Studies Into Equine Electrocardiography and Vectorcardiography

II. Cardiac Vector Distributions In Apparently Healthy Horses

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SUMMARY

The paper describes observations on the distributions of the P, QRS and T cardiac vectors in the horizontal plane in 377 apparently healthy horses. The possible usefulness of vectorcardiography in the clinical evaluation of cardiac function is briefly discussed.

Introduction

Conventional electrocardiographic techniques are particularly valuable in confirming the diagnosis of rhythm irregularities. If however electrocardiography is to be used fully as an aid in clinical diagnosis a greater understanding of the significance of E.C.G. patterns is necessary.

In a previous paper (15) theoretical consideration was given in two horses to the properties of the electric field created by the equine heart acting as a simple electric generator. Apart from the work of Brooijmans (5) little attention has so far been given to an analysis of vectorcardiographic data in horses. Much work has been done in this field in man (2, 4, 6, 8, 9, 11, 12, 14, 19, 20, 27, 28).

Observations have been reported in cattle (23, 24), on the third dimensional orientations of P, QRS and T vectors in inbred lines of beef calves in which changes occurred with increasing age.

Materials and Methods

A single channel Cossor electrocardiograph was used to record bipolar extremity lead (horizontal or H — plane) E.C.G.'s from 377 Army and Three day event horses. Traces were made with the horses at rest standing insulated on neoprene and rubber mats. The electrocardiograph was calibrated to a sensitivity of 1mV. = 1 cm. deflection.

The postural position of horses being examined by electrocardiography should be standardised. Changes particularly in the position of the forelimbs can considerably alter the configuration of the QRS complex in lead I. In this work recordings were taken with the left forelimb slightly in front of the right. When the right forelimb led, a deep Q wave appeared in lead I and occasionally the S waves were deepened in leads II and III.

All the horses showed regular cardiac rhythm but not all of them were examined by auscultation.

Modal P, QRS and T vectors were calculated for Einthoven's triangle in the H — plane (17). Vector distributions were plotted on circles divided into intervals of 10° from 0° through + 90° to + 180° and 0° and occasionally the S waves were deepened ranges in a similar way to that adopted in human work (13).

The amplitudes of individual E.C.G. waves represent measurements from their peaks to the isoelectric line. According to Lewis (17), in order to ensure the greatest accuracy of construction of vectors, the corresponding time phases for each lead should fall precisely on the same vertical line. This degree of accuracy can only be obtained with a multichannel electrocardio-

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Table I. P, QRS and T Vector Distribution Based on Einthoven's Triangle in the Horizontal Plane in 377 Horses

Vector	Vector Range (in degrees)	Percentage Distribution
P	0 to + 89	90.1
	+90 to +180	7.2
	0 to − 89	2.4
	−90 to −179	0.3
QRS	0 to + 89	61.0
	+90 to +180	9.3
	− 1 to − 89	24.4
	−90 to −179	5.3
T	0 to +180	89.6
	0 to − 89	0.8
	−90 to −179	9.6

graph but the discrepancies are not so great as to render observations with a single channel machine invalid.

Another method used to calculate the average direction taken by the activation process is to plot vectors for Einthoven's triangle on the basis of net positive and negative areas enclosed by E.C.G. waves (2, 3, 28). The mean electrical axes are then designated as $\hat{A}P$, $\hat{A}QRS$ and $\hat{A}T$. This technique is very time consuming and for the amount of information gained adds little to that obtained by wave amplitude vector construction.

Observations

The distributions of the P, QRS and T vectors are shown in Table I and Figs. 1, 2 and 3. They are presented as viewed from the ventral aspect of the horse (or frontal plane in man). An attempt has been made in Fig. 2 to show the relationship between the QRS and T vectors, that is, the QRS-T angles. The individual T vectors were drawn for each 10° interval range of QRS vectors (Fig. 2).

If human electrocardiographic terminology for normal, right and left axis deviation is applied to the data in this study, then 61.0 percent of cases had QRS vectors within the normal range of 0° to + 89°, 14.6 percent showed right axis deviation (9.3 percent between + 90° and +180°, and 5.3 percent between —90° and —179°) and 24.4 percent showed left axis deviation (between — 1° and —89°).

In the range 0° to + 89° the QRS deflections were predominantly positive in leads I, II and III. Right axis deviation in the horse was characterised by a deep Q wave in lead I. Where the QRS vector was between + 90° and + 180° the QRS positivity was small in lead II but large in lead III. Between — 90° and — 179° leads II and III showed predominantly negative QRS deflections. Left axis deviation was characterized by a positive QRS deflection in lead I and predominantly negative QRS in leads II and III.

Discussion

Lewis (17) defined the electrical axis of muscle as "the line along which the greatest electromotive force is developed at a given instant in time, while the muscle is entering upon or recovering from the excitatory process." This force can also be considered in terms of a vector since it has both magnitude and direction. Vectors can be added or subtracted geometrically to give a resultant. Innumerable vectors represent the electrical forces acting in the myocardium for any given instant during depolarization and repolarization. Thus for any given instant of time during the cardiac cycle a resultant vector represents the integral of all the elementary vectors acting at that instant.

Einthoven, Fahr and de Waart (7) first conceived the idea of the heart acting as an electric generator producing an electric field in the body tissues. They assumed that the body was a volume conductor whose size was large compared with the heart size and whose tissues possessed a uniform conductivity. It was also assumed that the

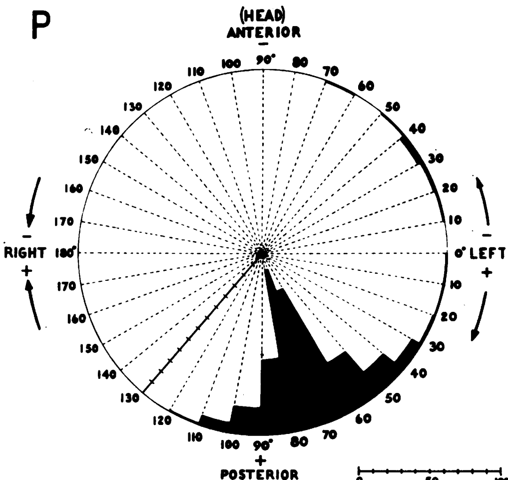

Fig. 1. Distribution of the P vectors in the horizontal plane in 377 horses, viewed from the ventral aspect.

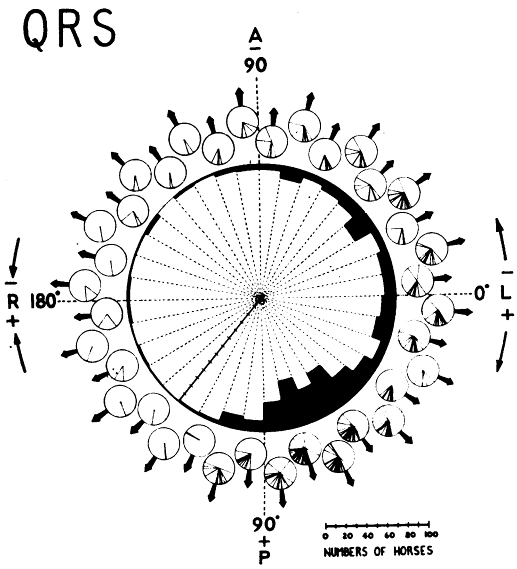

Fig. 2. Distribution of the QRS vectors in the horizontal plane in 377 horses, viewed from the ventral aspect. The corresponding directions of T vectors for each 10° segment of QRS are also shown.

electrical activity of the ventricles was condensed into the centre of the ventricular mass. This point was the hypothetical location of the dipole centre or isoelectric point of the heart vectors. The method was only approximate since it did not consider the spatial distribution of electrical forces, although Einthoven and his co-workers were aware that cardiac electrical forces have a third dimensional activity. They realised the limitations of their hypothesis but considered the triangle theory applicable in the horse since according to Brooijmans (5) they used bipolar leads in this species.

THE P VECTOR

In man the mean electrical axis of the P wave (ÂP) is from 0° to +90° although in rare instances it may be located between 0° and —30° (8). In the horse the mean P vector lies between + 50° and + 90° but usually occurs between + 80° and + 90° in the horizontal plane (5). In our observations the P vector was usually in the range from + 30° to + 110° but was mainly from +50° to + 90°. All studies support the concept that the sinus impulse spreads in a craniocaudal direction across to the left atrium and atrioventricular node. It could be that those horses observed to have P vectors between — 10° and — 70° are normal variants (Fig. 1). A vector in this range may indicate that the activation impulse is originating from an ectopic atrial focus but it may also depend on the size and exact anatomical situation of the sinus node.

THE QRS VECTOR

Studies on the ventricular activation sequence in man show that the mean or modal QRS vector reflects the main ventricular depolarization potentials (17). It is well known in man (8, 20, 28) that a number of factors influence the orientation of the modal or mean QRS vector, such as the position of the heart in the chest, its anatomical rotation about its longitudinal, transverse and anteroposterior axes, the thickness of its ventricular walls and the rate and sequence of ventricular activation. These factors can produce a "shift" or "deviation" of the QRS electrical axis or vector beyond the normal range. In man normal axis deviation refers to a range of 0° to +90°. A range of + 90° through 180° to — 90° represents right axis deviation and left axis deviation is from 0° to — 90°. The term axis deviation is not applied to the P and T vectors but their direction is stated.

The fact that the left ventricular forces usually dominate the right cause the QRS vector to be directed to the left and caudally in the horizontal plane in the horse, or leftward and inferiorly in the frontal plane of man. The QRS electrical axis in man usually makes an angle of + 60° with the

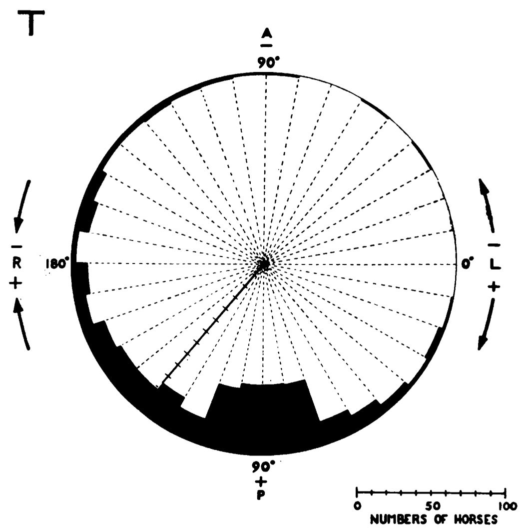

Fig. 3. Distribution of the T vectors in the horizontal plane in 377 horses, viewed from the ventral aspect.

horizontal (17) although it normally varies several degrees on either side and the mean QRS axis (ÂQRS) averages about + 60° which corresponds more or less with the direction of the cardiac anatomical axis (longitudinal axis from apex to base) (28). According to Wood (28) left axis deviation occurred in 10 percent of normal humans, right axis deviation was the rule in newly born infants and was common in very young children. Right axis deviation occurred in one percent of normal children over the age of eight but was rarely seen in normal adults. Friedman (8) stated that the mean QRS axis lay between + 30° and + 90° in man.

Brooijmans (5) determined the direction of the mean QRS electrical axis for 38 normal "crossbred thoroughbred" horses. Although his numbers were small he stated that there was wide variation between different individuals. The majority of horses showed QRS axes between 0° and + 90°. In our observations the QRS vector mainly varied from —80° to + 110°. The majority were in the range + 30° to + 90°.

THE T VECTOR

Relatively little is known about the sequence of ventricular repolarization in any species. If the processes of depolarization and repolarization followed the same course, a wave of repolarization should produce potentials opposite in sign from those developed during depolarization. This would result in a T vector opposite in direction to the QRS vector. Whereas the process of depolarization follows a specific pathway in the ventricles (Purkinje system) repolarization relies on the ability of individual myocardial fibres, or even regions of the syncytium, to recover their excitability and it takes longer than depolarization (16). According to Rushmer (20), repolarization is affected by factors which alter the physiological condition of the myocardium such as temperature, pressure, electrolyte concentrations (potassium and calcium salts), oxygen supply and drugs. For all these reasons the T vector has the most labile orientation of all the major cardiac vectors.

In man the QRS and T waves and hence their respective vectors occur in approximately the same direction. The mean electrical axis of the T wave (ÂT) in man lies between -11° and + 76° (8). Grant (11) showed how intraventricular conduction disturbances caused by myocardial infarction affected the form of the S-T segment and the T wave in man.

In this study the T vector had a positive direction in the majority of horses. 89.7 percent were between 0° and + 180° but + 60° to + 160° seemed to be the usual range. Whether a T vector was greater or smaller than + 90° depended on the sign of the T wave in lead I. It was frequently negative whereas in man it is normally positive.

THE QRS-T ANGLE

The angular relationship between the QRS and T vectors is considered to be of especial importance in man when determining the presence of myocardial disease and cardiac hypertrophy (20). The QRS-T angle is usually narrow in man, measuring up to 45° in the frontal plane in adults and 90° or more in children. This is probably due to the fact that some children may normally show right axis deviation of the QRS vector (8).

It can be seen from Fig. 2 that the QRS-T angle shows considerable variation in the horse. It may vary from about 3° to 180° in apparently quite healthy horses showing no sign of circulatory dysfunction but this is largely a reflection of the common occurrence of negative T waves in lead I. Too much significance should not be attached at the moment to the value of the QRS-T angle. Consideration must also be given to the orientation of the respective vectors since a narrow or wide QRS-T angle can exist with the QRS vector in any direction.

POSSIBLE SIGNIFICANCE OF VECTOR ORIENTATION

It is important to consider whether the same terminology used to express axis deviation in man can be applied in the case of the equine. It is evident that the distributions of both the QRS and T vectors in the horse are much greater than in man although the P vector is nearly the same in both species.

The questions arise as to whether in the horse the direction of the various vectors can be related specifically to cardiac depolarization and repolarization and what effect, if any, age and the anatomical position of the heart including cardiac enlargement have on vector orientation. It appears that each of the above factors are capable of producing shifts in vector direction.

There are basic differences in the pathway of ventricular depolarization in the horse compared with man although the overall apico-basal sequence is the same (21, 25, 26). Vectorcardiographic studies employing spatial loops will provide accurate information on these differences (1).

Age is probably an important factor to consider in its effect on cardiac regional anatomy. Preliminary investigations on heart position in horses by anatomical dissection indicate that in foals the heart has a near vertical position in the thorax whereas in older horses it tends to adopt a more horizontal position. Szakmary (22) described characteristic features of bipolar E.C.G's in old horses with cardiac hypertrophy. However, not enough information is available at present to correlate age, heart size and position to specific E.C.G. patterns.

In man physiological or pathological processes which cause a shift in heart position in the chest are often observed to affect the configuration of E.C.G.'s. A natural phasic change is brought about by movement of the heart in relation to respiration (17) and in pregnancy the increasing space occupied by the foetus can cause temporary displacement. In cattle the foetus has no effect because the large volume of the rumen acts as a buffer (18). Evidence is presently being accumulated in mares to show that changes possibly occur in the configuration of QRS complexes towards the end of pregnancy (after 7 months) and immediately after foaling.

In man the destruction of lung tissue in pulmonary emphysema increases its electrical resistivity since the larger pockets of stationary air are poor conductors. Because electrical current travels along channels of least resistance the electrical field presented at the body surface is altered and although the fundamental electrical changes in the heart may remain the same, the vectors derived from peripheral E.C.G.'s may show unusual directions (19). Horses suffering from pulmonary emphysema may show similar changes.

Serial E.C.G.'s often provide useful vector information on the progress of cardiac disease and may prove to be especially important in studying the development of cardiac enlargement, dilatation and heart failure. Although the horses in this study were classified as healthy not all of them were examined by auscultation and so they might not all have been normal. This might account for some of the scatter in results but the observations indicate that a range of $-40°$ to $+90°$ might be regarded as normal for the QRS axis in the horse, that the common range for the P vector was $+50°$ to $+90°$ and for the T vector the range was most commonly $+60°$ to $+160°$ in the horizontal plane.

At present we can merely record what appear to be the normal vector angles and discuss their possible clinical significance. Confirmation of the usefulness of this method in diagnostic cardiology requires further studies including correlation of vectors with postmortem findings.

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The illustrations were photographed by Mr. M. H. C. Parsons and Miss J. Rawlings assisted with the vector constructions.

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Doctor Charles B. Baker

The Veterinary Profession of Canada was saddened by the death of Dr. Charles Baker, one of the well known practitioners of this country. Few had learned that he was in critical health and therefore, to the majority, his passing on May 6 was unexpected.

Recently in this Journal there was finished a series of articles dealing with the practice in which Dr. Baker was active. It is the oldest of Canada and has played an important part in Canadian affairs.

Dr. Baker was born in Montreal in 1897, the son of Dr. Malcolm C. Baker and his wife Mary Lovell. He received his preliminary education in the schools of Montreal and his Collegiate education in the Montreal High School, after which he entered the Ontario Veterinary College and graduated in 1923. After spending two years internship with his father, he was taken in as a partner and has remained connected with the practice since. On the death of his father in 1931, he carried on with the aid of assistance until his son, Dr. Malcolm Baker joined him in 1951.

In addition to his professional qualifications, he possessed many qualities that endeared him to his colleagues and others. He was an extraordinarily able impersonator but unlike many, this gift was not used to belittle persons. He possessed in a marked degree a sense of ethical propriety and consequently was much admired personally by professional brethren with whom he came in contact.

In 1924 he married Miss Florence Graper whose business acumen was an invaluable asset to the extensive practice. Their son Malcolm followed in the grandfather's and father's footsteps. One striking feature was the unusually close relationship between father and son. They were often together at public events and evidently thoroughly enjoyed this association.

The passing of a colleague is always an unhappy event, but the passing of one who has brought friendship and cheer to so many is a tragedy indeed. To his devoted wife and family is extended the deepest sympathy of his professional colleagues. — C.A.M.