Rumen Function and Development

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KEYWORDS

• Rumen • Epithelium • Metabolism • Development • Differentiation

KEY POINTS

- Rumen epithelial character and composition are unique among other gastrointestinal tissues that serve both protective and metabolic functions of critical importance to productive ruminants.
- Rumen epithelial development is incomplete at birth and requires the establishment of ruminal fermentation, and the production of short-chain fatty acids (the most potent is butyrate) to initiate the maturation processes.
- Metabolic and physical adaptations occur simultaneously and result in altered production efficiency, depending on dietary composition.
- Regulatory control in response to butyrate seems to be a result of both proliferative and metabolism-specific adaptations driven by differential expression of key regulatory genes.

INTRODUCTION

The ruminal epithelium is uniquely placed to affect the net use of nutrients of the whole body. The symbiosis between the microbiome inhabiting the lumen and the host largely depends on the provision of a constant supply of nutrients from roughage that would otherwise be unusable to the mammalian digestive system. Physically a barrier to the contents of the lumen, the rumen epithelium serves an obvious protective function, which, when compromised, results in disease states. The ruminal epithelium is a stratified squamous epithelium which are typically associated with protective functions rather than absorption. As such, ruminal epithelium is unlike other gastrointestinal tissue barriers. Metabolically, the ruminal lining serves a critical role in

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mitigating the diffusion of end products of fermented feedstuffs into circulation. The metabolic contributions of the ruminal epithelium have received a great deal of research attention because the impact of the tissue on production efficiency is undeniable. Moreover, the process and regulation of the developing rumen epithelium has received a great deal of research interest because the tissue is incompletely developed at birth and requires the establishment of a viable ruminal fermentation for complete development by weaning. This developmental process has been viewed with interest not only from the health and well-being aspect of rearing replacement heifers and production animals but also as a unique model system for the investigation of nutrient-gene interactions occurring naturally. This article describes the basic structure and metabolic characteristics of the epithelial lining of the rumen, and discusses the importance of the differentiation of the tissue during normal development production practices.

IMPORTANCE OF GASTROINTESTINAL TISSUES TO PRODUCTION EFFICIENCY

The gastrointestinal tract has a large impact on the nutrient economy of the whole animal by virtue of its critical position in the process and the large cost of nutrient extraction from feedstuffs required before delivery of metabolites to the productive tissues (ie, mammary gland, muscle). Thus, production-oriented research has been interested in these tissues and their contribution to the maintenance requirements. From a metabolic standpoint, maintenance functions of the visceral organs primarily include Na^+-/K^+-ATPase activity, protein synthesis and degradation, substrate cycling, and urea synthesis.[1] The ruminant gastrointestinal tract as a whole is responsible for 40% of the whole- body ATP use.[1] In addition, a simulation of protein turnover in growing lambs predicts that 19% of total-body ATP expenditure is caused by protein turnover and that 25% to 27% is caused by gastrointestinal tract protein turnover.[2] Because of these aforementioned energetic and nutrient costs, the maintenance of the gastrointestinal tract tissues in growing ruminants has an extensive impact on whole-body metabolism. However, in production settings, defining the cost of the gut tissues is complicated by the mass of these tissues changing in response to plane of nutrition, dietary chemical composition, and the physiologic status of the animal.[3–6] It has been generally observed that cell-specific or mass-specific changes in metabolism are largely unaffected by plane of nutrition.[7–10] However, as discussed later, dietary composition and nutrient delivery to the tissue do affect metabolism, and, thus, understanding both proliferative and metabolic control is necessary for accurate prediction of nutrient use efficiency.

STRUCTURE AND FUNCTION OF THE RUMINAL EPITHELIUM IN MATURE RUMINANTS

Rumen epithelium provides several physiologically vital functions, including absorption, transport, volatile fatty acid metabolism, and protection.[11,12] The ruminal epithelium is a stratified squamous epithelium consisting of 4 strata: stratum basale, stratum spinosum, stratum granulosum, and stratum corneum (**Fig. 1**).[13,14] Cell layers vary within each stratum and vary starkly depending on diet, stage of ruminal development, and feeding pattern. The cells of the stratum basale, adjacent to the basal lamina, contain fully functional mitochondria and other organelles, and are the cells of the rumen that contribute most significantly to the metabolic properties of the tissue (ie, ketogenesis). Ketogenic enzymes are principally located within the mitochondria of the ruminal epithelium. Consequently, basale cells are likely the most important ruminal layer relative to the energy metabolism of the whole animal.[15] The stratum spinosum and stratum granulosum are the intermediate cell layers and are not separated