Comparative Study of the Body Surface Electrocardiogram in Double-muscled and Conventional Calves

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ABSTRACT

The purpose of this work was to study electrocardiographic features of double-muscled beef cattle.

Electrocardiograms were recorded on one to six occasions from each of a group of 18 conventional calves of the Friesian breed and 29 double-muscled calves of the Belgian White and Blue breed. Ages of the calves at the times of examination ranged from eight to 348 days.

The Holmes semi-orthogonal lead system was used. The waves and interval durations and the tridimensional P, QRS, and T modal vector orientation and amplitude were calculated.

The magnitude of the cardiac vectors was significantly lower and the ventricular waves and QT interval duration significantly shorter in the double-muscled than in the conventional calves. The P modal vector pointed significantly less downwards and the QRS modal vector pointed significantly more forwards and less up- and rightwards in the Belgian White and Blue, than in the Friesian group.

Most of the observed differences might be a consequence of the bodily, and more specifically the thoracic, conformation of the former calves. However, the lower cardiac vector magnitude and shorter wave and interval durations might also reflect lower cardiac mass in the double-muscled subjects.

RÉSUMÉ

Le but de cette étude était d'étudier les spécificités électrocardiographiques des bovins de boucherie de conformation hypermusclée.

Des enregistrements électrocardiographiques ont été réalisés de une à six reprises chez chacun des 18 veaux conventionnels de la race Frisonne et des 29 veaux hypermusclés de la race Blanc Bleu Belge investigués et répartis en deux groupes. L'âge des veaux au moment des investigations était compris entre huit et 348 jours.

Le système de dérivation semi-orthogonal de Holmes a été appliqué. La durée des ondes et des intervalles électro-cardiographiques ainsi que l'orientation et l'amplitude des vecteurs cardiaques tridimensionnels P, QRS et T ont été calculées.

L'amplitude des vecteurs cardiaques était significativement plus petite et la durée des ondes ventriculaires et de l'intervalle QT significativement plus courte chez les veaux hypermusclés que chez les veaux conventionnels. Le vecteur P était orienté dans une direction significativement moins ventrale et le vecteur QRS dans une direction significativement plus craniale et moins dextro-dorsale chez les veaux hypermusclés que chez les veaux conventionnels.

La plupart des différences observées pourraient être attribuées à une conformation corporelle, et particulièrement thoracique, spécifique chez les veaux hypermusclés. Cependant, la plus faible amplitude des vecteurs cardiaques et la durée plus courte des ondes et intervalles électro-cardiographiques pourraient également constituer le signe d'une réduction de la masse myocardique chez ces derniers.

INTRODUCTION

In meat production, interest in double-muscled cattle is increasing because of the exceptional commercial value of these cattle. As regards the feed-conversion ratio, the selling price per kilogram liveweight, the daily net income, the killing-out percentage, the carcass composition, the fat deposition and the meat tenderness, purebred Belgian White and Blue double-muscled cattle are significantly superior to dairy and crossbred types (1–3). However, double-muscled cattle have higher morbidity and mortality rates than do cattle with conventional conformation (4). This has been related to a lower oxidative metabolic capacity. When exposed to stress, such as muscular exercise, metabolic needs are met earlier by anaerobic metabolism in double-muscled than in conventional cattle (5,6). Each step of the oxygen-transport pathway may be responsible for this lower oxidative capacity in double-muscled cattle, including the cardiovascular system, which is considered a potential limiting factor. Indeed, selection of the gene responsible for the double-muscled conformation in the bovine species induced reduction of the heart weight-to-body weight ratio (7,8) and lower cardiac pumping capability during exercise (6). The study of the causes and mechanisms of the potential limiting role of the cardiovascular system in the aerobic metabolism of double-muscled cattle is thus of great interest.

In human and small animal species, electrocardiography is a useful noninvasive tool for detecting changes in cardiac size induced both by pathological conditions (9,11–14) or by

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physiological adaptation to training (15–20). In these species, the diagnosis of cardiac-chamber hypertrophy or enlargement is generally based on the scoring of several electrocardiographic criteria, i.e. waveform durations, voltage of waves in different leads, interval segment shifts, and magnitude and orientation of the cardiac vectors (21–24). In ungulates, electrocardiography is a relatively insensitive indicator of cardiac-chamber enlargement. Indeed, the specific disposition of the Purkinje fibers leads to extensive cancellation of cardiac electrical forces in the body surface electrocardiogram (10,13,25–27). In spite of this limitation, however, some authors have suggested that physiological or pathological changes in myocardial mass might be associated with alterations in various electrocardiographic and vectocardiographic parameters in horses (28–32). The same might be true in the bovine species. However, in the latter species, vectocardiographic data are incomplete (33–38). Moreover, the data reported are of limited value because of the great variation and lack of accuracy in the lead systems used (39). To resolve this latter problem, a semi-orthogonal lead system has been developed for cattle and has been shown to generate reproducible and mutually comparable measurements of tridimensional cardiac modal vectors (39).

The purpose of the present study was to use this lead system to compare electrocardiographic and vectocardiographic data in double-muscled calves and in calves of conventional conformation.

MATERIALS AND METHODS

ANIMALS

Two groups of calves were investigated. The first one consisted of 18 calves of the Friesian breed, 8-to 348-days old, weighing 27 to 275 kg, and with a conventional conformation. The second group consisted of 29 calves of the Belgian White and Blue breed selected for their double-muscled conformation. These calves were aged from 27 to 343 days and weighed 56 to 297 kg. All calves were healthy on the basis of clinical history and a careful physical examination.

In the first group, seven, five, one, and three calves were studied three, four, five and six times, respectively, as they grew, producing a total of 64 electrocardiograms. In the second group, four calves were studied twice as they grew and four others four times, two calves were studied five times and two others six times, and 17 calves were studied once, producing a total of 63 electrocardiograms.

PROTOCOL

Electrocardiograms were obtained by means of a one-channel recorder (Cardiofax GEM, Nihon-Kondem, Tokyo, Japan) connected to a rapid writing polygraph (ES 1000, Gould, Brussels, Belgium) which allowed recording at a paper speed of 100 mm/sec. Before and after each investigation, calibration was performed at a sensitivity ranging from 4 to 8 cm per mV. The calves stood on a rubber mat for insulation during the recording sessions. The electrocardiogram was only recorded when the heart rate was in the resting range and when the calf was standing in a square position. The animals were not sedated.

Cardiac electrical activity was analyzed using the semi-orthogonal lead system initially developed for horses (40,41), and recently adapted for cattle (39). The anteroposterior (Y axis) lead consisted of two electrodes, the positive being sited on the abdomen on the midline, cranial to the xyphoid process, and the negative cranial to the manubrium's anterior point midway between the shoulders. The dorsoventral (Z axis) lead consisted of a positive electrode sited on the withers at the level of the dorsal spinous process of the sixth thoracic vertebra and a negative electrode sited on the sternum midline midway between the two elbows. The left to right (X axis) lead consisted of two tin plates 15 cm square, which were held in place by means of a large thoracic elastic strap in the right and left lower third of the thorax just behind and under the elbow in front of the fourth to the seventh intercostal space. The left and right tin plates were the positive and negative electrodes, respectively. Electrocardiograms were recorded using a bipolar lead.

CALCULATIONS

The waves and interval durations were measured as described (36) and averaged from five successive beats. The values derived from the Y, Z and X leads were averaged. For each of the Y, Z, and X leads, the morphology of P, QRS, and T complexes was analyzed following the usual conventions (36). For five successive cardiac cycles, the sum of the positive and negative deflections was calculated for the P, QRS, and T complexes. In order to allow magnitude and angle measurement, modal P, QRS, and T vectors were graphically constructed, as described elsewhere (39), in the horizontal, transverse, and sagittal planes and in space. The terminology in measuring angles and viewing planes recommended by Holmes (42) was adopted.

STATISTICAL ANALYSIS

In order to examine the effect of breed on heart rate and vectocardiographic parameters (i.e. vector amplitudes and orientation), a mixed model for repeated measures was fitted to the data (43) and analyzed using a computer program (SAS PROC GLM, SAS Institute Inc., Cary, North Carolina). The model was in general form:

$$Y = \mu + B_i + a_{ij} + b. (X_{ijk} - X) + e_{ijkl}$$

where

Y = vectocardiographic variable;
μ = overall mean;
B_i = fixed effect of the i^{th} breed;
a_{ij} = random effect of the j^{th} individual of the i^{th} breed;
b = linear regression coefficient for each vectocardiographic parameter on body weight (X); and
e_{ijkl} = residual error

In the second step, the same analysis was made within each breed, and the least-squares mean was calculated.

In order to examine the effect of breed on waves and interval durations, the same model was applied, with heart rate as an additional effect.

RESULTS

The relationship between age and body weight of the calves was close in each group, as demonstrated by a correlation coefficient of 0.96 in both groups. The magnitude of most of the cardiac modal vectors was significantly ($p \leq 0.001$) lower in the double-muscled than in the conventional calves (Table I).

In both groups, the mean P and T modal vectors pointed downwards, backwards and to the left (Table II, Fig. 1), while the mean QRS modal vectors pointed upwards, forwards and to the right (Table II). The modal P vector tended to be slightly more sinistrocaudal and pointed significantly ($p \leq 0.01$) less downwards in the Belgian White and Blue than in the Friesian calves (Table II, Fig. 1). The orientation of the QRS modal vector was significantly ($p \leq 0.01$ to 0.001) less upwards, more forwards, and less rightwards in the double-muscled calves than in the calves with conventional conformation (Table II).

The heart rate did not differ between the two groups (Table III).

The duration of the P wave tended to be shorter in the Belgian White and Blue than in the Friesian calves, but this difference was not statistically significant. The duration of the QRS and T waves was significantly ($p \leq 0.001$) shorter in the double-muscled than in the conventional calves (Table III).

The duration of the QT interval was significantly ($p \leq 0.05$) longer in the Friesian than in the Belgian White and Blue calves. The duration of the ST interval was significantly ($p \leq 0.01$) shorter in the conventional than in the double-muscled calves (Table III).

TABLE I. Least square mean (LSM) and level of significance (LS) of the breed effect on the tridimensional and spatial cardiac vector magnitude (in mV) in 18 Friesian (F, n = 64) and 29 double-muscled Belgian White and Blue (BMB, n = 63) healthy calves

		LSM ± SEM F calves	LSM ± SEM BWB calves	LS	R^2
P	Hor	0.156 ± 0.006	0.155 ± 0.007	NS	0.56
	Trans	0.172 ± 0.007	0.129 ± 0.008	***	0.51
	Sag	0.211 ± 0.005	0.177 ± 0.006	***	0.65
	Spat	0.222 ± 0.006	0.189 ± 0.007	***	0.60
QRS	Hor	0.581 ± 0.021	0.581 ± 0.024	NS	0.80
	Trans	0.877 ± 0.015	0.624 ± 0.017	***	0.81
	Sag	1.006 ± 0.014	0.835 ± 0.016	***	0.83
	Spat	1.208 ± 0.140	0.919 ± 0.161	***	0.85
T	Hor	0.312 ± 0.018	0.179 ± 0.021	***	0.60
	Trans	0.434 ± 0.012	0.269 ± 0.014	***	0.77
	Sag	0.510 ± 0.015	0.305 ± 0.016	***	0.71
	Spat	0.527 ± 0.016	0.319 ± 0.018	***	0.72

*** $p \leq 0.001$

Hor, Trans, Sag, Spat = horizontal, transversal, sagittal, and spatial vector, respectively; R^2 = determination coefficient of the linear model; NS = not significant

TABLE II. Least square mean (LSM) and level of significance (LS) of the breed effect on the tridimensional cardiac vector orientation and on the angle of elevation of the spatical vector to the horizontal plane (in °) in 18 Friesian (F, n = 64) and 29 double-muscled Belgian White and Blue (BMB, n = 63) healthy calves

		LSM ± SEM F calves	LSM ± SEM BWB calves	LS	R^2
P	Hor	67.5 ± 1.9	64.0 ± 2.2	NS	0.37
	Trans	287.3 ± 5.0	299.9 ± 5.8	NS	0.27
	Sag	307.6 ± 5.6	319.5 ± 6.5	NS	0.28
	Spat	−44.1 ± 2.2	−35.3 ± 2.5	**	0.36
QRS	Hor	245.4 ± 3.3	259.3 ± 3.8	**	0.50
	Trans	106.4 ± 1.7	102.7 ± 1.9	NS	0.68
	Sag	122.4 ± 1.5	132.3 ± 1.7	***	0.77
	Spat	54.5 ± 1.4	46.1 ± 1.6	***	0.76
T	Hor	80.0 ± 10.6	81.9 ± 12.2	NS	0.36
	Trans	284.7 ± 3.8	287.9 ± 4.3	NS	0.44
	Sag	289.9 ± 4.8	302.1 ± 5.9	NS	0.39
	Spat	−53.1 ± 2.2	−52.1 ± 2.5	NS	0.54

** $p \leq 0.01$; *** $p \leq 0.001$

See Table I for key

DISCUSSION

The amplitude of the potentials recorded on the body surface is determined by the nature of the electrical generator, the conductive properties of the body volume, and the spatial relationship between the surface point and the heart within the thorax (44). In this way, all of the following factors affect the magnitude of the electrocardiographic waves: 1) thickness of the thoracic wall (12,45), 2) shape of the thorax (12,20,44,46), 3) conductive properties of the volume conductor that surrounds the heart (11,45,47–49), 4) intracardiac blood volume (47,50–53), 5) blood resistivity (51,52), 6) extent of cancellation of mirror-image forces (54), 7) myocardial electrical properties (11,47, 55–57), 8) cardiac mass (11,12,29,48, 52,54), 9) distance between the cardiac generator and the exploring electrodes (48), and 10) position of the anatomical and electrical axis of the heart within the thorax (11,44,47, 54,58).

In our study, the tridimensional modal vectors, except for the horizontal P and QRS vectors, were of significantly lower magnitude in the double-muscled than in the conventional calves. Several of the aforesaid factors might account for these differences. For example, as compared with dairy or crossbred cattle, purebred Belgian White and Blue double-muscled cattle are smaller and shorter, so their index of compactness is higher (3). The chest is significantly more shallow and the heart girth is higher in double-muscled than in conventional cattle. A round rib cage with a large thorax, moreover, is used as a criterion for the selection of double-muscled subjects in the Belgian White and Blue breed (59). The thoracic shape, which is narrower in the Friesian calves than in the double-muscled Belgian White and Blue calves, likely contributed to a proximity effect and thus to higher cardiac modal vector amplitudes in the former group.

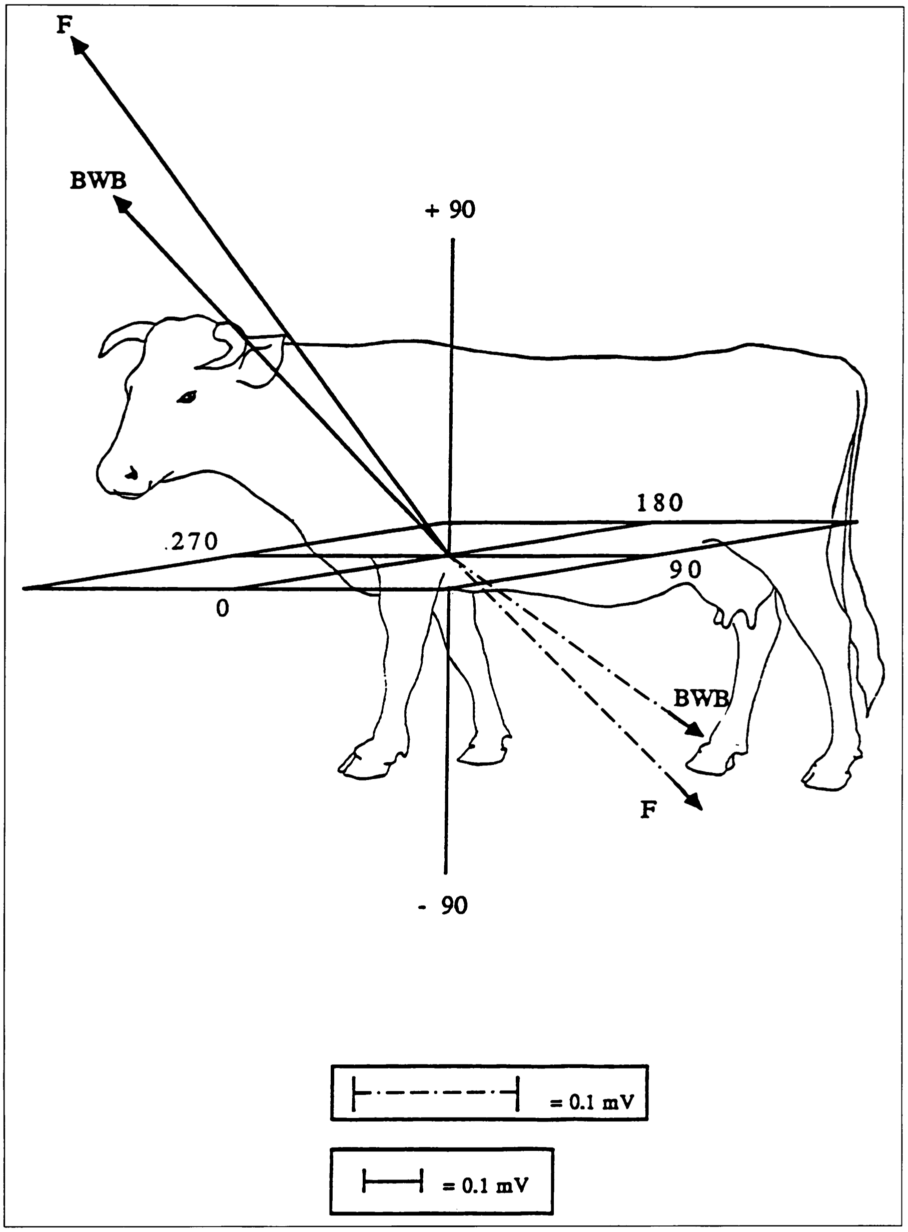

Fig. 1. Mean spatial orientation of the P (solid lines) and the QRS (dotted lines) cardiac vector obtained from Friesian (F, n = 64) and Belgian White and Blue (BWB, n = 63) healthy calves.

Enlargement of the thorax in the double-muscled calves, as compared to calves with the conventional conformation, may also cause the lungs to envelope the heart to a large extent, thus leading to a greater insulating effect of inspired air. However, this hypothesis is unlikely because the lung weight-to-body weight ratio (7,8) and respiratory specific tidal volume (4) have been shown to be lower in double-muscled than in conventional cattle. Thoracic-wall thickness of double-muscled calves is greater than in conventional calves because of greater development of the trapezius and latissimus dorsi muscles (1,3). This may cause a decrease in the voltage of the surface electrocardiogram. If the cardiac index was lower in double-muscled than in conventional calves, lower intracavitary blood volume might also play a role in lower vector magnitude because of the so-called Brody effect. When there is an increase in low resistance intracardiac blood volume in dogs and human beings, dipoles orientated radially are increased while tangentially oriented dipoles are decreased (47,50,51). Resistivity of the intracardiac blood is unlikely to account for the vector amplitude differences observed in the two groups of calves studied here, because the hematocrit, which is the major determinant of blood resistivity, is similar in double-muscled and conventional calves (60).

In the bovine species, the relationship between cardiac vector magnitude and myocardial muscle mass is essentially unknown. The relationship is likely to be of less value in cattle than in human beings and small animals, however, because of the more profound penetration of the Purkinje fibers in the myocardium of the former species. Previous postmortem studies reported a 10 to 15% reduction in the heart weight-to-body-weight ratio in double-muscled cattle as compared with conventional cattle (7,8). Therefore, the lower cardiac vector magnitude found in double-muscled calves in our study might also reflect a lower myocardial mass.

In the Friesian calves, orientation of the P modal vector was significantly more downwards and QRS modal vector significantly less forwards, and more rightwards and upwards than in the Belgian White and Blue calves. Several factors are known to affect orientation of spatial vectors. For example, in human, canine and equine species, pathological (9,11,12,13,27–30,57) or training-induced physiological (15,19,20,32) hypertrophy of atrial and ventricular walls have been suspected of inducing a shift of the corresponding vectors towards the hypertrophied chamber. In our study, the orientation of the cardiac vectors did not appear to be indicative of relative hypertrophy of a cardiac chamber in one of the two groups of calves. The significant leftwards shift of the QRS modal vector found in double-muscled calves was not associated with a shift backwards. A backwards shift of vectors usually occurs in cases of left ventricular hypertrophy (12,27,28,30), since the left ventricle lies in a caudal position in animals (44). On the contrary, in the present study, the leftwards shift of the QRS modal vector in the Belgian White and Blue calves was associated with a shift forwards, in the direction of the right ventricle.

Bundle branch block (11) and diseases associated with electrolytic imbalance (29,57) are also conditions that are known to induce a shift in cardiac vector orientation. Since all the animals in our study were healthy and had a regular rhythm, such factors most probably did not account for the differences observed between the two groups. However, the position of the heart within the thorax is a factor that might be involved. Indeed, changes in the position of the heart within the thorax induced by respiration (11,53,61), somatic growth (61,62), obesity (11,63), or any increased pressure on the diaphragm caused by abdominal fill, such as occurs with recumbency (11) or gestation (61,62), are known to produce a rotation of cardiac vectors.

The P and QRS modal vectors pointed in a direction more vertical in the Friesian calves than in the Belgian White and Blue calves. This may have been induced by a caudal rotation of the apex of the heart around its dorsoventral axis in the double-muscled calves, which produces a slightly more tilted heart position within the thorax. This, in turn, might be due to a specific topographic relationship between the heart and other thoracic organs. The QRS modal vector orientation in our double-muscled calves was closer to that found in horses by Holmes and Else (41) than to that found in conventional calves. This might be interpreted as being due to thoracic conformation of the double-muscled calves, which is closer to that of the equine thorax than to that of conventional calves (3). However, differences in topographic relationship between the cardiac electrical axis and body surface electrode positions might also account for differences in cardiac vector orientation between the two groups.

The duration of the QRS and T waves and of the QT interval was significantly shorter and the duration of ST interval significantly longer in the Belgian White and Blue than in the Friesian group. This might be due to a shorter impulse conduction pathway through the ventricles in the double-muscled than in the conventional calves. However, capacitance effects, proximity effects, variation in conductance, and variation in electrode position are also factors which might be responsible for the observed differences.

TABLE III. Least square mean (LSM) and level of significance (LS) of the breed effect on heart rate (HR, in beats/min) and on duration of waves and intervals (in msec) in 18 Friesian (F, n = 64) and 29 double-muscled Belgian White and Blue (BMB, n = 63) healthy calves

	LSM ± SEM F calves	LSM ± SEM BWB calves	LS	R^2
HR	89.2 ± 2.0	92.9 ± 2.3	NS	0.60
P	80.4 ± 2.4	74.6 ± 2.8	NS	0.36
QRS	81.8 ± 2.0	68.2 ± 2.4	***	0.51
T	121.8 ± 2.9	94.5 ± 3.3	***	0.59
PR	151.8 ± 3.4	151.5 ± 3.9	NS	0.55
QT	323.6 ± 5.9	302.6 ± 6.8	*	0.61
ST	121.1 ± 4.0	138.8 ± 4.6	**	0.64

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$
See Table I for key

The heart-score theory proposes a relationship between the duration of the QRS complex and ventricular weight, allowing some prediction of aerobic work capacity (27). This theory has been widely applied, although with considerable controversy, in man (64), dog (65), and horse (66–72). However, an increase in QRS duration also occurs with pathological or physiological ventricular hypertrophy in man (11,12,16,21), dog (9,14,73), pig (74), and horse (27,30). In cattle, no attempt has been made to correlate the duration of the QRS complex with heart weight.

In conclusion, while the study identifies significant breed differences, the results do not allow the source of these differences to be determined. However, while the lower amplitude of the cardiac modal vectors found in double-muscled than in conventional calves might be attributed to the characteristic thoracic shape of the former, they would also be consistent with the lower heart weight-to-body weight ratio previously demonstrated in double-muscled cattle (7,8). The shorter ventricular wave and interval durations found in the double-muscled calves would also be consistent with lower cardiac mass.

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