Electrocardiographic Studies in Normal Infants and Children

By

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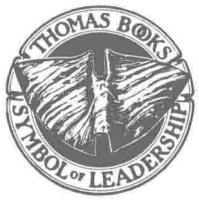

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This Book

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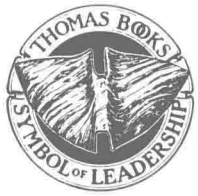

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The work represented within these pages is dedicated hopefully to the proposition that it will contribute to the health, and thereby to the happiness of children everywhere.

Preface

PROGRESS, which we understand to mean an advance in our knowledge of fundamental *Truth*, is said to result, in part at least, from an effort to find something of permanent value in the presence of adversity and insecurity together with their attendant distortion of individual or social sense of perspective. Such creative effort takes many forms and is productive of a variety of results, only a small proportion of which prove to be of lasting value. But regardless of their success or failure, as judged by their contribution to a growing body of fundamental Truth, such efforts are always of real value to the individual or group engaged in a search after knowledge. The benefits accruing to an individual doing honest research are well known to include an improvement in one's personal knowledge of not only the problem under investigation, but of many other related problems as well; a refinement of intellectual discipline and a resulting improvement in the individual's ability to successfully investigate any problem; and, possibly of greatest importance, a sense of personal satisfaction and pride in the accomplishment of that which perhaps no one else has previously done.

The small but vigorous infant, *Electrocardiographic Studies in Infants and Children*, has been growing in an atmosphere permeated by the foregoing philosophy. It was conceived in a union of interest and ignorance; interest in the subject of cardiology, and ignorance of its application to problems of infancy and childhood. It has subsisted, and in fact thrived, on a somewhat strange variety of circumstances, not the least of which has been adversity. It has been nourished, as it were, by the fruits of its own labor — the ever-increasing interest of encountering and attempting to solve the innumerable new problems which have arisen in the course of what was originally a simple search for standards of normal. Strangely enough, and standing as a notable example of the perversity of human nature, this child — even at such an early age — has profited greatly from the misfortune of others and, most particularly, from those of other small children. As in most other problems of life, an improved perspective has been gained by comparing opposites: normal with abnormal, good with bad, truth with falsehood, and others of like variety, rather than by limiting one's interest to only one phase of the subject. Another factor which has stimulated healthy growth has been the challenge of ignorance in the scientific world, which, unfortunately, has been widely upheld as intended truth. Not to be forgotten in an appraisal of reasons for growth and development are certain intangible, though no less real, factors, including an honest desire to be of some value to a world in need; perhaps some elemental sense of, or desire for, self-importance; and certainly an extra-ordinary determination and will to live even against the opposition of at times overwhelming difficulties.

This brief biographical sketch would be incomplete without mention of a serious, indeed nearly fatal, illness which threatened the already troubled existence of this interesting and promising infant. At the age of two-and-a-half years, a fundamental error in its way of living [1] nearly cost it its life; and only with considerable expense, both of time and effort, and the help of friends and professional associates was the child able to gain in stature and in wisdom.*

* Without the assistance of the following people, this work would have been virtually impossible: Invaluable technical assistance in the difficult work of recording the electrocardiograms was generously and ably given by Miss Wilma Schoof, Mrs. Hope Goodman, Miss Miriam White, Mrs. Nina Gielen, and Mrs. Edith Cochran. The tedious and time-consuming task of preparing the charts and tables, as well as the preparation of the manuscript, the bibliography, and much of the index has been facilitated by the cheerful and capable efforts of my secretary, Miss Irene Murray. The statistical data for the study was prepared by Mr. Ronald Wilson and his associates, of the Wayne University College of Business Administration. Many valuable suggestions, advice, and constant encouragement have been offered by members of the staff of Henry Ford Hospital, including Dr. F. Janney Smith, Physician-in-Charge of the Cardio-Respiratory Division; Dr. Frank J. Sladen, Physician- →

Finally, having reached a precocious maturity at the age of five years, it has achieved a sufficient degree of perfection, or perhaps better has rid itself of a sufficient degree of imperfection, to be presented to the medical public. In making its debut it hopes to be useful, to make a few friends, and perhaps to be remembered by someone. It also entertains an unspoken aspiration to having a little brother or sister in the not too distant future [2, 3, 4] and even now is anticipating a perpetuation and purification of its spirit in future generations.

R. F. Z.

← in-Chief; and Dr. Roy D. McClure, Surgeon-in-Chief; also, by Dr. Frank N. Wilson, of the University of Michigan, Ann Arbor. The cooperation of the Obstetrical and Pediatric Divisions of the Henry Ford Hospital has also helped materially in the collection of the necessary data. I am indebted to the Henry Ford Hospital and the Ford Foundation for financial support for the material and equipment involved in this study. I am also indebted to my associates, who have ably carried on the work of the Division of Pediatric Cardiology and thus made additional time available for the completion of this study; these include Dr. F. M. Sones, Jr., Dr. Arthur Azevedo, of Rio de Janeiro, Brazil, and Dr. Otto Ritter, of Lausanne, Switzerland. These acknowledgments would not be complete without expressing gratitude to the many parents whose kind cooperation in the matter of making their children available for this electrocardiographic study has been deeply appreciated.

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Chapter I

Introduction and Review of the Literature

IT IS PROBABLY fair to state that adequate standards of normal have never been determined for the electrocardiogram of infants and children. A certain amount of statistical data has accumulated concerning the various intervals and deflections in the standard extremity leads; but with a decreasing value of these derivations in favor of multiple precordial leads and unipolar extremity leads, the need for newer and more adequate data has become apparent. Only a few incomplete observations have been reported in which the electrocardiogram, from either extremities or the precordium, represents the potential variations of a single electrode; [73, 74] and no studies have concerned themselves with a detailed investigation and interpretation of the electrical events associated with the cardiac cycle in this age group. Despite these facts, a number of electrocardiographic studies in children with heart disease have been reported with the unfortunate result of all too frequently misleading, if not actually incorrect, conclusions having been reached. It consequently became the purpose of this publication to present a detailed study of the electrocardiograms of infants and children from which certain definitive types of information might be derived. The first is the establishment of complete normal standards for each of the deflections and intervals in the various leads from those parts of the body surface usually utilized for electrocardiographic exploration. The second is the critical interpretation of these data in terms of current concepts of electrocardiography, together with suggested applications of such concepts to the clarification of certain problems in clinical electrocardiography. On the basis of these types of information, it is hoped that a more accurate interpretation of abnormal and borderline electrocardiograms will become possible.

It is by no means intended that this publication represent a complete study of electrocardiography in infants and children. Even a lifetime of uninterrupted effort could not make it so. It is hoped, however, that the purpose of providing a sound fundamental foundation upon which further studies may be based will have been accomplished.

In providing a background for this present study, the most significant contributions of previous publications have been reviewed. No attempt has been made to cite all of the literature, although for possible usefulness to the interested reader, a complete list of references has been included in the bibliography.

In 1908, five years after Einthoven's invention of the string galvanometer, Nicolai and Funaro [50] published the first study of electrocardiography in infants and children. They recorded standard lead I only in a series of forty-five children and noted in this lead the frequent occurrence of a prominent S deflection, which they interpreted as evidence of either left ventricular hypertrophy or transverse position of the heart in the thorax. Later in the same year, Huebner [29] made similar observations and, in addition, emphasized the fact that the R deflection in lead I in infants and young children was either small or absent. He considered these features of the electrocardiogram to be evidence of delay in the development of the heart. The first comprehensive study, including the use of all three extremity leads, was published in 1913 by Hecht,[28] who, in addition to reviewing the available literature, summarized original data from records of seventy premature infants, full-term infants, younger and older children, and three hundred abnormal children.

It has been generally observed that the most characteristic, though not necessarily constant, feature of the standard lead electrocardiogram in infants and young children is right axis deviation of QRS; yet up to the present time, no completely satisfactory explanation has been given for the significance of this finding.

On the basis of electrocardiographic, clinical, and anatomic studies of normal adults, adults with

heart disease, and a small number of normal infants, Lewis [39] concluded in 1913 that right axis deviation constituted evidence of right ventricular hypertrophy, thus confirming the electrocardiographic criteria for ventricular preponderance previously established by Einthoven. This belief was further supported by the anatomic investigations of Müller,[47] Falk,[16] Wideroe,[72] and others.[4, 18, 30, 70] Although apparently not derived from this study of infants and children, Lewis made an important observation relative to the occasional absence of correlation between deviation of the mean electrical axis of QRS to right or left and the presence of a comparable type of ventricular hypertrophy. He stated: "Nevertheless, in a routine examination of a large number of cardiac patients, it has not infrequently happened that the curves obtained from patients in whom other physical signs pointed to preponderance of one or other ventricle disappointed the expectations raised by these signs." He considered, finally, that a more nearly adult form of the electrocardiogram (standard extremity leads) was attained by about the third month of extra-uterine life, the time at which the adult ratio of mass of right to mass of left ventricle was also supposed to be approximated.

In an excellent article published in 1937, Krumbhaar and Jenks [32] reported electrocardiograms consisting of the three standard extremity leads in a series of 42 normal children ranging from newborn to eleven years. They noted the frequency of right axis deviation, particularly in infancy, and presented composite electrocardiographic patterns from birth to adult life, together with a discussion of the various features considered by them to be indicative of right ventricular hypertrophy. They stated:

> "Preponderance of the right ventricle is uniformly present at birth and in the early weeks of infancy, and gradually disappears in the second or third month. The various factors, however, change at different periods; thus R_2 becomes greater than R_3 about the sixth week, but S_1 persists abnormally large for several months. It usually becomes smaller than R_1 about the eighth to tenth week. By the sixth month, the infant's electrocardiogram has become practically the same as that of the adult."

They also emphasized the incidence of prominent Q waves in standard leads II and III, and, like Lewis, interpreted this as further evidence of preponderance of the right ventricle. It is of interest that in four cases of this series, the largest Q waves were found in lead I. These children were all between the ages of seven and 13 years, and "other commonly accepted signs of left ventricular preponderance were also present."

A number of other contributions to the problem of axis deviation deserve mention. In 1936, Burnett and Taylor [7] confirmed the observation that while the greatest number of instances of right axis deviation occur during the first three months of life, there is a notable decrease during the age period of four to six months. They also stated that left axis deviation occasionally occurs in normal children, but failed to explain this finding. Changes in the configuration of the thorax due to growth and development [60] have been mentioned as a factor in determining the form of the standard lead electrocardiogram, particularly in relation to changes in the position of the mean electrical axis of the heart due to age. Thus, in 1937, Hafkesbring and collaborators [26] stated that from the age of one to five years, the electrical axis tends to deviate more to the right because of increase in the length of the chest and the resulting vertical position of the heart during this age period. Likewise, in 1938, Ashman [2] similarly explained a slight rotation of the electrical axis from left to right from the age of three years to puberty. On the other hand, evidence has been presented which appears to invalidate any conclusions that might otherwise be made from the above observations. Thus, it is known that from about the sixth to the twelfth month, the diaphragm descends and the heart consequently assumes a more nearly vertical position. Yet during this period, as shown by Mannheimer,[42] the mean electrical axis of QRS rotates from right to left instead of in the opposite direction, as would be expected on the basis of change in the anatomical position of the heart from horizontal to vertical. Finally, Ohr,[52] in 1940, mentioned rotation of the heart about its various anatomic axes as a factor in determining the position of the mean electrical axis of QRS, but dismissed

this consideration without further discussion. Furthermore, he considered ventricular hypertrophy an inadequate explanation, since, as he demonstrated in the case of certain individuals, the electrical axis may undergo marked changes in too short a time to be accounted for by necessarily slower change in relative ventricular mass. He consequently believed that some more or less indefinite functional factor must be important in explaining rotation of the electrical axis to right or left. It seems fair to conclude that, up to the present time, no satisfactory interpretation has been given for the characteristic form of the ventricular deflections in the standard lead electrocardiogram of infants and children. Despite this, it has been a common experience for cardiologists and others to attach great clinical importance to the factor of "axis deviation."

Chest lead electrocardiograms have been recorded in infants and children since 1934, two years after the introduction of the use of the precordial leads in clinical electrocardiography by Wolferth and Wood. All of the studies published to the present time are subject to one or more of certain important criticisms. These include: (1) failure to utilize the unipolar technique; (2) inadequate numbers of exploring chest leads; (3) the employment of careless techniques in the application of excessive electrode paste to the precordium; and, (4) statistically insufficient numbers of children in age groups through which significant electrocardiographic changes are now known to occur.

Two fundamental differences have been observed in the form of the ventricular deflections of the precordial leads of infants and children as compared with those of adults.* The first, noted originally by Moia,[46] in 1935, and confirmed in 1936 by Robinow, Katz, and Bohning,[56] was the fact that the R deflection tended to be larger than usual in leads from the region of the sternum, this difference being much less marked in leads from the region of the cardiac apex. No explanation was offered for this particular finding. The second, described originally in 1934 by Levy and Bruenn [38] and later by a number of other workers, was the frequent occurrence of inverted T waves in the precordial leads. This was at first thought to represent evidence of active myocardial involvement in acute rheumatic fever. Subsequent investigations, however, clearly demonstrated the fact that T waves could be either upright or inverted in the precordial electrocardiogram of children without constituting evidence of heart disease. Because of this reported variability in different individuals and even in the same individual at different times, it has become a generally accepted opinion that the precordial electrocardiogram of infants and children is of limited clinical value and that any changes must be interpreted with caution even in serial records.

A number of theoretical explanations have been offered for the occurrence of T wave inversion in the precordial leads of infants and children, but to the present time none have been adequately confirmed by factual data. In 1936, Robinow, Katz, and Bohning [56] suggested that the position of the heart in the thorax might be an important factor in determining the configuration of the T waves in the precordial leads, the position of the heart being dependent on the shape and size of the chest cavity as well as on rotation of the heart about its various anatomic axes. In opposition to this theory is the complete lack of uniformity of opinion concerning the relationship, if any, between the configuration of the T waves in the precordial leads and the direction of the electrical axis in the extremity leads or the position of the heart in the thorax as determined by roentgenographic examination. In 1937, Master, Dack, and Jaffe [44] explained the form of the T waves in the precordial leads of infants and children on the basis of anatomic and functional predominance of the right ventricle and deviation of the interventricular septum to the left. It was also stated that upon this basis, the normal ratio of mass of the left ventricle to that of the right ventricle would be expected at the age of approximately sixteen

* Many of the early chest lead electrocardiograms were recorded in such a way that positive deflections occurred below and negative deflections above the isoelectric line; or, in other words, opposite to the standard method currently recommended by the American Heart Association. For purposes of conformity throughout the paper, all electrocardiograms will be described in terms of modern nomenclature.

years. Other possible factors which have been mentioned include variations in contact of the heart with the chest wall, extent and position of the precordial area not covered by lung (differential conductivity of tissues), thinness of the chest wall, and shape and size of the chest cavity. Other factors which are probably of much greater significance than those already mentioned have been demonstrated, although their significance was not appreciated at the time. These include the effect of the "indifferent electrode" on the form of the precordial electrocardiogram [10, 31] and the effect of surface transmission of potential variations from one side of the precordium to the other as the result of the application of an excessive amount of electrode paste on and between exploring points on the precordium.[75]

The most significant study of the precordial electrocardiogram of infants and children was published in 1938 by Lepeschkin,[35] whose original work consisted of recording as many as 10 to 20 different chest leads in a series of 50 children ranging in age from two weeks to 15 years. In addition, he reviewed fairly comprehensively the most important literature and discussed such problems as the sequence of ventricular activation, the relation of potential variations of the extremities to the form of the ventricular deflections in the standard and precordial leads, the effect of the "indifferent electrode" on the precordial electrocardiogram, and the principles of unipolar electrocardiography. As the result of this study, it was demonstrated that the form of the ventricular deflections changes progressively from infancy through early childhood, the normal adult pattern being attained at the age of approximately six to 10 years. In infants, the precordial electrocardiogram was found to possess two major characteristics: the first was the presence of large R waves in leads from the right side of the precordium, which was believed to represent evidence of relative hypertrophy of the right ventricle; the second was the frequent occurrence of inverted T waves in leads from points farther to the left than in adults (this was thought to be due to a shift of the position of the interventricular septum towards the left in infants and young children, T waves supposedly being inverted over the right side and upright over the left side of the interventricular septum). It was further demonstrated that the location of the "indifferent electrode," as well as that of the exploring electrode, was important in determining the exact configuration of the ventricular deflections in precordial leads. Thus, a Q wave was more frequently present in leads from the left side of the precordium, particularly when paired with the right arm. Likewise, T waves were more often positive with the right arm lead (CR) and negative with the left leg lead (CF), positive in leads from the left side of the precordium, and negative in leads from the right or mid-precordium, depending on the age of the individual. The factor of position of the heart in the thorax was also considered, particularly as influenced by the shape and size of the chest cavity and the relative mass of the right ventricle as compared with that of the left ventricle. Several other papers concerning the precordial electrocardiogram of infants and children have been published recently [3, 15, 21, 33, 67] but none have contributed significantly to a further understanding of the basic problems involved.

To summarize the literature to date on the electrocardiogram of infants and children, it seems fair to state that the form of the ventricular deflections has never been satisfactorily explained. It is generally agreed that right axis deviation is a characteristic feature of the standard leads in infancy, though opinion is divided as to whether this is due to an unusual position of the heart in the thorax or to relative hypertrophy of the right ventricle. The majority of workers have favored the latter hypothesis; correlating changes in the form of the electrocardiogram with measurements of ventricular weight and thickness, and stating that the adult form of the electrocardiogram and the adult proportion of right and left ventricular mass are attained equally at about the third month of extrauterine life. Studies of precordial leads indicate two major characteristics during the period of infancy and early childhood. The first is the occurrence of large R waves in leads from the right side of the precordium, and the second is the frequent occurrence of T wave inversion

in leads from the right and mid portion and even the left side of the precordium. The large R waves have been interpreted as evidence of relative hypertrophy of the right ventricle; and the adult form of QRS has been found to occur at the age of approximately six to 10 years. T wave inversion has not been satisfactorily explained, although it has been suggested that an important factor is the position of the heart in the thorax, particularly as it determines the position of the interventricular septum.[35] Adequate studies of unipolar extremity and precordial electrocardiograms in infancy and childhood have not to the present time been reported.

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