

# Determination of electrocardiographic parameters in healthy llamas and alpacas

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**Objective**—To determine electrocardiographic parameters in healthy llamas and alpacas.

**Animals**—23 llamas and 12 alpacas.

**Procedure**—Electrocardiography was performed in nonsedated standing llamas and alpacas by use of multiple simultaneous lead recording (bipolar limb, unipolar augmented limb, and unipolar precordial leads).

**Results**—Common features of ECGs of llamas and alpacas included low voltage of QRS complexes, variable morphology of QRS complexes among camelids, and mean depolarization vectors (mean electrical axes) that were directed dorsocranially and to the right. Durations of the QT interval and ST segment were negatively correlated with heart rate.

**Conclusions and Clinical Relevance**—ECGs of acceptable quality can be consistently recorded in nonsedated standing llamas and alpacas. Features of ECGs in llamas and alpacas are similar to those of other ruminants. Changes in the morphology of the QRS complexes and mean electrical axis are unlikely to be sensitive indicators of ventricular enlargement in llamas and alpacas. (*Am J Vet Res* 2004;65:1719–1723)

The increasing popularity of camelids is accompanied by a growing need to collect data that may be used to aid recognition of cardiac disease in these species. The prevalence of cardiac rhythm abnormalities has only been reported in llamas. In 1 study,<sup>1</sup> a low prevalence (1.2%) was found via analysis of short ECG traces; however, long-term ambulatory ECG (Holter) recordings are required for accurate determination of the prevalence of cardiac rhythm abnormalities in camelids. Electrocardiographic abnormalities that have been identified in llamas include atrial premature complexes, second-degree atrioventricular block, atrial fibrillation, and sinus bradycardia.<sup>1</sup>

Bastres et al<sup>2</sup> obtained ECGs from 3 llamas and reported that P wave morphology was positive and monophasic; the QRS complex deflection was negative, consisting of an rS or QS pattern; and the T wave morphology changed polarity depending on heart rate. Martinez et al<sup>3</sup> compared ECG parameters of South

American camelids living at sea level (170 m) with those of camelids living at high altitude (4,400 m); the only substantial differences in ECG parameters between groups were found in heart rate, which was lower in camelids living at high altitude than in camelids living at low altitude, and in QT interval, which was longer in camelids living at high altitude than in those living at low altitude. The reason for the slower heart rate at high altitude is uncertain, but it is likely an adaptive response and may be associated with polycythemia. In a review article,<sup>1</sup> cardiac auscultation, electrocardiography, echocardiography, and prevalence of cardiovascular disease in llamas were discussed. The purpose of the study reported here was to determine ECG parameters (reference values) in healthy llamas and alpacas.

## Materials and Methods

**Camelids**—Thirty-five overtly healthy male and female camelids (23 llamas and 12 alpacas) with mean  $\pm$  SD weight of  $81 \pm 45$  kg were used in the study. The study group included 3 crias ( $< 6$  months of age), 12 adolescent (6 months to 2 years of age), 14 adult ( $> 2$  to 8 years of age), and 6 geriatric ( $> 8$  years of age) llamas and alpacas. No abnormalities were detected on physical examination of each camelid. Echocardiography and thoracic radiography were not performed. All study animals were housed at the camelid research facility at The Ohio State University. The study was approved by the Institutional Animal Care and Use Committee.

**ECG procedure**—All ECGs were performed while the llamas and alpacas were standing. Animals were not sedated and were restrained by the halter by an assistant. For each recording, ECG electrodes (alligator clips) were attached to the caudal aspects of the left and right forelimbs 2 cm dorsal to the olecranon and to the cranial aspects of the left and right hind limbs approximately 4 cm dorsal to the proximal attachment of the patellar ligament. For each recording, the lead V<sub>3</sub> electrode was attached to the skin overlying the left sixth intercostal space approximately 1 cm ventral to the costochondral junction and the lead V<sub>10</sub> electrode was attached to the skin overlying the spinous process of the seventh thoracic vertebra (precordial leads). The coat was parted at the points of electrode attachment, and the skin was saturated with a 0.9% NaCl solution. An electrocardiography unit<sup>4</sup> with a frequency range of 0.5 to 150 Hz was used. A high-pass filter of 0.5 Hz was used to minimize artifact and baseline wander. All ECGs were recorded on a single day at the camelid research facility at The Ohio State University. All ECGs were recorded at a paper speed of 50 mm/s. The voltage calibration was set at 10 mm of deflection/mV input.

**Data analyses**—The R wave amplitude and standard durations (P wave, QRS complex, PQ interval, ST segment, and QT interval) were calculated to the nearest 0.1 mV and 10 milliseconds, respectively. Mean values for 3 consecutive QRS complexes were calculated. The QRS waveforms were

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identified by use of uppercase or lowercase letters when their amplitudes were  $\geq 0.3$  mV or  $< 0.3$  mV, respectively. The mean electrical axis (MEA) of ventricular depolarization was estimated by plotting the algebraic sum for Q, R, and S wave components of ventricular depolarization from the frontal (leads I and aVF), sagittal (leads aVF and  $V_{10}$ ), and transverse (leads I and  $V_{10}$ ) planes (Figure 1) and determining the resultant vectors. Axes were expressed in degrees from 0 moving counterclockwise through  $-90^\circ$ ,  $-180^\circ$ , and  $-270^\circ$ .

**Statistical analyses**—Linear correlation coefficients were determined to detect relationships between heart rate and durations of the PR interval, QT interval, and ST segment. Unpaired *t* tests (*df* = 10) were performed to determine differences in measured parameters between llamas and alpacas. Differences in ECG parameters among age groups were analyzed by use of 1-way ANOVA. Values of  $P < 0.05$  were considered significant.

## Results

Cardiac murmurs and arrhythmias were not detected via auscultation in any of the llamas or alpacas. Acceptable quality ECGs were recorded in all camelids without use of sedation. No significant differences in P wave or QRS complex morphology and standard durations between llamas and alpacas or among the 4 age groups were detected (Table 1). The durations of the QT interval and ST segment were significantly ( $P < 0.001$ ) correlated with heart rate, with faster heart rate associated with shorter durations. However, correlation coefficients were not high (for heart rate and duration of the QT interval,  $r = -0.56$ ; for heart rate and duration of the ST segment,  $r = -0.66$ ). No correlation between heart rate and duration of the PR interval was found. As expected, durations of the ST segment and QT interval were significantly correlated ( $r = 0.74$ ).

The QRS complex morphology of the bipolar limb, unipolar precordial, and unipolar augmented limb leads varied widely among camelids (Table 2; Figure 2). On some recordings, small R wave and S wave apical notches were detected. From 14 to 18 variations of QRS complex morphology were recorded among the bipolar limb and unipolar augmented limb leads. For leads I, II, and III, mean polarities of the QRS complexes were negative in 21 of 35 (60%), 19 of 34 (56%), and 18 of 35 (51%) camelids, respectively. For leads aVR, aVL, and aVF, mean polarities of the QRS complexes were negative in 9 of 35 (26%), 15 of 34 (44%), and 23 of 35 (66%) camelids, respectively.

Morphology of the QRS complex in lead  $V_3$  was variable, and 7 types of complexes were found (Table 2). Algebraic sum voltages of the QRS complexes were negative in 19 of 32 (59%) camelids, positive in 6 (19%), and isoelectric in 7 (22%). Most common were QRS complexes with algebraic sum voltages that were negative ( $[-rs; n = 7]$ ,  $[rS; 7]$ ) or isoelectric ( $[rs; 7]$ ,  $[QS; 4]$ ).

The QRS complex morphology was least variable for lead  $V_{10}$ . The S waves were absent, and the algebraic sum voltages of the QRS complexes were positive in 28 of 32 (88%) camelids. The morphology was qR ( $n = 17$ ), +qR (10), and isoelectric qR (4).

Most R and S waves in leads I, II, III, and aVF

were of low voltage. In lead aVF, mean  $\pm$  SD R wave voltage for positive QRS complexes was  $0.53 \pm 0.23$  mV (range, 0.0 to 1.0 mV). Mean  $\pm$  SD S wave voltage was  $0.43 \pm 0.22$  mV (range, 0.0 to 0.7 mV). Corresponding values for lead II were similar, and voltages for the other leads were lower than these values.

Polarity of the T wave in leads  $V_3$  and  $V_{10}$  was variable. In lead  $V_3$ , T wave polarity was positive in 15, negative in 16, and isoelectric in 1 camelid. In lead  $V_{10}$ , T wave polarity was positive in 13, negative in 17, and isoelectric in 2 camelids. Relative to the polarity calculated via the algebraic sum of the QRS complex voltages in lead  $V_3$ , the T wave polarity was discordant in 11 and concordant in 14 camelids; in lead  $V_{10}$ , the T wave polarity was discordant in 16 and concordant in 12 camelids. Occasionally in lead  $V_{10}$ , either the QRS complex ( $n = 4$ ) or the T wave (2) polarity was isoelectric. In lead  $V_3$ , the QRS complex (7) or the T wave (1) polarity was isoelectric. The T wave polarities in leads I, II, III, aVR, aVL, and aVF varied. The T wave polarities in leads II, III, and aVF were concordant with the QRS complex polarity in 29 of 34 (83%) camelids.

In leads  $V_3$  and  $V_{10}$ , T wave voltage was low ( $\leq 0.35$  mV positive or negative deflection), with 1 exception. One camelid had a T wave amplitude of

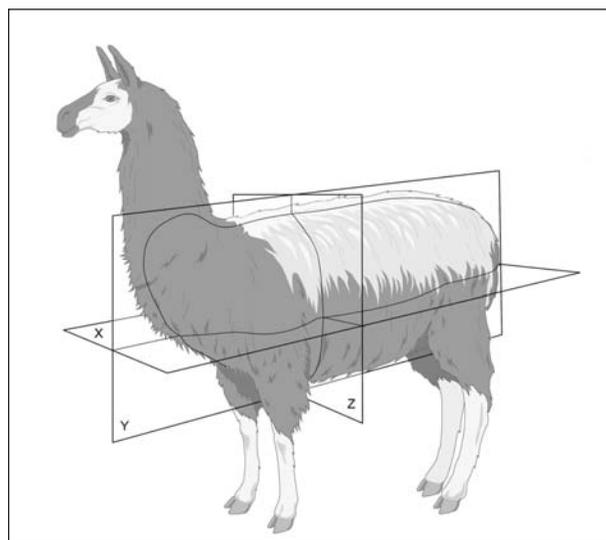


Figure 1—Schematic representation of the 3 planes of the body in llamas and alpacas. X = frontal plane; Y = sagittal plane; and Z = transverse plane. The limb leads (leads I and aVF) lie within the frontal plane. The sagittal plane can be approximated by leads aVF and  $V_{10}$ . The transverse plane can be approximated by leads I and  $V_{10}$ .

Table 1—Surface electrocardiographic parameters (standard durations and heart rate) in 35 healthy llamas and alpacas.

Parameter	Mean $\pm$ SD	Median (range)
P wave (ms)	40 $\pm$ 12	40 (20-80)
PQ interval (ms)	150 $\pm$ 33	140 (100-200)
QRS complex (ms)	50 $\pm$ 8	50 (30-60)
QT interval (ms)	360 $\pm$ 60	360 (240-480)
ST segment (ms)	230 $\pm$ 46	240 (125-300)
Heart rate (beats/min)	80 $\pm$ 18	80 (60-100)

Table 2—Morphology of the QRS complex in bipolar limb leads (leads I, II, and III), unipolar augmented limb leads (leads aVR, aVL, and aVF), and unipolar precordial leads (leads V3 and V10) recorded from 35 healthy llamas and alpacas.

Morphology	Lead							
	I	II	III	aVR	aVL	aVF	V <sub>3</sub>	V <sub>10</sub>
-qrs	0	0	1	0	0	2	0	0
+qrs	1	1	0	0	0	0	0	0
Qrs	1	0	0	0	0	0	0	0
QRs	1	0	1	0	1	1	0	0
QrS	1	1	1	0	0	4	0	0
qR	0	6	5	0	0	4	0	17
+qr	4	0	5	5	3	1	0	10
-qr	7	2	5	1	3	5	0	0
Qr	1	2	0	0	1	0	0	0
isoelectric qr	2	1	0	2	1	0	0	4
isoelectric QR	0	0	0	1	0	0	0	0
isoelectric rsr'	0	0	0	0	0	1	0	0
qs	3	2	5	0	1	4	0	0
QS	1	0	0	0	0	0	0	0
QS	3	2	1	1	4	3	4	0
Rs	2	1	1	1	0	0	5	0
-RS	0	0	0	0	0	0	1	0
isoelectric RS	0	1	1	0	0	1	0	0
-rs	2	6	3	5	4	5	7	0
+rs	2	2	2	4	6	1	1	0
rS	1	4	2	0	1	0	7	0
isoelectric rs	1	1	0	2	2	2	7	0
rSr'	1	1	1	1	1	0	0	0
-rsr'	1	0	0	2	1	0	0	0
R	0	1	0	3	1	1	0	1
r	0	0	1	1	2	0	0	0
rr'	0	0	0	5	2	0	0	0
rR'	0	0	0	1	0	0	0	0

The Q wave is the first negative deflection and the R wave is the first positive deflection of the QRS complex. The S wave is the negative deflection that occurs after a negative Q wave or positive R wave deflection or both (if no positive waves are present the negative deflection is a QS complex). Positive or negative deflections that occur after the R or S wave has returned to baseline are R' or S' waves. The QRS waveforms were identified by uppercase and lowercase letters when their amplitudes were  $\geq 0.3$  mV and  $< 0.3$  mV, respectively.

+ = Polarity of the algebraic sum of the indicated wave forms was slightly positive. - = Polarity of the algebraic sum of the indicated wave forms was slightly negative. For each lead n = 35, except for leads II, aVL, V<sub>3</sub>, and V<sub>10</sub>, for which the number of camelids was  $< 35$  because acceptable recordings were not attainable in all camelids.

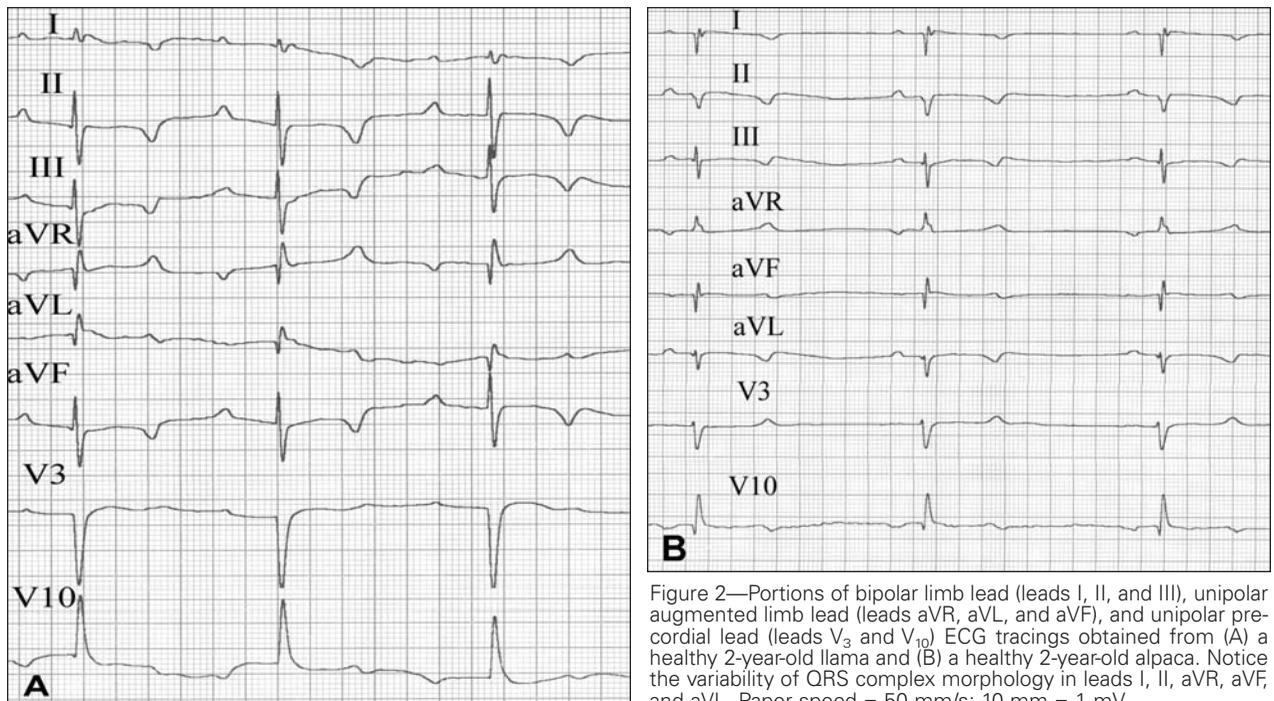


Figure 2—Portions of bipolar limb lead (leads I, II, and III), unipolar augmented limb lead (leads aVR, aVL, and aVF), and unipolar precordial lead (leads V<sub>3</sub> and V<sub>10</sub>) ECG tracings obtained from (A) a healthy 2-year-old llama and (B) a healthy 2-year-old alpaca. Notice the variability of QRS complex morphology in leads I, II, aVR, aVF, and aVL. Paper speed = 50 mm/s; 10 mm = 1 mV.

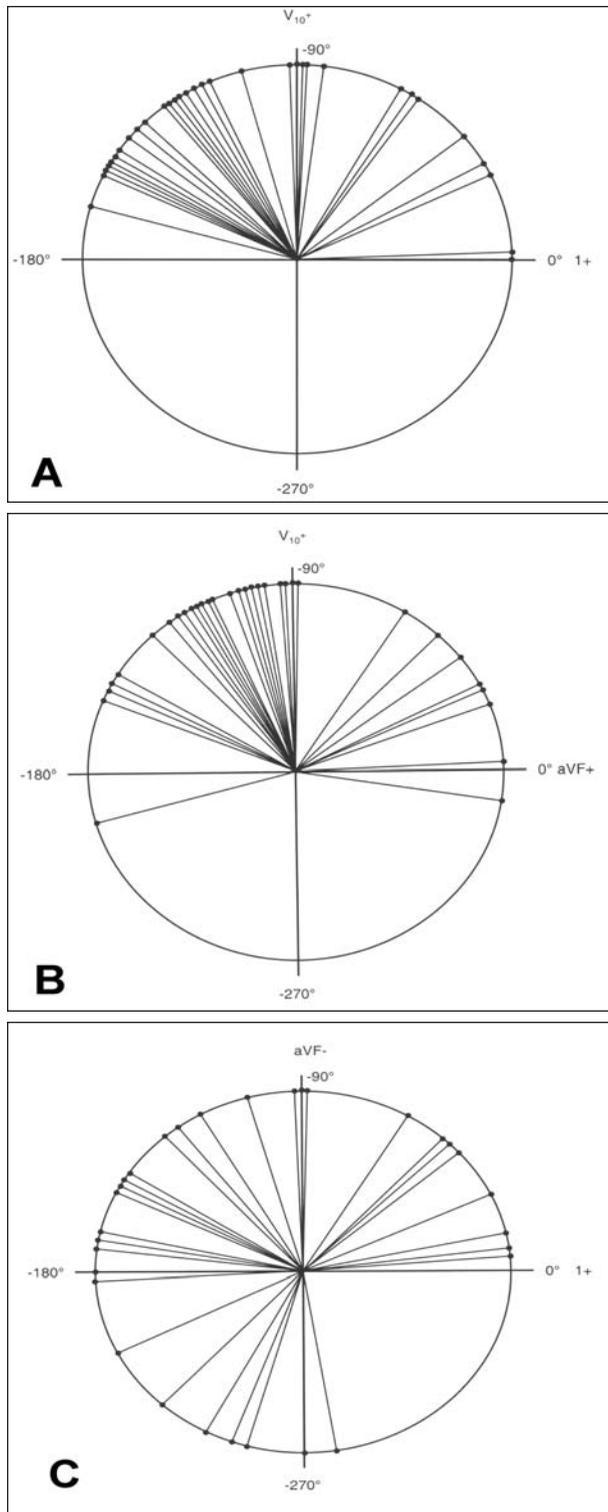


Figure 3—Schematic representations of mean electrical axes (MEAs) in 3 planes in 35 healthy camelids. The positive (+) and negative (-) electrodes are indicated. (A) In the transverse plane, MEA ranged from 0° to approximately -164°. Most MEAs were between approximately -90° and -155°. (B) In the sagittal plane, MEA ranged from -3° to -351°. Most MEAs were between -90° and -155°. (C) In the frontal plane, MEA ranged from -4° to -278°. Most MEAs were between -90° and -270°. The mean MEAs for the 3 planes were directed dorsocranially and slightly to the right. Three data points are superimposed in the transverse and sagittal planes, and 4 data points are superimposed in the frontal plane.

+0.8 mV in lead  $V_3$  and -0.6 mV in lead  $V_{10}$ . In leads I, II, III, aVR, aVL, and aVF, T wave voltages ranged from 0.1 to 0.7 mV.

The MEAs for the 3 planes were directed dorsocranially and slightly to the right (Figure 3). In the frontal plane (leads I and aVF), mean  $\pm$  SD MEA was  $-133^\circ \pm 76^\circ$  (range,  $-4^\circ$  to  $-278^\circ$ ). The axis was vertical in 1 camelid. In the sagittal plane (leads aVF and  $V_{10}$ ), mean  $\pm$  SD MEA was  $-97^\circ \pm 47^\circ$  (range,  $-3^\circ$  to  $-351^\circ$ ). In the transverse plane (leads I and  $V_{10}$ ), mean  $\pm$  SD MEA was  $-102^\circ \pm 43^\circ$  (range,  $0^\circ$  to  $-164^\circ$ ).

## Discussion

The pattern of ventricular excitation or depolarization in most ruminants is similar and differs from that of dogs and cats.<sup>4</sup> The common features of the surface ECG among ruminants are the result of similar anatomic position of the heart, deep myocardial penetration of Purkinje fibers, and pathways of ventricular depolarization.<sup>4,5</sup> In ruminants, the mean vector of depolarization is directed toward the heart base rather than toward the cardiac apex as in dogs and cats.<sup>4</sup>

Heart sounds in camelids are generated in a similar manner to those in dogs, cats, horses, and other ruminants. The prevalence of heart murmurs, gallop sounds, and abnormal first and second heart sounds is low<sup>1</sup>; none of these abnormalities were detected in our study. To the authors' knowledge, the study reported here is the first to analyze ECGs obtained by use of multiple simultaneous lead recordings (bipolar limb, unipolar precordial, and unipolar augmented limb leads) in a large number of llamas and alpacas.

Three common characteristics of ECGs of camelids were revealed in our study. Many variations of QRS complex morphology were detected; the lowest number of variations was found in leads  $V_3$  and  $V_{10}$ . In lead  $V_{10}$ , there was a qr or qR pattern in all but 1 camelid. In lead  $V_3$ , s or S waves were always present and the complexes were Rs, rS, or rs in most camelids. Care was taken to attach the electrodes of the precordial leads in the same positions for each recording. Minor deviations in lead positioning can induce minor variations of QRS complex morphology.<sup>6,7</sup> Among leads I through aVF, there were 14 to 18 variations of the QRS complex morphology, and these variations were similar to those reported in other ruminants.<sup>8-10</sup> The deep penetration of Purkinje fibers results in nearly simultaneous depolarization of the myocardium that induces small variable deflections as detected by the limb leads. This results in many variations of QRS complex morphology in these leads.<sup>1,3,5,11,12</sup>

A second common characteristic of ECGs of camelids was the low voltage of QRS complexes. The R and S wave voltages did not exceed 1.0 mV and 0.7 mV, respectively, in all leads. This finding is similar to previous findings in llamas.<sup>1</sup> The surface ECG is generated by regional asynchronous depolarization of the myocardium. In dogs and cats, the lack of deep penetration and finite conduction velocity of Purkinje fibers results in moving boundaries with differences of voltage potentials between polarized and depolarized myocardium. In horses and ruminants, the deep penetration of Purkinje fibers to nearly all regions of the

myocardium results in near simultaneous depolarization of all regions, minimal moving boundaries, and small differences in voltage potential between one region of the myocardium and another. The resultant surface ECG is therefore composed of low voltages and variable QRS complex morphologies.<sup>1,3,5,9,10</sup>

A third common characteristic of ECGs of camelids was MEAs that were largely directed dorsocranially. During the first few milliseconds of activation, vectors in camelids of our study were directed ventrocranially and usually slightly to the right. The median MEA in each plane was approximately  $-105^\circ$  to  $-145^\circ$ . In the transverse and sagittal planes, most MEAs ranged from approximately  $-90^\circ$  to  $-155^\circ$ ; therefore, the mean vector of depolarization was dorsocranial. The range of MEAs in the frontal plane was more variable, but the mean vector of depolarization was most commonly directed to the right.

Nearly simultaneous depolarization of the ventricular myocardium induces only small voltage differences (small vectors) across the myocardium as detected by frontal plane leads. The variable morphology of QRS complexes in leads I and aVF was largely responsible for the variations in MEAs, which were most pronounced in the frontal planes (Figure 3). The QRS complex morphology was least variable and most often of relatively high voltage in lead  $V_{10}$ . This resulted in MEAs in the transverse plane that were directed dorsally.

On the basis of our results, it is evident that acceptable quality ECGs can be consistently recorded in nonsedated standing llamas and alpacas and that ECG features are similar to those of other ruminants. The ECG is most useful for evaluation of heart rhythm; however, a short ECG recording is insensitive to minor or infrequent heart rhythm disturbances. The prevalence of heart rhythm disturbances in llamas as detected by static ECGs is low.<sup>1</sup> Because of the ventricular

depolarization process, neither the ECG voltages nor the MEAs are likely to be sensitive tests for detection of ventricular enlargement in llamas and alpacas; however, it is possible that prolonged QRS complex duration may be an indicator of ventricular enlargement. Whether an ECG recorded by use of an orthogonal (X,Y,Z) lead system would be of use remains to be determined.

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<sup>a</sup>Pagerwriter XLS, Hewlett-Packard, Palo Alto, Calif.

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## References

1. Boon JA, Knight AP, Moore DH. Llama cardiology. *Vet Clin North Am Large Anim Pract* 1994;10:353–356.
2. Bastres MC, Sakabe N, Yasuda J, et al. Electrocardiogram studies in llamas. *Jpn J Vet Res* 1989;37:85–95.
3. Martinez R, Urquieta B, Rojas J, et al. Electrocardiographic comparative study in South American camelids living at high and low altitude environments. *Adv Ciencias Vet* 1988;3:92–99.
4. Hamlin RL, Scher AM. Ventricular activation process and genesis of QRS complex in the goat. *Am J Physiol* 1961;200:223–228.
5. Hamlin RL, Glower DD Jr, Pimmel RL. Genesis of QRS in the ruminant: graphic simulation. *Am J Vet Res* 1984;45:938–941.
6. Krebs ME, Krause PC, Engelstein ED, et al. Ventricular tachycardias mimicking those arising from the right ventricular outflow tract. *J Cardiovasc Electrophysiol* 2000;11:45–51.
7. Rishniw M, Porciello F, Erb H, et al. Effect of body position on the 6-lead ECG of dogs. *J Vet Intern Med* 2002;16:69–73.
8. Raphel CF, Fregin GF. Clinical examination of the cardiovascular system in cattle. *Compend Contin Educ Pract Vet* 1980;2:52–59.
9. Sellers AF, Hemingway A, Simonson E, et al. Unipolar and bipolar electrocardiographic studies in dairy cattle. *Am J Vet Res* 1958;19:620–628.
10. Upadhyay RC, Sud SC, Joshi HC, et al. Electrocardiographic studies in Jersey cattle. *Indian Vet J* 1976;53:953–957.
11. Hamlin RL, Smith CR. Electrophysiology of the heart. In: Swensen MJ, ed. *Duke's physiology of domestic animals*. 9th ed. Philadelphia: Comstock Publishing Associates, 1970;112.
12. Hilwig RW. Cardiac arrhythmias of the horse. *J Am Vet Med Assoc* 1977;170:153–159.