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AN ELECTROCARDIOGRAPHIC STUDY OF NORMAL SHEEP USING A MODIFIED TECHNIQUE

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ABSTRACT

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A technique was developed which allowed a reproducible electrocardiogram to be recorded in normal sheep. Einthoven's triangle was moved to the sagittal plane and the needle electrodes were positioned at fixed points. Six electrocardiographic leads and the phonocardiogram were registered. High amplitudes and reproducible wave configurations were produced.

INTRODUCTION

A great deal of information is currently available regarding the normal and abnormal electrocardiograms (ECG) encountered in man. However, only a limited number of studies have been carried out in animals and the ECG of domesticated animals do not at the present time have the same diagnostic significance as those of man (Crawley & Swenson, 1966). This is mainly due to wide individual variations which are normally encountered in animals when using the standard method. Consequently the ECG has been primarily used for experimental purposes, where the ECG of the same animal may be followed and large numbers of animals are involved in a single experiment.

The heart is specifically affected in several plant poisoning syndromes of ruminants which are of economic importance in South Africa. These include cardiac glycoside intoxication due to a variety of plants from several families, fluoro-acetate poisoning due to *Dichapetalum cymosum* Engl. and a chronic fibrocytic myocarditis ("gousiekte") due to plants of three genera of the Rubiaceae (Steyn, 1949; Watt & Breyer-Brandwijk, 1962.)

In order to investigate these conditions more fully, it was essential to develop a practical ECG technique which would result in reproducible patterns in normal sheep. Only then would it be possible to distinguish between normal and pathologically induced variations in the ECG.

Using standard limb and unipolar leads a constant ECG could not be demonstrated by either Pretorius & Terblanche (1967) in sheep and goats or by Szabuniewicz & Clark (1967) in goats. Too, Nakamura & Hirao (1958) concluded that fundamental data on cardiac conditions in cattle could not be obtained when only limb leads were used, because variations in electrical changes could not be fully determined. In the bovine they obtained better results when they moved the points of Einthoven's triangle nearer to the heart and when the planes were changed.

In an attempt to reduce the large ECG variations that are encountered in normal animals when recordings are made with Einthoven's triangle in the ventral plane, the triangle was moved to the sagittal plane for the present investigation.

The main differences in topographical position of the heart between man and domestic mammals is the slant of the longitudinal axis of the heart (from base to apex) and the degree of rotation around this axis, i.e. the extent to which the right ventricle extends around to the left. Broadly speaking, man and the domestic ruminants represent two opposite extremes in this respect, with the dog (closest to man), pig and horse occupying intermediate positions between the two extremes.

The axis of the human heart slants antero-inferiorly and to the left, making an angle of 40° to the horizontal plane (Parsons Schaeffer, 1953). The axis of the ruminant heart, by contrast, approximates to the vertical plane, lying almost dorsoventrally (postero-anteriorly in terms of the human position) and virtually in the median plane, with no deflection toward the left. Such a deflection is impossible in view of the narrow transverse diameter of the ruminant thorax at its sternal level.

From the ventral aspect, the right ventricle in man does not reach the left side and the anterior longitudinal sulcus faces, as its name indicates, anteriorly. In domestic animals, and particularly in the ruminant, the right ventricle extends around to the left side, so that this sulcus has been termed the left longitudinal sulcus. One may consider the ruminant heart to be rotated to the left relative to the human heart.

In view of these anatomical differences, therefore, a change from the standard electrode positions to give a more realistic indication of the actual conduction changes in the heart of the sheep seemed indicated. Furthermore, a considerable additional advantage would be gained, because the patient need not be immobilized with the use of drugs and the subsequent changes in conduction caused by these compounds would be avoided.

MATERIALS AND METHODS

In a pilot experiment ECG recordings were taken three times on 10 clinically normal Merino sheep. This was done in order to establish whether the recordings were reproducible if the subcutaneous needle electrodes were removed from the sites mentioned below and then replaced.

For the main experiment 31 normal two-tooth to fullmouth Merino wethers varying between 36 and 49 kg live mass were used. They were stabled and fed on lucerne hay *ad libitum*, received *c.* 500 g of standard concentrate per day and had free access to water. With the exception of weekends, daily ECG and phonocardiographic recordings were made for approximately 9 consecutive days. The recordings were done on the animals in the standing position without the use of any sedative or tranquilizing drugs. Before making a re-

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cording the sheep was placed in a wooden crate with a wooden floor and the head was fixed by means of a leather strap and buckle. Lateral movement was controlled by a horizontal metal pipe on each side of the crate. A total of 266 recordings was made on these sheep.

In order to determine the effect of body position on ECG, successive recordings were made of six sheep while they were standing and these were compared with the readings when they were lying down either in the dextro-lateral or in the dorsal position. These sheep were selected at random from those in the main experiment.

Similarly the effect of a varying ruminal volume on the ECG was determined by making recordings of four sheep after they had been deprived of food and water for 24 h and then 1 to 2 h after they had been fed and watered again.

The subcutaneous needle electrodes (21 gauge), were positioned so as to place Einthoven's triangle on a sagittal plane by moving the standard and unipolar limb electrodes as follows:

(a) Right fore limb to head between ears,
(b) left fore limb to sacrum,
(c) left hind limb to the median sternal region 2 cm anterior to the infra-sternal angle (Fig. 1). In addi-

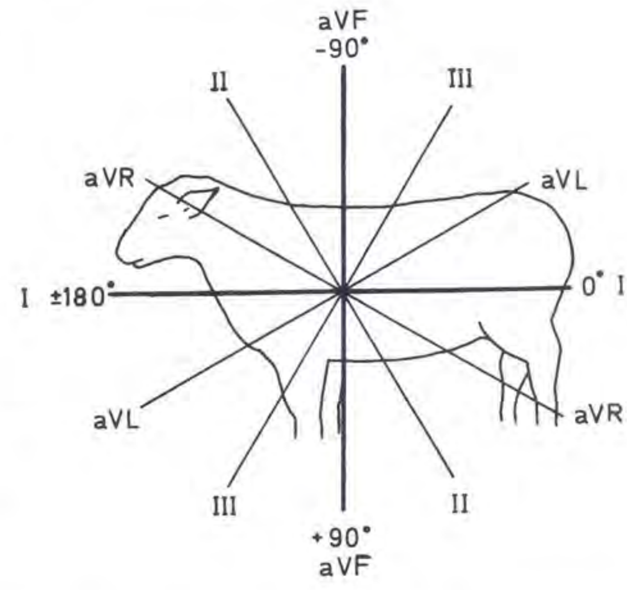

FIG. 1 The sagittal plane vectors of the QRS complex (degrees) and the position of the leads for the modified method

TABLE 1 The mean values of three recordings of ten sheep obtained in the pilot trial to establish the variations due to removal and replacement of the electrodes

Mean heart rate 72,2 (57-90)/min

Recording No.	Lead	Time intervals of waves in seconds			Electrical axis
		PQ	QRS	QT	
1					—112° (—90° to —144°)
	I	0,107 (0,09 — 0,12)	0,06 (0,05 — 0,08)	0,322 (0,29 — 0,36)	
	II	0,106 (0,09 — 0,12)	0,06 (0,04 — 0,08)	0,323 (0,29 — 0,36)	
	III	0,105 (0,08 — 0,12)	0,06 (0,04 — 0,08)	0,321 (0,29 — 0,36)	
	aVR	0,05 (0,09 — 0,13)	0,062 (0,07 — 0,06)	0,323 (0,29 — 0,37)	
	aVL	0,105 (0,09 — 0,13)	0,061 (0,05 — 0,08)	0,328 (0,29 — 0,36)	
	aVF	0,109 (0,09 — 0,13)	0,055 (0,04 — 0,08)	0,328 (0,30 — 0,37)	
2					—109° (—90° to —143°)
	I	0,108 (0,10 — 0,12)	0,06 (0,04 — 0,08)	0,321 (0,29 — 0,37)	
	II	0,107 (0,09 — 0,19)	0,06 (0,04 — 0,08)	0,317 (0,29 — 0,36)	
	III	0,108 (0,09 — 0,12)	0,057 (0,04 — 0,09)	0,321 (0,29 — 0,36)	
	aVR	0,11 (0,10 — 0,12)	0,055 (0,04 — 0,09)	0,319 (0,29 — 0,36)	
	aVL	0,111 (0,09 — 0,13)	0,053 (0,03 — 0,09)	0,317 (0,30 — 0,35)	
	aVF	0,11 (0,09 — 0,12)	0,051 (0,04 — 0,06)	0,318 (0,29 — 0,36)	
3					—106° (—90° to —138°)
	I	0,110 (0,10 — 0,12)	0,063 (0,04 — 0,09)	0,321 (0,29 — 0,36)	
	II	0,111 (0,10 — 0,12)	0,062 (0,04 — 0,08)	0,319 (0,29 — 0,36)	
	III	0,101 (0,09 — 0,11)	0,062 (0,04 — 0,08)	0,317 (0,29 — 0,36)	
	aVR	0,106 (0,09 — 0,12)	0,064 (0,04 — 0,08)	0,325 (0,30 — 0,36)	
	aVL	0,108 (0,09 — 0,12)	0,061 (0,04 — 0,08)	0,325 (0,30 — 0,36)	
	aVF	0,112 (0,10 — 0,12)	0,056 (0,04 — 0,09)	0,322 (0,29 — 0,37)	

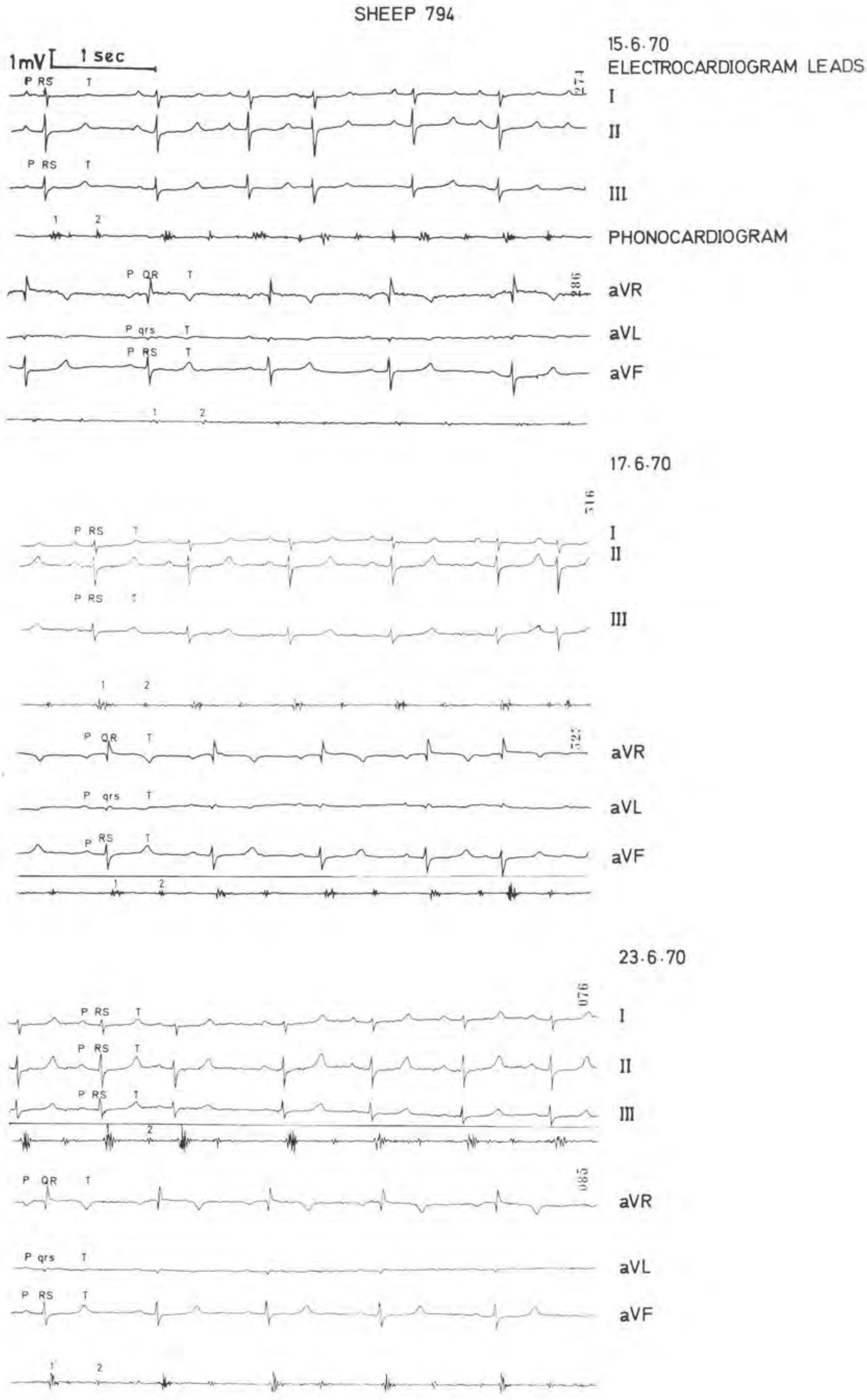

FIG. 2 The six leads of the electrocardiogram and the phonocardiogram of a normal sheep recorded on three different days

tion the earth electrode was positioned on the left hind leg just above the hock.

An Elema Mingograph 81 multichannel recorder at a sensitivity 1 cm = 1 mV was used. The paper speed was 100 mm/s. The heart rate, various time intervals, and wave forms and amplitudes were determined from these registrations. The PQ interval was measured from the beginning of the P wave to the start of the QRS complex. In the main experiment it was, however, also measured from the peak of the P wave and is indicated as such in the tables.

The sagittal plane QRS electrical axis was calculated by determining the algebraic sum of the deflections on leads I and II as described by Rushmer (1961) (Fig. 1). The QRS configuration for each sheep was determined in all six leads. The nomenclature used for the QRS wave shapes is according to Szabuniewicz & Clark (1967), where the first and second downward waves are successively denoted as Q and S and the first upward wave as R (Fig. 2). The relative amplitudes of the different waves are reflected by the use of small and capital letters.

An Elema-microphone was used for phonocardiographic recordings. The duration of mechanical systole was calculated as being the time interval between the beginning of the first and the beginning of the second heart sounds.

All the data of the main experiment were processed by computer to determine the mean values and standard deviations for each individual sheep as well as those of all the sheep when regarded as a group.

Results

1. *Pilot experiment*

The results of this experiment are summarised in Table 1. When the values of the mean, minimum and maximum time intervals of all six leads of the ECG, the heart rate and the electrical axis of series recordings were compared it was evident that little variation occurred in the series of three recordings. Consequently, the main experiment was conducted on the same lines.

2. *Main experiment*

In Fig. 2 an example is given of the typical recordings obtained for the six ECG leads and the phonocardiogram on a normal sheep on three different occasions.

A. *Heart rate and time intervals*

The heart rate of the 31 sheep varied between 60 and 197 beats/min with a mean of 107,4 and a standard deviation of 24,2. The values of the minimum, maximum, mean and standard deviation of the heart rate and the time intervals of all the leads of the ECG for all the sheep are shown in Table 2. In Tables 3, 4 and 5 the same parameters of three individual sheep, which served as random samples of the 31 sheep, are given.

For example, with lead II of Sheep 754, the mean durations of the PR, QRS and QT intervals were 0,101, 0,039 and 0,227 s respectively, whereas the same means for all the sheep were 0,102; 0,046 and 0,262 s respectively.

TABLE 2 The time intervals (seconds) of the PR, QRS and QT waves of the electrocardiogram of 31 sheep[1]
Heart rate/min: 107 ± 24
(60 — 197)

Lead	P-R	QRS	Q-T[2]
I	0,105 ± 0,016 (0,070 — 0,140)	0,031 ± 0,009 (0,015 — 0,060)	0,259 ± 0,033 (0,170 — 0,350)
II	0,102 ± 0,016 (0,060 — 0,140)	0,046 ± 0,009 (0,025 — 0,080)	0,262 ± 0,034 (0,170 — 0,343)
III	0,094 ± 0,018 (0,050 — 0,140)	0,045 ± 0,007 (0,015 — 0,060)	0,259 ± 0,033 (0,170 — 0,336)
aVR	0,110 ± 0,016 (0,070 — 0,160)	0,045 ± 0,010 (0,012 — 0,080)	0,262 ± 0,034 (0,170 — 0,356)
aVL	0,105 ± 0,016 (0,060 — 0,150)	0,024 ± 0,009 (0,010 — 0,050)	0,258 ± 0,033 (0,160 — 0,330)
aVF	0,100 ± 0,016 (0,065 — 0,156)	0,047 ± 0,009 (0,004 — 0,075)	0,265 ± 0,034 (0,165 — 0,360)

[1]Mean values of 266 recordings of 31 sheep are expressed with ± standard deviation; minimal and maximal values are in parentheses

[2]The heart frequency is disregarded in these values

TABLE 3 The time intervals (seconds) of the PR, QRS and QT waves of the electrocardiogram of Sheep 754[1]
Heart rate = 142 ± 14
(106 — 155)

Lead	P-R[2]	P-R[3]	QRS	Q-T	Corrected QT[4]
I	0,102 ± 0,006 (0,093 — 0,115)	0,119 ± 0,006 (0,110 — 0,130)	0,027 ± 0,002 (0,025 — 0,030)	0,226 ± 0,021 (0,200 — 0,260)	0,290 ± 0,018 (0,259 — 0,315)
II	0,101 ± 0,006 (0,093 — 0,115)	0,118 ± 0,007 (0,110 — 0,130)	0,039 ± 0,005 (0,030 — 0,050)	0,227 ± 0,021 (0,200 — 0,260)	0,289 ± 0,017 (0,254 — 0,310)
III	0,081 ± 0,009 (0,083 — 0,110)	0,104 ± 0,007 (0,097 — 0,120)	0,038 ± 0,006 (0,025 — 0,050)	0,227 ± 0,018 (0,200 — 0,253)	0,289 ± 0,017 (0,254 — 0,310)
aVR	0,102 ± 0,003 (0,100 — 0,110)	0,118 ± 0,007 (0,110 — 0,130)	0,045 ± 0,004 (0,040 — 0,050)	0,229 ± 0,016 (0,210 — 0,256)	0,282 ± 0,016 (0,254 — 0,310)
aVL	0,104 ± 0,003 (0,100 — 0,110)	0,116 ± 0,005 (0,110 — 0,126)	0,021 ± 0,009 (0,015 — 0,040)	0,223 ± 0,020 (0,190 — 0,256)	0,289 ± 0,018 (0,262 — 0,324)
aVF	0,104 ± 0,003 (0,100 — 0,110)	0,115 ± 0,006 (0,110 — 0,130)	0,040 ± 0,002 (0,035 — 0,045)	0,230 ± 0,015 (0,210 — 0,260)	0,281 ± 0,013 (0,260 — 0,310)

(1) Mean values over a period of 9 days are expressed with ± standard deviation; minimal and maximal values are in parentheses

(2) Measured from the peak of the P wave

(3) Measured from the beginning of the P wave

(4) Bazett's formula (Alfredson & Sykes, 1942) is used

TABLE 4 The time intervals (seconds) of PR, QRS and QT of the electrocardiogram of Sheep 794[1]
Heart rate: 123 ± 13
(104 — 150)

Lead	P-R[2]	P-R[3]	QRS	Q-T	Corrected QT[4]
I	0,108 ± 0,007 (0,095 — 0,120)	0,110 ± 0,006 (0,100 — 0,122)	0,028 ± 0,005 (0,020 — 0,036)	0,220 ± 0,013 (0,193 — 0,240)	0,319 ± 0,012 (0,301 — 0,340)
II	0,105 ± 0,009 (0,095 — 0,123)	0,112 ± 0,006 (0,100 — 0,122)	0,034 ± 0,004 (0,025 — 0,040)	0,220 ± 0,012 (0,200 — 0,240)	0,318 ± 0,011 (0,298 — 0,333)
III	0,097 ± 0,009 (0,085 — 0,110)	0,097 ± 0,007 (0,090 — 0,110)	0,037 ± 0,004 (0,030 — 0,045)	0,217 ± 0,008 (0,200 — 0,225)	0,315 ± 0,009 (0,297 — 0,335)
aVR	0,108 ± 0,006 (0,100 — 0,120)	0,114 ± 0,007 (0,100 — 0,130)	0,032 ± 0,004 (0,025 — 0,040)	0,224 ± 0,016 (0,190 — 0,243)	0,321 ± 0,016 (0,293 — 0,338)
aVL	0,106 ± 0,009 (0,090 — 0,120)	0,111 ± 0,008 (0,100 — 0,125)	0,026 ± 0,009 (0,016 — 0,043)	0,213 ± 0,016 (0,180 — 0,240)	0,306 ± 0,018 (0,260 — 0,343)
aVF	0,107 ± 0,008 (0,096 — 0,120)	0,111 ± 0,007 (0,103 — 0,123)	0,038 ± 0,006 (0,030 — 0,050)	0,223 ± 0,019 (0,180 — 0,250)	0,319 ± 0,021 (0,286 — 0,347)

(1)Mean values over a period of 11 days are expressed with ± standard deviation; minimal and maximal values are in parentheses
(2)Measured from the peak of the P wave
(3)Measured from the beginning of the P wave
(4)Bazett's formula (Alfredson & Sykes, 1942) is used

TABLE 5 The time intervals (seconds) of PR, QRS and QT of the electrocardiogram of Sheep 789[1]
Heart rate = 79 ± 12
(60 — 112)

Lead	P-R[2]	P-R[3]	QRS	Q-T	Corrected QT[4]
I	0,108 ± 0,005 (0,100 — 0,120)	0,135 ± 0,010 (0,113 — 0,160)	0,030 ± 0,002 (0,025 — 0,035)	0,303 ± 0,015 (0,280 — 0,330)	0,350 ± 0,023 (0,036 — 0,093)
II	0,108 ± 0,005 (0,100 — 0,120)	0,133 ± 0,011 (0,110 — 0,150)	0,048 ± 0,002 (0,040 — 0,050)	0,301 ± 0,013 (0,280 — 0,320)	0,348 ± 0,024 (0,310 — 0,402
III	0,098 ± 0,005 (0,090 — 0,110)	0,116 ± 0,009 (0,100 — 0,140)	0,048 ± 0,003 (0,040 — 0,050)	0,296 ± 0,015 (0,270 — 0,320)	0,342 ± 0,025) (0,306 — 0,388)
aVR	0,120 ± 0,006 (0,110 — 0,130)	0,136 ± 0,007 (0,126 — 0,150)	0,045 ± 0,005 (0,040 — 0,055)	0,303 ± 0,011 (0,280 — 0,320)	0,345 ± 0,021 (0,323 — 0,402)
aVL	0,111 ± 0,005 (0,100 — 0,120)	0,128 ± 0,007 (0,116 — 0,140)	0,033 ± 0,008 (0,025 — 0,050)	0,290 ± 0,012 (0,270 — 0,310)	0,333 ± 0,019 (0,313 — 0,375)
aVF	0,103 ± 0,006 (0,090 — 0,115)	0,124 ± 0,008 (0,110 — 0,140)	0,050 ± 0,005 (0,040 — 0,060)	0,303 ± 0,014 (0,280 — 0,325)	0,348 ± 0,021 (0,323 — 0,388)

(1) Mean values over a period of 13 days are expressed with ± standard deviation; minimal and maximal values are in parentheses
(2) Measured from the peak of the P wave
(3) Measured from the beginning of the P wave
(4) Bazett's formula (Alfredson & Sykes, 1942) is used

B. *Wave Amplitudes and Configurations*

The values of minimum, maximum, mean and standard deviation of the P, QRS and T wave amplitudes in all six leads for all the sheep are given in Table 6. Values of these parameters for three individual sheep selected at random are given in Tables 7, 8 and 9.

TABLE 6 The amplitudes (mV) of the P, QRS and T waves of the electrocardiogram of 31 sheep[1]

Lead	P	QRS	T
I	0,203 ± 0,064 (0,020 — 0,400)	0,776 ± 0,238 (0,090 — 1,700)	0,285 ± 0,143 (0,100 — 1,000)
II	0,203 ± 0,065 (0,100 — 0,500)	1,498 ± 0,382 (0,200 — 2,900)	0,443 ± 0,268 (0,100 — 1,600)
III	0,064 ± 0,047 (0,000 — 0,500)	0,867 ± 0,306 (0,050 — 2,330)	0,223 ± 0,147 (0,050 — 0,900)
aVR	0,195 ± 0,061 (0,020 — 0,360)	1,077 ± 0,316 (0,100 — 2,300)	0,352 ± 0,193 (0,020 — 1,200)
aVL	0,106 ± 0,037 (0,010 — 0,250)	0,309 ± 0,169 (0,050 — 1,700)	0,126 ± 0,082 (0,010 — 0,900)
aVF	0,115 ± 0,066 (0,010 — 0,750)	1,122 ± 0,323 (0,110 — 2,000)	0 304 ± 0,201 (0,010 — 1,100)

[1]Mean values of 266 recordings of 31 sheep are expressed with ± standard deviation; minimal and maximal values are in parentheses

TABLE 7 The amplitudes (mV) of the P, QRS and T waves of the electrocardiogram of sheep 754[1]

Lead	P	QRS	T
I	0,211 ± 0,022 (0,200 — 0,250)	1,256 ± 0,075 (1,100 — 1,350)	0,216 ± 0,090 (0,100 — 0,400)
II	0,216 ± 0,035 (0,200 — 0,300)	2,007 ± 0,244 (1,560 — 2,300)	0,347 ± 0,165 (0,150 — 0,600)
III	0,081 ± 0,067 (0,030 — 0,200)	0,953 ± 0,561 (0,350 — 2,330)	0,167 ± 0,074 (0,100 — 0,300)
aVR	0,238 ± 0,033 (0,200 — 0,300)	1,583 ± 0,136 (1,400 — 1,800)	0,294 ± 0,128 (0,150 — 0,600)
aVL	0,114 ± 0,022 (0,100 — 0,150)	0,327 ± 0,137 (0,200 — 0,650)	0,077 ± 0,036 (0,050 — 0,150)
aVF	0,102 ± 0,025 (0,050 — 0,150)	1,347 ± 0,332 (0,630 — 1,800)	0,222 ± 0,093 (0,100 — 0,350)

[1]Mean values over a period of 9 days are expressed with ± standard deviation; minimal and maximal values are in parentheses

TABLE 8 The amplitudes (mV) of the P, QRS and T waves of the electrocardiogram of Sheep 794[1]

Lead	P	QRS	T
I	0,204 ± 0,035 (0,150 — 0,300)	0,736 ± 0,242 (0,090 — 1,000)	0,256 ± 0,087 (0,150 — 0,420)
II	0,204 ± 0,041 (0,150 — 0,300)	1,590 ± 0,245 (1,150 — 1,960)	0,389 ± 0,160 (0,200 — 0,700)
III	0,063 ± 0,023 (0,050 — 0,100)	0,821 ± 0,224 (0,400 — 1,230)	0,214 ± 0,112 (0,050 — 0,400)
aVR	0,187 ± 0,052 (0,030 — 0,230)	1,092 ± 0,373 (0,100 — 1,430)	0,387 ± 0,161 (0,200 — 0,800)
aVL	0,096 ± 0,032 (0,100 — 0,150)	0,193 ± 0,051 (0,150 — 0,330)	0,109 ± 0,020 (0,100 — 0,150)
aVF	0,124 ± 0,047 (0,020 — 0,200)	1,164 ± 0,297 (0,600 — 1,700)	0,326 ± 0,173 (0,100 — 0,700)

[1]Mean values over a period of 11 days are expressed with ± standard deviation; minimal and maximal values are in parentheses

TABLE 9 The amplitudes (mV) of the P, QRS and T waves of the electrocardiogram of Sheep 789[1]

Lead	P	QRS	T
I	0,161 ± 0,036 (0,100 — 0,200)	0,696 ± 0,047 (0,600 — 0,800)	0,207 ± 0,075 (0,100 — 0,400)
II	0,150 ± 0,035 (0,100 — 0,200)	1,273 ± 0,112 (1,150 — 1,500)	0,350 ± 0,129 (0,200 — 0,600)
III	0,057 ± 0,018 (0,050 — 0,100)	0,723 ± 0,107 (0,600 — 0,900)	0,265 ± 0,106 (0,100 — 0,500)
aVR	0,165 ± 0,031 (0,100 — 0,200)	0,930 ± 0,063 (0,800 — 1,000)	0,250 ± 0,081 (0,200 — 0,400)
aVL	0,103 ± 0,013 (0,100 — 0,150)	0,303 ± 0,024 (0,250 — 0,350)	0,150 ± 0,067 (0,050 — 0,300)
aVF	0,092 ± 0,018 (0,050 — 0,100)	0,984 ± 0,080 (0,900 — 1,100)	0,300 ± 0,119 (0,150 — 0,500)

[1]Mean values over a period of 13 days are expressed with ± standard deviation; minimal and maximal values are in parentheses

P wave

Except in lead aVR, where it was negative, the P wave was generally positive in all the leads. However, negative P waves were recorded 25 times in lead III in 13 sheep, as well as three times in lead I in two sheep, six times in lead aVL in four sheep and once in lead aVR.

In two of the 31 sheep a P wave with a double peak was encountered throughout.

T wave

The T wave was usually positive in leads I, II, III, aVL and aVF and negative in lead aVR. The following exceptions were noted: In leads I, II, III and aVF, negative waves were encountered in *c.* 40 instances in 13 sheep. In lead aVL this exception was encountered in 101 instances in 27 sheep. In lead aVR a positive T wave was recorded in 57 instances in 15 sheep.

QRS Wave

Since little variation in the QRS configuration occurred in individual sheep in consecutive registrations, the most general configuration for each sheep was selected and this is expressed in percentages in Fig. 3. Monophasic and diphasic wave configurations predominated. In only one of the six leads, lead aVL, a triphasic wave (qrs) was recorded in nine out of the 31 sheep.

Mainly two groups of configurations occurred: one where the size of the S wave remained constant and R was either absent, small or large (QS, rS, RS), and the other where S was always absent and Q and R always present, though they varied in size (QR, qR, qr). In lead aVL a very small QRS wave was registered under which the configurations qrs, rs and r were seen.

C. *Electrical axis and mechanical systole*

The QRS electrical axis in the sagittal plane had a mean value of 126° ± 14° for the group of 31 sheep (Table 10). This indicated that the mean vector was directed dorso-anteriorly (Fig. 4). These values varied from —90° to —198°. The above values for three individual sheep are shown in Table 10.

Mechanical systole is the time interval between the starting points of the first and second heart beats, as

Lead	QS	rS	RS	QR	qR	qr	qrs	rs	r
I	32	55	13						
II		87	13						
III	3	41	36						
aVR				3	97				
aVL						58	29	10	3
aVF		90	10						

FIG. 3 The QRS configurations of the electrocardiograms of 31 normal sheep given in precentages

determined on the phonocardiogram. This was found to be 0,282 ± 0,032 s (0,188 - 0,360). In Table 10 the data for three individual sheep and for the group as a whole are given.

3. *Influence of body position and of ruminal volume on the ECG*

Limited experiments were conducted to determine whether these changes had a significant influence on the ECG. Only minor QRS pattern changes were noticed in the electrocardiograms of the five sheep during alteration in body position, even though the amplitudes changed, as is implied by the changes in the electrical axes.

The influence on the sagittal QRS electrical axis was clear when the sheep were in dorsal recumbency, namely a shift of between 9° and 85° to a more vertical direction, as is shown in data summarized in Table 11. The biggest changes (34° and 85°) were encountered in Sheep 794, which also showed large variation in the standing position (± 26°, Fig. 4). The values in the other four sheep varied between 9° and 20°.

A change to the dextro-lateral position had a varying influence on the mean sagittal vector. In four instances out of nine a change of not more than 5° was encountered, in four cases a change of between 8° and 55° to a more vertical position was found and in one case a change of 46° in the opposite direction was seen. It was again Sheep 794 which showed the largest variation.

No significant changes were noted in the P and T waves.

Similarly, only very minor pattern changes due to an alteration in ruminal volume were noticed in the ECG of any of the four sheep examined. The QRS electrical axis, however, showed a slight trend towards a decreased angle when the ruminal volume increased. These results are summarized in Table 12. This indicates a more vertical direction of the electrical axis.

Discussion

Crawley & Swenson (1966) came to the conclusion that even though much was known about the use of the ECG in dogs, uncertainty still existed as to what could be considered a normal ECG and what changes in the recordings would indicate cardiac lesions. They found wide variations in the daily recordings of the dog. Their results also indicated that the wave forms of the

TABLE 10 The mean values, for 31 sheep and three individual sheep, of the electrical axes and mechanical systoles

	Mean	Sheep 754	Sheep 794	Sheep 789
Electrical axes	—126° ± 14° (—90° — —198°)	—131° ± 6° (—120° — —147°)	—138° ± 26° (—102° — —198°)	—124° ± 6° (—117° — —138°)
Mechanical systoles in sec	0,282 ± 0,032 (0,188 — 0,360)	0,235 ± 0,013 (0,216 — 0,260)	0,244 ± 0,010 (0,230 — 0,260)	0,329 ± 0,019 (0,298 — 0,360)

Standard deviations are given and minimal and maximal values are in parentheses

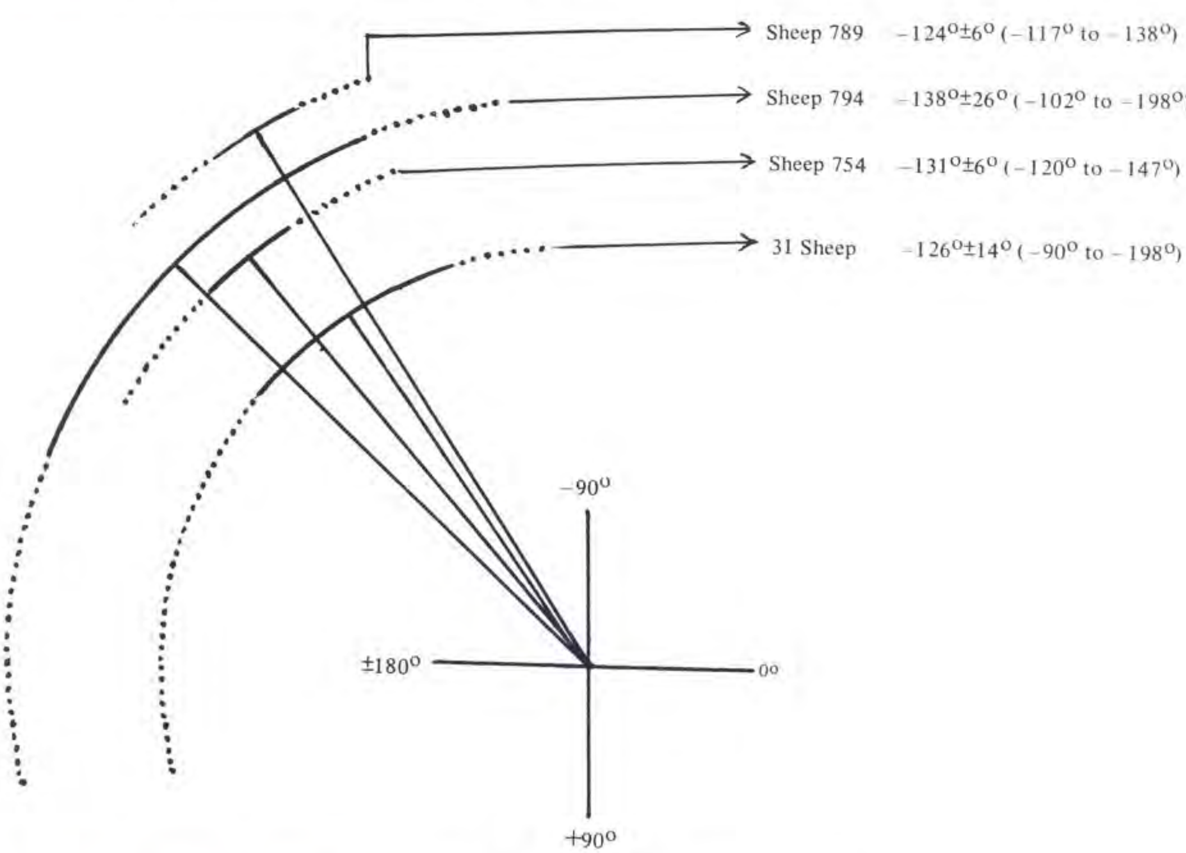

FIG. 4 The mean sagittal plane electrical axes of QRS for 31 sheep and three individual sheep

TABLE 11 Changes in the direction of the QRS electrical axes with changes of the body position

Sheep No.	Standing position	Dextro-lateral position	Change in axis	Dorsal position	Change in axis
754	—126°	—131°	—5°	—106°	+20°
761	—129°	—134°	—5°	—120°	+9°
	—133°	—138°	—5°	—118°	+15°
785	—118°	—117°	+1°	—108°	+10°
	—123°	—110°	+13°	—104°	+19°
788	—117°	— 90°	+27°	—97°	+20°
	—110°	—102°	+8°	—96°	+14°
794	—134°	—180°	—46°	—100°	+34°
	—175°	—120°	+55°	—90°	+85°

TABLE 12 The influence of the ruminal volume on the electrical axis during the QRS complex

Sheep No.	Small ruminal volume	Increased ruminal volume	Change
754	—134°	—123°	+11°
	—130°	—130°	0
761	—126°	—129°	— 3°
	—127°	—127°	0
785	—129°	—126°	+ 3°
	—129°	—117°	+12°
788	—122°	—115°	+ 7°
	—110°	—110°	0

conventional standard limb and unipolar lead methods were strongly influenced by body position, including the position of the feet. Smith, Hamlin & Crocker (1965) found that the same applied to ruminants.

Newton, Ellis & Zarmski (1960) using the standard limb lead method and working on anaesthetised dogs in dorsal recumbency, concluded that variations occurred between different dogs although day-to-day variation did not occur.

According to Szabuniewicz & Clark (1967) the QRS pattern in the goat, using the standard limb and unipolar lead methods, varied so much that no normal configuration could be described. However, variations between different goats were greater than the daily variations in the same goat.

As fixed points for the electrodes on the sheep's body had been used during this investigation on 31 sheep the position of the feet was not regarded as being important and thus not considered. With the Einthoven triangle in the sagittal plane, the wave forms were of a much more constant pattern than those obtained by other authors using the standard limb leads.

The high mean heart rate registered during this investigation, viz. 107 beats/min can be attributed to the fact that the recordings were done immediately after the sheep had been placed in the crate and consequently they had not calmed down sufficiently to have heart rates within normal limits, 75(60-120)/min (Swenson, 1970). Apart from the QT interval (where Bazett's formula was used to compensate for the high heart rate) this had no significant influence on the results.

The P wave varied little except in lead III where it was negative in 9,4% of the total number of recordings in 42% of the sheep. In Tables 6, 7, 8 and 9, however, it is indicated that the P wave in this lead is extremely small. Lead II consistently produced a positive P wave whereas in lead aVR it was always negative. In 6,4% of the sheep negative waves were occasionally encountered in lead I; these amounted to only 1,1% of such recordings for the whole group. Similarly in leads aVL and aVF respectively 13% and 3,2% of the sheep showed this change, amounting to 2,2% and 0,4% of such recordings for the entire group.

More variation was encountered with the T wave than with the P wave. In leads I, II, III and aVF the variation was approximately the same and the T wave generally assumed a positive form except in 15% of the recordings in 42% of the total number of sheep where a negative form was recorded. In lead aVR this wave was generally negative except in 21,4% of the recordings in 48,3% of the total number of sheep. In lead aVL the amplitudes of the T waves (as well as those of all the other waves) were very small and difficult to define with accuracy: they seemed, however, to vary greatly.

As far as the QRS pattern is concerned, it would appear that a much greater uniformity was encountered in this investigation than in those reported by other authors. In leads I and III the S wave remained constant while the R wave was either absent, small or large (Fig. 3). In leads II and aVF the same pattern occurred except that the R wave was always present. In lead aVR, the R wave was constant but the size of the Q wave varied, though it was always present. In lead aVL the QRS complex was always extremely small with a great variation in configuration.

In comparison with the results of Szabuniewicz & Clark (1967), the amplitudes of all the waves recorded during this investigation were much greater.

A vector study of the QRS complex in the sagittal plane indicated that the electrical axis had a mean value of —126° during total depolarization of the ventricles (Table 2). This is in agreement with the observations of Hamlin & Scher (1961), who obtained sagittal plane recordings in the goat and concluded that the activation of the ventricles occurs chiefly in a dorsal and slightly cranial direction, i.e. from the apex to the base of the heart. Hamlin & Smith (1960) had obtained the same results. Hamlin, Smith & Redding (1960) found the electrical axis to be —150°. Their recordings were also made in the sagittal plane, as in this investigation, though they employed different electrode positions.

Except for the QRS interval, which compares favourably with that reported in goats by Szabuniewicz & Clark (1967), the time intervals of all six leads in this investigation were comparatively shorter. This is possibly due to a lower mean heart rate obtained by the above authors. Pretorius & Terblanche (1967) found the mean values for lead II in sheep to be PQ = 0,109, QRS = 0,034 and QT = 0,302 s as compared with PQ = 0,102, QRS = 0,046 and QT (uncorrected) = 0,262 s in this investigation. Platner, Kibler & Brody (1948) reported the time intervals of the same parameters, when the mean of three leads was taken in 12 sheep, as

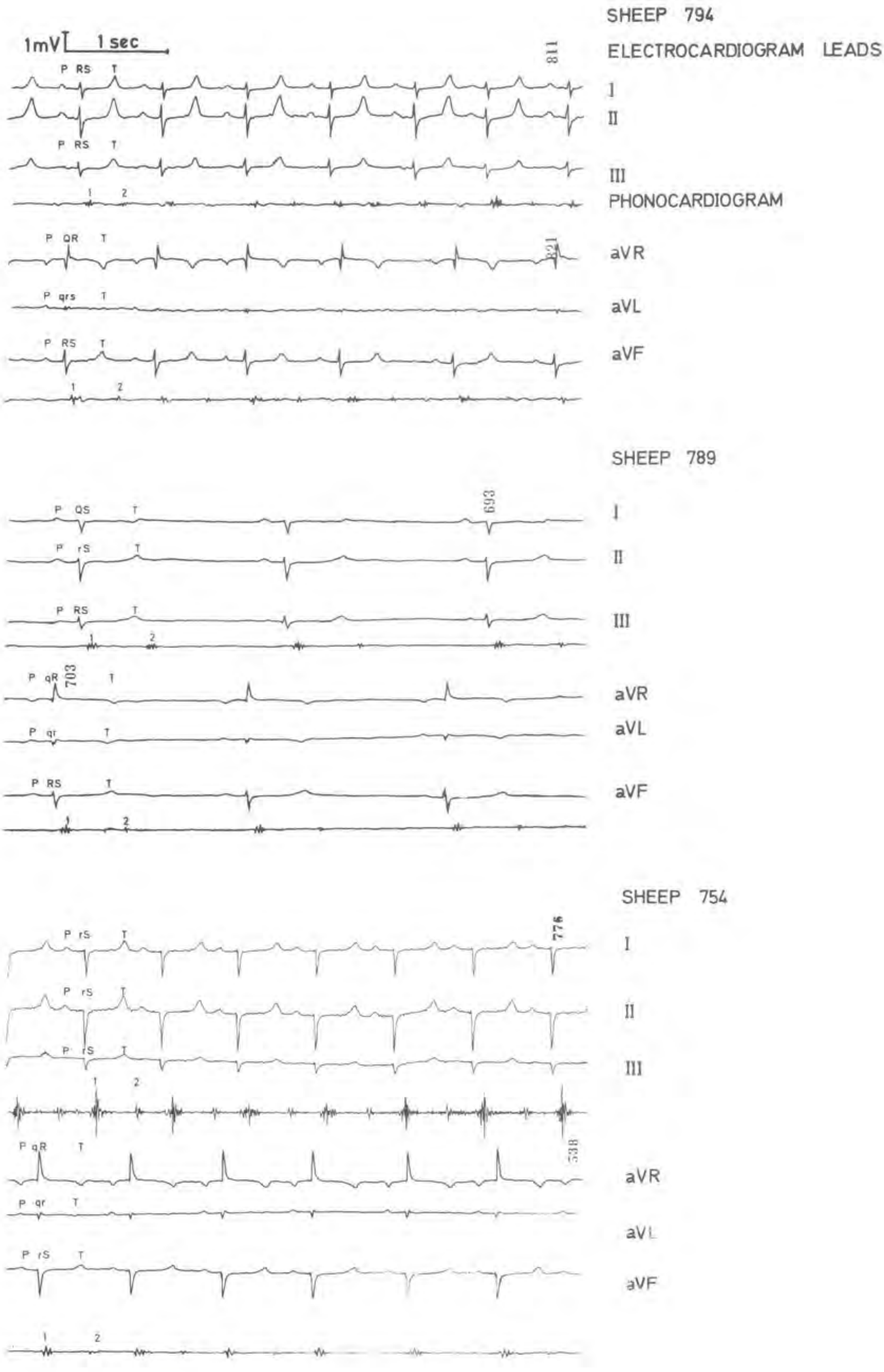

FIG. 5 The six leads of the electrocardiogram and the phonocardiogram of three normal sheep to demonstrate individual variations

0,115 ± 0,0099 (0,100 — 0,133), 0,076 ± 0,0027 (0,060 — 0,087) and 0,386 ± 0,0079 (0,327 — 0,427) s. In both the above reports the QT times were corrected with Bazett's formula, $K = \frac{QT}{\sqrt{RR}}$ (Alfredson & Sykes, 1942), whereas in the present investigation it was used only in three individual cases (Tables 3, 4 and 5). This resulted in longer QT times but the standard deviations were not decreased as expected. The excessively high heart rate registered could possibly explain this phenomenon.

Hamlin *et al.* (1960) found the QRS time interval in lead aVF to be 0,035 (0,028 — 0,045) s, which is somewhat shorter than the time interval recorded here, viz. 0,047 (0,004 — 0,075) s.

It can, therefore, be concluded that in the present investigation the problem of large individual variation was overcome to some extent. A more uniform QRS configuration (Fig. 3) was found than was reported in the case of goats by Szabuniewicz & Clark (1967).

The P and T waves also showed less confusing variation than was reported by Pretorius & Terblanche (1967) and the T wave less than that reported by Smith *et al.* (1965). Platner *et al.* (1948), however, also found a constant P wave. In accordance with the results of Szabuniewicz & Clark (1967) the wave configuration of each individual sheep varied less than that of the group (see standard deviations in Table 2 to Table 5) although the smaller number of animals used here could have influenced this. Larger variations were encountered in the P and T waves than in the QRS wave in lead III and aVL respectively (Fig. 3). Conspicuous QRS configuration changes did not occur in individual sheep, but the wave form did vary greatly in different sheep (Fig. 2 and 5).

In an effort to find the cause of the variation in wave configuration, limited experiments were conducted to determine the effect of body position and ruminal volume on the ECG. The QRS electrical axis was influenced by body position: when in dorsal recumbency, the QRS axis in all cases moved more vertically as compared with the standing position. Dextrolateral recumbency had the same effect in five instances out of the nine recordings (Table 11). A more vertical direction, though smaller than with dorsal recumbency, was also obtained in four out of nine cases with a larger ruminal volume (Table 12). Although changes in body position and ruminal volume influenced the QRS electrical axis, the P and T waves showed little change.

Summary

Electrocardiograms and phonocardiograms were recorded from 31 normal Merino wethers. Einthoven's triangle was moved to a sagittal position in an attempt to obtain uniform recordings in the same and in different sheep. Leads I, II, III, aVR, aVL and aVF were recorded. Heart frequency, time intervals, wave amplitudes, QRS electrical axes and durations of mechanical systole were obtained from these recordings.

Using this technique the P wave showed large variations in lead II only, whereas the QRS configuration could, with the exception of that for lead aVL, be divided mainly into two groups. These results are superior to those obtained by means of standard limb leads where no such groups could be detected.

Compared with the standard method, this modified technique resulted in more reproducible ECG recordings in the standing sheep which had not been treated with either sedative or tranquilizing drugs.

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