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Echocardiographic evaluation of cardiac morphologic and functional variables in double-muscled calves

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SUMMARY

We studied, by means of echocardiography in vivo, the cardiac consequences of the double-muscled character selection in beef cattle. Morphologic and functional echocardiographic variables were regularly estimated in 17 Friesian and 8 Belgian White and Blue calves during their growth. A total of 50 and 44 sets of data were collected in each group, respectively. Recordings were obtained, using 2-dimensional and M-mode echocardiography, and included measurements in long- and short-axis views of the heart.

Most of the diastolic measurements of the left ventricle were not significantly different between breeds when normalized for body weight. To the contrary, systolic measurements of left ventricular wall thickness and dimensions were significantly ($P \leq 0.001$) lower and greater, respectively, in Belgian White and Blue calves than in Friesian calves. This was interpreted as a result of significantly ($P \leq 0.001$) lower left ventricular systolic functional indices in Belgian White and Blue than in Friesian calves.

Echocardiographic evidence that the double-muscled selection in cattle induces alteration in morphologic variables of left ventricle was not found. However, results indicate that indices of left ventricular systolic function are lower in double-muscled calves than in calves with standard conformation.

In the field of bovine meat production, double-muscled cattle have gained great economic importance because of their marked muscular hypertrophy and the good organoleptic qualities of their meat. However, double-muscled cattle have greater morbidity and mortality than do cattle with standard conformation.[1] This has been related to a lower oxidative metabolism capacity. When exposed to stress, such as muscular exercise, metabolic needs are met earlier by anaerobic metabolism in double-muscled than in standard cattle.[2,3] Each step of the oxygen-transport pathway may be responsible for this lower oxidative capacity in double-muscled cattle. Among these steps, the cardiovascular system has been considered as a potential limiting factor. Selection of the gene responsible for the double-muscled conformation in the bovine species induced reduction of the heart weight-to-body weight ratio,[4,5] decrease in cardiac and stroke indices,[6] and lower cardiac pumping capability during exercise.[3] The study of the causes and mechanisms of the potential limiting role of the cardiovascular system in aerobic metabolism of double-muscled cattle is, thus, of great interest and requires complete investigation of cardiac morphology and function.

Echocardiography provides a safe and noninvasive means of obtaining quantitative information about cardiac morphology and function.[7] The technique, already applied in several other species, has been shown to be feasible,[8] accurate, and reproducible[9] in the bovine species.

The purpose of the study reported here was to apply echocardiography in cattle to investigate possible cardiac adaptations to the intensive selection of the double-muscled conformation in this species.

Materials and Methods

Calves—Two groups of calves were studied. The first consisted of 17 calves (body weight, 25 to 125 kg, with mean ± SEM of 70.7 ± 4.4 kg; age, 12 to 128 days, with mean ± SEM of 64.3 ± 5.4 days) of the Friesian breed, which was considered to be of standard conformation. For the second group, 8 calves (body weight, 45 to 144 kg, mean, of 89.6 ± 4.0 kg; age, 15 to 119 days, mean, of 70.3 ± 4.4 days) of the Belgian White and Blue breed were selected on the basis of their double-muscled conformation. The evolution of body weight with age in the 2 groups of calves was determined (Fig 1).

All calves were considered healthy and free of cardiac diseases, as determined by clinical history and lack of abnormalities on physical examination, auscultation, and electrocardiography.

In the first group, all calves were studied 3 times during their growth, except one, which was studied twice. A total of 50 sets of data was thus collected from this group, and the mean interval between successive echocardiographic investigations was 36 days.

In the second group, 4 calves were studied 5 times and the 4 others were studied 6 times. In this group, 44 sets of data were thus collected, and the mean interval between successive echocardiographic investigations was 17 days.

Echocardiographic protocol—Echocardiography was conducted as described.[9] Two-dimensional (2D) and cursor-directed M-mode echocardiograms were obtained, using electronic scanning ultrasound equipment[a] with a 5.0-

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[a] Sono Layer, model SAL 77B, Toshiba, Tokyo, Japan.

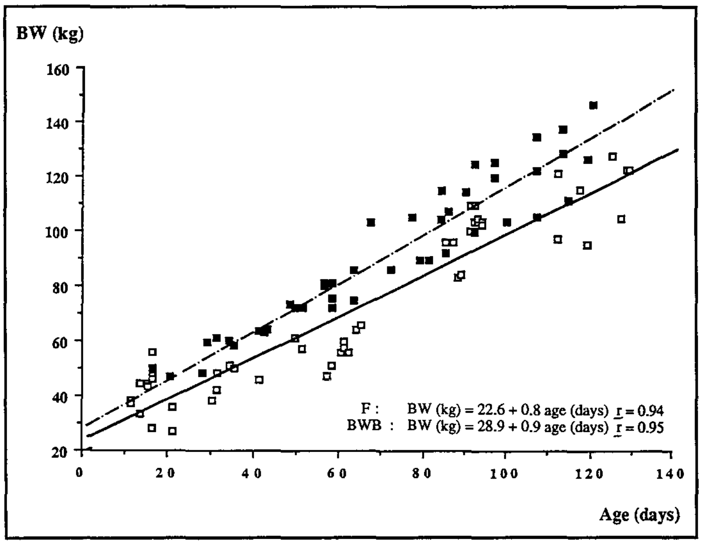

Figure 1—Relation between body weight (BW) and age of the 17 Friesian (F, open squares, solid regression line, n = 50) and the 8 Belgian White and Blue (BWB, closed squares, dotted regression line, n = 44) calves. The *r* value is correlation coefficient.

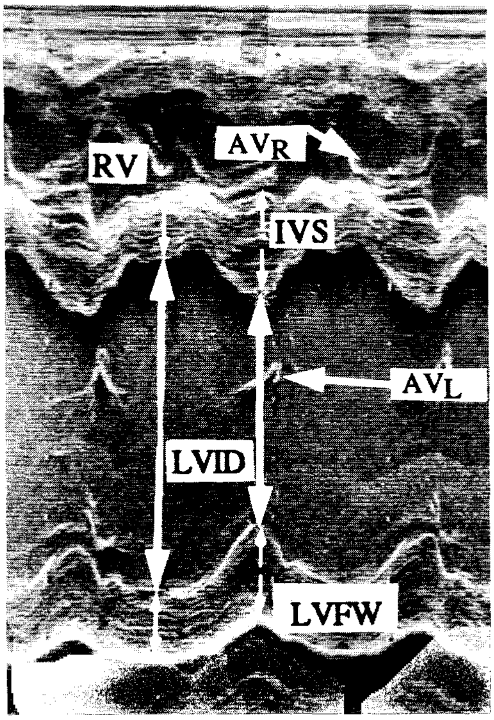

Figure 2—M-Mode long-axis view of the left ventricle obtained from a Friesian calf weighing 57 kg. Method of systolic and diastolic measurement of interventricular septum thickness (IVS), left ventricular internal diameter (LVID) and left ventricular free wall thickness (LVFW) is illustrated. AV_L and AV_R = left and right atrioventricular valves, respectively; RV = right ventricle.

MHz (display angle, 68°) or a 3.75-MHz (display angle, 98°) convex transducer, depending on size of the calf.

All measurements were made by the same investigator (HA) and were calculated in accordance with the recommendations of the American Society of Echocardiography.[7] Systolic and diastolic measurements were made at the minimal and maximal internal left ventricular dimension, respectively. All dimensions measurements were made by use of the leading-edge method. The mean of each measurement was derived from 5 recordings and cardiac cycles.

The transducer was first angled to obtain a right parasternal long-axis view in 2D mode of the left ventricle and atrioventricular valve. The M-mode cursor was directed perpendicularly through the left ventricular cavity at the level of the chordae tendinae just below the tips of the atrioventricular valve leaflets at the end of the diastolic excursion. In this position, recordings were obtained from the area of maximal left ventricular diameter. In the long-axis view of the heart in M-mode (TMLAx view), the width of the interventricular septum (IVS), left ventricular free wall (LVFW) thickness and left ventricular internal diameter (LVID) were measured in systole and in diastole (Fig 2), using electronic calipers.

The beam was then slightly rotated to a more craniocaudal orientation to obtain a long-axis view of the left ventricular outflow tract. When a satisfactory 2D image of the aortic root was obtained, it was frozen during the diastolic closure of the aortic valve. In this long-axis view in 2D mode (2DLAx view), the internal diameter of the aorta was measured at 3 levels: at the aortic anulus (Ao $_{an}$); at the aortic sinuses of the bulbus aortae (Ao $_{sin}$); and at the narrowest part of the aortic root just downstream to the aortic sinuses (Ao $_{min}$). Measurement of the left atrial (LA) dimension, which was not performed at the level of its major diameter in this view, included the caudal aortic wall thickness and excluded the left atrial wall thickness. The M-mode cursor was then directed across the proximal aortic root at the level of the aortic valve. In this TMLAx view, Ao $_{sin}$ was measured from the leading edge of its cranial wall to the leading edge of its caudal wall during middiastolic closure of the aortic valve, and LA diameter was measured at the same point of the cardiac cycle and as previously described.

Clockwise 90° rotation of the transducer produced a right parasternal short-axis view of the heart, in a plane perpendicular to its long-axis at the level of the papillary muscles. The M-mode cursor was directed through the diameter of the left ventricle. In the short-axis view in 2D mode (2DSAx view), the image was frozen in diastole and in systole, and IVS, LVFW, LVID and left ventricular internal circumference (LVIC) and external circumference (LVEC) were measured. The left ventricular internal surface (LVIS) and external surface (LVES) were calculated by planimetry, using electronic calipers. In the short-axis view in M-mode (TMSAx view), systolic and diastolic IVS, LVFW and LVID were measured.

The reliability and reproducibility of each of the aforementioned measurements have been documented in calves.[9] Mean heart rate during echocardiography was obtained by means of a telemetric system.[b]

Calculations—The LA-to-Ao $_{sin}$ and IVS-to-LVFW ratios LA/Ao and IVS/LVFW, respectively), systolic percentage thickening of the interventricular septum and of the left ventricular free wall (% Δ IVS and % Δ LVFW, respectively), fractional shortening of the left ventricle (% Δ D), circumferential fiber shortening of the left ventricle (% Δ circ) and left ventricular systolic fractional area change (FAC) were calculated (Table 1).[7,10]

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[b] Danika Electronics, Copenhagen, Denmark.

Table 1—Equations applied for calculation of the echocardiographic functional indices

Indices	Calculation
% Δ IVS	[IVSs – IVSd/IVSd] × 100
% Δ LVFW	[LVFWs – LVFWd/LVFWd] × 100
% Δ D	[LVIDd – LVIDs/LVIDd] × 100
% Δ circ	[LVICd – LVICs/LVICd] × 100
FAC	[LVISd – LVISs/LVISd] × 100

% Δ IVS and % Δ LVFW = systolic percentage thickening of the interventricular septum and of the left ventricular free wall, respectively; % Δ D = fractional shortening of the left ventricle; % Δ circ = circumferential fiber shortening of the left ventricle; FAC = left ventricular systolic fractional area change; s and d = systolic and diastolic measurement, respectively.

Table 2—Level of significance (LS) of breed effect and logarithmic regression equations for morphologic echocardiographic variables (obtained from an M-mode long-axis view of the heart) on body weight (BW) in 17 Friesian (n = 50) and 8 Belgian White and Blue (BWB, n = 44) calves

Variables	LS	Friesian calves	BWB
IVSs (mm)	*	– 13.3 + 18.0 log BW	– 17.2 + 18.8 log BW
IVSd (mm)	NS	0.01 + 6.9 log BW	– 5.3 + 9.3 log BW
LVIDs (mm)	NS	20.2 + 6.1 log BW	16.0 + 7.9 log BW
LVIDd (mm)	*	– 2.5 + 30.8 log BW	7.9 + 22.1 log BW
LVFWs (mm)	*	– 9.9 + 16.3 log BW	– 22.4 + 21.7 log BW
LVFWd (mm)	†	1.3 + 5.4 log BW	– 8.9 + 10.5 log BW
Ao_{sin} (mm)	*	– 1.0 + 18.0 log BW	1.6 + 14.3 log BW
LA (mm)	NS	1.4 + 13.9 log BW	– 8.2 + 17.8 log BW

* $P \leq 0.001$, † $P \leq 0.01$.

IVS = width of the interventricular septum; LVID = left ventricular internal diameter; LVFW = left ventricular free wall thickness; Ao_{sin} = aortic internal diameter at the level of the aortic sinuses of the bulbus aortae; LA = left atrial diameter; s and d = systolic and diastolic measurement, respectively; NS = not (statistically) significant.

Statistical analysis—To examine the effect of breed on echocardiographic variables (including morphologic variables and functional indices), a random linear nested model[11] was fitted to the data and analyzed, using a computer program.[c] The linear nested model was in general form:

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

where Y = echocardiographic 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 echocardiographic variable on decimal logarithm of body weight (X)
e_{ijkl} = residual error

In the second step, the same analysis was made within each of the 2 breeds. Heart rate was compared between the 2 groups, using one-way ANOVA.

Results

Mean ± SEM heart rate obtained in Friesian and Belgian White and Blue groups was 99.1 ± 2.7 and 99.2 ± 2.6 beats/min, respectively. The difference between these values was not statistically significant.

Most of the diastolic measurements of left ventricular dimensions and wall thicknesses were not significantly different between the breeds, whatever the echocardiographic mode or view applied to obtain them (Tables 2–4; Fig 3–5). To the contrary, most of these measurements obtained in systole were significantly different ($P \leq 0.001$) between the 2 groups: systolic left ventricular wall thicknesses were significantly greater in Friesian than in Belgian White and Blue calves (Tables 2–4; Fig 3 and 5), whereas systolic left ventricular dimensions were greater in Belgian White and Blue than in Friesian calves (Tables 2–4; Fig 4).

Table 3—Level of significance of breed effect and logarithmic regression equations for morphologic echocardiographic variables (obtained from a 2-dimensional short-axis view of the heart) on BW in 17 Friesian (n = 50) and 8 BWB (n = 44) calves.

Variables	LS	Friesian calves	BWB
IVSs (mm)	*	– 7.3 + 13.5 log BW	– 21.9 + 21.0 log BW
IVSd (mm)	NS	– 0.9 + 6.5 log BW	– 6.2 + 9.4 log BW
LVIDs (mm)	*	20.5 + 4.7 log BW	27.2 + 1.9 log BW
LVIDd (mm)	NS	6.3 + 23.0 log BW	3.8 + 22.9 log BW
LVFWs (mm)	*	– 9.3 + 14.2 log BW	– 30.7 + 25.3 log BW
LVFWd (mm)	NS	– 1.9 + 7.2 log BW	– 8.3 + 9.8 log BW
LVISs (cm^2)	*	5.7 + 0.1 log BW	7.6 – 0.7 log BW
LVISd (cm^2)	NS	– 5.9 + 12.6 log BW	– 6.8 + 12.1 log BW
LVICs (mm)	*	86.5 + 6.1 log BW	101.5 – 1.0 log BW
LVICd (mm)	NS	60.5 + 51.8 log BW	53.5 + 54.5 log BW
LVESs (cm^2)	*	– 23.2 + 31.5 log BW	– 41.1 + 40.6 log BW
LVESd (cm^2)	NS	– 21.3 + 33.1 log BW	– 41.3 + 43.0 log BW
LVECs (mm)	NS	31.7 + 97.2 log BW	– 0.4 + 113.0 log BW
LVECd (mm)	NS	58.3 + 90.4 log BW	– 0.9 + 119.5 log BW

* $P \leq 0.001$.

LVIS and LVIC = left ventricular internal surface and circumference, respectively; LVES and LVEC = left ventricular external surface and circumference, respectively.

See Table 2 for key.

Table 4—Level of significance of breed effect and logarithmic regression equations for morphologic echocardiographic variables (obtained from an M-mode short-axis view of the heart) on BW in 17 Friesian (n = 50) and 8 BWB (n = 44) calves

Variables	LS	Friesian calves	BWB
IVSs (mm)	*	– 8.7 + 14.9 log BW	– 16.3 + 18.0 log BW
IVSd (mm)	†	– 0.3 + 6.4 log BW	– 6.3 + 9.5 log BW
LVIDs (mm)	*	14.8 + 7.4 log BW	18.0 + 6.6 log BW
LVIDd (mm)	NS	1.4 + 26.3 log BW	11.3 + 20.0 log BW
LVFWs (mm)	*	– 8.4 + 15.2 log BW	– 26.9 + 23.5 log BW
LVFWd (mm)	NS	1.1 + 4.8 log BW	– 12.3 + 11.8 log BW

* $P \leq 0.001$; † $P \leq 0.05$.

See Table 2 for key.

Although LA diameter was not significantly different between the 2 groups of calves, the significantly ($P \leq 0.001$) smaller proximal aortic root dimensions in Belgian White and Blue calves explained the significantly ($P \leq 0.001$) greater LA/Ao in this latter group (Tables 2, 5, 6; Fig 6).

The aortic anulus diameter and the IVS/LVFW were not significantly different between the 2 groups of calves (Tables 5 and 6). Indices of left ventricular systolic function were significantly ($P \leq 0.001$) higher in Friesian than in Belgian White and Blue calves, whatever the echocardiographic mode or view applied.

Discussion

Although the quantitative evaluation of cardiac dimensions by echocardiography is subject to error, accurate and reproducible results have been shown to be available when recording is performed in a standardized way.[7] In this study, all echocardiographic measurements were made using such standardized way and following the method described for the bovine species.[9] Because the measurement of the right ventricular diameter and wall has been shown to be unreliable,[7,12,13] the dimensions of these structures were not measured in our study.

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[c] SAS software, SAS Institute Inc, Cary, NC.

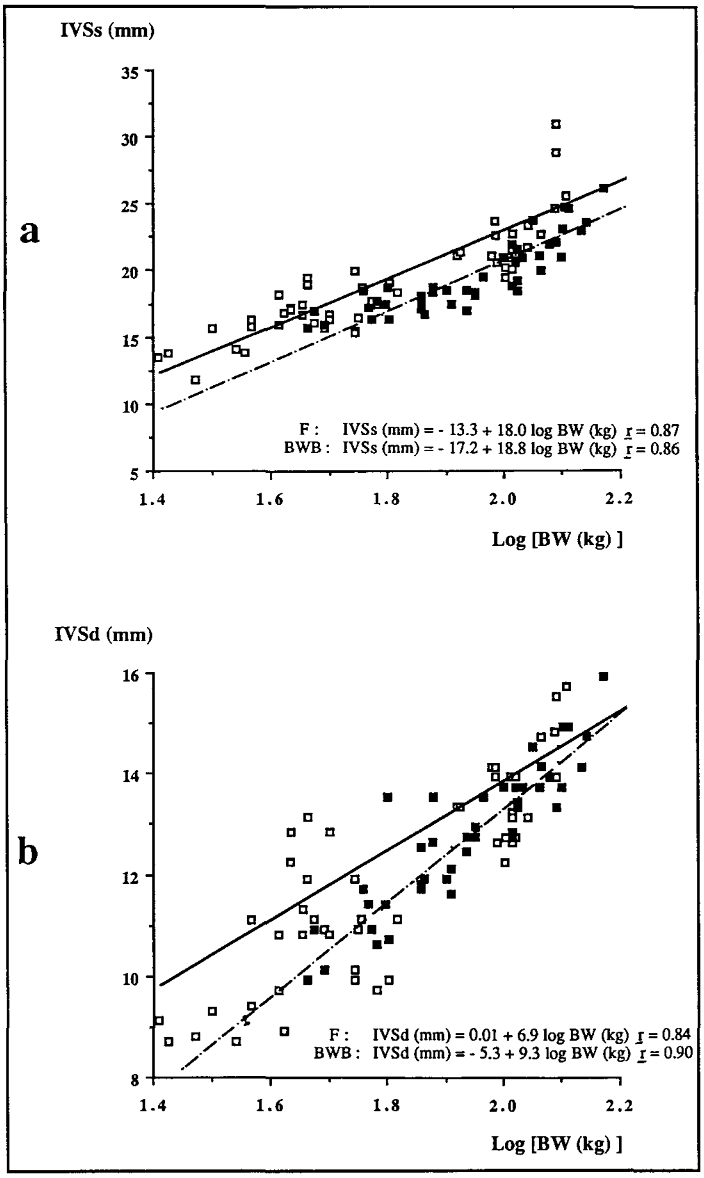

Figure 3—Evolution of systolic (s; a) and diastolic (d; b) interventricular septum thickness (IVS) values, obtained from an M-mode long-axis view of the heart, with BW in 17 Friesian (F, open squares, solid regression line, n = 50) and in 8 Belgian White and Blue (BWB, closed squares, dotted regression line, n = 44) calves. The *r* value is correlation coefficient.

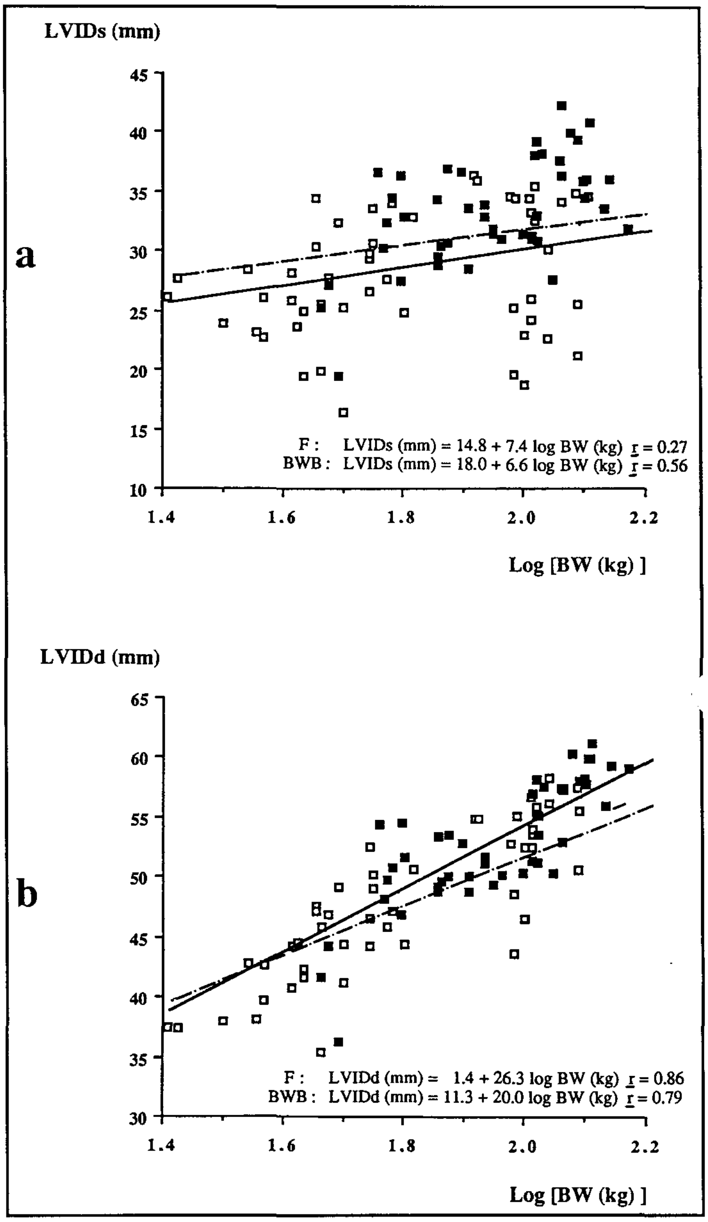

Figure 4—Evolution of systolic (a) and diastolic (b) left ventricular internal diameter (LVID) values, obtained from an M-mode short-axis view of the heart with BW. *See* Figure 3 for key.

The availability of the M-mode directed cursor in a 2D framework became routine with modern ultrasonic equipment, and increased the advantages of echocardiography for measurements of cardiac structures: the high sampling rate of M-mode allows better temporal resolution, and 2D mode permits acquisition of better spatial orientation of the cardiac structures.[7,14] In addition to these respective advantages, use of both modes in this study, together with the application of various views of the heart, permitted several measurements of each echocardiographic variable. This constituted, therefore, a way to further confirm reliability of the comparison of each echocardiographic measurement in the 2 groups of calves. In general, results of this comparison obtained from the various echocardiographic modes or views of the heart were in good agreement with each other.

In the investigated species, including cattle,[15] cardiac dimensions increase with age and body weight of the subject.[7,16,17] Therefore, it was essential in this study to take body size of the subjects into account to compare the 2 groups of calves. For this reason, the data were analyzed, using a mathematical model including not only the effect of breed and individual (this latter variable was taken into account because each calf was investigated several times during its growth), but also the effect of body weight of the calves. This mathematical model yielded satisfactory analysis of data, as viewed by a mean ± SEM model R^2 value of 0.79 ± 0.02. The choice of body weight, instead of age, for correcting the echocardiographic cardiac dimensions was dictated by 2 main reasons. Body weight has been shown to be closely correlated to echocardiographic morphologic variables, while being one of the easiest and most accurately determined anthropometric variable in cattle.[15] Also, although the 2 groups

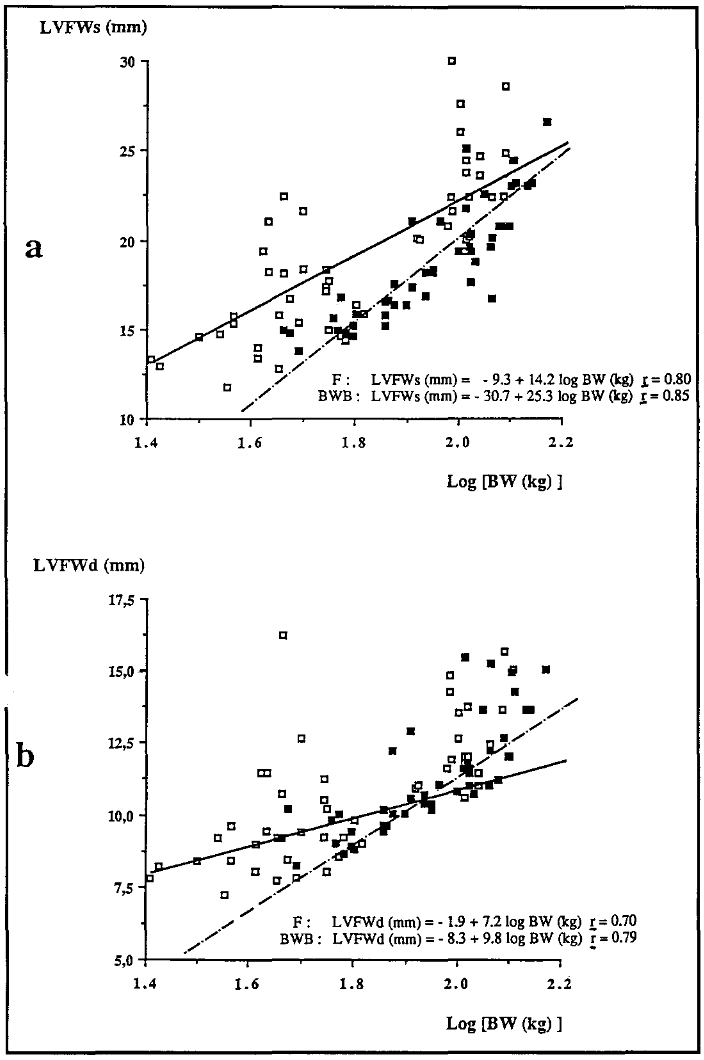

Figure 5—Evolution of systolic (a) and diastolic (b) left ventricular free wall thickness (LVFW) values, obtained from a 2-dimensional short-axis view of the heart with BW. *See* Figure 3 for key.

Table 5—Level of significance of breed effect and logarithmic regression equations for morphologic echocardiographic variables (obtained from a 2-dimensional long-axis view of the heart) on BW in 17 Friesian (n = 50) and 8 BWB (n = 44) calves

Variables	LS	Friesian calves	BWB
Ao_{an} (mm)	NS	−2.6 + 10.7 log BW	−36.1 + 26.9 log BW
Ao_{sin} (mm)	*	−10.5 + 23.8 log BW	−13.0 + 23.0 log BW
Ao_{min} (mm)	*	−6.9 + 17.5 log BW	−4.7 + 13.8 log BW
LA (mm)	NS	1.1 + 13.5 log BW	−12.0 + 20.1 log BW

* $P \le 0.001$.

Ao_{an} and Ao_{min} = aortic internal diameter at the level of aortic anulus and of the narrowest part of the aortic root, respectively.

See Table 2 for key.

Table 6—Least-square mean, SE, and LS of the breed effect on functional echocardiographic indices in 17 Friesian (n = 50) and 8 BWB (n = 44) calves

Indices	View and mode	Friesian calves	BWB	LS
LA/Ao	2DLAx	0.78 ± 0.01	0.91 ± 0.01	*
	TMLAx	0.82 ± 0.01	0.92 ± 0.01	*
IVS/LVFW	TMLAx	1.01 ± 0.02	0.94 ± 0.03	NS
	2DSAx	1.06 ± 0.01	1.08 ± 0.02	NS
	TMSAx	1.08 ± 0.02	1.00 ± 0.03	†
% Δ IVS (%)	TMLAx	63.6 ± 2.2	44.7 ± 3.1	*
	2DSAx	58.6 ± 1.7	42.9 ± 2.3	*
	TMSAx	64.3 ± 1.7	50.3 ± 2.5	*
% Δ D (%)	TMLAx	43.2 ± 0.7	40.0 ± 1.0	‡
	2DSAx	37.6 ± 0.9	30.7 ± 1.3	*
	TMSAx	43.3 ± 0.8	36.9 ± 1.2	*
% Δ LVFW (%)	TMLAx	71.3 ± 2.6	44.8 ± 3.7	*
	2DSAx	64.3 ± 2.4	38.1 ± 3.4	*
	TMSAx	82.0 ± 3.1	53.1 ± 4.6	*
% Δ circ (%)	2DSAx	41.0 ± 1.0	31.9 ± 1.4	*
FAC (%)	2DSAx	67.3 ± 1.1	57.4 ± 1.5	*

* $P \le 0.001$, † $P \le 0.05$; ‡ $P \le 0.01$.

2DLAx and TMLAx = 2-dimensional and M-mode long-axis view of the heart, respectively; 2DSAx and TMSAx = 2-dimensional and M-mode short-axis view of the heart, respectively.

See Table 2 for key.

of calves used in this study were of approximately the same age, body weight of the Belgian White and Blue calves, relative to age, was higher (Fig 1). This was attributable to the double-muscled conformation of these latter calves,[18-20] and further justifies the adjustment of echocardiographic measurements as a function of body weight instead of age when comparing the 2 groups of calves.

To assess cardiac morphology by echocardiography, measurements performed during the diastolic relaxation of the myocardium are usually applied.[21-23] In our study, diastolic echocardiographic measurements of the left ventricle, when normalized for body weight, were not significantly different between the 2 groups of calves. Therefore, selection of the double-muscled gene in the Belgian White and Blue breed has not been associated with either modification of the left ventricular transversal dimensions or wall thicknesses. This statement is not in agreement with the study of Ansay and Hanset.[5] Indeed, those authors highlighted a significant 15% reduction of heart weight in double-muscled calves, compared with conventional calves, all animals being slaughtered at constant body weight of 83 kg. In view of those results, it would thus not have been surprising to find, using the echocardiographic technique, thinner walls or narrowed diameter of the heart in double-muscled subjects. This hypothesis was not confirmed by us. However, the reduced heart weight found by Ansay and Hanset[5] in double-muscled calves could also be associated with reduced cardiac length, volume, or both.

Unfortunately, estimates of the ventricular volumes calculated from M-mode echocardiographic measures may be inaccurate because cardiac measurements are mainly derived, using this method, from changes in length of a single short-axis dimension of the left ventricle.[24] Quantitative 2D echocardiography permits more accurate calculations of cardiac volumes than does M-mode echocardiography because of its ability to display multiple tomographic cross sections of the heart and, therefore, to measure multiple diameters of the ventricle.[25] However, it has been pointed out that in dogs, left ventricular longitudinal diameter can be underestimated because of the difficulty in ensuring that its 2D echocardiographic measurement is made through the apex of the left ventricle.[24,25] This lack of accuracy is particularly true in cattle because of the difficulties in obtaining an image of good quality from the base to the apex of the heart in this species. Moreover, lack of equations that could allow de-

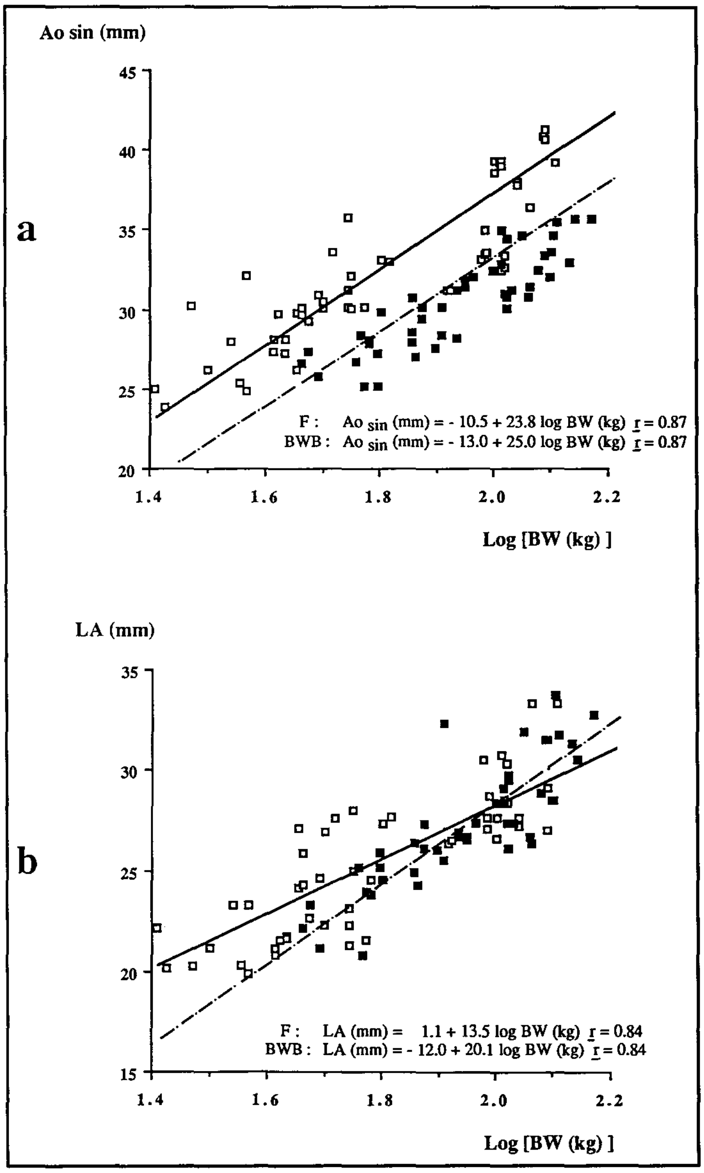

Figure 6—Evolution of aortic sinus (Ao sin, a) and left atrial diameter (LA, b) values, obtained from a 2-dimensional long-axis view of the heart with BW. *See* Figure 3 for key.

termination of left ventricular volume in the bovine species precluded comparison of the left ventricular volumetric indices between the 2 breeds of calves in our study.

To further explain which part of the heart is implicated in the lower heart weight-to-body weight ratio found in double-muscled calves, it should be interesting to carry out careful postmortem comparison of the weight and dimensions of the various cardiac chambers in conventional and double-muscled calves. Systolic measurements of left ventricular wall thicknesses and dimensions were significantly higher and lower, respectively, in Friesian calves. These differences were interpreted as a result of significantly higher left ventricular functional indices in this latter group, indices that are known to constitute a sensitive measure of left ventricular contractility when cardiac rhythm and loading conditions are constant.[7,26,27] These indices have been shown to increase in association with inotropic stimulation, such as isoproterenol administration,[28] and to decrease in diseases with myocardial depressant effect.[29-34] Therefore, the lower values of left ventricular functional indices obtained in double-muscled calves could be the sign of lower basal myocardial contractility in these subjects. This interesting finding could explain why double-muscled cattle appear to be disadvantaged concerning their cardiac function not only at rest, as indicated by reduced resting cardiac index,[6] but especially under conditions of stress, such as experimentally induced acute hypoxia[6] or muscular exercise.[3] In these conditions, double-muscled calves have been shown to be unable to maintain appropriate cardiac output.

Echocardiography did not provide a way to accurately estimate cardiac loading conditions in the 2 groups of calves. The lower values of left ventricular systolic functional indices obtained in the Belgian White and Blue calves may thus be associated either with lower preload or with higher afterload in this group. A complete hemodynamic investigation of cardiac function by use of invasive techniques, providing simultaneous evaluation of cardiac loading conditions, contractility, and cardiac output, appears necessary to further interpret these results.

It has been shown in various species, such as cats,[35,36] dogs,[33,37,38] sheep,[13] pigs,[14] horses,[39,40] human beings,[41,42] and calves,[15] that morphologic echocardiographic variables are best predicted by allometric regression on body weight, whereas functional indices are not modified by somatic growth. Therefore, in this study, results relative to the morphologic variables are reported as logarithmically transformed data on body weight (Tables 2–5), whereas those relative to the functional indices are reported as least-square means (Table 6).

In this study, mean heart rate throughout echocardiography was closely similar in the 2 groups of calves, but this does not exclude the fact that heart rate probably affected each single measurement of cardiac contraction. It has been reported in human beings,[43,44] cats,[28,36] and dogs[45,46] that left ventricular dimensions are correlated to heart rate. However, in the aforementioned studies, the influence of heart rate on left ventricular echocardiographic measurements was analyzed over a wide range of heart rates induced by pacing. In our study, the calves were investigated under quite conditions. By means of the continuous display of heart rate on ECG and echocardiogram, the moments during which external conditions had large influence on adrenergic status of the calf were immediately pointed out. When such influence was observed, the echocardiogram was interrupted until quiet conditions were established. Consequently, during echocardiography, heart rate variations were not wide. For this reason, the influence of heart rate on echocardiographic measurements was probably low. Moreover, studies performed in people[43,44] and dogs[46] indicated that several echocardiographic variables are not correlated to heart rate. For instance, % Δ D is not influenced by atrial pacing-induced heart rate variation. In our study, several left ventricle functional indices, including % Δ D, were compared between the 2 groups of calves; all these indices were significantly different between Friesian and Belgian White and Blue calves. Finally, several authors compared echocardiographic morphologic variables and functional indices in various groups of human beings[23,47-49] or horses[50] to estimate the effects of training on these variables. In those studies, echocardiographic data were adjusted for body weight without taking heart rate into account. Therefore, despite comparison of the echocardiographic data between the 2 groups of this study without examining heart rate as a covariant to these measurements, left ventricular functional indices were probably effectively lower in double-muscled subjects.

Reduced aortic root dimensions in Belgian White and Blue calves might be a congenital consequence of selection of the double-muscled gene or reflection of reduction of aortic compliance.[21-23] However, this might also be consistent with reduction in blood flow in double-muscled calves. It has been shown that under basal conditions, cardiac index is significantly lower in these latter subjects.[6] Moreover, in our study, aortic diameter was lower in the Belgian White and Blue calves only when measured in the proximal aortic root at the level of the aortic sinuses, an area of the aorta known to increase in size during the systolic ejection phase of the left ventricle, owing to the elastic properties of the aortic wall.[51] On the contrary, the aortic anulus changes minimally in size during ejection, and for this reason it constitutes the site commonly used to estimate the aortic area for determination of cardiac output, using the Doppler echocardiographic technique.[51,52] In our study, the diameter of the aortic anulus was not significantly different between the 2 groups of calves. Therefore, the reduced values of aortic root diameter obtained in Belgian White and Blue calves, compared with Friesian calves, were likely associated with lower blood flow in double-muscled calves.

According to the results of this investigation, double-muscled selection in cattle does not induce alteration in left ventricular wall thicknesses or dimensions when echocardiographic measurements are normalized for body weight. However these data indicate that left ventricular systolic functional indices are lower in double-muscled calves than in calves with standard conformation.

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