Reprinted from the AMERICAN JOURNAL OF VETERINARY RESEARCH, Vol. 45, No. 10, Pages 2003-2007.

Effect of somatic growth on pulmonary function values in healthy Friesian cattle

P. Lekeux, DVM, PhD; R. Hajer, DVM, PhD; H. J. Breukink, DVM, PhD

SUMMARY

Growth-related changes in pulmonary function values (PFV) of cattle were investigated by a cross-sectional study of 40 healthy Dutch Friesian cattle, 3 days to 13 years of age and weighing 37 to 660 kg. Technical and methodologic procedures and body conformation and condition were standardized.

A regression analysis was done with 4 independent variables (body weight, thoracic perimeter, body surface area, and age) and with PFV measured in this study.

Ventilation values, dynamic lung compliance, and viscous work of breathing changed linearly with somatic growth. Respiratory frequency, total pulmonary resistance, and arterial oxygen tension showed an exponential relationship with all the independent variables. On the other hand, intrapleural pressure values were weakly correlated with body size indexes.

The most important growth-related changes in PFV occurred at approximately 1 year of age. A significant ($P \leq 0.05$) difference between immature and mature cattle was shown for the blood-gas values and the specific values of the breathing mechanics. The dynamic lung compliance/lung weight was lower and the total pulmonary resistance × minute volume was higher in cattle than in other domestic mammals.

The regression equation, giving the best fit of the data, was selected for each PFV.

Reproducibility and individual variation of pulmonary function values (PFV) have been reported in unsedated calves.[1,2] However, data on growth-related changes of physiologic PFV are not currently available in cattle. They are required for interpretation of individual PFV and for determination of pathologic changes in long-term respiratory studies.

In this report, effects of somatic growth on ventilation, mechanics of breathing, and gas exchange were evaluated in healthy Friesian cattle using a cross-sectional study performed under standardized conditions.

Received for publication Oct 31, 1983.

From the Department of Large Animals Medicine, Faculty of Veterinary Medicine, State University of Utrecht, Yalelaan, 16, Utrecht, The Netherlands. Dr. Lekeux's present address is Department of Large Animals Medicine, State University of Liege, Rue des Veterinaires, 45, Brussels, Belgium.

The authors thank Drs. Geubelle, Hanset, Oyaert, Bienfet, Lomba, Leroy, Michaux, Viel, and Coignoul for counseling and advice.

Materials and Methods

Forty healthy Dutch Friesian cattle (14 males and 26 females), 3 days to 13 years of age, weighing 37 to 660 kg, and with a thoracic perimeter (TP) of 72 to 210 cm were used. Cattle were obtained from the experimental farm of the University of Utrecht, The Netherlands. All cattle were healthy on clinical examination. Body conformation and condition were normal. No cow was more than 2 months pregnant.

The cattle were assigned into 6 groups according to body weight (BW) and age (Table 1). Females were unevenly distributed; 3 were in groups 1 and 2, 2 in group 3, 5 in group 4, 6 in group 5, and 7 in group 6. Food was removed 12 hours before each measurement.

Respiratory airflow ($\dot{V}$) was measured using a Fleisch pneumotachograph[a] and tidal volume (V_t) was derived electronically by integrating $\dot{V}$ with respect to time.

A breathing mask was built for each group of animals.[2] The maximal dead space of the breathing apparatus was approximately 15% of the V_t.[2] Intrapleural pressure (Ppl) was measured with an esophageal balloon.[2] The tip of the catheter was positioned in the thoracic portion of the esophagus, at the crossing point between aorta and caudal mediastinal lymph nodes.[3] To allow accurate Ppl measurements with the pressure transducer (model P23Db[a]), the balloon-tubing gauge system was inflated with a minimum of air, within the range of high compliance of the balloon wall. Accuracy of $\dot{V}$, V_t, and Ppl measurements were checked according to methods previously described.[2,4]

All measurements were performed in resting, nonanesthetized, and unsedated cattle and in constant air pressure (770 mm of Hg) and temperature (18 C) conditions. Position of the head and neck was standardized.[3] Before each measurement, the pressure transducer was calibrated with a mercury manometer and the pneumotachograph with a flow calibration set[a]; both instruments were checked for phase compatibility.[2]

Cattle were given a 5-minute adaptation period after the mask and the balloon catheter were placed. The $\dot{V}$, V_t, and Ppl were recorded simultaneously on the polygraph (Brusch 2600[a]). Mean PFV were derived from measurements on 5 normal and quiet respiratory cycles. Only data from a series of 10 regular, successive, and artifact-free cycles were evaluated.

Determinants measured were: respiratory frequency (f), inspiratory and expiratory time (tI and tE, respectively), peak inspiratory and expiratory $\dot{V}$ ($\dot{V}$Imax and $\dot{V}$Emax, respectively), V_t, the lowest Ppl during inspiration (Pplmin), the highest Ppl during expiration (Pplmax), and Ppl at the functional residual capacity level (Ppl_{frc}).

The following PFV was calculated: ratio of tI to the total time of the breathing cycle (tI/tTOT), mean inspiratory and expiratory $\dot{V}$ (m$\dot{V}$I and m$\dot{V}$E, respectively), minute volume ($\dot{V}$e), peak-to-peak change in Ppl (maxdPpl), dynamic lung compliance (Cdyn), total pulmonary resistance (R_L), viscous work of breathing (Wvis), and power of breathing ($\dot{W}$vis).

[a] Gould Godart, Bilthoven, The Netherlands.

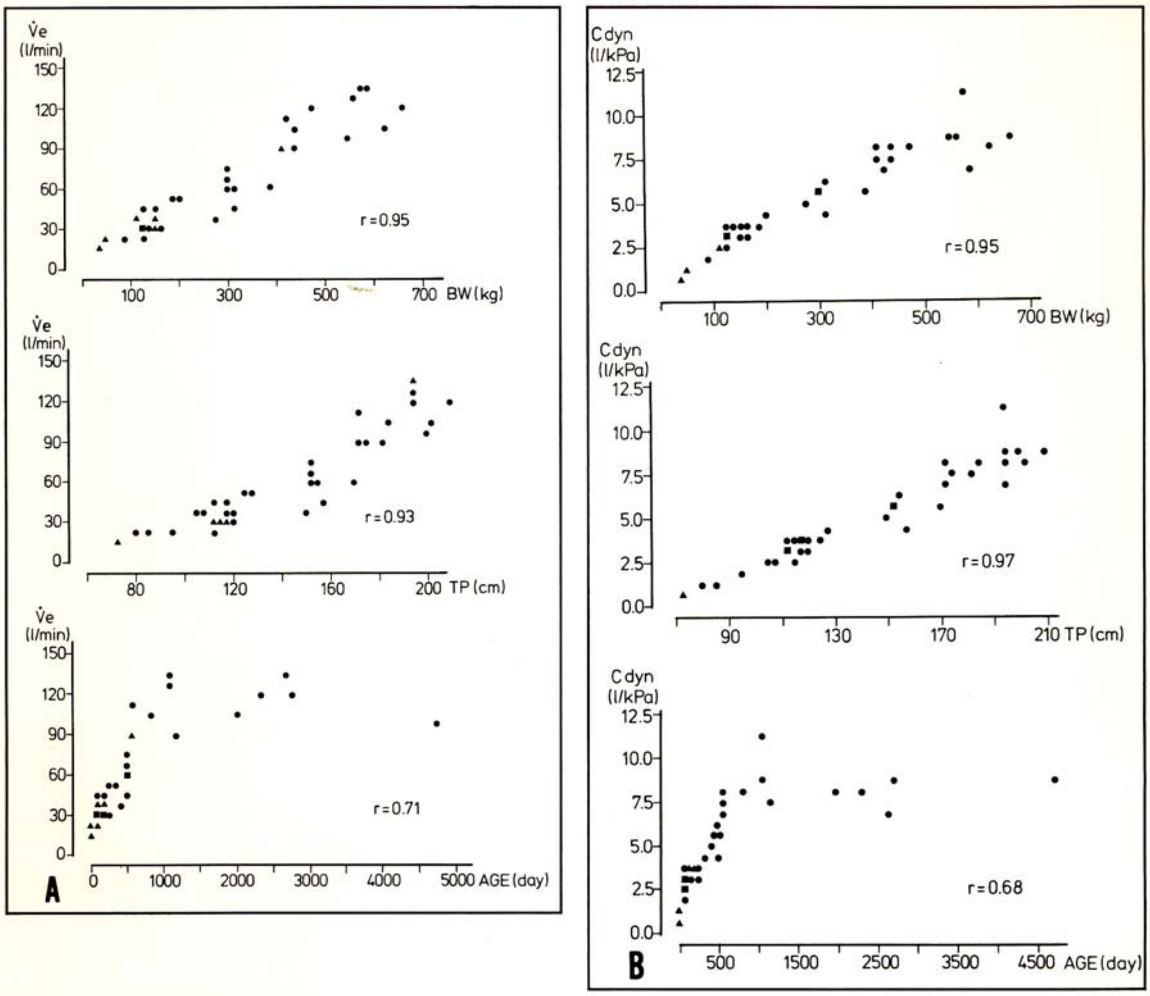


Fig 1—Relationship between pulmonary function values and the BW, TP, and age in healthy Friesian cattle (● = 1 value; ▲ = 2 values; ■ = 3 values). r = correlation coefficient. l/min = L/min; l/kPa = L/kPa; kPa·sec/l = kPa·sec/L.

Specific values for some PFV were also calculated as propposed by Stahl[5]: V_t/BW (sV_t), $\dot{V}e$/body surface area (BSA)-$s\dot{V}e$), Cdyn/lung weight (sCdyn), $R_L \times \dot{V}e$ (sR_L), Wvis/lung weight (sWvis), and $\dot{W}vis/\dot{V}e$ ($s\dot{W}vis$). The BSA and lung weight were calculated using Brody's equations.[6] Lung volume determinations were corrected to body temperature pressure-satured (BTPS) units.

After recording, arterial blood was sampled from the brachial artery[7] and was analyzed immediately for partial pressures of oxygen (Pa_{O_2}) and carbon dioxide (Pa_{CO_2}) with a blood gas analyzer.[b] Blood-gas pressures were corrected for rectal temperature.[8] Alveolar-arterial oxygen gradient (A-adO_2) was determined for each animal.[9]

A regression analysis was performed with 4 independent variables (BW, TP, age, and BSA) and with 20 dependent variables (Table 2).

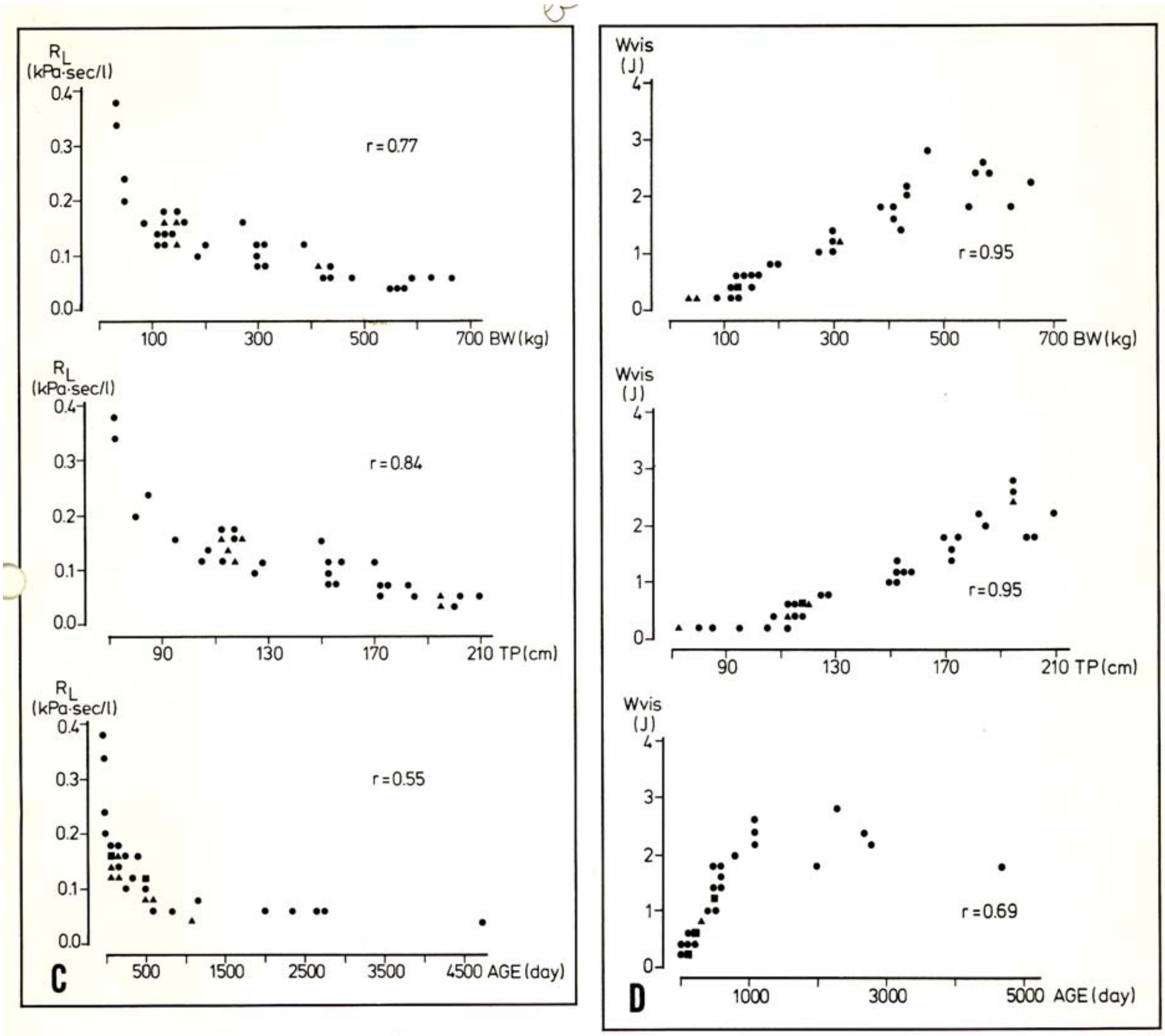
Linear, curvilinear, multiple, and allometric regression equations were calculated for each dependent variable. The determination coefficent (R^2) and the significance of the variance ratio (variance regression/variance error) were calculated for each equation.[10] The statistically significant equation, whether linear, curvilinear, multiple, or allometric, that gave the best fit of the data was selected.

[b] AVL gas check 93750, Schaffhausen, Switzerland.

Results

Mean PFV of the 6 groups of cattle (Tables 1 and 3) and growth-related changes of PFV (Fig 1) were determined. The Ppl values, tI/tTOT, and sV_t were weakly correlated with body size indexes (Table 2).

Ventilation values and some changes of the mechanics of breathing (Cdyn, Wvis, and $\dot{W}vis$) were linear with somatic growth. The Pa_{O_2}, A-adO_2, R_L, f, sCdyn, and sWvis relation with all independent variables were exponential. The sR_L and $s\dot{W}vis$ values were high in groups 4, 5, and



◀ Legend for figures on facing page.

6 (adult), less in group 1 (newborn), and least in groups 2 and 3 (immature; Table 2).

Blood-gas values, Ppl values, and specific values of the mechanics of breathing differed significantly ($P \leq 0.05$) before and after 1 year of age (Table 4).

Regression equations, giving the highest R^2 (Table 3), had BW and TP as the most frequently selected independent variables. However, age was selected for the regression equation of tI/tTOT and Ppl values.

Discussion

Results of PFV in group 1 were in agreement with previous data of Bisgard et al[11] (mean BW = 60 kg) and Kiorpes et al[1] (mean BW = 59 kg), and the values of group 4 were in agreement with data reported by Musewe et al[12] (mean BW = 355 kg).

Data collected on adult cattle in the present study compared with data proposed by Stahl[5] for common mammals (Table 5), indicated that the s$\dot{V}$e and sR_L were higher and the sV_t and sCdyn were lower in cattle than in other species (mainly persons, dog, cat, and rat).

The same observations were made in regard to healthy adult horses.[13-18,c] A partial explanation could be found in the anatomical specificity of the bovine lung, ie, higher compartimentalization of the bovine lung without collateral ventilation and smaller cross-sectional area of upper airways.[18-19]

Ventilation data reported for persons,[19-25,d] dog,[26] and

[c] Sasse HHL: *Some pulmonary function tests in horses.* PhD Thesis, University of Utrecht, 1971.

[d] Gaultier Cl: *Développement Postnatal de la Fonction Pulmonaire Chez l'Enfant.* PhD Thesis, University of Paris-sud UER Kremlin-Bicêtre, 1980.

TABLE 1—Pulmonary function values of healthy Friesian cattle of different ages

Value	Unit	Groups 1 (n = 5)	2 (n = 11)	3 (n = 5)	4 (n = 6)	5 (n = 6)	6 (n = 7)	$\overline{X}$ (n = 40)
Age	days	17 ± 11	135 ± 10	228 ± 24	500 ± 20	715 ± 93	2366 ± 470	664 ± 152
BW	kg	53 ± 8	130 ± 4	170 ± 9	303 ± 6	419 ± 8	577 ± 21	273 ± 29
BSA	m^2	1.10 ± 0.09	1.83 ± 0.03	2.13 ± 0.06	2.94 ± 0.03	3.53 ± 0.04	4.22 ± 0.09	2.62 ± 0.17
TP	cm	81 ± 4	113 ± 1	122 ± 2	153 ± 1	176 ± 3	199 ± 2	141 ± 6
f heart	min^{-1}	94 ± 3	80 ± 2	82 ± 2	70 ± 1	67 ± 2	61 ± 1	75 ± 2
f	min^{-1}	44 ± 4	31 ± 2	26 ± 2	24 ± 2	23 ± 2	23 ± 1	28 ± 1
tI	s	0.71 ± 0.09	0.93 ± 0.07	1.14 ± 0.09	1.15 ± 0.06	1.25 ± 0.13	1.11 ± 0.06	1.04 ± 0.04
tE	s	0.72 ± 0.07	1.11 ± 0.11	1.27 ± 0.12	1.40 ± 0.16	1.42 ± 0.08	1.51 ± 0.13	1.24 ± 0.06
tI/tTOT	–	0.49 ± 0.02	0.46 ± 0.01	0.47 ± 0.02	0.46 ± 0.02	0.46 ± 0.02	0.42 ± 0.01	0.46 ± 0.01
$\dot{V}$Imax	L/s	0.8 ± 0.1	1.6 ± 0.1	1.9 ± 0.2	2.7 ± 0.2	4.4 ± 0.5	5.8 ± 0.2	2.9 ± 0.3
$\dot{V}$Emax	L/s	1.0 ± 0.2	1.9 ± 0.1	2.0 ± 0.2	3.0 ± 0.3	4.3 ± 0.5	6.2 ± 0.4	3.1 ± 0.3
m$\dot{V}$I	L/s	0.7 ± 0.1	1.3 ± 0.1	1.5 ± 0.1	2.2 ± 0.2	3.3 ± 0.3	4.7 ± 0.2	2.3 ± 0.2
m$\dot{V}$E	L/s	0.7 ± 0.1	1.1 ± 0.1	1.3 ± 0.1	1.9 ± 0.2	2.8 ± 0.2	3.5 ± 0.2	1.9 ± 0.2
V_t	L	0.49 ± 0.08	1.15 ± 0.06	1.62 ± 0.07	2.47 ± 0.11	3.95 ± 0.25	5.17 ± 0.08	2.45 ± 0.27
$\dot{V}$e	L/min	20 ± 1	35 ± 2	42 ± 4	59 ± 5	91 ± 7	121 ± 6	61 ± 6
Pplmin(−)	kPa	1.27 ± 0.12	1.24 ± 0.04	1.32 ± 0.05	1.39 ± 0.04	1.43 ± 0.05	1.57 ± 0.12	1.35 ± 0.03
Pplmax(−)	kPa	0.61 ± 0.15	0.59 ± 0.03	0.58 ± 0.04	0.59 ± 0.04	0.65 ± 0.03	0.77 ± 0.11	0.62 ± 0.03
maxdPpl	kPa	0.67 ± 0.05	0.65 ± 0.03	0.74 ± 0.03	0.79 ± 0.03	0.78 ± 0.03	0.80 ± 0.03	0.73 ± 0.02
Ppl_{frc}(−)	kPa	0.70 ± 0.15	0.70 ± 0.03	0.71 ± 0.04	0.79 ± 0.04	0.77 ± 0.03	0.88 ± 0.09	0.74 ± 0.03
Cdyn	L/kPa	1.14 ± 0.20	3.20 ± 0.13	3.81 ± 0.13	5.55 ± 0.25	7.31 ± 0.34	8.66 ± 0.45	4.94 ± 0.41
R_L	kPa/L/s	0.27 ± 0.04	0.15 ± 0.01	0.14 ± 0.01	0.11 ± 0.01	0.08 ± 0.01	0.06 ± 0.01	0.13 ± 0.01
Wvis	J	0.18 ± 0.03	0.44 ± 0.04	0.65 ± 0.05	1.19 ± 0.08	1.79 ± 0.11	2.30 ± 0.15	1.08 ± 0.13
$\dot{W}$vis	J/min	7.6 ± 0.7	13.1 ± 0.6	17.1 ± 2.0	28.1 ± 2.5	40.7 ± 2.1	54.7 ± 5.8	26.6 ± 2.9
Pa_{O_2}	kPa	12.4 ± 0.4	13.3 ± 0.3	13.8 ± 0.4	14.7 ± 0.3	15.2 ± 0.2	14.9 ± 0.3	14.0 ± 0.2
Pa_{CO_2}	kPa	5.8 ± 0.2	5.7 ± 0.1	5.7 ± 0.2	5.5 ± 0.1	5.3 ± 0.2	5.4 ± 0.1	5.6 ± 0.1
A-aDO_2	kPa	2.3 ± 0.2	1.5 ± 0.1	1.0 ± 0.1	0.3 ± 0.05	0.1 ± 0.05	0.2 ± 0.05	0.9 ± 0.1

Data are expressed as mean ± SEM. J = joule.

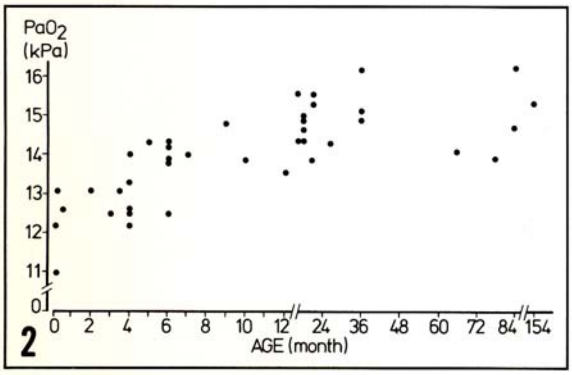


Fig 2—Relationship between Pa_{O_2} and age in healthy Friesian cattle.

TABLE 2—Selected regression equations for reference values of pulmonary function tests in healthy Friesian cattle

Value	Unit	Regression equations	R^2	DS
f	min^{-1}	$+ 104 - 0.97 \times TP + 0.0028 \times TP^2$	0.66	XXX
tI	s	$- 0.52 + 0.017 \times TP - 0.003 \times BW$	0.43	XXX
tE	s	$- 0.31 - 0.007 \times BW + 0.0002 \times age + 1.24 \times BSA$	0.53	XXX
tI/tTOT	–	$+ 0.47 - 0.00002 \times age$	0.20	XX
$\dot{V}$Imax	L/s	$+ 0.32 + 0.009 \times BW$	0.91	XXX
$\dot{V}$Emax	L/s	$+ 0.49 + 0.009 \times BW$	0.84	XXX
m$\dot{V}$I	L/s	$+ 0.20 + 0.008 \times BW$	0.92	XXX
m$\dot{V}$E	L/s	$+ 0.38 + 0.006 \times BW$	0.86	XXX
V_t	L	$0.009 \times BW^1$	0.98	XXX
$\dot{V}$e	L/min	$+ 9.23 + 0.19 \times BW$	0.91	XXX
Pplmin	kPa	$- 1.19 - 0.0004 \times age + 0.00000009 \times age^2$	0.46	XXX
Pplmax	kPa	$- 0.52 - 0.0003 \times age + 0.00000006 \times age^2$	0.22	X
maxdPpl	kPa	$+ 0.67 + 0.0002 \times age - 0.00000004 \times age^2$	0.30	XX
Ppl_{frc}	kPa	$- 0.64 - 0.0003 \times age + 0.00000006 \times age^2$	0.37	XX
Cdyn	L/kPa	$- 3.96 + 0.063 \times TP$	0.94	XXX
R_L	kPa/L/s	$2.68 \times BW^{-0.59}$	0.85	XXX
Wvis	J	$0.002 \times BW^{1.1}$	0.95	XXX
$\dot{W}$vis	J/min	$0.24 \times BW^{0.83}$	0.89	XXX
Pa_{O_2}	kPa	$8.64 \times BW^{0.09}$	0.68	XXX
Pa_{CO_2}	kPa	$+ 5.8 - 0.001 \times BW$	0.22	XX

R^2 = determination coefficient; DS = degree of significance of the variance ratio; X = $P \le 0.05$; XX = $P \le 0.01$; XXX = $P \le 0.001$; TP (cm); BW (kg); BSA (m^2); age (day); J = joule.

rat,[27] showed similar variations with somatic growth as corresponding values observed in cattle. Furthermore, the relation between body size indexes and mechanical values (Cdyn, R_L, sCdyn, and sR_L) were similar in persons and cattle.[28,29,d] Therefore, the growth of the respiratory tract could be nonisotopic in cattle, as it has already been postulated in persons.[30,d]

The Pa_{O_2} increased slightly from birth to 1 year of age and then remained constant (Fig 2). This growth-related change of Pa_{O_2} was not observed in Beagles,[26] in contrast with persons where the adult value of Pa_{O_2} was reached at 8 years of age.[31] In persons, the number of alveoli and alveolar capillary segments found in adults is only reached at 8 years of age.[32,33] Another possible explanation may be related to the closing volume, which has been shown to decrease with age in children.[34,35] These assumptions could also be true in cattle, because A-adO_2 was much greater in younger cattle (< 1 year) and airway closure has been shown to appear at high lung volume in calves,[36] probabaly inducing ventilation/perfusion disturbances.

The Ppl_{frc} was more negative in mature cattle than in calves. Therefore, it would be useful to study the correlation between Pa_{O_2}, Ppl_{frc}, and the closing volume.

Results of the present study indicated that the most important growth-related changes of breathing mechanics occurred at approximately 1 year of age in cattle, the energetic cost of respiration was proportionally lower in immature cattle, and the maximal gas exchange efficiency was reached around 1 year of age, in cattle. This

TABLE 3—Specific pulmonary function values of healthy Friesian cattle of different ages

Value	Unit	Groups 1 (n = 5)	2 (n = 11)	3 (n = 5)	4 (n = 6)	5 (n = 6)	6 (n = 7)	$\bar{X}$ (n = 40)
sV_t	ml/kg	9.1 ± 0.6	8.8 ± 0.2	9.5 ± 0.4	8.4 ± 0.3	9.4 ± 0.4	9.0 ± 0.4	9.0 ± 0.2
$s\dot{V}e$	$L/min \times m^2$	18 ± 1	19 ± 1	20 ± 1	20 ± 2	26 ± 2	29 ± 1	22 ± 1
sCdyn	L/kPa × kg	1.14 ± 0.18	1.98 ± 0.15	2.06 ± 0.13	2.22 ± 0.21	2.48 ± 0.30	2.47 ± 0.42	2.09 ± 0.37
sR_L	kPa	5.5 ± 0.5	5.1 ± 0.2	5.5 ± 0.3	6.4 ± 0.3	7.3 ± 0.2	7.3 ± 0.2	6.0 ± 0.2
sWvis	J/kg	0.20 ± 0.03	0.25 ± 0.02	0.35 ± 0.02	0.50 ± 0.01	0.62 ± 0.03	0.64 ± 0.02	0.43 ± 0.01
$s\dot{W}vis$	kPa	0.40 ± 0.04	0.38 ± 0.02	0.39 ± 0.02	0.48 ± 0.01	0.46 ± 0.03	0.46 ± 0.03	0.42 ± 0.01

Data are expressed as mean ± SEM. J = joule.

TABLE 4—Comparison of pulmonary function values between immature and mature healthy Friesian cattle

Value	Unit	< 1 Year (n = 21)	> 1 Year* (n = 19)
Pa_{O_2}	kPa	13.2 ± 0.2	14.9 ± 0.2
Pa_{CO_2}	kPa	5.7 ± 0.1	5.3 ± 0.1
$A\text{-}aDO_2$	kPa	1.5 ± 0.1	0.2 ± 0.05
sCdyn	L/kPa × kg	1.75 ± 0.10	2.38 ± 0.18
sR_L	kPa	5.3 ± 0.2	6.9 ± 0.2
$s\dot{W}vis$	kPa	0.39 ± 0.02	0.46 ± 0.02
Ppl_{frc}	kPa	0.69 ± 0.04	0.80 ± 0.04

* Significant difference ($P \leq 0.05$; Students' t test) was observed compared with the < 1 year mean ± SEM.

Data are expressed as mean ± SEM.

TABLE 5—Pulmonary function values in adult Friesian cattle compared with data proposed by Stahl[5] for common mammals and with normal values reported for adult horses

Value	Unit	Cattle	Horse	Common mammals*
sV_t	ml/kg	8.9	11.0	9.9
$s\dot{V}e$	$L/min \times m^2$	25	23	14
sCdyn	L/kPa × kg	2.4	4.3	3.3
sR_L	kPa	7.0	3.6	1.6
$s\dot{W}vis$	kPa	0.47	0.46	0.22

* Persons, dog, cat, and rat.

may explain clinical observations in feedlot cattle[37] of respiratory problems that often were more severe in cattle < 1 year of age, independent of immunologic status.

References

1. Kiorpes AL, Bisgard GE, Manohar H: Pulmonary function values in healthy Holstein Friesian calves. *Am J Vet Res* 39:773–778, 1978.
2. Lekeux P, Hajer R, Breukink HJ: Pulmonary function testing in calves. *Am J Vet Res* 45:342–345, 1984.
3. Lekeux P, Hajer R, Breukink HJ: Intrathoracic pressure measurement in cattle: Standardization procedure. *Can J Comp Med* 48: in press, 1984.
4. Lekeux P, Hajer R, Breukink HJ: Elastic properties of the esophageal wall in the dynamic measure of intrathoracic pressure in cattle. *Res Vet Sci* 36: in press, 1984.
5. Stahl WR: Scaling of respiratory variables in mammals. *J Appl Physiol* 22:453–460, 1967.
6. Brody S: *Bioenergetics and Growth*. New York, Rheinhold, 1945, pp 615–649.
7. Fischer EW: Arterial puncture in cattle. *Vet Rec* 68:691–692, 1956.
8. Kelman GR, Nunn JF: Nomograms for correction of blood P_{O_2}, CO_2, pH and base excess for time and temperature. *J Appl Physiol* 21:1484–1490, 1966.
9. Donawick WJ, Baue AE: Blood gas, acid-base balance, and alveolar arterial oxygen gradient in calves. *Am J Vet Res* 29:561–567, 1968.
10. Snedecor GW, Cochran WG: *Statistical Methods*, ed 7. Ames, Iowa, Iowa State University Press, 1980.
11. Bisgard GE, Ruiz AV, Grover RF, et al: Ventilatory control in the Hereford calf. *J Appl Physiol* 35:220–226, 1973.
12. Musewe VO, Gillepsie JR, Berry JD: Influence of ruminal insufflation on pulmonary function and diaphragmatic electromyography in cattle. *Am J Vet Res* 40:26–31, 1979.
13. Muylle E, Oyaert W: Lung function tests in obstructive pulmonary disease in horses. *Equine Vet J* 5:37–42, 1973.
14. Gillepsie JR, Tyler WS, Eberly VE: Pulmonary ventilation and resistance in emphysematous and control horses. *J Appl Physiol* 21:416–420, 1966.
15. Robinson NE, Sorenson PR, Globe DO: Patterns of airflow in normal horses and horses with respiratory diseases. *Am Assoc Equine Pract* 21:11–20, 1975.
16. McPherson EA, Lawson GHK, Murphy JR, et al: Chronic obstructive pulmonary disease (COPD): Identification of affected horses. *Equine Vet J* 1:47–53, 1978.
17. Willoughby RA, McDonnell WN: Pulmonary function testing in horses. *Vet Clin North Am* 1:171–196, 1979.
18. Robinson NE: Some functional consequences of species differences in lung anatomy. *Adv Vet Sci Comp Med* 26:1–33, 1982.
19. Veith HP, Farrell RL: The anatomy and physiology of the bovine respiratory system relating to pulmonary disease. *Cornell Vet* 68:555–581, 1978.
20. Geubelle F, Breny H: Volumes pulmonaires des filles et des garçons sains âgés de 5 à 16 ans. *Poumon Coeur* 10:1051–1064, 1969.
21. VonDerHardt H, Nowak A: Mechanics of respiration in healthy children 6 to 15 years of age. *Pneumologie* 153:261–274, 1976.
22. Zapletal A, Motoyama E, Van de Woestijne K, et al: Maximum expiratory flow-volume curves and airway conductance in children and adolescents. *J Appl Physiol* 26:308–316, 1969.
23. Briscoe WA, Dubois AB: The relationship between airway resistance, airway conductance, and lung volume in subjects of different ages and body size. *J Clin Invest* 37:1279–1285, 1958.
24. Cook CD, Helliesen PJ, Agathon S: Relation between mechanics of respiration, lung size and body size from birth to young adulthood. *J Appl Physiol* 13:349–352, 1958.
25. Hellieson PJ, Cook CD, Friedlander L, et al: Studies of respiratory physiology in children. I. Mechanics of respiration and lung volumes in 85 normal children. *Pediatrics* 22:80–93, 1958.
26. Mauderly JL: Effect of age on pulmonary structure and function of immature and adult animals and man. *Fed Proc* 38:173–177, 1979.
27. Leong K, Dowd G, McFarland H: A new technique for tidal volume measurement in unanesthetized small animals. *Can J Physiol Pharmacol* 42:189–198, 1964.
28. Krieger I: Studies on mechanics of respiration in infancy. *Am J Dis Child* 105:439–448, 1963.
29. Geubelle F, Vavrova V: Compliance et résistance pulmonaires au débit aérien chez l'enfant sain. *Poumon Coeur* 25:1085–1099, 1969.
30. Mead J: Mechanical properties of lungs. *Physiol Rev* 41:281–330, 1961.
31. Gaultier Cl, Boulé M, Allaire Y, et al: Determination of capillary oxygen tension in infants and children: Assessment of methodology and normal values during growth. *Bull Eur Physiopath Respir* 14:287–297, 1978.
32. Dunnill M: Postnatal growth of the lung. *Thorax* 17:329–333, 1962.
33. Weibel E, Gomez D: Architecture of the human lung. *Science* 137:577–585, 1962.
34. Mansell A, Bryan C, Levison H: Airway closure in children. *J Appl Physiol* 33:711–714, 1972.
35. Gaultier Cl, Allaire Y, Pappo A, et al: Etude du volume de fermeture chez l'enfant sain et atteint d'obstruction bronchique. *Colloq Inst Natl Santé R Méd* 51:365–372, 1975.
36. Slocombe RF, Robinson NE, Derksen FJ: Effect of vagotomy on respiratory mechanics and gas exchange in the neonatal calf. *Am J Vet Res* 43:1168–1171, 1982.
37. Lekeux P, Lomba F, Bienfet V: Affections respiratoires enzootiques dans les unités d'engraissement de taurillons en Belgique, in *Proceedings*, 12th World Congr Cattle Dis, vol 1, 1982, pp 49–53.