

# THE CONDUCTION SYSTEM OF THE HEART

STRUCTURE, FUNCTION AND  
CLINICAL IMPLICATIONS

1978年11月25日



edited by Wellens, Lie and Janse

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H.J.J. WELLENS, M.D.,  
K.I. LIE, M.D. AND M.J. JANSE, M.D.



H. E. STENFERT KROESE B.V. - LEIDEN  
1976

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K. I. LEE, M.D. AND M. J. JANSE, M.D.  
H. J. WILLEN, M.D.

ISBN 90.207.0576.8

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## PREFACE

This monograph had its genesis in a workshop on the specific conduction held in the spring of 1975.

The meeting was organized to discuss present knowledge on structure and function of the cardiac specialized tissues with emphasis on their clinical implications. Since much new information was presented, the participants agreed to prepare manuscripts and make their material available for publication. This has resulted in a book in which the cardiac specialized tissues are discussed by different specialists: the electron-microscopist, anatomist, pathologist, physiologist, physicist and clinician. Apart from their interest in the cardiac conduction system the participants shared the opinion that their contribution should be relevant to the understanding and treatment of patients with cardiac arrhythmias. The book should be useful for the clinician, the morphologist and the physiologist.

The workshop took place at the University Department of Cardiology, Wilhelmina Gasthuis, Amsterdam, The Netherlands. This is the home ground of one of the most outstanding electrocardiologists of our time, Dr. Dirk Durrer. By pairing genius and originality with endless fund of energy and dogged persistence he made several important contributions to modern cardiac electrophysiology. In recent years he created a cardiological institute where workers from various disciplines cooperate in the study and treatment of cardiac disease. Several of his pupils participated in the workshop and contributed to this volume.

In appreciation and thankfulness we want to dedicate this book to Dr. Dirk Durrer.

Hein J. J. Wellens

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# CONTENTS

Preface	V
List of contributors	X
<b>Anatomy and electrophysiology of the developing conducting system</b>	
1. The development of the cardiac specialized tissue	3
ROBERT H. ANDERSON, M.D., ANTON E. BECKER, M.D., ARNOLD C.G. WENINK, M.D., and MICHEL J. JANSE, M.D.	
2. Electrophysiology of the intact neonatal canine atrioventricular conducting system	29
HENRY GELBAND, M.D., KRISTINA NILSSON, RUEY J. SUNG, M.D., ARTHUR L. BASSETT, Ph.D., and ROBERT J. MYERBURG, M.D.	
<b>Electronmicroscopy of the conducting system</b>	
3. The fine structure of the atrial and atrio-ventricular (AV) junctional specialized tissues of the rabbit heart	55
J. TRANUM-JENSEN, M.D.	
<b>Impulse formation and conduction</b>	
4. Recent observations supporting the role of the slow current in cardiac electrophysiology	85
DOUGLAS P. ZIPES, M.D.	
5. Effect of autonomic activity on pacemaker function and conduction	100
E. NEIL MOORE, D.V.M., Ph.D., and JOSEPH F. SPEAR, Ph.D.	
6. Supernormal excitability and conduction	111
JOSEPH F. SPEAR, Ph.D., and E. NEIL MOORE, D.V.M., Ph.D.	
7. The role of phase 3 and phase 4 block in clinical electrocardiography	126
MAURICIO B. ROSENBAUM, M.D., JULIO O. LAZZARI, M.D., and MARCELO V. ELIZARI, M.D.	



8. The electrophysiologic basis of parasystole and its variants 143  
ALFRED PICK, M.D.
9. Some effects of electrical stimulation on impulse initiation in cardiac fibers;  
its relevance for the determination of mechanisms of clinical cardiac  
arrhythmias 163  
ANDREW L. WIT, Ph.D., JAY R. WIGGINS, Ph.D., and PAUL F. CRANEFIELD,  
M.D., Ph.D.
10. The effect of antiarrhythmic agents on impulse formation and impulse  
conduction 182  
LEONARD S. DREIFUS, M.D., YOSHIO WATANABE, M.D., HENRY N. DREIFUS,  
and IRANY DE AZEVEDO, M.D.

#### Sinus node and atrium

11. The sinoatrial node and its connections with the atrial tissues 209  
RAYMOND C. TRUEX, Ph.D.
12. Direct and indirect techniques in the evaluation of sinus node function 227  
HAROLD C. STRAUSS, M.D., and ANDREW G. WALLACE, M.D.
13. Studies on the effect of drugs on sinus node-atrial conduction 238  
IWAO YAMAGUCHI, M.D., and WILLIAM J. MANDEL, M.D.
14. Observations on circusmovement tachycardia in the isolated rabbit atrium 249  
MAURITS A. ALLESSIE, M.D., FELIX I.M. BONKE, M.D., and FRANCIEN J.G.  
SCHOPMAN, M.D.

#### The atrioventricular junction, the bundle branches and the ventricle

15. Morphology of the human atrioventricular junctional area 263  
ANTON E. BECKER, M.D., and ROBERT H. ANDERSON, M.D.
16. Pathological basis of concept of left hemiblock 287  
H. E. KULBERTUS, M.D., and J. Cl. DEMOULIN, M.D.
17. Electrophysiology and structure of the atrioventricular node of the isolated  
rabbit heart 296  
MICHIEL J. JANSE, M.D., FRANS J. L. van CAPELLE, Ph.D., ROBERT H.  
ANDERSON, M.D., PAUL TOUBOUL, M.D., and JACQUES BILLETTE, M.D.
18. Influence of geometry on the shape of the propagated action potential 316  
FRANS J. L. VAN CAPELLE, Ph.D., and MICHIEL J. JANSE, M.D.
19. Electrophysiology of endocardial intraventricular conduction: The role and  
function of the specialized conducting system 336  
ROBERT J. MYERBURG, M.D., HENRY GELBAND, M.D., AGUSTIN CASTELLANOS,

Jr., M.D., KRISTINA NILSSON, RUEY J. SUNG, M.D., and ARTHUR L. BASSETT, Ph.D.	
20. The experimental evidence for the role of phase 3 and phase 4 block in the genesis of A-V conduction disturbances	360
MARCELO V. ELIZARI, M.D., ALEJANDRO NOVAKOSKY, M.D., RICARDO A. QUINTERO, M.D., RAÚL J. LEVI, M.D., JULIO O. LAZZARI, M.D. and MAURICIO B. ROSENBAUM, M.D.	
21. Ventricular activation in human and canine bundle branch block	377
RUDOLF Th. VAN DAM, M.D.	
22. Depressed conduction and unidirectional block in Purkinje fibers	393
EUGENE DOWNAR, M.D., and MENASHE B. WAXMAN, M.D.	
23. Newer aspects of concealed conduction of the cardiac impulse	410
RICHARD LANGENDORF, M.D.	
24. The role of the conduction system in supraventricular tachycardia	424
PHILIPPE COUMEL M.D., PATRICK ATTUEL, M.D., and DANIEL FLAMMANG, M.D.	
25. Electrophysiological diagnosis and manifestation of dual A-V nodal pathways	453
KENNETH M. ROSEN, M.D., PABLO DENES, M.D., DELON WU, M.D., and RAMESH C. DHINGRA, M.D.	
26. Incidence of different types of A-V block and their localization by His bundle recordings	467
PAUL PUECH, M.D., ROBERT GROLLEAU, M.D., and CLAUDE GUIMOND, M.D.	
27. Patterns of V-A conduction in the human heart in the presence of normal and abnormal A-V conduction	485
REINIER M. SCHUILENBURG, M.D.	
28. Gap phenomena: Antegrade and retrograde	504
ANTHONY N. DAMATO, M.D., MASOOD AKHTAR, M.D., JEREMY RUSKIN, M.D., ANTONIO CARACTA, M.D., and SUN H. LAU, M.D.	
29. Accommodation of A-V nodal conduction and fatigue phenomenon in the His-Purkinje system	529
ONKAR S. NARULA, M.D., and MANFRED RUNGE, M.D.	
30. Epicardial mapping and surgical treatment in six cases of resistant ventricular tachycardia not related to coronary artery disease	545
G. FONTAINE, M.D., G. GUIRAUDON, M.D., R. FRANK, M.D., R. COUTTE, M.D., and C. DRAGODANNE, M.D.	
<b>The Wolff-Parkinson-White syndrome</b>	
31. The electrophysiologic properties of the accessory pathway in the Wolff-Parkinson-White syndrome	567
HEIN J. J. WELLENS, M.D.	

32. Correlation between catheter electrophysiologic studies and findings on mapping of ventricular excitation in the W.P.W. syndrome 588  
JOHN J. GALLAGHER, M.D., WILL C. SEALY, M.D., ANDREW G. WALLACE, M.D. and JACKIE KASSELL.
33. Ventricular excitation in the Wolff-Parkinson-White syndrome 613  
ANDREW G. WALLACE, M.D., WILL C. SEALY, M.D., JOHN J. GALLAGHER, M.D., and JACKIE KASSELL.

### Myocardial infarction

34. Mechanisms of ectopic rhythm formation due to myocardial ischemia: Effects of heart rate and ventricular premature beats 633  
BENJAMIN J. SCHERLAG, Ph.D., RONALD R. HOPE, M.B., F.R.A.C.P., DAVID O. WILLIAMS, M.B., M.R.C.P., NABIL EL-SHERIF, M.D., and RALPH LAZZARA, M.D.
35. Observations during electrical stimulation of the heart in patients with sinus bradycardia following acute myocardial infarction 650  
HEIN J. J. WELLENS, M.D., HENK J. M. DOHMEN, M.D., and K. I. LIE, M.D.
36. A-V nodal block in acute myocardial infarction 655  
ALFRED C. TANS, M.D., and K. I. LIE, M.D.
37. Bundle branch block and acute myocardial infarction 662  
K. I. LIE, M.D., HEIN J. J. WELLENS, M.D., REINIER M. SCHUILENBURG, M.D.
- Bibliography on the conduction system 673  
Index of subjects 706

ANATOMY AND ELECTROPHYSIOLOGY OF THE  
DEVELOPING CONDUCTING SYSTEM





# 1 THE DEVELOPMENT OF THE CARDIAC SPECIALIZED TISSUE

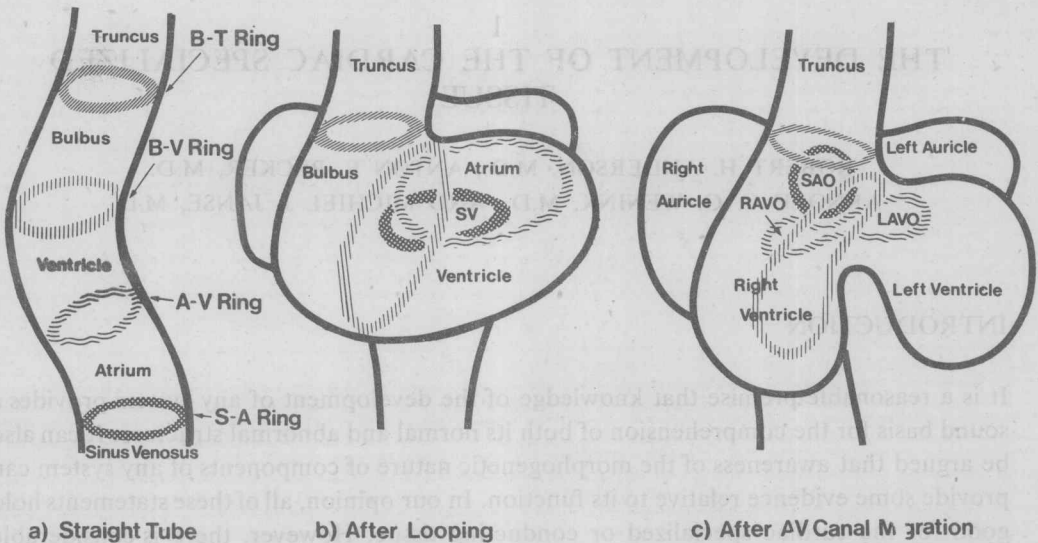
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ARNOLD C. G. WENINK, M.D., AND MICHEL J. JANSE, M.D.

## INTRODUCTION

It is a reasonable premise that knowledge of the development of any system provides a sound basis for the comprehension of both its normal and abnormal structure. It can also be argued that awareness of the morphogenetic nature of components of any system can provide some evidence relative to its function. In our opinion, all of these statements hold good for the cardiac specialized or conducting tissue. However, there is considerable divergence of opinion regarding the precise origin of certain parts of the conducting system, in particular the atrioventricular junctional area, while controversy continues to rage concerning the extent of specialized structures within the atrial tissues. Review of the relevant literature shows that in many cases these disagreements relate more to differences in interpretation than to variation in observations, while other arguments relate more to definitions and semantics. In this review we will present our own observations relative to the development of the cardiac specialized tissue. These have been based on histologic study of human embryos and specimens of congenitally malformed human hearts, together with combined morphologic and electrophysiologic studies of human fetal hearts. Where any topic is contentious we shall refer to the results of previous investigators. However, we shall not attempt to provide an exhaustive review of prior studies of development of the cardiac specialized tissue. Rather we will attempt to provide an outline of embryogenesis which we hope will facilitate interpretation and aid comprehension of the subsequent contributions to this book.

## EARLY STAGES OF DEVELOPMENT

At the stage at which the heart is represented by a straight tube (approximately 2 mm CR length—3 weeks intrauterine development—Horizon X), various segments are recognizable. These can be designated, following the precedent of Keith (432), as sinus venosus, primitive atrium, primitive ventricle, bulbus and truncus. Each of the segments is separated by a constricted ring, and close examination of these rings reveals that they are histologically distinct from the walls of the intervening segments (fig. 1a) (62, 920). A close parallel to this situation is to be found in the hearts of lower vertebrates where some authorities hold the junctional tissues to be specialized (658). In contrast, others contend that conducting tissues are only observed in birds and mammals (179). Nonetheless, examination of the precise effect of cardiac looping and development on the disposition of

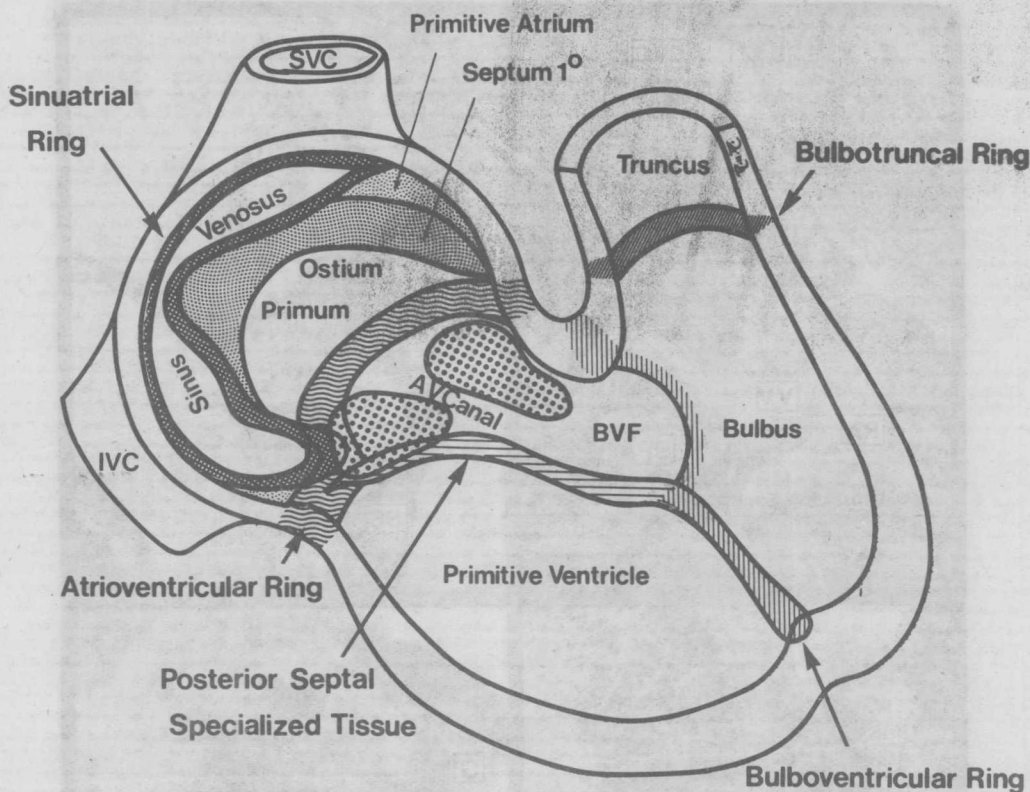


### Early Stages - Distribution of Ring Specialized Tissues (Wenin<sup>\*</sup>, 1975)

Fig. 1. Diagrams showing the effect of looping upon the rings of specialized tissue separating the components of the primitive heart tube, viz: sinus venosus, atrium, ventricle, bulbus and truncus. The four rings, the sinuatrial (SA), atrioventricular (AV), bulboventricular (BV) and bulbotruncal (BT) rings are indicated by differing varieties of cross-hatch or stipple, and these symbols will continue to be used throughout the subsequent diagrams. After looping (fig. 1b), the formation of the inner curvature brings the AV, BV and BT rings into close apposition. After canal migration, the SA ring is brought into contact with the AV ring posteriorly, while the BV ring is now juxtaposed to the AV ring in both medial and lateral parts of the right bulboventricular junction. These ring juxtapositions are of considerable significance to subsequent development of AV junctional specialized tissues. Other abbreviations: SAO = sinuatrial orifice. RAVO = right atrioventricular orifice. LAVO = left atrioventricular orifice.

these junctional rings is of considerable significance to the subsequent formation of conducting structures (fig. 1).

Absorption of the sinus venosus into the right atrium places the sinuatrial ring in the posterior wall of the right atrial chamber. It impinges postero-inferiorly upon the atrioventricular ring, which following formation of the right ventricle is itself in apposition to the anteriorly situated bulboventricular ring in two sites, one septally and the other laterally (fig. 1c). Since the looping process produces an exceedingly short inner curvature of the heart, the cono-ventricular flange, it follows that atrioventricular, bulboventricular and bulbotruncal rings are all in close apposition at this point (fig. 2). This concept of disposition of the rings is dependent upon the premise that the definitive right ventricle is formed in part from the primitive ventricle and in part from the bulbus. Although some maintain that the right ventricle is an entirely bulbar structure (868), our own studies do not support this contention (34). Furthermore, if the primitive ventricle does contribute to both ventricles, as we believe, then the posterior ventricular septum is formed *de novo* from the primitive ventricle and is not a bulboventricular structure. As we shall show, conducting elements formed astride the posterior interventricular septum are of particular



## Horizon XV

Fig. 2. Diagram illustrating the disposition of specialized tissues following looping and canal migration, but prior to fusion of the endocardial cushions (bold stipple). The specialized rings are in the same symbols as for figure 1. The atrial septal primordia are depicted by various forms of hatching (primitive atrium, septum 1°). The heart is depicted as viewed from its right side looking through the as yet unseptated ostium atrioventriculare. The primitive ventricle is shown as though septated by the posterior septum. The primordium of the compact node is astride this septum (posterior septal specialized tissue). Although drawn in a differing cross-hatch, our results indicate that this tissue is derived from a posterior invagination of the atrioventricular ring. Note that the sinuatrial ring is in the posterior atrial wall. SVC = superior vena cava. IVC = inferior vena cava. BVF = bulboventricular foramen. 1° = primum.

significance to development of the junctional area. In the ensuing account, therefore, we will presume that the right ventricle is derived in part from the primitive ventricle and in part from the primitive bulbus.

## CONDUCTING TISSUES PRIOR TO COMPLETION OF ATRIOVENTRICULAR SEPTATION

Study of embryos in the stage at which fusion of the endocardial cushions is about to occur (Horizon XV) is of major significance to concepts of subsequent development of the conducting tissues. At this stage the septum primum is growing down to the cushions and is



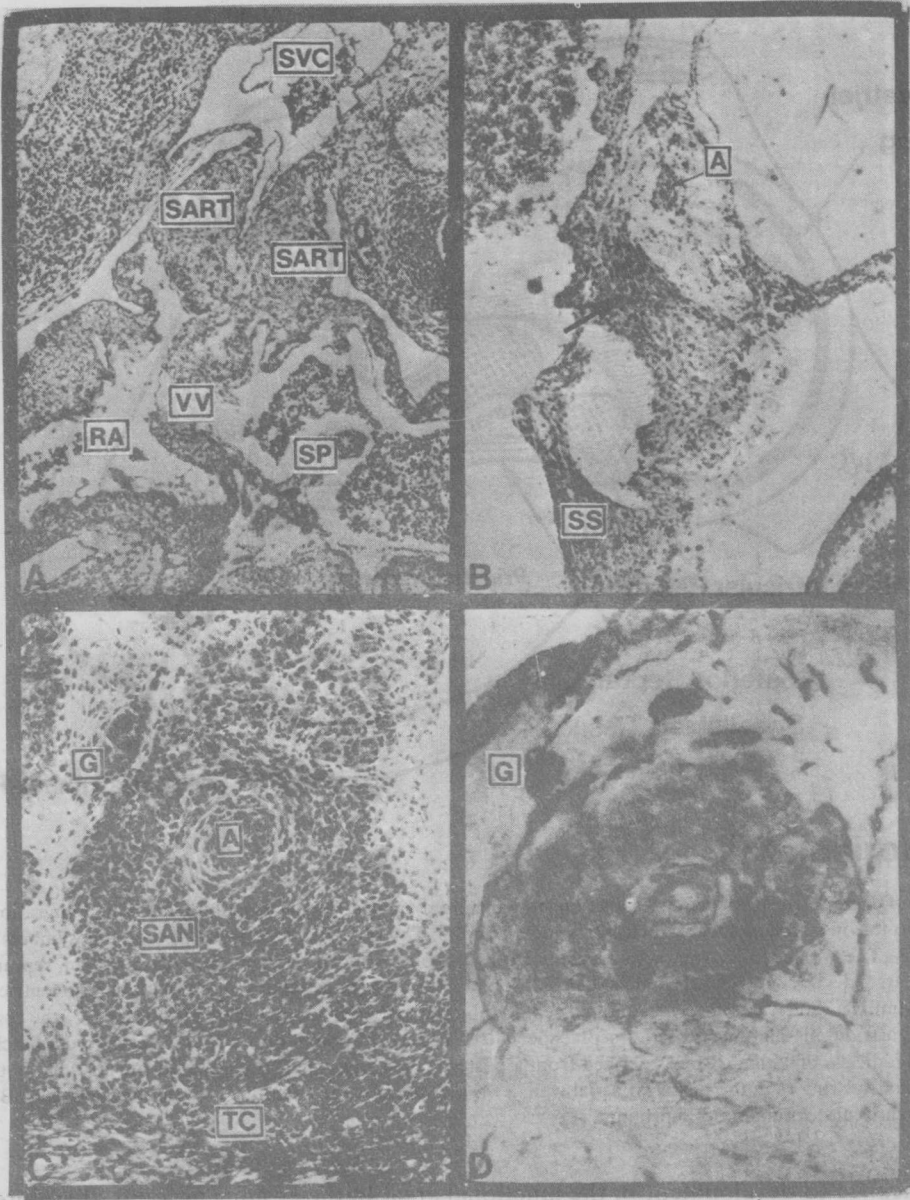


Fig. 3. Photomicrographs illustrating the development of the sinoatrial node. At approximately six weeks of development (fig. 3a) the sinoatrial ring tissue (SART) is thickened at the junction of the superior vena cava (SVC) with the right atrium (RA). Note the prominent venous valves (VV) depending from the sinoatrial junction and the perforated septum primum (SP) which is an outgrowth from the primitive atrial tissue. At approximately 8 weeks of development (fig. 3b) the sinoatrial ring thickening is confined to a small area of tightly packed cells (arrowed) above the septum spurium (SS). The cells do not surround the prominent artery seen at the cavo-atrial junction (A). By 10–12 weeks of development (fig. 3c and d) the cells have proliferated and now surround the nodal artery (A). The sinoatrial nodal cells (SAN) are minimally differentiated from those of the crista terminalis (TC) in histological terms (fig. 3c). However, an adjacent section processed for cholinesterase activity (fig. 3d) shows that the nodal cells are ChE positive and are supplied by ChE containing nerves. Note the ganglion cell body which is also ChE positive (G).