OPTIMUM PLACEMENT OF ELECTRODES FOR HEART RATE TELEMETRY

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ABSTRACT

Heart rate transmitters are triggered by changes in cardiac electropotentials. Knowledge of electrocardiogram (ECG) amplitude, variability, and form can improve the performance of the transmitters. ECGs taken along and across the sternum on elk (Cervus elaphus) and wolves (Canis lupus) revealed significant ($p < .01$) variability in signal strength among locations of electrodes and among individuals. Differences in form between wolf and elk ECGs were also apparent. Recommended electrode placements are at the xiphoid process and midway to three-quarters up the midline of the sternum in wolves, and at the manubrium and 10-30 cm posteriorly along the midline in elk. Recommended minimum threshold voltages for transmitters are .4 mv in elk, and 1.0 mv in wolves at these locations. Use of an ECG monitor in the field is recommended because of the variability in ECGs.

INTRODUCTION

Heart rate telemetry is an increasingly viable method of remotely examining behavior and physiology of wild animals. Heart rate transmitters can be completely implantable, or operate in conjunction with a collar or backpack, allowing unrestrained movement in natural conditions. Usually the transmitter is designed to emit a pulse each time the heart beats. The transmitters are triggered by changes in electropotentials associated with the electrical activity of the heart, as detected by a pair of subcutaneous electrodes. In order to screen out the multiple electropotential changes associated with heart contraction, and extraneous electropotentials associated with skeletal muscle contraction, the transmitters are calibrated to transmit only when a minimum threshold voltage is exceeded. Often a maximum trigger

voltage is also specified. A higher threshold and a smaller range will reduce noise, but the transmitter must be calibrated to detect one wave of the ECG.

Little baseline information has been compiled on ECG voltages in wild animals or on the influence of electrode placement on electropotential amplitude. ECG amplitude in humans can vary when electrodes on the sternum are moved as little 2.5 cm (Folk and Folk 1979). We examined amplitude and variability of ECGs in elk and wolves on the midline and across the sternum. Limb leads I, II and III were also recorded in wolves.

METHODS

Paper trace ECG monitors were used to record electrocardiograms on 11 elk and five wolves. Between 6 November, 1987 and 26 January, 1988 four adult bull elk were immobilized with Xylazine (Rompun) and one ECG was taken along the midline of the sternum and one approximately 10 cm on either side of the sternum between the front legs for each elk. Seven adult cow elk (weight 205-310 kg) were also immobilized, with either 3 mg Carfentanil (Wildnil, Wildlife Laboratories, Inc, Fort Collins, Co.) or a combination of 4.7-7.7 mg Etorphine (M99) and 30 mg Xylazine, and ECGs were taken at 10 cm intervals from the manubrium along the midline of the sternum. All readings were made with the positive electrode in the posterior position and the elk in lateral recumbency on the left or right side. Needle electrodes were inserted subcutaneously or lubricated pads were affixed to shaved patches.

Five adult wolves (weight 30-39 kg) were anesthetized on 19 July, 1988 with Tiletamine and Zolazepam (Telazol, A.H. Robins, Richmond, VA.) at the rate of 10 mg/kg body weight. All ECGs were taken with the wolf in right lateral recumbency. Needle electrodes were inserted subcutaneously.

Measurements along the midline of the sternum were made by dividing the distance between the manubrium and the xiphoid process into four equal segments and placing the positive electrode at the anterior end of each segment and the negative electrode at the xiphoid process. Lateral measurements were made approximately over the heart, with the electrodes 10 cm from the midline on either side of the sternum and 10 cm anterior to the xiphoid process. Lead I, II, and III measurements were made with the limb electrodes approximately 5 cm from the junction with the body. The common mode point was connected to the right leg in all cases.

Electropotential amplitudes for elk and wolves were measured to the nearest .01 millivolts (mv) off strip chart recordings using calipers. Measurements were made from the baseline to the maximum deflection. Values reported represent either a negative or a positive deflection. All readings were calibrated with a one mv test voltage generated by the ECG monitor. Fifteen heart beats were measured for each location in wolves. Samples ranged from four to 24 heart beats in elk.

Amplitudes at different electrode positions in the same elk and at the same electrode positions in different elk were examined with a GLM one-way analysis of variance for unbalanced data, and Tukey's studentized range test ($a = .05$, SAS Institute 1985). Wolf ECG amplitudes were examined using a one-way completely randomized analysis of variance and Tukey's studentized range test ($a = .05$).

RESULTS

The elk electrocardiogram generally consisted of low amplitude positive P-waves and negative QS- and positive T- waves of similar amplitudes.

Occasionally the T-wave was diphasic or a positive R-wave was apparent. The amplitude of the T-wave was more variable than the QRS-waves in 6 out of 8 electrode locations. In wolves, the P- and T-waves along the sternum were relatively low in amplitude compared to high amplitude QRS waves (Table I). The R-wave measured across the heart in wolves was diphasic.

ECG amplitude was consistent within an individual at a given location. There were significant differences in mean amplitudes among locations in both elk ($p < .0001$) and wolves ($p < .01$), however, not all placements were different (Table II). There were also significant differences among individual elk ($p < .0001$) and wolves ($p < .01$), but not all individuals were different. Differences between minimum QRS- or T-waves at different locations ranged from 0 to .39 mv in elk and from 0 to .74 mv in wolves. QRS amplitudes were greater in wolves than in elk at all locations. Voltages ranged from .1 to 1.39 mv in elk and from .72 to 3.25 mv in wolves.

Amplitudes of QRS-waves across the sternum were not greater than midline measurements in elk, T-waves were higher than QRS-waves at this location. Similarly, QRS amplitudes over the heart were not greater than those on the midline in wolves. QRS amplitudes in wolves increased towards the manubrium. This did not hold true for elk (Table I).

DISCUSSION

Optimum locations for heart rate transmitter electrodes are where one wave of the electrocardiogram is maximized, and other electropotentials are minimized. At the same time, surgical trauma, and any movement of the electrodes which could cause them to break should be minimal.

The primary factor affecting electrocardiogram voltages is the

Elk

Electrode locations[a]		0,10	0,20	10,20	0,30	10,30	0,40	10,40	Lateral
n[b]		6	4	5	8	3	6	4	4
P-wave	$\bar{x}$	.07	.08	.07	.14	.09	.15	.12	.09
	Min	.02	.03	.05	.10	.07	.06	0	.08
	Max	.10	.10	.10	.22	.10	.25	.26	.10
	SD[c]	.04	.03	.03	.05	.02	.06	.11	.01
QRS-wave	$\bar{x}$	.80	.55	.33	.70	.53	.69	.91	.72
	Min	.41	.49	.31	.49	.10	.20	.34	.31
	Max	1.23	.70	.35	1.11	1.01	.97	1.39	1.10
	SD[c]	.38	.10	.03	.24	.34	.29	.53	.40
T-wave	$\bar{x}$	.62	.61	.39	.56	.47	.55	1.04	.65
	Min	.28	.41	.34	.39	.29	.28	.66	.56
	Max	1.33	.80	.47	.93	.81	1.03	1.31	.76
	SD[c]	.64	.33	.19	.38	.44	.51	.33	.16

Wolves

Electrode locations[d]		1	2	3	4	Lateral	I	II	III
n[b]		5	5	5	5	5	5	5	5
P-wave	$\bar{x}$	.45	.32	.03	0	.33	0	0	0
	Min	0	0	0	0	0	0	0	0
	Max	.74	.49	.17	0	.68	0	0	0
	SD[c]	.25	.17	.07	0	.34	0	0	0
QRS-wave	$\bar{x}$	2.52	2.50	2.16	1.09	2.39	.42	2.11	1.71
	Min	1.46	1.38	1.33	.72	1.33	0	1.32	1.40
	Max	3.09	3.25	2.85	1.39	3.28	.83	2.97	2.03
	SD[c]	.71	.77	.56	.24	.70	.31	.67	.28
T-wave	$\bar{x}$	.43	.40	.20	0	0	0	.40	.36
	Min	.24	.27	0	0	0	0	0	0
	Max	.71	.59	.47	0	0	0	.51	.55
	SD[c]	.16	.12	.18	0	0	0	.1	.20

Table I. Average, range and variability of elk and wolf electrocardiograms along the sternum, across the sternum, and in leads I,II and III.

[a] Locations in cm along the midline of the sternum from the manubrium, lateral position measured between the front legs, 10 cm on either side of the sternum.

[b] Number of individuals measured per location.

[c] Sample standard deviation.

[d] Locations measured by placing the negative electrode on the xiphoid process and the positive at the manubrium, and posteriorly along the midline at intervals of 1/4 the sternum length. Lateral position was measured 10 cm anterior to the xiphoid process, 10 cm on either side of the sternum. Leads I, II and III measured with the electrodes on the limb, 5 cm from the junction with the body.

Elk

Electrode placement	10,20	10,30	0,20	0,40	0,30	Lateral	0,10	10,40
$\bar{X}$	.33	.53	.55	.69	.70	.72	.80	.91

Wolves

Electrode placement	1	2	Lateral	3	4
$\bar{X}$	2.52	2.50	2.39	2.16	1.79

Table II. Diagram of similarities in mean QRS amplitudes between electrode locations. Mean amplitudes at electrode placements connected by lines were not different as determined with Tukey's HSD, a = .05. Electrode placements are identical to placements described in Table I.

relationship of the electrodes to the electropotential vector (Crady et al., 1966). Electropotentials are maximized when the electrodes are on the same axis as the electropotential vector and minimized when electrodes are on an axis perpendicular to the vector. Vectors are determined by the direction of electrical current in the heart, and the position of the heart in the thorax. The QRS vector is generally directed caudally and ventrally in dogs and anteriorly and dorsally in ungulates (Detweiler, 1984). However, normal QRS vectors can vary a great deal between individuals, for instance in humans the normal range of QRS vectors spans 135 degrees (Stein, 1976 p. 32). The location of the heart in the thorax may also change when the animal changes position which can affect the electropotential vector.

Another factor complicating vector analysis is that although the heart approaches a dipole distally, vectors are complex near the heart because of local geometry and electrical effects. Therefore, when electrodes are located

close to the heart, small changes in placement can affect electropotential voltages (Taccardi, 1962, Stein, 1976 p. 48, Rautaharju et al., 1980).

The weaker QRS amplitudes in elk are due to differences in the Purkinje fiber network which distributes the depolarization current. Purkinje fibers are subendocardial in canids, but penetrate the myocardium and distribute the electric current throughout the heart muscle in ungulates. These sychronized depolarization waves in ungulates tend to cancel each other out (Breazile, 1971). Other factors affecting amplitude include blood, lungs, muscle conductivity, obesity, thickness of the myocardium and heart size (Rudy et al., 1979).

SUMMARY AND RECOMMENDATIONS

Heart rate transmitter electrodes should be placed along the depolarization vector to maximize signal strength. This is generally longitudinally in both canids and ungulates, but varies among individuals. Vectors are complex near the heart, and small changes in electrode placement can affect ECG amplitudes. An ECG monitor is useful in determining optimum placement. Investigation into changes in ECG voltages associated with changes in animal position would also be helpful in determining electrode placement. Taking this into account, we recommend placement of electrodes at the manubrium and 10 to 30 cm posteriorly in elk, and at the xiphoid process and half-way to three-quarters anteriorly along the sternum in wolves. QRS electropotentials were maximized relative to the P- and T- waves at these locations. Even so, it was impossible to screen out the T-wave in elk on the basis of amplitude. These locations also reduced surgical trauma and potential electrode movement. Appropriate threshold amplitudes at these placements would be .4 mv for elk and 1.0 mv for wolves.

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REFERENCES

Breazile, J.E. (1971) Electrophysiology of the heart. Pp. 234-251 in Breazile, J.E. ed. Textbook of veterinary physiology. Philadelphia, Lea & Febiger.

Crady, J.D., Clark, D.R. & Szabuniewicz, M. (1966) Clinical use of the electrocardiogram in animals. Part III Vectorial analysis. Vet. Med. 61:973-980.

Detweiler, D.K. (1984) Electrophysiology of the heart. Pp 103-130 in M.J. Swenson ed. Dukes' physiology of domestic animals. Tenth ed. London, Cornell University Press Ltd.

Folk G.E. Jr. and Folk M.A. (1979) Physiology of large mammals by implanted radio capsule. Pp. 33-43 in C.J. Amlaner and D.W. MacDonald eds. A handbook on biotelemetry and radiotracking. Pergamon Press, Ltd.

Rudy, Y., Plonsey, R. & Liebman J. (1979) The effects of variation in conductivity and geometrical parameters on the electrocardiogram, using an eccentric spheres model. Circ. Res. 44(1):104-111.

SAS Institute Inc. (1985) SAS/STAT guide for personal computers, version 6 edition. SAS institute Inc., Cary N.C.

Stein, E. (1976) The electrocardiogram; a self study course in electrocardiography. Philadelphia/London/Toronto, W.B. Saunders Co.

Taccardi, B. (1962) Distribution of heart potentials on dog's thoracic surface. Circ. Res. 11:862-869.