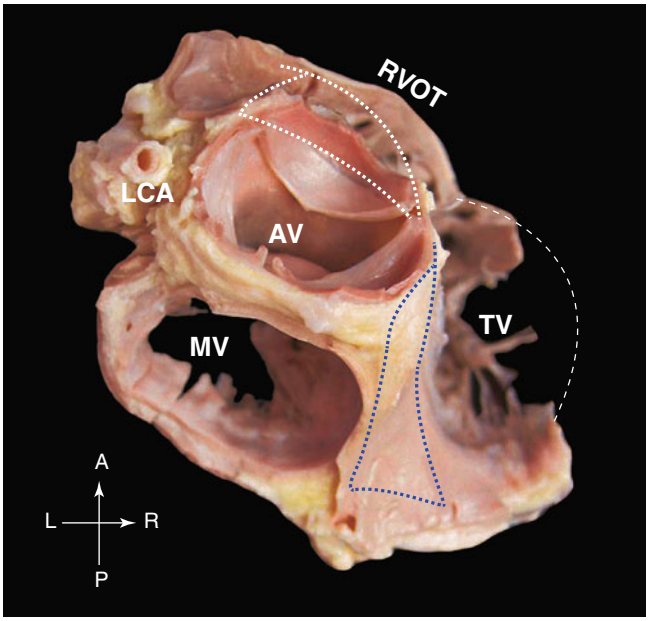

Fig. 1.9 Cross section of the interventricular septum (IVS) (from the upper view angle). *Blue dash line* shows the posterior portion of the IVS; *white dash line* shows the anterior portion of the IVS; between them is the thin and fibrous portion, the membranous septum. The right coronary cusp of the AV is adjacent to the IVS. *AV* aortic valve, *LCA* left coronary artery, *MV* mitral valve, *ROVT* right outflow of the ventricular tract, *TV* tricuspid valve

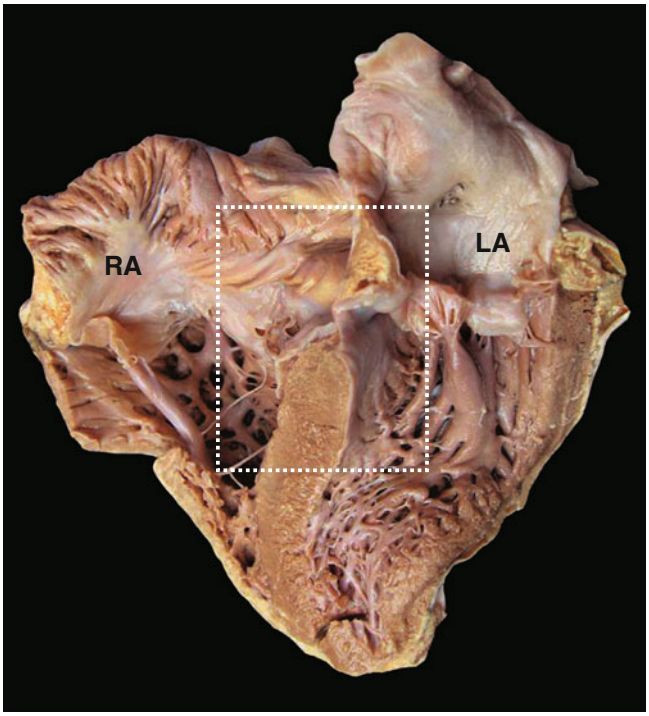

Fig. 1.10 Cross section of the posterior portion of the interventricular septum (IVS). From the anterior view angle, the posterior wall of the four chambers of the heart can be seen clearly. It also shows that the annulus of the MV lies a little higher than that of the TV

1.1.12 Atrioventricular Septum

The septum between the RA and the LV is called the *atrioventricular septum* (Fig. 1.11). Generally, no communication exists between the LA and the RV. The atrioventricular septum is located behind the membranous ventricular septum and below the atrial septum. Its left and right portions are located under the annulus of the MV and the annulus of the TV, respectively.

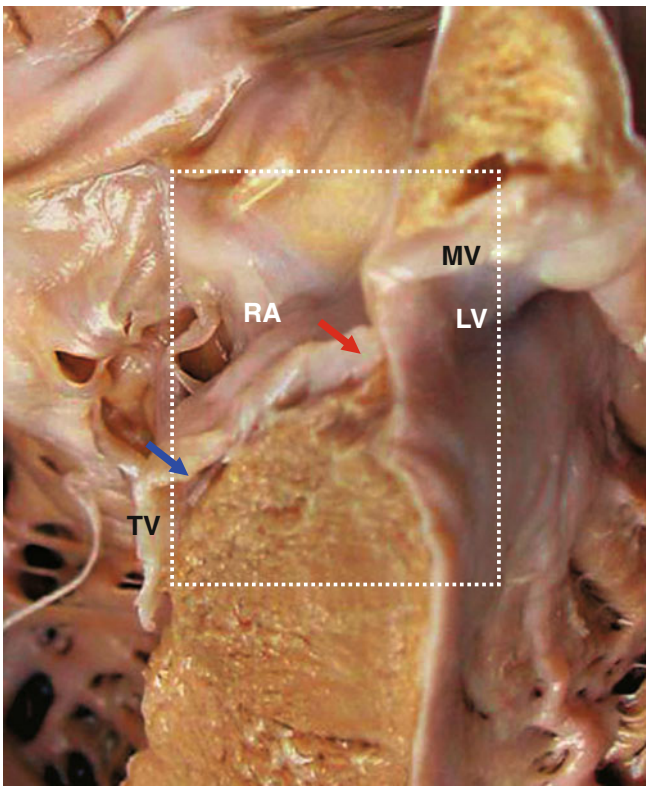

Fig. 1.11 The atrioventricular septum. The *red arrow* shows the membranous septum between the right atrium (*RA*) and the left ventricle (*LV*), *SVC* the *blue arrow* show the root of septal leaflet of tricuspid valve, *MV* mitral valve, *TV* tricuspid valve

1.1.13 Aorta

The aorta is a large artery arising from the base of the heart and extending down to the abdomen. It can be divided into five sections: ascending aorta, arch of aorta, descending aorta, thoracic aorta, and abdominal aorta. It gives rise to the main coronary arteries and the brachiocephalic trunk.

1.1.14 Main Pulmonary Artery (Pulmonary Trunk)

The main pulmonary artery is the portion of the pulmonary artery that originates from the base of the RV. It is short and wide, and it branches into the left and right pulmonary arteries. The function of the pulmonary artery is to transport deoxygenated blood from the RV to the lung.

1.2 Malformations of the Heart

1.2.1 Atrial Septal Defect (ASD)

As one of the most common congenital heart diseases, atrial septal defect (ASD) is a defect in the interatrial septum that enables oxygenated blood to pass from the LA to the RA directly, or vice versa. It can lead to right-sided volume overload of the heart, pulmonary hypertension, Eisenmenger syndrome, and other conditions.

1.2.1.1 Ostium Secundum Atrial Septal Defect

As the most common type of ASD, ostium secundum ASD is formed by dysplasia of the septum secundum in the embryonic period. It usually involves the foramen ovale and the posterior part of the interatrial septum, often close to the caval vein but away from the TV annulus (Fig. 1.12).