

Conducting Pathways of the Human Heart*

FERGUS O'M. SHIEL, M.D.

*Associate Professor of Pathology, Medical College of Virginia,
Health Sciences Division of Virginia Commonwealth University,
Richmond, Virginia*

FABIO GUTIERREZ, M.D.

*Resident in Department of Pathology, Medical College of Virginia,
Health Sciences Division of Virginia Commonwealth University,
Richmond, Virginia*

For over a century the cardiac beat has been experimentally observed and analyzed. To a surprising degree the relevancy of the early researches persists, and the views of the 19th century investigators though modified, have not been eclipsed by time. It may, therefore, be appropriate to preface this clinicopharmacological seminar on arrhythmias by a brief review of the cardiac conducting pathways whose existence is generally accepted today and to retrace the concepts which led to their discovery.

The phenomenon was already so familiar that by 1882 the Cambridge physiologist W. H. Gaskell (fig. 1) could neglect specific citations in his reference to the ease with which cardiac contractions in cold blooded animals are seen to commence in the sinus venosus and with distinct pauses, sequentially pass to the auricles and ventricles (3). From his writings and those of several contemporaries, it is clear that basic questions regarding cardiac conduction were not only well defined but could already be physiologically explored against a formidable background of embryology, comparative anatomy, and histology. The continuous tubal structure of the primitive heart permitting a wave of contracture was well known. In contrast were the obstacles to be circumvented when hearts evolved with interposing rings of fibrous (fig. 3) tissue which appeared to

separate the muscular continuity of the atria and ventricles.

Simple notions that contractions resulted from "direct stimulation of the blood on cardiac muscle" had long since been abandoned. In particular, the discovery of both cardiac nerves and the ganglionic masses of Remak (23), Bidder (2), and Ludwig (21) introduced the possibility of a much more plausible neurological explanation for the transmission of cardiac impulses. It was inferred that cardiac muscle contracted in response to a stimulus initiated at central nervous system or peripheral ganglionic level. Since neural connections between atria and ventricles could be demonstrated, the apparent muscular dissociation between these chambers could be disregarded.

The attraction of a neurological mechanism in explaining cardiac rhythm and contraction waves was further enhanced by the earlier experiments which purported to show that isolated portions of heart would contract only if they contained elements of neural ganglia. This comfortable situation was soon to be disturbed by Gaskell's instinct to challenge the accepted. Though his meager illustrations are poor quality woodcuts and his argument sometimes diffuse, two essential advances emerge from his research: 1) a recognition of inherent excitability in cardiac muscle independent of ganglia and 2) demonstration in a tortoise heart that a bridge of muscle tissue exists between the atria and ventricles (3).

* Presented by Dr. Shiel at the Symposium on Cardiac Arrhythmias, June 8, 1972, at Virginia Beach, Virginia.



Fig. 1—Walter H. Gaskell. 1847–1914.

With the identification of the fasciculus atrioventricularis, or “Gaskell’s Bridge,” the myogenic concept of cardiac conduction was established. It remained to show that the structure observed in poikilothermic animals had an analogous counterpart in mammals. This was accomplished by W. His, Jr. (fig. 2) in 1893 (7, 8, 9), and almost simultaneously by the independently working A. F. Stanley Kent (16). Predictably, the ensuing years were occupied in successful search and survey of alternate pathways. These major systems are depicted in the diagrams and discussed in the order of their discovery (figs. 3, 4, 5, and 6).

Following the identification of the atrioventricular fasciculus, the attached A-V node and the bundle branches curiously remained undescribed until the appearance of Tawara’s monograph in 1906 (24). In this year also, the sinoatrial node was dis-



Fig. 2—Wilhelm His, Jr. 1863–1934.

covered by Keith and Flack (13, 14, 15), an event which stimulated search for internodal tracts. Three bundles of Purkinje-like tissue associated with the names of Wenckebach, Thorel, and Bachmann (27, 25, 1) have been described. They are represented in figures 3, 4, and 5, and have been reidentified by James (11) as the middle, posterior, and anterior internodal tracts.

Though the bundle of His is apparently the sole atrioventricular muscular connection in normal human hearts, a number of accessory pathways have been found in fetal, infant, and pathological hearts. They are of particular interest and significance in explaining arrhythmias associated with the Wolff-Parkinson-White syndrome. Notably these tracts include the connections described by Kent (18, 19, 20) between the lateral walls of the right atrium ventricle, the paraspecific fibers of Mahaim

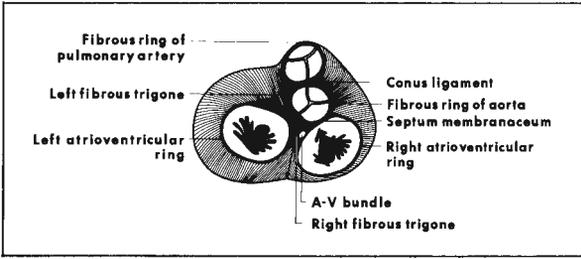


Fig. 3—The interatrioventricular fibrous skeleton: Note A-V bundle penetrating right fibrous trigone.

(22) which run from the left bundle branch to the upper interventricular septum, and the accessory fibers described by James (10). The vast and fastidious labors on the conducting system have even in modern times not deterred some investigators, notably, though not uniquely, Glomset and his associates (4, 5, 6) from denying the existence in man of a myogenic conduction system and attempting to reincarnate the supremacy of the neurogenic theory. Perusal of their papers will reassure the reader that, however he receives them, their views are not unsupported by much careful investigation. There are indeed many reasons for the doubts and discrepancies of various investigations. Anatomic certainty comes only from meticulous serial sectioning, and the tedium and labor involved have perhaps tempted some conclusions whose validity has been impaired by faulty techniques. On physiological grounds alone, the presence of conducting systems is incontrovertible, and there is abundant anatomical data testifying not only to specialized muscle paths but also to their intimate association with neural elements. Whether the situation of nerve and muscle indicates mere anatomic proximity or bespeaks a close functional connection, is, however,

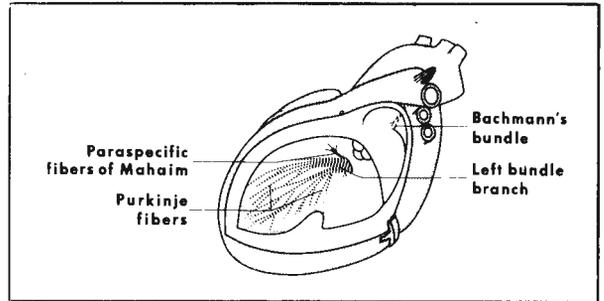


Fig. 5—Scheme of the conducting pathways viewed from the left atrioventricular aspect.

a question still unsettled. Though the long and current ascendancy of the myogenic theory reflects the accumulated evidence in its favor, this review of the discovery of the conducting system may bear witness to the dangers of facile acceptance. The myogenic theory was conceived in dissatisfaction with the neurogenic explanation and born in the labors of Gaskell, His, and Kent. Not all discoveries have survived attempts at confirmation, and in particular, the existence of the lateral A-V fibers described by Kent (fig. 3) have been successively accepted, rejected, and later reinstated as present in fetal and certain pathological hearts. Again, so far from excluding the possible contribution of neural elements to conduction, modern ultrastructural and histochemical studies of the S-A and A-V nodes have strengthened the evidence of autonomic nerves (26) and cholinesterase activity at these sites (12). Clearly, therefore, the identification of both neural and muscular components in no way abates the potential importance of either. On the contrary, continued exploration of the neuromuscular relationships is required, and it remains the task to solve the contribution of each before today's discordant views can harmonize.

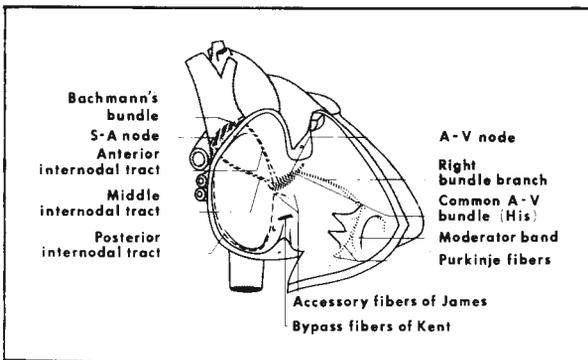


Fig. 4—Scheme of the conducting pathways viewed from the right atrioventricular aspect.

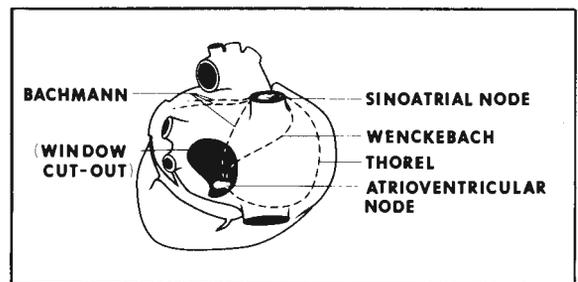


Fig. 6—Heart viewed from above showing the Wenckebach, Thorel, and Bachmann bundles (middle, posterior, and anterior internodal tracts of James).

REFERENCES

1. BACHMANN, G. The inter-auricular time interval. *Amer. J. Physiol.* 41:309, 1916.
2. BIDDER, F. H. Über functionell verschiedene und räumlich getrennte Nervencentra im Froschherzen. *Arch. Anat. Physiol. wissen. Med.*, p. 163, 1852. Cited by Hudson, R. E. B. In: *Cardiovascular Pathology*, Vol. I. p. 57. The Williams and Wilkins Co., Baltimore, 1965.
3. GASKELL, W. H. On the innervation of the heart. *J. Physiol.* 4:43, 1883.
4. GLOMSET, D. J. AND GLOMSET, A. J. A. A morphologic study of the cardiac conduction system in ungulates, dog and man. I. The sinoatrial node. II. The Purkinje system. *Amer. Heart J.* 20:389, 677, 1940.
5. GLOMSET, D. J. AND BIRGE, R. F. A morphological study of the conducting system. IV. The anatomy of the upper part of the ventricular system in man. *Amer. Heart J.* 29:526, 1945.
6. GLOMSET, D. J. AND CROSS, K. R. Morphologic study of the cardiac conduction system. VI. The intrinsic nervous system of the heart. *Arch. Intern. Med.* 89: 923, 1952.
7. HIS, W., JR. Die Thätigkeit des embryonalen Herzens und deren Bedeutung für Lehre von der Herzbewegung beim Erwachsenen. *Arbeit. med. Klin. Leipzig.* pp. 14-49, 1893.
8. HIS, W., JR. Herzmuskel und Herzganglien: Bemerkungen zu dem Vortrag des Herrn Geheimrath A. von Kölliker ueber die feinere Anatomie und physiologische Bedeutung des sympathischen Nervensystems. *Wien. med. Blätt.* 17:653, 1894.
9. HIS, W., JR. Zur Geschichte des Atrioventrikularbündels. *Klin. Wschr.* 12:569, 1933.
10. JAMES, T. N. Morphology of the human A-V node with remarks pertinent to its electrophysiology. *Amer. Heart J.* 62:756, 1961.
11. JAMES, T. N. The connecting pathways between the sinus node and the A-V node and between the right and left atrium of the human heart. *Amer. Heart J.* 66:498, 1963.
12. JAMES, T. N. AND SPENCE, C. S. Distribution of cholinestrase within the sinus node and A-V node of the human heart. *Anat. Rec.* 155:151, 1966.
13. KEITH, A. The auriculoventricular bundle of His. *Lancet* 1:623, 1906.
14. KEITH, A. AND FLACK, M. W. The auriculoventricular bundle of the human heart. *Lancet* 2:359, 1906.
15. KEITH, A. AND FLACK, M. W. The form and nature of the muscular connections between the primary divisions of the vertebrate heart. *J. Anat. Physiol.* 41: 172, 1907.
16. KENT, A. F. S. Researches on the structure and function of the mammalian heart. *J. Physiol.* 14:233, 1893.
17. KENT, A. F. S. Observations on the auriculoventricular junction of the mammalian heart. *Quart. J. Exp. Physiol.* 7:193, 1913.
18. KENT, A. F. S. The right lateral auriculoventricular junction of the heart. *J. Physiol.* 48:xxii, 1914.
19. KENT, A. F. S. Illustrations of the right lateral auriculoventricular junction in the heart. *J. Physiol.* 48: lxxiii, 1914.
20. KENT, A. F. S. A conducting path between the right auricle and the external wall of the right ventricle in the heart of the mammal. *J. Physiol.* 48:lvii, 1914.
21. LUDWIG, C. F. W. Über die Herznerven des Frosches. *Arch. Anat. Physiol. wissen. Med.*, p. 139, 1848.
22. MAHAJIM, I. Kent's fibers and the A-V paraspecific conduction through the upper connections of the bundle of His-Tawara. *Amer. Heart J.* 33:651, 1947.
23. REMAK, R. Ueber den Bau des Herzens. *Arch. Anat. Physiol. wissen. Med.*, p. 76, 1850. Cited by Hudson, R. E. B. In: *Cardiovascular Pathology*, Vol. I., p. 59. The Williams and Wilkins Co., Baltimore, 1965.
24. TAWARA, S. Das Reizleitungssystem des Säugetierherzens. Eine anatomisch-histologische Studie über das Atrioventrikularbündel und die Purkinjeschen Fäden. Fischer, Jena, 1906.
25. THOREL, C. Über den Aufbau des Sinusknotens und seine Verbindung mit der Cava superior und den Wenckebachschen Bündeln. *Much. med. Wschr.* 57:183, 1910.
26. TRUEx, R. C. Comparative anatomy and functional considerations of the cardiac conduction system. In: *The Specialized Tissues of the Heart, a Symposium.* (eds.) A. H. DeCarvalho, W. C. DeMello, and B. F. Hoffman. Elsevier, New York, 1961.
27. WENCKEBACH, K. F. Beiträge zur Kenntnis der menschlichen Herztätigkeit, Zweiter Teil. *Arch. Anat. Physiol. (Physiol. Abteil.)*, p. 1, 1907.