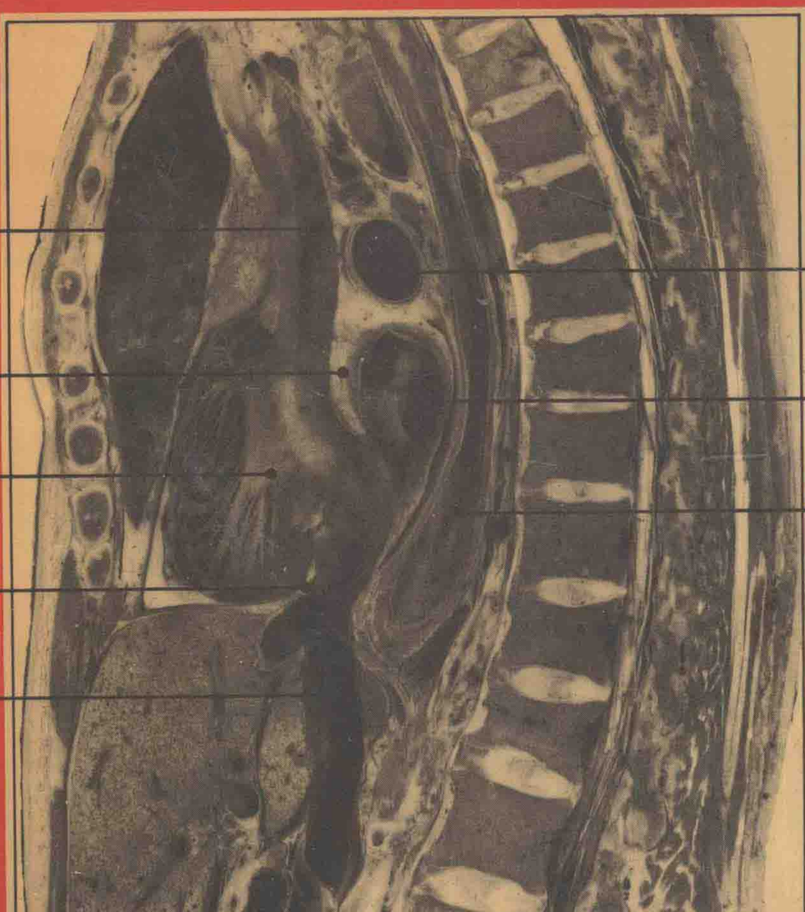
CLINICAL ANATOMY OF THE HEART

ROBERT WALMSLEY
HAMISH WATSON



Foreword by John W. Kirklin

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Foreword

Understanding the abnormal, one facet of the work of physicians and surgeons, requires an understanding of the normal. In the case of the heart, the complexity of its morphology has often frustrated the clinician's desire to be thoroughly familiar with normal cardiac anatomy. The authors of this text have provided important material, from which the clinician can derive most of the information he needs in this area. They have been imaginative in selecting their physical approaches to the heart so that they correspond to the projections commonly used in clinical work. Their illustrations are clear and detailed. Descriptions are readable but succinct. With publication of this textbook, many can absorb the knowledge which the authors have concentrated into these pages.

Birmingham,
Alabama, U.S.A.
1978

John W. Kirklin, M.D.

Preface

Recent developments in cardiology have given a new significance to the relationships of the heart and great vessels. The clinical anatomy of the heart, by which is meant its gross anatomy as it lies *in situ*, has assumed great practical importance not only at the bedside, in diagnostic laboratories, X-ray departments and surgical theatres, but also in such new techniques as echocardiography and body scanning radiography.

Although the structure of the heart has been studied for centuries, it has been customary to describe it as an isolated organ. Innumerable illustrations and descriptions depict the heart as it would be held in the hand following its removal from the body, with the apex pointing downwards and the atria lying above the ventricles. Furthermore, the atrial and ventricular septa are frequently shown to lie in a sagittal (vertical) plane; basic mistakes that have given rise to many false concepts and caused much confusion. Even the *Nomina Anatomica* (1966) has advocated terms that are obviously based on the *ex situ* heart resulting in such footnotes as 'the *posterior* sulcus is placed on the *diaphragmatic* surface and is therefore *inferior* in position', which it was felt '*would not give rise to confusion*'.

This book stresses the importance of studying the heart and great vessels with special regard to their position within the living body. The text is profusely illustrated by a series of thoracic sections, many of which have not been previously published and, where appropriate, by corresponding X-ray photographs.

The text has been prepared primarily for clinicians and the terms commonly used in current clinical practice have been preferred to those advocated in the *Nomina Anatomica*. To avoid misunderstanding, the latter are given in parenthesis where this seems appropriate. We hope that this approach to the heart will help all concerned to gain a better perspective of the relationships of the chambers of the heart and of the great vessels one to another and, having done so, to visualise their correct orientation within the living thorax in a more realistic way.

As it is essentially an annotated atlas, an effort has been made to ensure that so far as possible each illustration may be looked at and read about without constant turning of pages. Although this has inevitably resulted in some repetition, we believe that in the circumstances it is worthwhile repetition.

In the preparation of this material we have relied heavily over many years upon much skilled technical assistance. We record our gratitude to Miss Nancy Joy, now Professor of Medical Art in Toronto, for the meticulous drawings of the dissections; to Miss M. M. Benstead for diagrams in Chapters 1 and 9; to Mr. S. H. Fairhurst in the Department of Anatomy, St Andrew's University; to Mr T. King and the staff of the Department of Medical Photography and to Mr R. Fawkes and the photographic staff of the Department of Pathology in the Dundee Teaching Hospitals for many photographs; and to Mrs Irene Robertson and Miss Christine Russell who typed the manuscript. Mr R. J. Stuart and Mr James Brown deserve particular thanks for their help with the preparation of both the macroscopic and microscopic sections.

We are also grateful to the editors of the British Heart Journal and Circulation and to Lloyd-Luke (Medical Books) Ltd for permission to reproduce certain figures, to the staff of Churchill Livingstone for their help during the preparation and publication of the text, to Professor K. G. Lowe for reading proofs of the manuscript and to Sir Ian Hill whose encouragement did so much to initiate its production. It is a pleasure to record our thanks to Dr. John Kirklin for agreeing to write a Foreword.

St Andrews and Dundee, 1978 R.W., H.W.

Contents

CHAPTER 1

Introduction and general principles

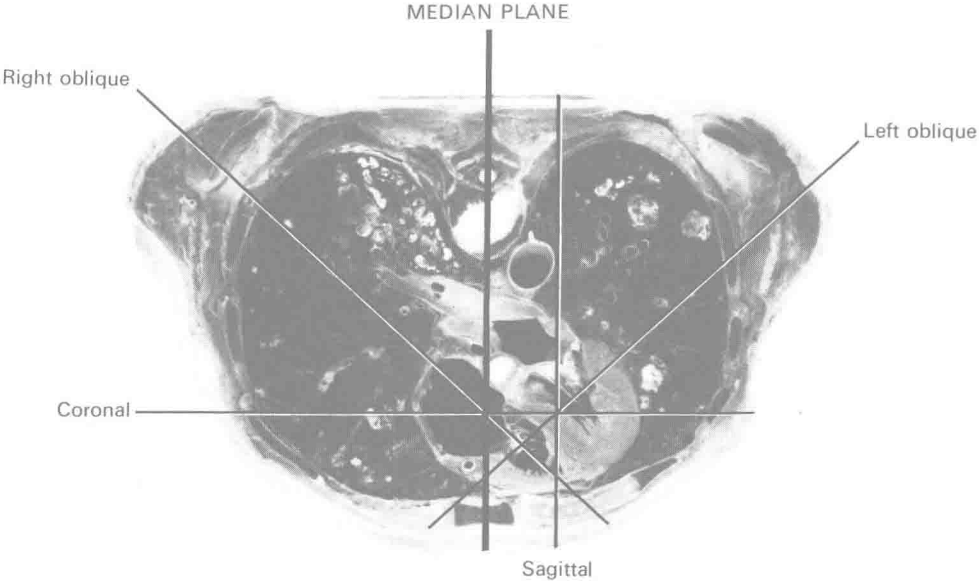

Fig. 1.1 A transverse section of the thorax with the heart *in situ*. It shows the median plane and examples of sagittal, coronal and oblique planes. A sagittal plane is a vertical plane that lies parallel to the median plane. A coronal or frontal plane is a vertical plane that intersects the median plane at right angles. An oblique plane, as used in this text, is a vertical plane that intersects the median plane; examples of right and left oblique planes are shown that intersect the median plane at angles of 45°.

As stated in the Preface, this book is essentially an annotated atlas of the human heart *in situ*. It has been compiled following the examination of many adult cadavers of different ages and sexes. Fetuses, infants and children have also been studied. Extensive experience during cardiac catheterisation and a large number of angiocardiograms and X-rays taken after injection of radio-opaque material into the chambers of the heart have been analysed and correlated with sections of the heart in the thorax. The changes that occur with alteration in posture, during distension or contraction of the upper abdominal contents and with movement of the heart

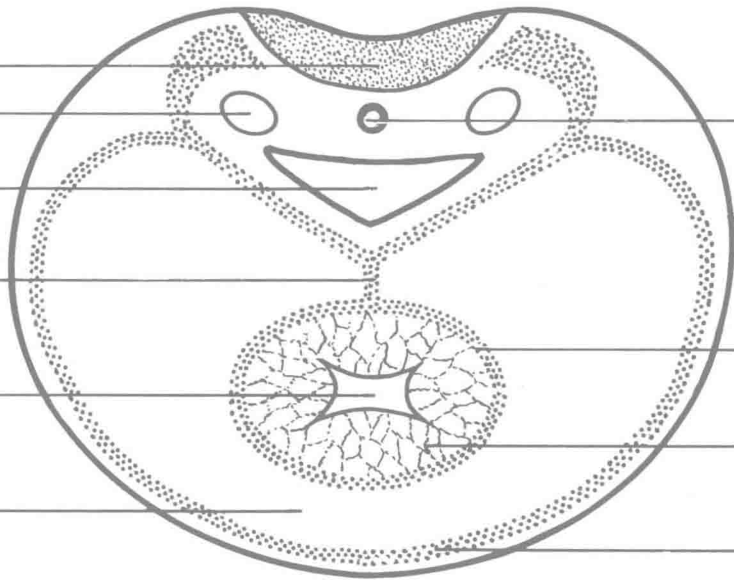

Fig. 1.2 Schematic diagram of a transverse section of an embryo to show the primitive cardiac tube lying within the pericardial cavity. The cardiac tube is suspended from the under (i.e. ventral) surface of the pharynx by a median longitudinal band of mesoderm called the dorsal mesocardium. The outer layer of the myoepicardium will become the visceral layer of the serous pericardium, the epicardium. The inner cells of the somatic mesoderm will differentiate as the parietal layer of the serous pericardium. The two dorsal aortae lie dorsal to the pharynx and between them is the notochord, the forerunner of the vertebral column.

itself within the thoracic cavity during systole and diastole have all been carefully considered in reaching the conclusions. Account has also been taken of the fact that the embalmed thoracic viscera usually lie about one vertebra higher than they do in the erect living person. When the isolated heart has been studied, great care has been taken to place the specimen as nearly as possible in the position it had occupied before its removal from the body.

The *in situ* heart has been approached from the front, the back, transversely and from the right and left sides in a series of sections and dissections, many of which are of the entire thorax (Fig. 1.1). Special attention has been given to the fibrous skeleton of the heart and to the right and left ventricular outflow tracts. The figures are mostly photographs of these preparations: drawings have only been used where photographs did not have sufficient clarity to justify their inclusion. Corresponding X-ray photographs have been used, where appropriate, to illustrate specific structures whose normal anatomy has been thus displayed. Many of these X-rays were chosen because they showed abnormalities that stressed the correlation and it must be emphasised that they have been included for this purpose only. *It is no part of the purpose to demonstrate the radiological features of the abnormal heart or to discuss anatomical abnormalities.*

Although the authors have made a special study of the heart itself, they make no claim to have made a special study of its blood supply or conducting tissues. The coronary arteries and the conduction system, which have been described in considerable detail by other workers, are, however, currently under such intense scrutiny that their anatomy has been reviewed in the final chapter for the sake of completeness. No attempt has been made to give an account of the innervation of the heart, which is considered to be outwith the scope of this book.

As it is impossible to understand many features of the heart without at least a basic knowledge of embryology, it seems appropriate to commence the text with a brief account of the well established features of cardiac development. No attempt has been made to describe embryogenesis in detail. The literature on the subject is considerable. Furthermore, much of it is controversial and of so little interest to most clinicians that to include it would defeat the purpose of a book basically concerned with the clinical anatomy of the normal postnatal heart.

Development of the heart

A functional cardiovascular system is required for the growth of the embryo. It is established at a very early stage and is the first system in the body to function. It is unnecessary for our purpose to discuss the development of the heart earlier than when it lies as a simple tube below the under surface of the pharynx, which is the longest and most cranial part of the foregut in the young embryo (Fig. 1.2). The cardiac tube itself consists of an inner layer of endothelium, an outer mantle of myoepicardium and an intermediate zone of loose mesodermal tissue, the reticulum. This reticulum is frequently called the subendothelial reticulum. Its proliferation in specific regions of the cardiac tube is associated with septation in the tube and truncus arteriosus. The myocardium and the visceral layer of the serous pericardium, the epicardium, develop from the myoepicardium.

The primitive heart lies within the mesodermal-lined pericardial cavity suspended from the ventral surface of the pharynx by a longitudinal midline band of mesoderm, the dorsal mesocardium (Fig. 1.2); in mammals there is no ventral mesocardium. The outer wall of the pericardial cavity has a surface layer of ectoderm and an underlying stratum of somatic mesoderm, whose deep

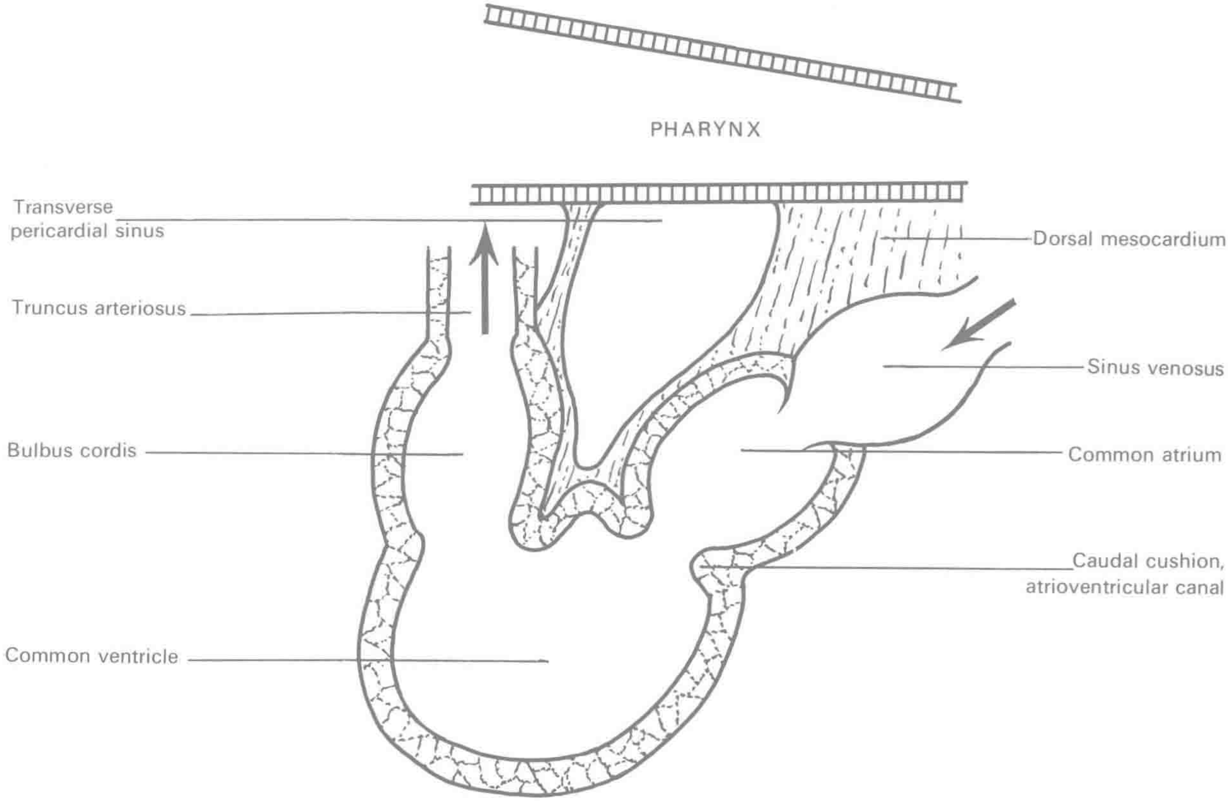

Fig. 1.3 Schematic diagram of a median longitudinal section of the cardiac tube to illustrate the four chambers of the primitive heart. From caudal to cranial ends these are the sinus venosus, the common atrium, the common ventricle and the bulbus cordis, which is continuous with the truncus arteriosus. The cardiac tube has commenced to bend on itself within the pericardial cavity, and the atrium lies dorsal to the ventricle and caudal to the bulbus cordis. The dorsal mesocardium has been partly absorbed and the deficiency in it represents the transverse pericardial sinus. The sinus lies between the receiving and outflow regions of the heart. The common atrioventricular canal is directed dorsoventrally from atrium to ventricle, is oval in shape and widened transversely so that it has cranial and caudal walls. On both its cranial and caudal walls there is a localised proliferation of the reticular tissue to form the cranial and caudal cushions of the atrioventricular canal (see Fig. 1.6).

cells adjacent to the cavity eventually differentiate as the parietal layer of the serous pericardium.

Three constrictions appear on the cardiac tube so that four chambers may be recognised. From caudal to cranial ends they are named the sinus venosus, atrium, ventricle and bulbus cordis in accordance with the direction in which blood flows through the primitive heart (Fig. 1.3).

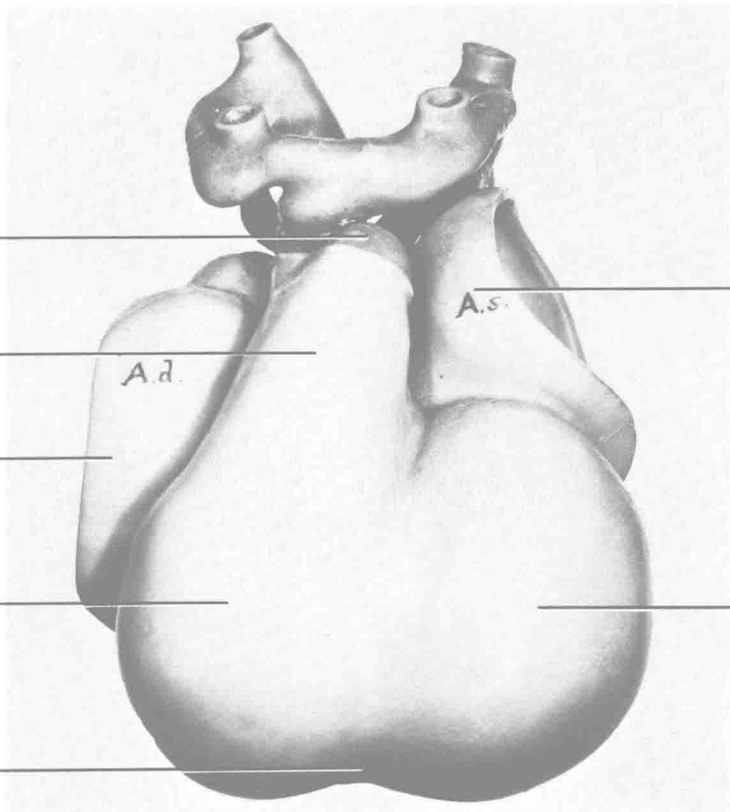

Fig. 1.4 A model of the developing heart of a young embryo after the cardiac tube has folded upon itself and assumed a U-shaped form. The heart is viewed from the ventral (anterior) aspect. The demarcation between the right and left ventricles is indicated on the surface by the interventricular sulcus. The bulbus cordis lies in close relation with the rightmost part of the common atrium and is continuous with the truncus arteriosus.

It is from the bulbus cordis, therefore, that blood passes cranially into the truncus arteriosus. The truncus arteriosus gives origin to the aortic arches and, as these pass to the dorsal aortae, the truncus is frequently called the ventral aorta. With the development of the aortic arches the cranial part of the truncus becomes dilated and this is often called the aortic sac.

After the four primitive chambers have become demarcated, the heart elongates more rapidly than the pericardial cavity. It assumes a U-shaped loop in a very constant manner as a result of differential growth in parts of the tube (Fig. 1.4). Assuming that blood normally flows from right to left in the U, the right limb is formed by the sinus venosus and the common atrium.

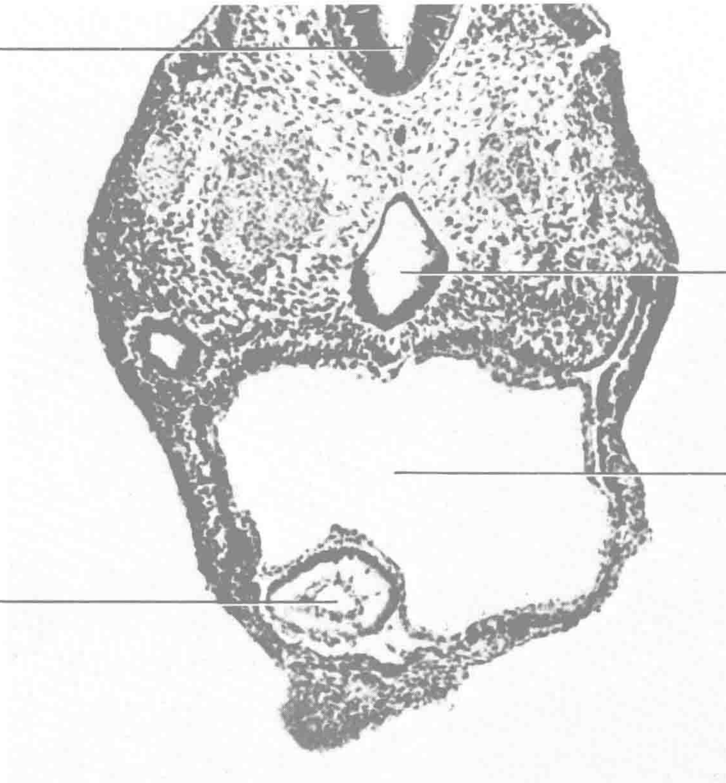

Fig. 1.5 A transverse section through the developing heart of a 3 mm human embryo. The bulbus cordis, which shows a definite reticular layer, is closely applied to the rightmost part of the common atrium as a result of the asymmetrical bending of the heart tube upon itself. Note that the common atrium shows no indication of septation at this stage of development.

The lower part and left limb are formed by the ventricle and the bulbus cordis. During the formation of the loop, the greater part of the suspending dorsal mesocardium is absorbed so that there is free communication above the heart between the right and left sides of the pericardial cavity, the transverse sinus of the pericardium. The transverse sinus, to which frequent reference is made in the adult heart, lies between the receiving region of the heart and the outflow vessels, the aorta and the pulmonary trunk, which develop from the truncus arteriosus.

As the loop develops, the bulbus cordis is displaced towards the right so that it has a close relationship to the rightmost part of the ventral (or anterior) surface of the common atrium. This is obvious in a 3 mm human embryo (Fig. 1.5), which is in the third week of development.

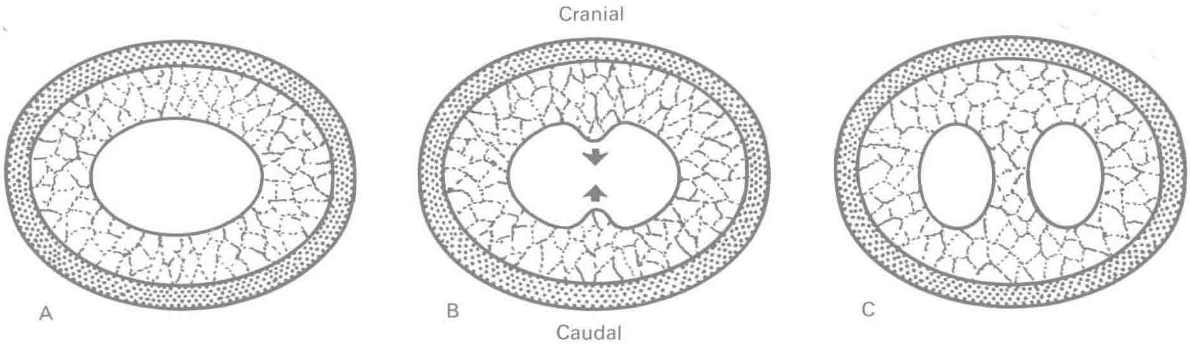

Fig. 1.6 Schematic diagrams of the atrioventricular canal as viewed from the dorsally placed atrium and looking ventrally into the ventricle. As seen in *A*, the common atrioventricular canal leads from the common atrium into the ventricle: it is oval in form, widened transversely and has cranial and caudal walls. As seen in *B*, a localised proliferation of the reticular tissue, the reticulum, takes place on the central regions of the two walls to form the cranial and caudal endocardial cushions. The cushions grow towards each other, meet and fuse to form the septum of the atrioventricular canal or septum intermedium (*C*). In this manner the single or common atrioventricular canal is divided into the right and left atrioventricular canals or orifices.

During the third to sixth weeks many vital and basic changes occur and it is at this vulnerable stage that most malformations originate in the developing heart.

It was Alexander Spitzer (Lev and Vass, 1951) who emphasised that one of the outstanding characteristics in the evolutionary development of the heart is that with the acquisition of lungs in mammals (as opposed to gills in fish) there is a concomitant necessity for septation of the heart: a right heart transporting venous blood and a left heart transporting oxygenated blood. No attempt is made here to support in full the Law of Recapitulation as originally defined by Haeckel (1874) in which it is claimed that embryonic development repeats in sequence the adult stages through which the race has passed during evolution. More succinctly, it may be stated that ontogeny (the development of the individual) repeats phylogeny (the development of the race). Nevertheless, it is of interest to note that the first indication of a respiratory system, the respiratory diverticulum in the floor of the pharynx, appears at about the same time as the first indication of the septation of the heart, late in the fourth week of development when the embryo is just less than 5 mm long.

Division of the atrioventricular canal After the heart has bent on itself, the common atrioventricular (AV) canal has an oval form widened transversely and

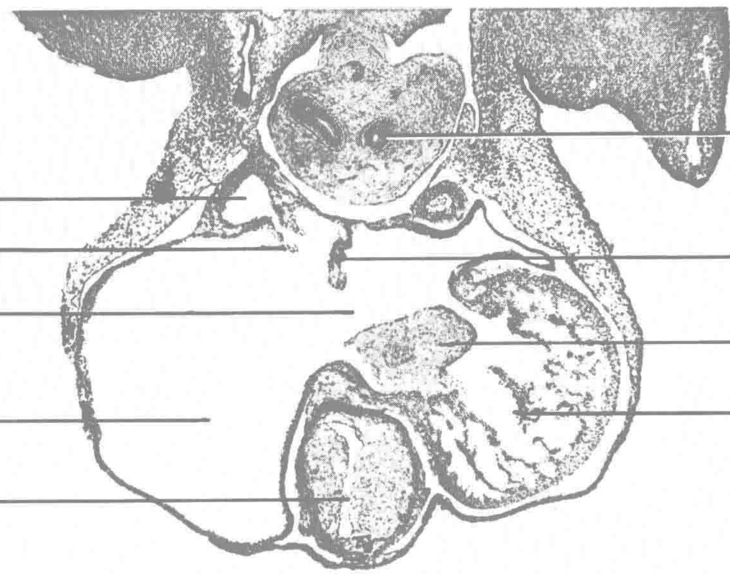

Fig. 1.7 A section through the cardiac region of a 6 mm human embryo. It shows the septum primum growing ventrally from the dorsal wall of the common atrium towards the septum of the atrioventricular canal from which it is separated by the ostium primum. Only the left orifice is seen in this section. The enlarged right horn of the sinus venosus lies in the dorsal (posterior) wall of the right atrium; the right and left venous valves protrude into its cavity. Immediately behind the atria is a mass of tissue in which the right and left main bronchi are developing.

directed ventrally from the atrium towards the ventricle. Two proliferations of the subendothelial reticulum occur, one on the middle of the cranial wall, the other on the middle of the caudal wall: these are the cranial and caudal endocardial cushions (many writers call them ventral and dorsal or anterior and posterior). They grow towards each other, meet and fuse (Fig. 1.6). In this way the septum of the AV canal (septum intermedium) divides the common canal into the right and left AV orifices. In the young embryo the cushion tissue is so large in amount and the orifices so narrow that it is difficult to visualise how blood is able to pass through them.

Division of the atrium Many references will be made to the atrial septum. Like the ventricular septum, it is a composite structure formed of two distinct parts. In both instances one part of the septum is muscular and the other is membranous. The membranous part of the atrial septum appears first and for that reason is called the septum primum. It grows downwards at the 5 mm stage (fourth week) from the dorsal wall of the common atrium

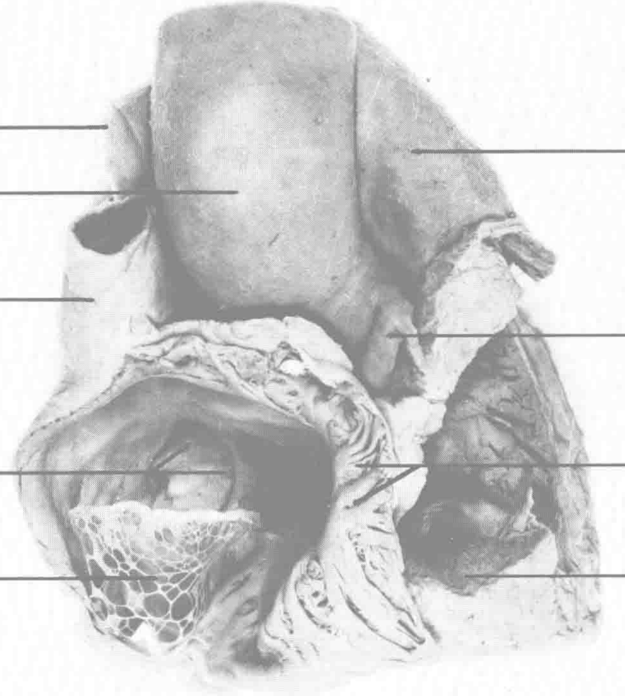

Fig. 1.8 An adult human heart with a fenestrated valve of the inferior vena cava (Chiari's network). The lateral wall of the right atrium was cut longitudinally immediately in front of the crista terminalis and the anterior wall of the chamber was retracted forwards so as to expose its interior. This is an unusually pronounced example of a fenestrated inferior caval valve. It extends through about half the length of the right atrium between the ostia of the superior and inferior cavae. Posteriorly, the valve is attached to the crista terminalis and in front to the lower part of the anterior limb of the limbus (annulus) fossae ovalis. The ostium of the coronary sinus lies immediately in front of the lower anterior part of the fenestrated valve. The fossa ovalis is seen lying behind the anterior limb of the annulus and the specimen illustrates clearly how the valve of the inferior vena cava directs venous return from the inferior vena cava towards the foramen ovale during fetal life.

The upper part of the right coronary artery is also a prominent feature of this specimen. Its first branch, the conal artery, arises about 0·5 cm from its origin.

towards the septum of the AV canal (Fig. 1.7). For a short time this growth process appears to halt so that the atria communicate through an ostium bounded above by the free lower border of the septum primum and below by the septum of the AV canal, the ostium primum. If further growth of the septum primum fails to occur the result is an atrial septal defect of the ostium primum type. Such defects are commonly associated with faulty development of the septum of the AV canal and clefts in the cusps of the mitral valve. Normally, there is no delay in the growth of the septum primum towards the septum of the AV canal, but before the ostium primum is obliterated, a new foramen is formed in the dorsal part of the septum primum that is appropriately called the ostium secundum. The formation of the ostium secundum occurs by punctate absorption of the dorsal part of the septum. The spaces that are formed coalesce and finally destroy this part of the septum. It is not uncommon to see the ostium secundum represented by a fenestrated membrane when the process of punctate absorption has been arrested. A similar process of malabsorption of the valve of the inferior vena cava results in the formation of a Chiari's network (Fig. 1.8).

In the seventh week of development (18 mm embryo), a second septum, the septum secundum, appears on the dorsal wall of the atrium immediately to the right of the septum primum. This is a muscular septum with an arched lower border and is essentially part of the muscular atrial wall. The limbs of the arch meet and fuse with the septum of the AV canal. The free border of the arch, which forms the limbus (annulus) of the fossa ovalis, grows downwards to overlap the ostium secundum and thereafter retains a fairly constant relationship to the upper part of the septum primum. The oval aperture between the lower margin of the septum secundum and the upper part of septum primum forms the foramen ovale. The valve of the inferior vena cava directs caval blood towards and against the membranous septum primum in the floor of the fossa ovalis and much of the inferior vena caval blood is shunted through the foramen from the right into the left atrium (Fig. 1.9).

Absorption of sinus venosus into right atrium The sinus venosus, which is the most caudal part of the early embryonic heart, has a middle section and a right and left horn. In the young embryo the venous system is symmetrical with corresponding veins on the right and left sides of the body. The veins from the cranial end of the body wall are the anterior cardinal veins and those from the caudal end, the posterior cardinal veins. The cardinal veins of each side unite to form the right and left common cardinal veins (the ducts of Cuvier), which open into the right and left horns of the sinus venosus. The right and left horns open into the small middle section or body of the sinus venosus. Each horn also initially receives an umbilical and vitelline vein but of these four only the right vitelline vein persists to form the terminal part of the inferior vena cava. There is also an anastomosis between the left and right anterior