Health status and risk factors associated with failure of passive transfer of immunity in newborn beef calves in Québec

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Abstract — Risk factors associated with failure of passive transfer of immunity (FPT) were evaluated among newborn beef calves in Québec. Physical examination was performed on calves born of a normal calving and blood samples were collected for determination of health status and measurement of serum concentration of immunoglobulin (Ig) G_1. Of 225 calves, from 45 herds, 19 % showed FPT (serum IgG1 concentration < 10.0 g/L). Calves born in a stanchion-stall were more likely to show FPT (OR: 10.2). Calves bottle-fed colostrum were less at risk for FPT (OR: 0.06). Calf gender, month of birth, dam parity, and dam body condition score were not associated with FPT. No association was detected between FPT and health status. Special care should be given to calves born from cows in a stanchion-stall to ensure adequate colostrum intake. Failure of passive transfer of immunity should be considered with other risk factors when investigating morbidity.

Résumé — TITLE MISSING.

L'échec du transfert de l'immunité passive (TIP) et les facteurs de risque associés ont été évalués chez des veaux de boucherie du Québec. Un examen physique et des prélèvements sanguins ont permis de déterminer l'état de santé et la concentration sérique d'IgG1 chez des veaux issus d'un vêlage normal. Parmi 225 veaux provenant de 45 troupeaux, le TIP ne s'est pas réalisés chez 19 % d'entre eux (concentration sérique d'IgG1 < 10 g/L). Les veaux nés en stabulation entravée étaient plus vulnérables à un échec du TIP (RC : 10,2). Les veaux ayant bu leur colostrum au biberon étaient moins exposés à l'échec du TIP (RC : 0,06). Le sexe du veau, le mois de naissance ainsi que la parité et l'état de chair de sa mère n'étaient pas associés à l'échec du TIP. Aucun lien n'a été décelé entre l'état de santé et la réalisation du TIP. On devrait veiller à ce que les veaux naissant d'une vache en stabulation entravée puissent ingérer une quantité suffisante de colostrum. En cas de problème de morbidité chez des nouveau-nés, l'échec du TIP devrait être inclus parmi les facteurs de risque.

(Traduit par les auteurs)

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Introduction

Inadequate serum concentration of immunoglobulins in newborn calves has been associated with increased disease susceptibility (1–7). In beef production, this may impair profitability through additional costs of treatment, reduced weight gain, and an increased risk of mortality (3,8). This is particularly true for the cow-calf units, but losses related to failure of passive transfer (FPT) can also apply to feedlots (7). Prevalence of FPT in beef calves has been reported to range from 11% to 31% in North America (3).

In Québec, results from a mailed questionnaire on management practices and herd performance estimated that, in herds of more than 40 females, the average perinatal and preweaning calf mortality rates were 5.2% and 5.6%, respectively (9). These rates were higher than those reported in the USA (3.2% and 2.3%, respectively) (10) and in Alberta (2.3% and 2.6%, respectively) (11). During the 1995 calving season, 57.9% of the respondents experienced a problem with calf diarrhea while 35.6% reported a problem with calf pneumonia (9). In 26 herds from northwestern Québec, Ganaba et al (12) evaluated the overall calf mortality at 14.7%. Extended calving seasons (9), as well as dystocias (9,12), were associated with poor health performance by beef calves in Québec. However, FPT and colostrum management practices in cow-calf units in Québec have not been studied for their impact on beef calves morbidity.

The objectives of this study were 1) to estimate the proportion of FPT among a selected population of beef calves born of normal calving in Québec, 2) to assess their health at the time of blood sampling, and 3) to identify risk factors associated with FPT and morbidity.

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Materials and methods

Herd sampling method

Five hundred and twenty producers, selected from a 1995 census of cow-calf producers in Québec and owning 12 or more cows, were invited to answer a mailed questionnaire about management practices and herd performance

Table 1. Criteria used to define ill individuals according to physical and laboratory results in 219 newborn beef calves

Criterion	Definition	Frequency of observation	Calves meeting criteria[a]
Dullness	Weak, need to be stimulated to rise or is recumbent	7	7
Diarrhea	Presence of diarrhea, dirty tail	14	14
Dehydration	If 2 of the following criteria are present:		9
	— Moderate to severe clinical dehydration: Skin fold persistency > 2 s; sunken eyes; dry muzzle	4	
	— Urea concentration > 6.5 mmol/L	7	
	— Creatinine concentration > 132 μmol/L	27	
	— PCV > 0.40 L/L	27	
Presence of an infection	If 2 of the following criteria are present:		30
	— Rectal temperature > 39.6°C	7	
	— Increased lung sounds; presence of crackles or wheezes	12	
	— Umbilicus inflammation	12	
	— Presence of arthritis, hypopyon, nasal purulent discharges, or abscess	7	
	— WBC < 4 ($\times 10^9$ cells/L) or > 12 ($\times 10^9$ cells/L)	32	
	— Plasma fibrinogen > 5 g/L	50	

PCV — Packed cell volume
WBC — White blood cell count
[a]Total of calves classified as diseased = 49

(9). A total of 332 producers (66.4%) completed and returned the questionnaire. Respondents were then invited to participate in the 2nd phase of the project, namely to study management and health data recording in cow-calf units. For convenience, all of the farms considered were from the central and southern area of the province, near the Faculté de médecine vétérinaire de l'Université de Montréal (FMV). Fifty-six owners were enrolled on a voluntary basis and agreed to collect herd information from 1996 to 1997. Finally, 45 owners contributed to the calf sampling of the present study.

The size of the participating herds varied from 13 to 220 breeding females, with an average size of 56 ($s = 6$) breeding females. The majority of the dams was crossbred, with a predominance of the Charolais, Simmental, Hereford, Limousin, and Angus breeds.

Calf selection and physical examination

Each herd was visited twice by a veterinarian during the 1997 calving season, from January to April. Calves from 24 h to 7 d old at the time of the visit were systematically enrolled in the study. Because dystocia had already been associated with a lower calf serum immunoglobulin (Ig) concentration (13,14), twins and calves delivered with assistance (strong assistance from producer; assistance from a veterinarian; caesarean) were not included. A physical examination was performed on each calf by using an evaluation grid adapted from the clinical sepsis score previously described by Fecteau et al (15).

Blood sampling and analytical methods

Blood samples were drawn from the jugular vein into a dry and an EDTA vacuum tube (Vacutainer; Becton Dickinson and Company, Franklin Lakes, New Jersey, USA). The serum was separated within 24 h of sampling and divided in 2 aliquots. One aliquot was kept frozen at -70°C until the concentration of IgG_1 was assessed using a commercial radial immunodiffusion kit (Bovine IgG_1 VET-RID; Bethyl Laboratories, Montgomery, Texas, USA). All serum IgG_1 assays were performed by the same technician. Lower and upper limits of the test were 3.2 and 26.0 IgG_1 g/L, respectively. Passive transfer of immunity was considered to be inadequate if IgG_1 serum concentration was < 10.0 g/L, as previously reported (16–18).

The other serum aliquot and the plasma were sent to the laboratory of the Faculté de médecine vétérinaire de l'Université de Montréal (FMV) for determination of hematological and biochemical parameters. Packed cell volume (PCV, L/L) and white blood cell count (WBC, $\times 10^9$ cells/L) were determined with a blood analyzer (Cell-dyn 3500 device; Abbott Laboratories Limited, Mississauga, Ontario). Plasma fibrinogen (g/L) was calculated with the heat precipitation method, using a refractometer (Goldberg; Cambridge Instruments, Optical Systems Division, Buffalo, New York, USA). Serum urea concentration (mmol/L) and serum creatinine concentration (mmol/L) were determined with a clinical laboratory system (Synchron CX5 device; Beckman Coulter, Brea, California, USA).

Determination of calf health status at the visit

The health status was based on the findings of a physical examination and blood analysis. A calf was considered ill if it showed dullness, dehydration, and signs of diarrhea or any other infectious problem (Table 1). The interpretation of laboratory results was based on reference values used at the FMV.

Data analysis

All analyses were performed by using software (Statistical Analysis System, version 8; SAS Institute, Cary, North Carolina, USA). Descriptive statistical analysis was done on biochemical and hematological

Table 2. Number and proportion of failure of passive transfer (FPT) (serum IgG_1 concentration < 10.0 g/L) according to the gender, the month of birth, the calving area location, and the type of inside calving area for 225 newborn beef calves

Variable	Number of calves	% of FPT
Calf sex		
Male	106	22.6
Female	119	16.0
Birth month		
January	59	22.0
February	81	12.4
March	67	23.9
April	18	22.2
Calving area location		
Inside	211	18.5
Outside	14	28.6
Type of inside calving area		
Box stall	73	6.8[a]
Stanchion-stall	123	23.8[b]
Pen	15	33.3[b]

[a,b]Proportions with different superscript letter differ ($P < 0.05$)

Table 3. Number and proportion of failure of passive transfer (FPT) (serum IgG_1 concentration < 10.0 g/L) according to dam parity and body condition score (BCS) for 225 newborn beef calves

Variable	Number of calves	% of FPT
Dam parity		
First	22	18.2
Second and more	203	19.2
Dam BCS		
≥ 1 and < 2	5	0
≥ 2 and < 3	85	21.2
≥ 3 and < 4	111	16.2
≥ 4 and < 5	8	25
Not evaluated	16	31.3

Table 4. Number and proportion of failure of passive transfer (FPT) (serum IgG_1 concentration < 10.0 g/L) according to type of assistance for colostrum intake in 225 newborn beef calves

Variable	Number of calves	% of FPT
No assistance	94	22.3[a]
Led to dam	105	18.1[a]
Bottle-fed	22	4.6[b]
Force-fed	4	50.0[a]

[a,b]Proportions with different superscript letter differ ($P < 0.05$)

Table 5. Biochemical and hematological variables in 170 healthy and 49 diseased newborn beef calves

Variables	Healthy calves Median, (*s*) Range Mean	Diseased calves Median, (*s*) Range Mean
Urea concentration (mmol/L)	3.2, (1.3) (1.1–10.1) 3.4	3.8, (1.8) (1.2–10.9) 4.0
Creatinine concentration (μmol/L)	103.0, (21.8) (66.0–219.0) 107.7	102.5, (31.6) (74.0–239.0) 111.7
Hematocrit (L/L)	0.33, (0.05) (0.17–0.46) 0.33	0.33, (0.07) (0.21–0.45) 0.33
White blood cell count ($\times 10^9$ cells/L)	7.3, (2.8) (1.7–20.1) 7.6	8.0, (3.5) (2.8–17.7) 8.9
Plasma fibrinogen (g/L)	4.0, (1.5) (1.0–12.0) 4.2	6.0, (2.1) (6.0–11.0) 5.9
IgG_1 (g/L)	21.4, (7.6) (3.2–26.0) 19.1	19.3, (8.4) (3.2–26.0) 17.3

variables. Independence of mean serum concentration of IgG_1 with age in days at sampling was verified with a Kruskal-Wallis test.

Individual animal factors investigated for association with FPT included calf gender, month of birth, type of calving area, colostrum feeding method, dam parity, and dam body condition score (BCS). Calves were born in stanchion stalls, box stalls, inside maternity pens, or outside maternity pens. The colostrum feeding assistance given by producers was classified in 4 categories: (0) no assistance, (1) calf led to the mammary gland, (2) calf bottle-fed, and (3) calf force-fed with a stomach tube. Cows with unknown parity were considered to be, at least, in their 2nd calving season, since they had calved at least once before the beginning of the study. Dam BCS was evaluated by a veterinarian, using a scale from 1 (thin) to 5 (fat) (19).

Independent variables were initially examined for bivariate association with FPT by using the likelihood ratio χ^2 test ($\alpha = 0.10$). Simple comparisons with *P* adjustment were applied as a post hoc test. The risk of having an abnormal health status as a newborn calf with an FPT was evaluated with a χ^2 test.

Interaction between all independent variables and FPT was tested with a logistic model in the genmod procedure of SAS. The clustering effect of the herd was treated as repeated measures. In this multivariate analysis, the type of calving area (tied versus untied), the dam parity (first calf versus others), and the dam BCS (≤ 2 and ≥ 4 versus others) were treated as a binomial variable. A stepwise backward elimination was used. Criteria to enter or leave the model was set at $P = 0.05$. By using the same procedure, a logistic regression model was used to identify risk factors associated with abnormal health status. The FPT status was then included with other dependent variables.

Results

A total of 225 calves, from 45 herds, were included in the study. Age in days at sampling was not related to mean serum immunoglobulin concentration of calves ($P = 0.83$). The mean concentration of IgG_1 was 18.9 g/L ($s = 7.8$ g/L). An FPT was estimated to occur in 19% of calves.

Distribution of the proportion of calves with FPT according to gender, month of birth, location of calving area, and type of inside calving area is shown in Table 2. Failure of passive transfer of immunity was associated with type of inside calving area ($P = 0.002$). The prevalence of FPT was significantly smaller in calves born in a box than in calves born in a stanchion stall or a pen ($P < 0.001$).

Table 6. Risk factors associated with failure of passive transfer (serum IgG_1 concentration < 10.0 g/L) in logistic regression model

Variable	Odds	95% CI	*P*-value
Calving area			
Untied[a]	referential category	—	—
Tied[b]	10.2	2.6–39.6	0.0009
Type of colostral feeding			
No assistance	referential category	—	—
Led to mammary gland	0.9	0.3–1.1	0.08
Bottle-fed	0.1	0.0–0.6	0.01

[a]Calves born in a stall or a pen
[b]Calves born in a stanchion stall

Table 7. Risk factors associated with abnormal health status in logistic regression model

Variable	Odds	95% CI	*P*-value
Type of colostrum feeding			
No assistance	Referential category	—	—
Led to mammary gland	1.2	0.4–2.0	0.68
Bottle fed	0.1	0.1–0.3	< 0.0001
Dam BCS			
> 2 or < 4	Referential category	—	—
≤ 2 or ≥ 4	2.4	1.1–5.2	0.03
Month of birth			
January	2.2	0.5–10.1	0.32
February	2.4	0.7–7.4	0.15
March	3.8	1.3–11.5	0.02
April	Referential category	—	—

BCS — Body condition score

Individual record keeping could not determine the exact parity for 118 mature cows. The average parity, excluding unknown cases, was 4.3 (s = 2.9) (n = 107). Parity was not identified as a risk factor for calf FPT (P = 0.91). Body condition score was recorded for 209 dams. Of these cows, 48.8% had a BCS between 3 and 3.5 at calving, as recommended (19). No cow was overly fat. Dam BCS was not significantly associated with calf FPT (P = 0.34). Proportions of calves with FPT according to parity and to dam BCS are shown in Table 3.

The presence of FPT was associated with type of colostrum assistance (P = 0.08, Table 4). The proportion of FPT was significantly smaller in the group of bottle fed calves than in other groups (P = 0.035). Their mean serum IgG_1 concentration was 22.6 g/L (s = 5.1 g/L) compared with 18.6 g/L (s = 7.9 g/L) for the calves left with their dam without intervention or led to the mammary gland. Due to its small numbers, the force-fed category was not included in post hoc test and multivariate analyses.

Type of calving area and type of assistance to colostrum intake were the only remaining variables in the logistic regression model (Table 6). Calves born in a stanchion stall were 10.2 times more likely to be diagnosed with FPT than were calves born in a box or a pen (P < 0.001). Calves that received their colostrum with a nipple-bottle were 0.06 times less likely to show FPT than those left with the dam with no assistance for colostrum intake (P = 0.014). Calves led to the mammary gland for colostrum intake had an equivalent chance of having FPT as did those left alone with the dam. Distribution of clinical examination and laboratory findings are given in Table 1. Six clinically healthy calves were excluded because of missing laboratory results. One calf with no available hematologic data but found to be dull upon clinical evaluation was kept in the analysis. By using the laboratory results as well as the physical examination observations, it was found that 22.4% of 219 calves had an abnormal health status at the time of the visit. The mean age at sampling for healthy and ill calves was 3.9 d (s = 1.9) and 3.9 d (s = 2.0), respectively. The mean rectal temperature for healthy and diseased calves was 38.9°C (s = 0.3) and 39.1°C (s = 0.4), respectively. Hematological and biochemical values were determined for each group of calves (Table 5). No significant difference was detected for mean serum IgG_1 concentration between diseased (17.3 g/L, s = 8.4) and healthy calves (19.1 g/L, s = 7.6) (P = 0.17). Failure of passive transfer of immunity was shown by 26.5% of diseased calves compared with 17.7% of healthy ones (P = 0.17). The abnormal health status was associated with the type of colostrum feeding, the dam BCS, and the month of birth (Table 7).

Discussion

The passive transfer of immunity was considered inadequate for 19% of 225 calves born from normal calving. This is slightly lower than previously reported for multiple beef herds, where the prevalence of FPT was 26% (n = 337) (20) and 29% (n = 82) (21). Lower serum concentration of IgG_1 in beef calves has been associated already with assisted delivery (13). The exclusion of calves born from dystocias probably contributed to the lower prevalence of FPT in our study. The 2 previously mentioned studies (20,21) included abnormal calvings in their overall results.

A higher proportion of FPT among male beef calves has been reported (13). However, this finding might have been due to an indirect association with dystocia, since the report included a greater number of complicated deliveries among males. Indeed, previous studies considering dystocia in a multivariate analysis did not find any variation in serum IgG level associated with the sex of the calf (22,23). In agreement with these results, FTP was not associated with calf gender in the present study.

Cold-stressed calves may have a slower rate of intestinal absorption (24) and may also be reluctant to stand and suckle voluntarily (6). Consequently, an increased risk of FPT was to be expected in January and February, the coldest months of the year in Québec (25). Nevertheless, FPT in calves was not related to the month of birth. The fact that most calves were born inside might have reduced the potential impact of cold stress.

In agreement with a study by Perino et al (22), where the age of the dam was not associated with the IgG level, parity of the dam was not recognized as a predicting factor in FPT. Nevertheless, Odde (13) reported that calves from primiparous beef cows had lower serum IgG_1 concentrations than did calves from older cows. He attributed this observation to decreased volume of colostrum produced by primiparous cows and to decreased calf vigour and suckling intensity. In our study, this possibility could have been overlooked because of misclassification of parity due to incomplete individual record keeping. Odde (13) also reported an association between heifer BCS and calf serum IgG_1. Calves from heifers with a BCS from 5 to 7 at parturition had higher serum concentration of IgG_1 than did heifers with a BCS of 3 and 4, on a 1 to 9 scale. However, when the BCS of cows of all ages were considered, such relation disappeared (13). Perino et al (22) found that cow BCS was not related to calf serum IgG concentration. Similarly, the present study failed to find an association between BCS of cows of different parities and FPT. A larger sample of cows distributed in every category of BCS might be required to detect an influence of BCS on FPT, if it exists.

In dairy production, intervention for colostrum ingestion is needed to achieve a protective level of serum IgG (26,27). In Québec, up to 44% of cow-calf producers have had previous experience with dairy production (9), and most of them keep animals in old stanchion-stall dairy barns. For this reason, it was expected that there would be a higher number of bottle-fed or force-fed calves. Interestingly, of the 22 bottle-fed calves, 21 showed a successful passive transfer. This observation does not agree with the belief that there is no advantage to assist beef calves with their first intake of colostrum (1,8,28,29). However, most (n = 19) of the bottle-fed calves were in the same herd, so the high proportion of well-protected calves could also be the result of general good management on this particular farm.

Birth in a stanchion-stall is associated with FPT. This type of stall, in contrast to the box-stall, does not provide ideal birth conditions. It does not allow the expression of normal behavioral patterns after parturition, such as calf grooming, which stimulates the calf to rise and directs its teat-seeking process (30). Moreover, most of the tied-stalls in Québec are made of concrete covered with a layer of straw or sawdust. This type of flooring can be slippery, which may delay the first rise of both the calf and the dam. Without intervention, all of these factors can delay the interval from birth to first suckling and impair immunoglobulin absorption. As many as 78% of calves born in a stanchion-stall and led to the mammary gland, were diagnosed with FPT. Presumably, some of these calves failed to get enough time to consume an adequate amount of colostrum, since many producers kept them tied between feedings.

Up to 22.4% of the calves were classified as having abnormal health status. Dystocia is known to be an important risk factor for beef calf morbidity (8,9,12,31,32). The inclusion of calves born with assistance could have resulted in a higher prevalence of calves with abnormal health status. Despite the fact that a classification based on an illness definition that included complementary laboratory results was used, this prevalence is much higher than expected for calves in their first week of life. Previously reported neonatal morbidity rates, based either on diseases recorded by farm personal or on treatment rates, were lower, ranging from 2.6% to 9.9% (7,8,32–34). Thus, one may postulate that the number of unhealthy newborn beef calves is underestimated by producers in the field.

Serum concentration of $IgG_1 < 10.0$ g/L was not associated with abnormal health status in calves at sampling. The role of the passive transfer of immunity in preventing morbidity is well documented (1–7,17,20, 22–24,26–29,37). In our study, health status was evaluated only once and at an early age. Information on diseases that develop later on was not collected. The fact that our illness definition was based on one clinical examination, combined with blood analysis, may have contributed to the expected FPT association with illness being missed. However, some authors have demonstrated that an adequate serum IgG level is not a perfect prognostic tool for health or disease in calves. Adams et al (35) did not detect a difference in the serum IgG_1 concentration between healthy and sick beef calves at 3 wk of age. Bradley et al (36) did not find a relation between the serum gammaglobulin level of beef calves and the subsequent incidence or severity of undifferentiated neonatal diarrhea. Logan (37) demonstrated that colostrum-fed calves can develop colibacillosis, if the pathogen challenge happens prior to feeding colostrum. Paré et al (38) reported that, in dairy calves, the serum concentration of IgG affected the length of the episode of diarrhea rather than the time of the onset of diarrhea. Failure of passive transfer of immunity is only one of the factors determining disease occurrence. Population density, general sanitation (4,8,39), and dam vaccination status (3,4,40) are management factors to consider when investigating morbidity in newborn calves.

Wittum and Perino (7) found that calves with inadequate serum concentration of IgG (< 8.0 g/L) were at greater risk of neonatal morbidity, with an odds ratio of 6.4, and that no other independent variables, such as calf gender, birth date, age of the dam, and dam BCS, were significantly associated with FPT. In our study, the risk of calves showing an abnormal health status at sampling was over 2 times greater for those born of cows that were either in poor body condition or overconditioned than for other calves. Poor body condition in cows might be due to lack of feed, presence of parasites, or illness. Overconditioning could be consecutive to poor milk production or failure to wean a calf (19). In both circumstances, the production of less vigorous calves may account for the observed association. Thin and fat cows might also reflect poor herd management.

Calves born in March were about 4 times more likely to be diagnosed with abnormal health status than were calves born in April. Bendali et al (41), in a study carried out in beef calf herds in the Midi-Pyrénées region in France, observed a higher risk for neonatal diarrhea in calves born in March. They attributed it to calf overcrowding, in addition to climate and weather conditions, and to a high potential for infection in the late calving season due to the accumulation of manure and contaminated bedding.

To decrease the risk of failure of passive transfer in newborn beef calves in Québec, emphasis should be placed on providing an adequate calving area and on giving special care to calves born from cows in a stanchion-stall in order to ensure adequate colostrum intake. It seems that the serum immunoglobulin concentration alone is not sufficient to explain abnormal health status in newborn beef calves. Quality of calf environment and management practices, such as monitoring of cows' BCS, should also be considered. CVJ

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BOOK REVIEW — COMPTE RENDU DE LIVRE

Marlin D, Nankervis K. ***Equine Exercise Physiology.*** Iowa State Press, Ames, Iowa, USA, 2002. ISBN 0-632-05552-9. US$49.99.

This well presented and illustrated book is aimed at people who are involved in training, managing, or working with different types of horses. According to the publishers, this book is the first to be aimed specifically at the equine science degree, as well as veterinary students. The book is formatted in the style of a manual that provides easy use for studying and reviewing subjects in equine exercise physiology. At the end of each chapter, there is a list of key points to remember, which is very useful. The book clearly aims to fill the gap between very basic books for laypersons and expensive technical and scientific books for researchers and veterinary clinicians.

Both authors are well known in their specific field of expertise and they complement each other in the different parts of the book. There are 3 major parts covering 21 chapters followed by an extensive recent bibliography. Part I "The Raw Materials," 6 chapters in all, covers the basics of the subject, including the pertinent vocabulary and definitions, as well as the basic biochemical aspects of different metabolic pathways used by the exercising horse in 2 introductory chapters, and then skillfully overviews anatomy and basic physiology of the 4 major organ systems involved in exercise: muscles, connective tissue, respiratory system, and cardiovascular system in the following 4 chapters. The use of illustrations and diagrams is excellent to clarify and emphasize important aspects of anatomy and physiology. Difficult physiologic concepts, such as the physics of basic lung function, are clearly and simply explained by using graphic illustrations. Part II "Exercise and Training Responses" consists of 7 chapters. The first 4 deal mainly with systemic responses to exercise and adaptations to different types of workloads used in the training of horses. This part is also very well done. The last 3 chapters of Part II cover aspects of physiologic stress and fatigue, thermoregulation, and an introduction to biomechanics. The chapter on thermoregulation is excellent, except for fluid loss, electrolyte imbalance, and body deficit of electrolytes induced by sweating, which is a touch confusing to the reader and could be strengthened considerably in a future edition. Part III, supposedly the "core of the book" entitled "Applications of Exercise Physiology," has 8 chapters (14 to 21). Chapter 14 gives a very basic overview of the different types of equestrian sports including sections on the physiological and biomechanical demands of the particular disciplines such as eventing, endurance, and racing, etc. The equestrian sports discussed are very much focused on a United Kingdom perspective, which is quite different from the North American situation. Chapter 15 "Training principles" is excellent and covers very succinctly the basics of training, the frequency and intensity thereof, and the advantages and disadvantages of different approaches to training. Chapters 16 to 19 deal with training facilities, including treadmills, water treadmills, and swimming pools; practical training; scientific exercise testing; and indicators of good and poor performance. Chapters 20 and 21, which are considerably weaker, try to address aspects of feeding the performance horse and aspects of transporting sport horses.

In summary, this book is a very useful and thorough source of information for trainers, interested horse lovers, veterinarians, and veterinary students interested in the subject of equine exercise physiology. The book reads well and easily and the price is right.

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