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Use of a computer-aided design to develop a stress simulation model for lactating dairy sheep

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Abstract

A mechanistic model of the mammary gland able to simulate the milk production process in dairy sheep was constructed by using a computer-aided simulation via object-oriented modelling. Such an approach, rather innovative in animal science, allows the construction of complex models avoiding the use of non-linear differential equations. The model was structured into three sub units: alveolar, energy and milk sub-models. It was used to mimic the milk production process of dairy sheep. Moreover, the model was used to simulate the effects on milk production of external stresses represented by the variation in milking frequency and a reduction in the energy supplied to the animal with the diet.

Keywords: Simulation model; Lactation curve; Stress; Dairy sheep

1. Introduction

Lactation is a physiological process characterized by synthesis and secretion of organic and inorganic compounds and also by active and passive blood filtration, by specialized epithelial cells of the mammary gland.

The description of the temporal evolution of milk production in domestic ruminants is one of the most important applications of mathematical modelling in animal science. It represents a fundamental step to achieve a deep understanding of the complex physiological mechanisms that underlie the milk secretion process. In addition, it is also often required for technical purposes, mainly for the improvement of management and breeding choices.

As in other fields of applied biology, the mathematical models suggested for studying the lactation pattern can be classified into two main groups: empirical models and mechanistic models.

Empirical mathematical models are essentially aimed at disentangling the deterministic component of lactation from the stochastic one. The first component is usually characterised by a continuous and regular pattern and it refers to genetic and environmental factors affecting the phenomenon under study; the second is peculiar to each animal and, therefore, unpredictable. Several mathematical functions have been proposed (Beever et al., 1991; Macciotta et al., 2005), differing mainly in the type of regression (linear or non-linear), in the number of parameters and in their degree of relationships with the main features of a typical lactation pattern, such as peak yield, time at peak and persistency.

The aim of the mechanistic approach is to better understand the mechanism of a particular biological

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phenomenon. Therefore, a mechanistic model is developed in an attempt to translate some hypotheses about the physiological and biochemical processes regulating the phenomenon of interest into mathematical terms. In our case, this means to elaborate more or less complex mathematical structures, based on differential equations, which simulate the fundamental biological processes involved in the secretion and ejection of milk.

As in other sectors of applied biology, empirical models are more largely used than mechanistic ones in the mathematical modelling of milk production. This can be attributed to the theoretical difficulty of building mechanistic models of biological processes, which are usually very complex and involve a large number of parameters, leading to severe computational problems. The fact that the results of mechanistic models are usually very difficult to interpret leads to the misconception that these models have a very limited practical relevance. This is obviously untrue, because the applicative results of an efficient explanatory model may be more incisive than those of an empirical one, although the latter are obviously more immediate. In fact, the mechanistic modelling of milk production can accommodate the effects of the main factors affecting milk yield during lactation such as feeding, pregnancy, milking frequency and health status of the mammary gland. It represents therefore a powerful tool to make simulations aimed at evaluating the effects of changes in management, selection strategy and production scenarios on milk production.

Aim of this work is to develop a mechanistic model of the mammary gland of dairy sheep by using a computer simulation technique. Moreover, the ability of the model to simulate effect of milking and feeding stress on milk production pattern is tested.

2. Methods and techniques

2.1. Mechanistic modelling and simulation

Mechanistic models of the mammary gland and of the process of milk production have been proposed for dairy cattle (Neal and Thornley, 1983; Dijkstra et al., 1997; Vetharaniam et al., 2003) and sheep (Cappio-Borlino et al., 1997). All of them reproduce the internal mechanisms of lactation by a series of differential equations. These models can be divided into the following two categories: linear models, whose equations can be solved analytically, and non-linear ones, which need approximate numerical methods of integration for their solution. The models developed by Neal and Thornley (1983) for cattle and by Cappio-Borlino et al. (1997) for dairy sheep are examples of linear models. These models take into consideration only some of the main factors influencing lactation, thus allowing the use of linear differential equations that, once integrated, give mathematical functions over time. However, when multiple factors, often inter-related by feedback processes, are introduced to these models, they become complex and require the use of non-linear differential equations solved only by numerical integration. The resultant models lose their mathematical rigour, because numerical integration necessarily leads to approximations. As models get more complicated, they start to be regulated by the theory of complexity, which involves mainly feedback processes. Therefore, these models become very sensitive to initial and boundary conditions. Even though complex models are more explicative than simpler ones, they are less precise too. The results of complex models consist of numbers (not functions) that once placed in a scatter plot show the behaviour of the studied phenomena over time. Some examples of these models are those proposed by Dijkstra et al. (1997) and by Vetharaniam et al. (2003).

The following questions arise from the unavoidable loss of mathematical rigour of a complex model: why keep developing models that use a normal mathematical language, which is harsh to many researchers not specialised in this field and is very difficult to use anyway? Why not using modern simulators that perform the same task, with the advantage of not using pure mathematical language?

Recent advances in computer simulation allow developing mechanistic models using computer not only as a calculation instrument, but also as an active means to model construction. This modelling procedure is known as a computer-aided design and does not require a programmer or mathematician, provided that an object-oriented methodology is used. Object-oriented modelling solves problems using models organised around real-world concepts. Data are organised into discrete, recognisable entities called objects that incorporate both data structure and system behaviour (Simonovic et al., 1997). The advantages of using computer-aided modelling are not limited to the simplification of the modelling process. They are also related to the graphic representation of the model, inside the calculation software, which allows to check the objects, and to modify and/or complete the model easily. In addition, a computer-aided model provides a common language for discussion and contains data that can be easily explained to and intuitively understood by others. Nevertheless, it is fundamental to have an environment software that is able to interpret these objects and their linkages and to explain the behaviour of the model in the form of output.