Validation of a Two-Interacting Compartmental (TIC) Model for Estimating Digesta Passage in Horses

C. Corino, F. Fontana, N. Miraglia and *P. Zanetti*

Dept. Scienze Animali, Vegetali e dell'Ambiente

Key words: horses, nutrition, rate of passage, mathematical modeling

Summary

Even though encouraging results have been obtained by several authors about modeling of the rate of passage in ruminants, several problems arise if one attempts the straightforward application of those models to horses. One possible reason for such a discrepancy might lie in the underevaluation of the role of feedback mechanisms occurring between the two compartments. To take into the right account the influence of these mechanisms, a modified Two-Interacting Compartment (TIC) model has been already proposed in a preliminar form (*Corino* et *al.*, 1992). In this work the full development and validation of that model are presented. Experimental data used to refer to three heavy-breed dry mares, three light horses and three heavy-breed mares in late pregnancy and early lactation using different feeding levels; a single dose of Cr-mordanted hay was employed as marker (*Miraglia* et *al.*, 1992). The correlation between the numerical values of the model parameters and the physiological features of horses is not yet firmly understood. However, it is shown that a tight correlation exists between those values, the feeding level and the kind of horses.

Bewertung eines 2-Kompartment-Modells für die Abschätzung der Chymuspassage beim Pferd.

Trotz ermutigender Ergebnisse bezüglich der Ingestapassage beim Wiederkäuer, ergeben sich mehrere Probleme bei der direkten Übertragung dieser Modelle auf das Pferd. Eine mögliche Ursache für die Diskrepanz ist möglicherweise die Unterbewertung von Feedback-Mechanismen zwischen den Kompartments des Magen-/Darmtraktes. Unter Berücksichtigung dieser Zusammenhänge wurde bereits früher in vorläufiger Form ein „interagierendes 2-Kompartment-Modell" beschrieben (*Corino* et *al.*, 1992). In vorliegender Arbeit wird das vollständige Modell vorgestellt und bewertet. Die Daten entstammen Versuchen mit je 3 güsten Stuten schwerer und leichter Rassen sowie 3 Stuten schwerer Schläge in der späten Trächtigkeit und frühen Laktation bei unterschiedlichem Fütterungsniveau. Cr-markiertes Heu wurde in Einzeldosis appliziert (*Miraglia* et *al.*, 1992) als Marker verwendet. Die Beziehungen zwischen zahlenmäßigen Modellparametern und physiologischen Merkmalen des Pferdes sind noch schwer verständlich. Dennoch besteht eine enge Beziehung zwischen diesen Parametern und dem Fütterungsniveau sowie dem Pferdetyp.

Schlüsselwörter: Pferd, Ingesta, Passage, Modell

Introduction

Even though encouraging results have been obtained by several authors about modeling of the rate of passage in ruminants (*Blaxter* et *al.*, 1956; *Grovum* and *Williams*, 1973; *Faichney*, 1975; *Ellis* et *al.*, 1979; *Dhanoa* et *al.*, 1985), several problems arise if one attempts the straightforward applications of those models to horses (*Rittenhouse* et *al.*, 1982). One possible reason for a such discrepancy might lie in the underevaluation of the role of feedback mechanisms occurring between the different components of the digestive apparatus. To take into the right account the influence of these mechanisms, a modified Two-Interacting Compartmental (TIC) model has been already proposed in a preliminar form (*Corino* et *al.*, 1992). In this work a full development and the validation of that model are presented. Since it bases on some fundamental assumptions about the use of the experimental data which are quite different from those usually made, the main aim of the work will be the discussion of the consequences of those assumptions leaving for another paper the descriptions of all the mathematical details.

The experimental data refer to three heavy-breed dry mares and three light horses both fed at maintenance and ad libitum and three heavy-breed mares fed ad libitum in late pregnancy and in early lactation. A single dose of Cr-mordanted hay was employed as marker (*Miraglia* et *al.*, 1992).

The model

Physiological aspects

Many attempts exist in literature to fit experimental data related to digesta passages in herbivores using the well-known Grovum and Williams two-compartment model. Even if in some case the application of that model completely failed, in the majority of cases it leads to satisfactory results.

The comprehension of the phenomena about the rate of passage of feeds in the herbivores gastrointestinal tract is often represented by a two-compartments model like that proposed by *Grovum* and *Williams* (1973). In a previous work (*Corino* et *al.*, 1992) we also suggest the possibility of application of a two-compartments model to evaluate the rate of passage in horses. Our model is different if compared to the others models, as far as it takes in to account the possibility of interaction between the two compartments.

We assume that the two compartments take account for the contribution to the digestive mechanism respectively of the stomach and cecum (first volume), and the colon (second volume). This hypothese doesn't contrast with the quite reliable experimental results of *Argenzio* et *al.* (1974) and of *Bertone* et *al.* (1989) and is substantiated by the numerical outcomes we obtained as far as they can be compared the experimental results.

Mathematical aspects

The most important difference between our model and those reported in literature consists in assuming that the two compartments assumed to mainly influence the digesta passage interact among them through a feedback mechanism.

If y(t) represents the cumulative amount of the marker collected in the faeces (we assume that the total amount of marker is equal to 1, and then y(t) is variable between [0.1]) and $y_1(t)$ and $y_2(t)$ are the functions which describe the amount of marker (i. e. of digesta) flowing from the first toward the second volume and the amount of marker (i. e. of digesta) which accounts for the reciprocal influence of the two volumes, the TIC model is described by the following equations (usually reported as master equation; *Prigogine*, 1961):

$$\gamma(t) = (1 - \gamma[t]) \cdot \gamma_1(t) + \gamma(t) \cdot \gamma_2(t) \quad (1)$$

which lead to

$$\gamma(t) = \frac{\gamma_1(t)}{1+\gamma_1(t) - \gamma_2(t)} \quad (2)$$

where $\gamma_1(t)$ and $\gamma_2(t)$ are described by the following analytical form:

$$\gamma_1(t) = 1 - \exp\left(\frac{t - t_0}{k_1}\right) \quad (3)$$

$$\gamma_2(t) = 1 - \exp\left(\frac{t - t_0}{k_2}\right) \quad (4)$$

where t_0, k_1 and k_2 are the parameters to be determined.

Analysis of the experimental data

In opposition to the ordinary approach in literature, in this paper we refer to the cumulative data and not to the concentration distribution. The aim of such a choice is to avoid the problems depending on the sampling technique (we leave to another paper the detailed discussion about this aspect of the problem).

Table 1: Numerical values of the model parameters

Horses	Feeding Level	t_0	k_1	k_2
Pregnant mare	Ad lib. (1.7)	19.8	1916.8	4.3
Pregnant mare	Ad lib. (1.7)	18.6	3971.9	3.7
Pregnant mare	Ad lib. (1.7)	17.8	3499.7	3.8
Lactating mare	Ad lib. (2.5)	21.3	828.6	5.3
Lactating mare	Ad lib. (2.5)	21.5	1019.1	5.0
Lactating mare	Ad lib. (2.5)	19.3	1609.8	4.5
Saddle horse	Maintenance (1.1)	19.4	628.3	5.7
Saddle horse	Maintenance (1.1)	21.8	601.2	5.8
Saddle horse	Maintenance (1.1)	22.9	1036.2	5.0
Saddle horse	Ad lib. (1.5)	25.7	361.1	6.9
Saddle horse	Ad lib. (1.5)	22.8	562.4	5.9
Saddle horse	Ad lib. (1.5)	18.1	442.7	6.4
Dry mare	Maintenance (1.2)	28.5	339.8	7.1
Dry mare	Maintenance (1.2)	31.2	210.1	8.7
Dry mare	Ad lib. (1.7)	24.6	354.4	6.9
Dry mare	Ad lib. (1.7)	26.9	307.9	7.3

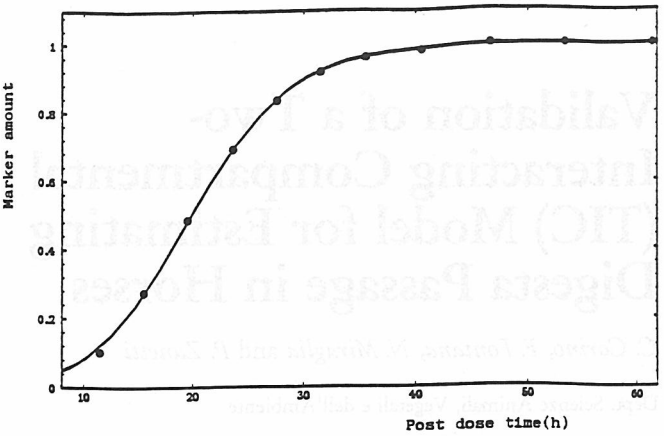

Figure 1: Cumulative curve of the marker in a saddle horse fed at maintenance level.

A typical example of the data used is given in Figure 1. To make the comparison between the different set of data easier, all the sets were normalized. Fitting of the experimental data were performed by an ordinary least square procedure applied to find the numerical values of the fitting parameters k_1 and k_2. The package used to this aim was: Mathematica by Wolfram Research Inc.

Table 1 shows the numerical values of the parameters t_0, k_1 and k_2, in relation to the kind of horses and the feeding level.

The errors associated to the data basically depend on two causes: the technique of collecting the feces and on the kind of marker. From the first only a small random error might arise, the second was avoided introducing the normalized data. In any case the application of the x^2 test returned a confidence level, above 95 percent.

Conclusions

The numerical values of k_1 would seem not be dependent on the physiological mechanisms of the gastrointestinal tract of horses. k_2 has numerical values comparable to those obtained by *Bertone* et *al.* (1989). At a first glance it seems that no evident relationships appear between k_1 and k_2: nevertheless it could be a consequence of the arbitrariness

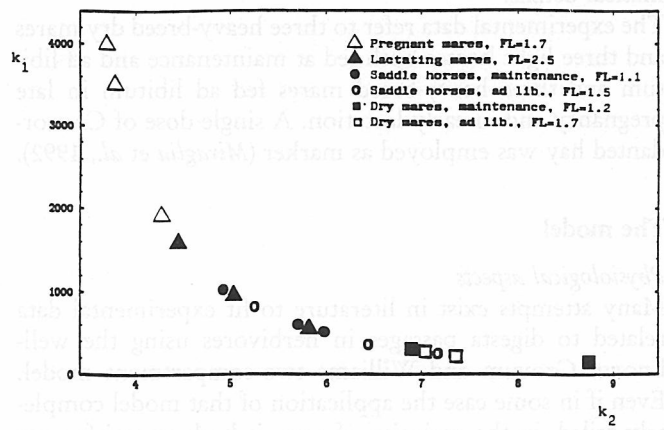

Figure 2: Relation between the parameters k_1 and k_2 of the kind of horses.

due to the comparison between different experimental data without any definite reference time and relaxating the curves for all the samples over this time. This arbitrariness can be removed assuming the time of highest rate of passage as the reference time. With this bond in the fitting procedure we obtain new values of k_1 and k_2 as shown in figure 2. In this figure k_1 and k_2 are in relation between them and with the kind of animal and the feeding level.

References

Argenzio, R. A., Lowe, J. E., Pickard, D. W., and *Stevens, C. E.* (1974). Digesta passage and water exchange in the equine large intestine. Amer. J. Physiol., 126(5), 1035 – 1042.

Bertone, A. L., Van Soest, P. J., Jhonson, D., and *Ralston, S. L.* (1989). Large intestinal capacity, retention times, and turnover rates of particulate ingesta associated with extensive large-colon resection in horses. Amer. J. Vet. Res. 50(9), 1621 – 1626.

Blaxter, K. L., Graham, N., McC., and *Wainman, F. W.* (1956). Some observations on the digestibility of food by sheep, and on related problems. Br. J. Nutr., 10, 69 – 91.

Corino, C., Fontana, F., Miraglia, N., and *Zanetti, P.* (1992). Development and application of a compartmental model for estimating digesta passage in horses. 7th Journée herbivores, Paris, march 25 – 26.

Dhanoa, M. S., Siddons, R. C., France, J., and *Gale, D. L.* (1985). A multicompartmental model to describe marker excretion patterns in ruminant faecis. Br. J. Nutr., 58, 663 – 671.

Ellis, W. C., Matis, J. H., and *Lascano, C.* (1979). Quantitating ruminal turnover. Fed. Proc. Amer. Soc. Exp. Biol., 38(13), 2702 – 2706.

Faichney, G. J., 1975. The use of markers to partition digestion within the gastro-intestinal tract of ruminants. Proc. IV Int. Symp. Ruminant Physiol., Ed. by I. W. McDonald and A. C. I. Warner. Armidale, N. S. W. Australia: Univ. of New England Press, 277 – 291.

Grovum W. L., and *Williams, V. J.* (1973). Rate of passage of digesta in sheep. 4. Passage of marker through the alimentary tract and biological relevants of rate-constants derived from the changes in concentrations of marker in faeces. Br. J. Nutr., 30, 313 – 329.

Miraglia, N., Poncet, C., and *Martin-Rosset, W.* (1992). Effect of feeding level, physiological state and breed on the rate of passage of particulate matter through the gastro-intestinal tract of the horse. Anm. Zootech., in press.

Prigogino, I. (1961). Thermodynamics of irreversible processes. Flamingo Ed., New York.

Rittenhouse, L. R., Johnson, D. E., and *Borman, M. M.* (1982). Comparison of faecal excretion and intake estimates obtained from external markers and total faecal collection. Proc., West. Sect., Amer. Soc. Anim. Sci., 33, 106 – 108.

C. Corino
Dept. Scienze Animali, Vegetali e dell'Ambiente
Università del Molise
Via Cavour 50
I-86100 Campobasso