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Spirometric performance in Belgian Blue calves: II. Analysis of environmental factors and estimation of genetic parameters¹

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ABSTRACT: Genetic parameters and environmental effects for spirometric variables (SV) in calves were estimated using 734 Belgian Blue calves (15 to 297 d of age), sired by 20 AI bulls. For each calf, the following SV were measured: 1) the average ventilation (l/min) recorded during the 15 s of maximal ventilatory changes induced by lobeline administration (0.25 mg/kg, i.v.) (15-s MV_L); 2) the vital capacity, and the maximal peak expiratory and inspiratory flows recorded after lobeline administration; and 3) the ventilatory reserve (15-s MV_L – ventilation at rest). Analysis of environmental factors showed age of calf, herd, sex, and

vaccination status had significant effects on SV. A sire model and a multiple-trait derivative-free REML procedure were used to estimate genetic parameters for SV, body weight, and muscling score. Heritabilities for SV ranged from 0.28 ± 0.11 to 0.44 ± 0.16. Genetic correlations among SV varied from 0.76 to 0.98 and environmental correlations from 0.69 to 0.80. Genetic correlations of SV with body weight (0.25 to 0.56) and with muscling score (0.21 to 0.76) were positive, as were environmental correlations of SV with body weight (0.44 to 0.70) and muscling score (0.09 to 0.25). These results suggest that selection may improve SV without impairing other traits of economic importance.

Key Words: Calves, Environmental Factors, Genetic Parameters, Physiology

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Introduction

Bovine respiratory disease (BRD) is a multifactorial syndrome resulting from interactions between different pathogens, physical constitution of host, and environmental conditions. Bovine respiratory disease is the most costly health problem in calves (Toombs et al., 1994). Costs arise from veterinary treatments, reduced growth rates, and mortality. Vaccination programs against the most common agents have been developed but are not completely efficient in providing protection against BRD. Heritability for BRD occurrence is low, ranging from 0.01 to 0.11 (Lyons et al., 1991; Muggli-Cockett et al., 1992). Therefore, selection for more resistant animals using respiratory disease occurrence as a selection criterion may be very slow.

Measurement of spirometric variables (SV) is used in human and veterinary medicines to estimate the efficiency of respiratory function and to diagnose some types of respiratory defects in patients (Taylor et al., 1989; Bureau et al., 1999). In human medicine, patients with high SV are likely to avoid respiratory failure in exacerbation of pulmonary diseases (Beachey and Olson, 1990). Furthermore, low spirometric performances are associated with increased incidence, severity, and cost of respiratory disorders in calves (unpublished observations), suggesting that improvement of spirometric performances could result in increased resistance to respiratory disease in calves. Amelioration of environmental factors favorable to SV and selection for increased SV are two possible ways to improve these performances. Therefore, objectives of this study were to 1) analyze environmental factors influencing SV; 2) estimate heritability for SV; and 3) estimate genetic and environmental correlations among SV and between SV, live weight, and muscling score.

Material and Methods

Animals. Spirometric variables were measured in the spring of 1997 on 734 double-muscléd calves of the Belgian Blue breed (357 males and 387 females, 15 to 297 d old, and weighing 33 to 270 kg), sired by 20 AI bulls,

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with a range of 18 to 75 calves per sire. The calves were born and phenotypes recorded on 66 farms. All animals had no signs of clinical disease on preexperimental clinical examination and had no history of respiratory disease. A fasting period was imposed for at least 6 h before SV measurement and weighing. The muscular development of each calf was assessed by scoring on a scale from 1 (moderately muscled calves) to 9 (extremely muscled calves).

Measurement Techniques. Spirometric performances of calves were assessed during a period of maximal ventilatory changes induced by lobeline (a respiratory analeptic) administration (0.25 mg/kg, i.v., Lobelin, Boehringer Ingelheim, Ingelheim, Germany) (Bureau et al., 1999). Each calf received a single dose of Lobeline. Ventilatory variables (respiratory frequency [min^{-1}], tidal volume [L], ventilation [L/min], and peak expiratory and inspiratory flows [L/s]) were measured at rest and continuously from the injection until complete recovery. The respiratory flow was measured by the use of a heated Fleisch pneumotachograph Nr. 3 mounted on an air-tight face mask and coupled to a differential pressure transducer (Validyne DP45-14, Validyne Engineering, Northridge, CA) with two identical catheters. The Po Ne Mah system (Gould Instrument Systems, Valley View, OH) was used to derive ventilatory values from flow measurements on each artifact-free respiratory cycle. The Po Ne Mah system was calibrated by forcing a known volume of air (0.5 L) through the pneumotachograph. Linearity and symmetry of airflow measurements were tested with a flow rotameter suitable for measuring flow rates from 1 to 16 L/s.

For each calf, the following SV were calculated: **15-s MV_L** , average ventilation recorded during the 15 s of maximal ventilatory changes induced by lobeline administration; **VC_L** , **$MPEF_L$** , and **$MPIF_L$** , representing vital capacity, maximal peak expiratory flow, and maximal peak inspiratory flow recorded after lobeline administration, respectively; and **VR_L** , ventilatory reserve ($VR_L = 15\text{-s } MV_L - \text{ventilation at rest}$).

Statistical Analysis. Effects of environmental factors on spirometric variables were analyzed by ANOVA using the GLM procedure of SAS (SAS Inst., Inc., Cary, NC). The fixed linear model included effects of sire ($n = 20$), herd ($n = 66$), sex (male vs female), body condition score (lean vs slightly fat), vaccination status (vaccinated vs unvaccinated against bovine adenovirus type 3, bovine herpesvirus type 1, parainfluenza 3 virus, and bovine respiratory syncytial virus), age as linear and quadratic covariables, and all first-order interactions (only the sex \times vaccination status interaction was significant and included in final analysis). Least squares means were estimated for main effects and the PDIFF option of the GLM procedure was used for mean separation. Variance and covariance components were estimated with a sire model and the multiple-trait derivative-free REML procedure using MTDFREML programs by Boldman et al. (1995). Sire's numerator relationships matrix was constructed from the sires and their maternal grandsires and in-

cluded a total of 808 animals. Single-trait analyses were performed first to obtain heritability estimates. Next, genetic and environmental correlations between each pair of SV and between SV, weight, and muscling score were estimated in a series of 21 bivariate analyses. The model for these analyses included fixed effects of herd, sex-vaccination status, and age as a linear covariable. Body condition score and age as a quadratic covariable were added when significance was established by the analysis of environmental factors. Approximate standard errors for heritability estimates were obtained by the formula of Swiger et al. (1964).

Results and Discussion

Environmental Factors. Mean squares for analysis of variance for SV, body weight, and muscular score are presented in Table 1. The linear effect of age was highly significant for all studied SV, whereas the quadratic effect of age was only significant for 15-s MV_L and VC_L (Table 1). The effect of body condition score was not significant for any of the studied SV, except on VC_L (Table 2). The herd effect was highly significant for all investigated SV (Table 1). Available space for physical activity, quality of air, and diet could be involved in this important effect. In humans, high levels of physical activity during growth enhance pulmonary function (Palka, 1982). In the present study, calves' physical activity was related with available space, and differed among farms in this study. Indeed, calves were tied close to each other in sheds, confined in individual pens, free and housed in collective pens, free and housed in open-front barns, or allowed to pasture with their dams. Air pollution also affects SV. For instance, workers in swine confinement facilities, who are exposed daily to high concentrations of carbon dioxide (CO_2) and hydrogen sulfide (H_2S), have drastic decrements of $MPEF$ (Donham et al., 1984). Moreover, ammonia alters all SV in humans (Voisin et al., 1970). If one assumes that changes in SV of calves exposed to CO_2 , H_2S , and ammonia are similar to those observed in humans, air pollution at farms could be a source of variation in SV. The relationships between diet and SV have also been intensively investigated in humans. High intakes of eicosapentaenoic acid, vitamin A, vitamin C, iron, and zinc improve SV, whereas high fat and sodium intakes have deleterious effects (Strachan et al., 1991; Carey et al., 1993; Schwartz and Weiss, 1994; Shahar et al., 1994). Similarly, diet also may influence SV in calves.

Spirometric performances were significantly greater in female calves than in male calves (Table 2). This finding could explain the higher incidence of respiratory disease in male calves than in female calves (Muggli-Cockett et al., 1992). Another possible explanation could be an immune difference between male and female. However, previous immunological studies failed to verify this hypothesis (Muggli et al., 1987). Indeed, the sole sex difference in immune traits measured in calves--a higher se-

Table 1. Mean squares from ANOVA for spirometric variables, live weight, and muscling score in Belgian Blue calves

Source of variation	df	15-s MV _L	VC _L	MPEF _L	MPIF _L	VR _L	Weight	Musc. score
Sire	19	2,962.3***	0.82***	10.17***	6.79***	1,685.5***	952.9*	1.51*
Herd	65	2,345.8***	1.21***	9.23***	6.65***	1,508.0***	1,833.6***	4.20***
Sex	1	10,726.4***	8.77***	70.14***	21.71*	12,147.7***	564.4	15.43***
Body condition	1	3,054.6	1.48*	6.63	2.05	906.5	8,376.0***	4.52*
Vaccination st.	1	12,609.9***	8.62***	19.15*	35.76***	9,267.8***	4,138.2**	4.80*
Sex × vaccination st.	1	5,920.6**	6.66***	32.54**	22.22**	5,638.3**	3,662.4**	6.60**
Age linear	1	10,585.7***	3.88***	58.38***	22.49**	8,672.9***	20,842.7***	2.64
Age quadratic	1	3,701.4*	3.12**	0.85	7.04	338.3	1,081.2	0.05
Error	643	847.6	0.33	3.33	2.53	600.9	501.4	0.90

* $P < 0.05$, ** $P < 0.01$, *** $P < .0001$. Vaccination st. = vaccination status. Musc. score = muscular score. 15-s MV_L = average ventilation recorded during the 15 s of maximal ventilatory changes induced by lobeline administration; VC_L, MPEF_L, and MPIF_L = vital capacity, maximal peak expiratory flow, and maximal peak inspiratory flow recorded after lobeline administration; VR_L = ventilatory reserve (VR_L = 15-s MV_L – ventilation at rest).

rum concentration of complement C3 in males--is not thought to be detrimental to health.

Vaccinated calves had significantly higher SV than unvaccinated calves (Table 2). In humans, a decrease in SV precedes clinical signs in respiratory disorders (Taylor et al., 1989). This suggests that there were subjects with subclinical respiratory disease among the unvaccinated calves. This is consistent with previous studies that showed, in calves, high rates of seroconversion and high rates of seropositivity to bovine adenovirus type 3, bovine herpesvirus type 1, parainfluenza 3 virus, and bovine respiratory syncytial virus associated with a lack of clinical signs of respiratory disease (Lehmkuhl et al., 1979; Collins et al., 1988).

Highly significant sex × vaccination status interaction was observed for all SV (Table 1). The differences between sexes were greater in vaccinated calves than in unvaccinated ones and vaccinated females exhibited the highest spirometric performances. In unvaccinated calves, 15-s MV_L, VC_L, and MPIF_L were not significantly different between sexes and MPEF_L and VR_L were significantly higher in females, whereas spirometric perfor-

mances were highly significantly greater in vaccinated females than in vaccinated males.

Genetic Parameters. Estimates of heritabilities, and genetic and environmental correlations for the five SV and for weight and muscular development are shown in Table 3. Heritability estimates for the five SV ranged from 0.28 to 0.44, suggesting a potential response to selection for increased SV. Heritability estimates for live weight and muscling score were low (0.16) and agree with other estimates obtained in Belgian Blue calves of similar age and rearing conditions (unpublished observations). Genetic correlations among the five SV ranged from 0.76 to 0.98, and environmental correlations were slightly lower, ranging from 0.66 to 0.80. The high genetic correlations among SV indicate that selection for any SV would result in correlated response in all SV. Genetic correlations of SV with live weight ranged from 0.25 to 0.56, and genetic correlations with muscling score ranged from 0.21 to 0.76. They were all positive, which suggests that genes promoting overall body growth and muscular growth also promote respiratory tract development. Environmental correlations of SV with live weight ranged

Table 2. Least squares means and standard errors for the effects of body condition score, sex, and vaccination status on spirometric performances in Belgian Blue calves

Item	n	15-s MV _L , L/min	VC _L , L	MPEF _L , L/s	MPIF _L , L/s	VR _L , L/min
Body condition						
Lean	588	91.90 ± 3.06 ^a	2.00 ± 0.06 ^a	5.24 ± 0.19 ^a	4.98 ± 0.17 ^a	62.88 ± 2.58 ^a
Slightly fat	156	99.47 ± 3.94 ^a	2.17 ± 0.08 ^b	5.59 ± 0.25 ^a	5.17 ± 0.22 ^a	67.01 ± 3.31 ^a
Sex						
Male	357	89.5 ± 3.45 ^a	1.91 ± 0.07 ^a	4.92 ± 0.22 ^a	4.80 ± 0.19 ^a	58.36 ± 2.91 ^a
Female	387	101.9 ± 3.34 ^b	2.26 ± 0.07 ^b	5.92 ± 0.21 ^b	5.35 ± 0.18 ^b	71.52 ± 2.81 ^b
Vaccination status						
Vaccinated	106	107.69 ± 5.51 ^a	2.40 ± 0.11 ^a	5.89 ± 0.34 ^a	5.71 ± 0.30 ^a	75.24 ± 4.64 ^a
Unvaccinated	638	83.68 ± 2.45 ^b	1.77 ± 0.005 ^b	4.95 ± 0.15 ^b	4.44 ± 0.13 ^b	54.65 ± 2.07 ^b

^{a,b}Means within the same column and the same row lacking a common superscript letter differ ($P < 0.05$). 15-s MV_L = average ventilation recorded during the 15 s of maximal ventilatory changes induced by lobeline administration; VC_L, MPEF_L, and MPIF_L = vital capacity, maximal peak expiratory flow, and maximal peak inspiratory flow recorded after lobeline administration; VR_L = ventilatory reserve (VR_L = 15-s MV_L – ventilation at rest).

Table 3. Estimates of heritabilities, genetic and environmental correlations for spirometric variables, live weight, and muscling score in Belgian Blue calves^a

Trait	15-s MV _L	VC _L	MPEF _L	MPIF _L	VR _L	Weight	Musc. score
15-s MV _L	0.44 (0.16)	0.97	0.84	0.98	0.97	0.56	0.63
VC _L	0.67	0.28 (0.11)	0.95	0.76	0.92	0.54	0.34
MPEF _L	0.78	0.66	0.32 (0.13)	0.98	0.91	0.25	0.58
MPIF _L	0.80	0.69	0.80	0.28 (0.11)	0.98	0.31	0.21
VR _L	0.77	0.67	0.68	0.69	0.36 (0.14)	0.50	0.76
Weight	0.63	0.70	0.55	0.60	0.44	0.16 (0.08)	0.56
Musc. score	0.19	0.22	0.21	0.25	0.09	0.41	0.16 (0.08)

^aHeritability estimates on diagonal. Genetic correlations in upper right and environmental correlations in lower left. Parenthetical values are standard errors of the estimates. Musc. score = muscular score; 15-s MV_L = average ventilation recorded during the 15 s of maximal ventilatory changes induced by lobeline administration; VC_L, MPEF_L, and MPIF_L = vital capacity, maximal peak expiratory flow, and maximal peak inspiratory flow recorded after lobeline administration; VR_L = ventilatory reserve (VR_L = 15-s MV_L - ventilation at rest).

from 0.44 to 0.70, and environmental correlations with muscling score ranged from 0.09 to 0.25. Thus, environments favorable to weight and muscular growth are also favorable to the respiratory tract development.

Implications

Previous studies suggested that high spirometric performances are related to increased resistance to respiratory disorders in calves. Here, we show that spirometric variables have heritabilities ranging from 0.28 to 0.44 and that genetic correlations between spirometric variables and weight and muscular development are positive, indicating that response to selection for improved spirometric performances would be possible, without impairing traits of economical importance. Further studies are needed to estimate genetic correlations between spirometric variables and the occurrence and severity of respiratory disorders.

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