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FUNDAMENTAL STUDIES ON ELECTROCARDIOGRAMS OF THE HORSE

II. BIPOLAR LEAD

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In a previous paper[2], the method of a unipolar and several bipolar leads which had been used for the horse were criticized, in view of the anatomic position of the heart in the equine body. From the results of experiments on the unipolar lead in which the indifferent electrode was set on the root of the tail, a discussion was presented on the subject of how depolarization and repolarization travels in the heart.

In the present paper, are reported the results of experiments using the limb lead and the 3 bipolar leads devised with regard to the criticism in the previous paper.

METHOD AND MATERIAL

The electrocardiograph employed in the experiments reported in the previous paper was also used for the present bipolar leads. The sensibility was adjusted so that 1 mv corresponded to an amplitude of 20 mm. The electrodes consisted of quadrangular pieces of metal, which were used for the indifferent electrode in the previous paper, fastened with gum bandage on the position described later. A piece of gauze soaked with saturated natrium chloride solution was applied between the skin and electrode. The registration was carried out with the horse in a standing position with the extremities, if possible equally loaded. Of course, the 3 leads were registered synchronously. The following 4 kinds of bipolar lead were used.

1. Lead A (Limb lead)

Lead I: Left foreleg → Right foreleg
Lead II: Left hindleg → Right foreleg
Lead III: Left hindleg ——→ Left foreleg

The electrodes were fastened on the inner side of the limb at a point about 2 cm above the chestnut. Eleven normal healthy horses were examined by this method. They were pure bred or mongrel Percheron, from 3 to 15 years old, including 8 females and 3 geldings.

2. Lead B

Lead I: Left foreleg ——→ Right foreleg
Lead II: Withers ——→ Right foreleg
Lead III: Withers ——→ Left foreleg

Then lead AI is the same as lead BI. The 11 horses used in lead A were examined with this lead.

3. Lead C

Lead I: Midway on the straight line connecting right shoulder joint and withers. (RM) ⟶ Left foreleg
Lead II: Midway on the straight line connecting left shoulder joint and withers. (LM) ⟶ Left foreleg
Lead III: LM ——→ RM

Ten out of the 11 horses used in lead A were examined.

4. Lead D

Lead I: The 10th intercostal space at the same horizontal level as shoulder joint. (IC) ⟶ Left foreleg
Lead II: LM ——→ Left foreleg
Lead III: LM ——→ IC

Then lead CII is the same as lead DII. Nine out of the 11 horses used in lead A were examined.

Current flowings in direction as indicated by the arrows produced upward deflection for each of these 4 kinds of leads.

EXPERIMENTAL RESULTS

1. P Wave

The configuration was usually W-form or inverted W-form in these leads, but frequently monophasic, diphasic or more complicated. In order to express the complexity of the P wave, the number of extremes was counted and shown in table 1. When this number is 1, 2 or 3, then evidently it corresponds to monophasic, to diphasic or to triphasic wave which involves notched monophasic wave and then is expressed with W-form or inverted W-form. Lead A: As compared with the other leads, the most multiform P wave appeared in lead A, especially in lead III. The maximum number of extremes was 4 in lead I and 6 both in lead II and in lead III. Lead B: Lead BI is the same as lead AI. By both of the methods, the same 11 horses were examined on respective different days. Then considerable differences were found either in number of the extremes or in the amplitude of these same leads. Maximum of the extremes is 4 in lead B. Lead C: The waves obtained by lead CIII were observed only in 2 out of 10 cases. The maximum number of extremes is 3 in lead C. Lead D: The maximum number of extremes is 5 in lead I and 3 in the other leads.

From these results, it is evident that P wave obtained with the 2 electrodes on a horizontal plane is, as a rule, multiform, while the configuration obtained with the 2 electrodes on a vertical plane is usually W-form or inverted W-form.

The signs of initial deflection in the P wave were shown in table 2. Lead A: The number of positive (upward) deflections was about equal to that of negative (downward) deflections in lead I, but more numerous both in lead II and in lead III. Lead B: The number of negative deflections predominated. Lead C: In leads I and II, only negative deflections appeared, but positive alone, or none, appeared in lead III. Lead D: In lead I, positives were more numerous than negatives. In lead II, only positives appeared. Most of lead III represented negative deflections. These results may prove to illustrate that the initial depolarization travels from anterior superior right to posterior inferior left

TABLE 1. *Number of Extremes in the P Wave*

LEAD METHOD		NUMBER OF EXTREMES					
		1	2	3	4	5	6
Lead A	I	1	0	7	3	0	0
	II	2	3	1	3	1	1
	III	2	2	1	4	1	1
Lead B	I	2	1	7	1	0	0
	II	0	0	10	1	0	0
	III	0	0	10	1	0	0
Lead C	I	0	0	10	0	0	0
	II	0	0	10	0	0	0
	III	1	0	1	0	0	0
Lead D	I	0	0	4	4	1	0
	II	0	0	9	0	0	0
	III	0	1	8	0	0	0

TABLE 2. *Signs of Initial Deflections in the P Wave*

LEAD METHOD	SIGN	LEAD		
		I	II	III
Lead A	Positive	6	8	10
	Negative	5	3	1
Lead B	Positive	8	1	1
	Negative	3	10	10
Lead C	Positive	0	0	2
	Negative	10	10	0
	None	0	0	8
Lead D	Positive	6	9	1
	Negative	3	0	8

in the auricles and that the direction in which the initial depolarization travels from side to side is multifarious.

The signs of the maximum amplitudes are shown in table 3. These results as tabulated indicate that usually predominant depolarization travels from anterior superior right to posterior inferior left in the auricles. This conjecture has already been expressed before in the previous paper based upon the experimental results with the unipolar lead.

Positive and negative maximum deflections in the wave were measured respectively and the amplitudes are shown in table 4. Interrelation of the mean upward deflection greater than 0.1 mv was AII> AIII> DI> 0.1 mv and that of the mean downward deflection was DIII> CI> CII> BII> DII> 0.1 mv.

TABLE 3. *Signs of Maximum Amplitudes in the P Wave*

LEAD METHOD	SIGN	LEAD I	LEAD II	LEAD III
Lead A	Positive	8	11	11
	Negative	3	0	0
Lead B	Positive	8	5	6
	Negative	3	6	5
Lead C	Positive	0	0	2
	Negative	10	10	0
	None	0	0	8
Lead D	Positive	8	0	0
	Negative	1	9	9

TABLE 4. *Amplitude of the P Wave (mv)*

LEAD METHOD	VALUE	LEAD I +	LEAD I −	LEAD II +	LEAD II −	LEAD III +	LEAD III −
Lead A	Mean	0.047	0.021	0.167	0.011	0.158	0.020
	Minimum	0	0	0.076	0	0.028	0
	Maximum	0.089	0.088	0.300	0.038	0.224	0.062
Lead B	Mean	0.068	0.021	0.010	0.119	0.017	0.126
	Minimum	0	0	0	0.057	0	0.179
	Maximum	0.127	0.104	0.080	0.165	0.164	0.069
Lead C	Mean	0	0.176	0.003	0.151	0.015	0.001
	Minimum	0	0.105	0	0.088	0	0
	Maximum	0	0.221	0.033	0.298	0.088	0.014
Lead D	Mean	0.115	0.031	0.017	0.118	0.007	0.257
	Minimum	0.025	0	0	0.072	0	0.129
	Maximum	0.221	0.071	0.152	0.171	0.063	0.384

The width of the P wave in each lead ranged from 0.090 to 0.194 second, as shown in table 5.

TABLE 5. *Width of the P Wave (sec.)*

LEAD METHOD	VALUE	LEAD I	LEAD II	LEAD III
Lead A	Mean	0.131	0.143	0.143
	Minimum	0.090	0.100	0.093
	Maximum	0.160	0.182	0.185
	σ*	±0.023	±0.024	±0.028
Lead B	Mean	0.132	0.165	0.166
	Minimum	0.100	0.110	0.130
	Maximum	0.180	0.210	0.212
	σ	±0.024	±0.029	±0.027
Lead C	Mean	0.163	0.169	0.134
	Minimum	0.142	0.140	0.130
	Maximum	0.193	0.194	0.139
	σ	±0.015	±0.023	±0.004
Lead D	Mean	0.162	0.161	0.150
	Minimum	0.143	0.140	0.126
	Maximum	0.180	0.180	0.178
	σ	±0.013	±0.014	±0.016

* Standard deviation.

2. Q Wave

The occurrence of Q wave is shown in table 6. Leads AI, BI, CIII and DIII fail to produce this wave usually. From this result, it may be concluded that the QRS complex

TABLE 6. *Occurrence of the Q Wave*

LEAD METHOD	OCCURRENCE	LEAD I	LEAD II	LEAD III
Lead A	Present	4	11	10
	Absent	7	0	1
Lead B	Present	4	11	10
	Absent	7	0	1
Lead C	Present	10	10	4
	Absent	0	0	6
Lead D	Present	9	9	6
	Absent	0	0	3

obtained by 2 points in front of the heart on a horizontal plane has no Q wave. The interrelation of the mean amplitudes beyond 0.1 mv was BII> AIII> 0.1 mv, as shown in table 7. The interrelations of the amplitudes obtained by each of 3 leads are shown in table 8.

TABLE 7. *Amplitude of the Q Wave (mv)*

LEAD METHOD	VALUE	LEAD I	LEAD II	LEAD III
Lead A	Mean	0.008	0.061	0.104
	Minimum	0	0.022	0
	Maximum	0.035	0.216	0.411
Lead B	Mean	0.026	0.093	0.139
	Minimum	0	0.011	0
	Maximum	0.200	0.363	0.251
Lead C	Mean	0.089	0.091	0.013
	Minimum	0.021	0.027	0
	Maximum	0.164	0.182	0.055
Lead D	Mean	0.073	0.081	0.088
	Minimum	0.030	0.048	0
	Maximum	0.200	0.145	0.324

TABLE 8. *Interrelation of Amplitudes of the Q Waves in Each Lead*

RELATION	LEAD A	LEAD B	LEAD C	LEAD D
I> II> III	0	1	4	3
I> III> II	0	0	0	0
II> I> III	1	2	5	2
II> III> I	4	1	0	1
III> I> II	1	0	0	1
III> II> I	5	7	1	2
Sum	11	11	10	9

3. R Wave

The amplitudes of R wave are shown in table 9. Large values were obtained by the leads nearly in accordance with the electrical axis of the heart, viz., BII, BIII, CII and CIII. The interrelation of the amplitudes in each of 3 leads in shown in table 10. The relation of the mean amplitudes beyond 1 mv was BII> BIII> DII> CII> CI> 1 mv. The wave obtained either by lead A or by lead DI was frequently accompanied with notching or with splintering.

TABLE 9. *Amplitude of the R Wave (mv)*

LEAD METHOD	VALUE	LEAD I	LEAD II	LEAD III
Lead A	Mean	0.370	0.617	0.563
	Minimum	0.083	0.324	0.041
	Maximum	0.737	1.787	1.231
Lead B	Mean	0.315	1.651	1.554
	Minimum	0	0.728	0.778
	Maximum	0.667	2.450	2.228
Lead C	Mean	1.138	1.426	0.419
	Minimum	0.676	0.618	0.200
	Maximum	2.160	3.040	0.849
Lead D	Mean	0.704	1.494	0.838
	Minimum	0.154	0.713	0.385
	Maximum	1.448	2.952	1.685

TABLE 10. *Interrelation of Amplitudes of the R Waves in Each Lead*

RELATION	LEAD A	LEAD B	LEAD C	LEAD D
I> II> III	2	0	2	0
I> III> II	1	0	0	0
II> I> III	2	0	8	5
II> III> I	2	8	0	4
III> I> II	0	0	0	0
III> II> I	4	3	0	0
Sum	11	11	10	9

TABLE 11. *Occurrence of the S Wave*

LEAD METHOD	OCCURRENCE	LEAD I	LEAD II	LEAD III
Lead A	Present	6	3	7
	Absent	5	8	4
Lead B	Present	7	0	0
	Absent	4	11	11
Lead C	Present	0	0	0
	Absent	10	10	10
Lead D	Present	1	0	0
	Absent	8	9	9

TABLE 12. *Amplitude of the S Wave (mv)*

LEAD METHOD	VALUE	LEAD I	LEAD II	LEAD III
Lead A	Mean	0.033	0.014	0.102
	Minimum	0	0	0
	Maximum	0.105	0.071	0.264
Lead B	Mean	0.107	0	0
	Minimum	0	0	0
	Maximum	0.264	0	0
Lead C	Mean	0	0	0
	Minimum	0	0	0
	Maximum	0	0	0
Lead D	Mean	0.002	0	0
	Minimum	0	0	0
	Maximum	0.014	0	0

4. S Wave

The occurrence of S wave is shown in table 11. The obtained results indicate that the QRS complex obtained by the lead from the 2 points respectively before and behind the heart has the S wave. The amplitudes are shown in table 12. It is largest in lead AIII.

5. QRS Complex

In order to express the configuration in each lead, the numbers of the extremes in the respective waves are shown in table 13. It was noticed that the feature obtained by lead A resembled one by NEHB's lead in man. Generally speaking, the QRS complex obtained by 2 points on a horizontal plane was multiform. Its width ranged from 0.090 to 0.180 second as shown in table 14.

TABLE 13. *Number of Extremes in the QRS Complex*

LEAD METHOD		NUMBER OF EXTREMES 1	2	3	4	5
Lead A	I	3	1	2	4	1
	II	0	2	4	4	1
	III	0	2	0	8	1
Lead B	I	2	6	0	3	0
	II	0	11	0	0	0
	III	1	9	0	1	0
Lead C	I	0	10	0	0	0
	II	0	9	1	0	0
	III	5	5	0	0	0
Lead D	I	0	6	0	2	1
	II	0	9	0	0	0
	III	1	6	2	0	0

TABLE 14. *Duration of the QRS Interval (sec.)*

LEAD METHOD	VALUE	LEAD I	LEAD II	LEAD III
Lead A	Mean	0.109	0.125	0.126
	Minimum	0.090	0.105	0.092
	Maximum	0.140	0.160	0.176
	σ*	±0.017	±0.015	±0.025
Lead B	Mean	0.117	0.133	0.133
	Minimum	0.090	0.110	0.113
	Maximum	0.137	0.165	0.160
	σ	±0.015	±0.015	±0.014
Lead C	Mean	0.129	0.131	0.121
	Minimum	0.100	0.100	0.090
	Maximum	0.178	0.150	0.168
	σ	±0.020	±0.014	±0.024
Lead D	Mean	0.132	0.129	0.132
	Minimum	0.116	0.110	0.102
	Maximum	0.146	0.145	0.180
	σ	±0.011	±0.010	±0.019

* Standard deviation.

6. T Wave

Lead CIII frequently lacked this wave showing it in only 4 out of 10 cases. Most of the leads yielded diphasic waves but lead DI had only monophasic waves. Type and amplitude of the wave are shown respectively in tables 15 and 16. The wave is plus minus type in leads BII, BIII, C and D except for leads A and BI whose wave is minus plus type. The width was from 0.065 to 0.430 second as shown in table 17. When it was measured, the decision as to the point of outset in the wave was often difficult, because of gradual deflection at the start. So the standard deviations in the widths were large.

7. PQ, QT and RR Interval

The values are shown in tables 18 and 19. The PQ interval ranged from 0.220 to 0.399 second. The QT interval ranged from 0.370 to 0.681 second. The RR interval ranged from 0.845 to 1.866 second.

TABLE 17. *Width of the T Wave (sec.)*

TABLE 15. *Type of the Wave in Each Lead*

LEAD METHOD	TYPE	LEAD I	LEAD II	LEAD III
Lead A	Monophasic	9 (1 (+), 8 (−))	6 (3 (+), 3 (−))	6 (4 (+), 2 (−))
	Diphasic	2 (−+)	5 (−+)	5 (−+)
Lead B	Monophasic	6 (1 (+), 5 (−))	6 (1 (+), 5 (−))	7 (3 (+), 4 (−))
	Diphasic	5 (−+)	5 (4 (+−), 1 (−+))	4 (+−)
Lead C	Monophasic	5 (3 (+), 2 (−))	5 (3 (+), 2 (−))	3 (2 (+), 1 (−))
	Diphasic	5 (+−)	5 (+−)	1 (+−)
	None	0	0	6
Lead D	Monophasic	9 (8 (+), 1 (−))	2 (1 (+), 1 (−))	2 (−)
	Diphasic	0	7 (+−)	7 (+−)

TABLE 16. *Amplitude of the T Wave (mv)*

LEAD METHOD	VALUE	LEAD I +	LEAD I −	LEAD II +	LEAD II −	LEAD III +	LEAD III −
Lead A	Mean	0.060	0.255	0.133	0.188	0.158	0.125
	Minimum	0	0	0	0	0	0
	Maximum	0.381	0.760	0.468	0.534	0.374	0.394
Lead B	Mean	0.073	0.265	0.123	0.205	0.223	0.175
	Minimum	0	0	0	0	0	0
	Maximum	0.371	0.656	0.688	0.537	0.625	0.441
Lead C	Mean	0.308	0.161	0.258	0.212	0.035	0.011
	Minimum	0	0	0	0	0	0
	Maximum	0.827	0.526	0.714	0.737	0.283	0.066
Lead D	Mean	0.225	0.027	0.252	0.157	0.182	0.232
	Minimum	0	0	0	0	0	0.019
	Maximum	0.522	0.245	0.603	0.362	0.620	0.445

TABLE 17. *Width of the T Wave (sec.)*

LEAD METHOD	VALUE	LEAD I	LEAD II	LEAD III
Lead A	Mean	0.147	0.177	0.167
	Minimum	0.106	0.105	0.120
	Maximum	0.244	0.430	0.275
	σ*	±0.041	±0.090	±0.049
Lead B	Mean	0.130	0.151	0.143
	Minimum	0.110	0.116	0.100
	Maximum	0.168	0.190	0.182
	σ	±0.020	±0.023	±0.025
Lead C	Mean	0.147	0.144	0.126
	Minimum	0.066	0.065	0.110
	Maximum	0.188	0.185	0.142
	σ	±0.039	±0.033	±0.005
Lead D	Mean	0.164	0.164	0.171
	Minimum	0.107	0.103	0.094
	Maximum	0.219	0.225	0.215
	σ	±0.031	±0.040	±0.035

* Standard deviation.

TABLE 18. *PQ Interval (sec.)*

LEAD METHOD	VALUE	LEAD I	LEAD II	LEAD III
Lead A	Mean	0.271	0.254	0.258
	Minimum	0.227	0.224	0.220
	Maximum	0.327	0.311	0.302
	σ*	±0.024	±0.073	±0.021
Lead B	Mean	0.278	0.285	0.289
	Minimum	0.227	0.253	0.245
	Maximum	0.326	0.336	0.332
	σ	±0.030	±0.027	±0.026
Lead C	Mean	0.292	0.295	0.279
	Minimum	0.255	0.243	0.260
	Maximum	0.340	0.337	0.399
	σ	±0.029	±0.032	±0.006
Lead D	Mean	0.282	0.289	0.297
	Minimum	0.232	0.225	0.239
	Maximum	0.331	0.360	0.364
	σ	±0.029	±0.038	±0.032

* Standard deviation.

TABLE 19. *QT and RR Interval (sec.)*

LEAD METHOD	VALUE	QT I	QT II	QT III	RR
Lead A	Mean	0.491	0.511	0.508	1.272
	Minimum	0.408	0.445	0.429	0.865
	Maximum	0.581	0.681	0.645	1.866
	σ*	±0.053	±0.063	±0.061	±0.308
Lead B	Mean	0.464	0.491	0.483	1.261
	Minimum	0.370	0.380	0.380	0.883
	Maximum	0.567	0.588	0.585	1.756
	σ	±0.053	±0.181	±0.059	±0.286
Lead C	Mean	0.502	0.490	0.524	1.284
	Minimum	0.395	0.384	0.490	0.877
	Maximum	0.573	0.562	0.559	1.785
	σ	±0.049	±0.051	±0.010	±0.239
Lead D	Mean	0.516	0.526	0.519	1.359
	Minimum	0.417	0.403	0.395	0.845
	Maximum	0.582	0.584	0.598	1.815
	σ	±0.045	±0.053	±0.053	±0.257

* Standard deviation.

8. PR and ST Segment

The PR segment often showed upward convexity, when the amplitude of the R wave was large. When the T wave was high, then the ST segment ascended or descended obliquely.

DISCUSSION

Lead A, that is the limb lead which has been usually employed in the horse, has a similarity to NEHB's lead in man, in respect to the position of the electrodes in relation to the heart. Therefore, the features of the electrocardiogram obtained by lead A offer resemblance to one derived from NEHB's lead in man. Because of the eccentric position of a horse's heart, as discussed in the previous paper, the limb lead except for lead I should be termed a unipolar lead rather than a bipolar lead. It is principally by means of the limb lead that the function in the neighbourhood of the apex of the heart is investigated. This opinion may be also applied to NEUMANN-KLEINPAUL's lead.

What lead is, then, suitable for a bipolar lead ? The method of placement of bipolar leads should be selected from the viewpoints of practical convenience

and of successfully investigating the functions of the heart. For the purpose of practical convenience, the positions on which electrodes are settled should be easy to establish exactly. Furthermore, tracing free from artifacts should be obtained with ease. Leads A and B as described in this paper are propitious from this standpoint.

By lead A, evidently only the electrical changes on the under horizontal plane are examined. Therefore, it may also be necessary to observe the electrical changes either on a vertical plane or on the plane which involves the long axis of the heart, exactly speaking, the electrical axis of the heart. Leads B, C and D may serve this purpose. In practice, which lead is selected should be decided eventually by the purpose and circumstances of the case. For instance, lead D may be most suitable for experiment when the animal is laid on his side.

However, from the viewpoint of practical convenience, the writers recommend lead B as the one to be employed in as much as the EINTHOVEN triangle theory may be accepted as more applicable in lead B than in other leads, because of the position of a horse's heart in the body. Thus, it is rendered less difficult to deduce theoretical considerations from the electrocardiogram. Of course, the positions on which electrodes are put are readily found out exactly; they are less influenced by movements of the body than other leads. So a tracing which is free from artifacts is obtained without difficulty. Moreover, WILSON's terminal electrode may be more suitable theoretically on the 3 points of lead B than on the points of limb lead.

Finally, the writers would emphasize that the limb lead which has been commonly used with quadruped animals in the field of experimental human medicine or of veterinary clinical investigation is not equivalent to the one used in man. Accordingly its electrocardiogram should be interpreted circumspectly.

SUMMARY

In this paper, 4 kinds of bipolar leads have been tested. The results obtained have been compared with each other. The employment of lead B has been recommended as the most practical method. Normal values obtained by these leads have been reported.

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