GI Tract: Animal/Microbial Symbiosis

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INTRODUCTION

The gastrointestinal tract is indispensable for an animal's well-being. Food is consumed through the mouth and digested by host enzymes in the stomach and small intestine, and nutrients are extracted and absorbed in the small and large intestines. In this nutrient-rich environment, microorganisms can colonize and grow, and as a result, numerous interactions or symbioses between microorganisms and the animal exist that impact the health and well-being of the host animal.

Symbiosis is defined biologically as ''the living together in more or less intimate association or even close union of two dissimilar organisms'' and this, in a broad sense, includes pathogens. Thus, symbiosis is living together, irrespective of potential harm or benefit, and living together is no more apparent than in the animal gastrointestinal system. This symbiosis can be relatively defined by the degree of benefit to one or both partners within the association, as well as by the closeness of the association.

GASTROINTESTINAL ECOSYSTEM

Microorganisms within the gastrointestinal system are predominantly strict anaerobes, the study of these bacteria was greatly limited until culture techniques capable of excluding oxygen were developed.[1] Prior to the 1940s, theories of microbial fermentations of fiber contributing energy to the host abounded, but little direct evidence was found. Since that time, microbiologists have refined the culture techniques and conditions to support the growth of numerous gastrointestinal bacteria. Additional works with nutritionists and physiologists have identified more specific interactions between the host and microbes.

The gastrointestinal tract begins at the mouth and ends at the anus and is colonized with bacteria in nearly its entirety. The system contains over 400 species of microorganisms and the gastrointestinal microbial cells outnumber the animal cells nearly 10:1. This diverse, dynamic population of bacteria in the gastrointestinal system is referred to as the microflora or microbiota. The specific species (or strains of species) of microorganisms can vary with animal host, diet, and environment, but in general the predominant species are associated with a limited number of bacterial genera.

Parasitic or pathogenic microorganisms incur a cost on the host and have been studied more extensively. The mutualistic microorganisms generate a benefit to the host. If the interaction is not parasitic or mutualistic, it is then considered to be commensal. However, animal/microbe interactions are difficult to define and study; thus, most interactions are considered commensal. The Vin diagram (Fig. 1) best indicates the complexity of these animal/microbe interactions.

PARASITISM

When symbiosis confers benefit to one organism at the cost of the other (i.e., the host), the relationship is often viewed as being parasitic.[2] Many parasites, such as the parasitic protozoa *Entamoeba*, can persist as a common inhabitant of the gastrointestinal system. These inhabitants compete for nutrients and impair production, but seldom generate acute symptoms associated with disease. When symptoms of disease are observed, the organism is then considered to be pathogenic. Typically, pathogenic microbes are thought to be transient inhabitants, but disruption of the ecosystem can provide opportunity for indigenous microbes to overwhelm the host.

The host has several mechanisms to prevent infection of the gastrointestinal tract. Acid secretion by the stomach, intestinal motility and secretions, and the indigenous flora are deterrents to pathogen colonization. Nonetheless, microbes have adapted and evolved to overcome or, in some cases, take advantage of the preventive mechanisms. Specialized immune cells (Peyer's patch) in the intestine secrete antibodies to protect the body against toxins and potential pathogens, but some pathogenic

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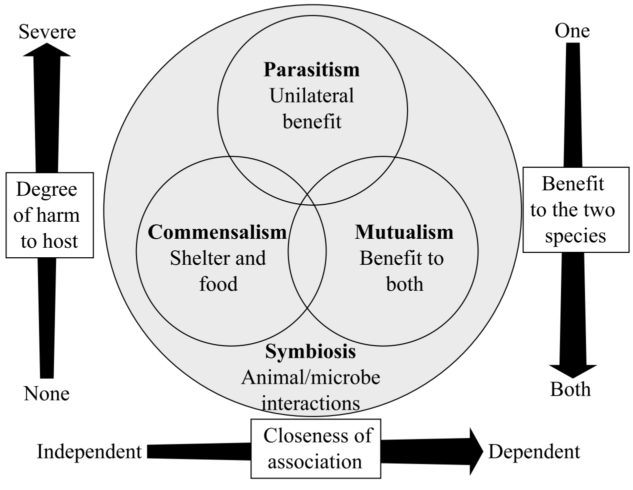

Fig. 1 Vin diagram showing interrelationships of various symbioses and the relationship to the host. (Adapted from Ref. 4.) (*View this art in color at www.dekker.com.*)

bacteria can bind and invade these specialized immune cells.

Zoonotic pathogens are a problem in animal production. These microorganisms may be commonly found in animals without any apparent disease, and yet are potentially disease-causing to humans. *Salmonella*, *Campylobacteria*, *Shigella*, *Enterococcus*, and the *Escherichia coli* Shiga toxin-producing strains are all potential pathogens to humans and are commonly associated with animal waste.[3] As a result, potential for fecal adulteration of meats and the possible contamination of water and food supplies from land application of animal waste are burdening issues of food safety and animal production.

MUTUALISM

Most examples of mutualistic interactions in animals demonstrate a positive gain for the host. Farm animals require nutrients for growth and most examples of mutualism are based on synthesis of nutrients by the microflora. The specific benefit to the host is dependent on the animal's gastrointestinal anatomy (Table 1). Many herbivores have specialized digestive systems to harness the ability of the microflora to degrade indigestible feeds and supply the host with volatile fatty acids, which the animal can utilize for energy. In addition, amino acids and vitamins may be synthesized by the microflora and may be utilized by the animal host.

Ruminant animals such as deer, sheep, and cattle have a large pregastric compartment called the rumen that can account for 15% of the gastrointestinal system.[1] Microbial enzymes, in contrast to mammalian enzymes, can digest cellulose. Under anaerobic conditions, the microbes generate volatile fatty acids as end products of fermentation. The rumen environment is adapted for microbial fermentations, and this interaction allows these animal species to utilize the complex carbohydrates and nonamino-nitrogen for energy and protein needs. Ruminants complement microbial activity by regurgitating (rumination), which permits additional chewing of the large feed particles (bolus). Movement of muscles in the rumen wall allows for the continuous mixing of rumen contents to maintain digestion by microbes and absorption of volatile fatty acids by the host. The volatile fatty acids, acetate, propionate, and butyrate, can contribute up to 80% of the animal's energy needs.

In all animals, some microbial fermentation occurs in the colon or large intestine. The extent of fermentation and energy contribution to the host is highly variable, but typically correlated with the transit time of digesta through the intestine. Some herbivores, such as horses, rabbits, and chickens, utilize postgastric compartmentalization (e.g., cecum) to derive additional energy from the diet by means of microbial fermentations. In these species, the energy contribution from microbial fermentation in the cecum is much less than in the rumen.

In addition to energy from the microbial fermentation of cellulose, amino acids can be derived from microbial

Table 1 Examples of gastrointestinal adaptations of animals to benefit from the presence of microorganisms

Animal	Dietary classification	Gastrointestinal adaptation	Host benefit
Cattle, sheep, goats	Herbivore	Ruminant (pregastric adaptation)	Fermentation of cellulose, protein, vitamins
Swine, rodents, humans	Omnivore	Simple stomach with elongated colon (postgastric adaptation)	Fermentation, vitamin K
Horses, rabbits	Herbivore	Hindgut fermenter (postgastric adaptation)	Fermentation of cellulose, some vitamins

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activity. In ruminants, microbial cells (~50% protein) amass from fermentation and pass out of the rumen into the stomach and small intestine. Microbes thus serve as a protein source for the ruminant animal and can contribute over 50% of the animal's protein needs. Postgastric fermenters do not benefit appreciably from microbial biosynthesis because fermentation is beyond the sites of digestion and absorption. Some animals, such as rabbits, practice copraphagy to circumvent limitations associated with postgastric fermentation. However, recent work with pigs has shown that bacteria in the small intestine may contribute 10% of a young pig's lysine dietary requirement and a majority of a grown pig's lysine dietary requirement.[4]

Ruminant animals typically do not require vitamin supplementation to their diet. In particular, the B vitamins are synthesized by the rumen microflora, often in excess of the animal's requirement. Fermentation in the lower gastrointestinal system also generates vitamins, but absorption in the lower gut is limited.[5] Germ-free animals appear to require more B vitamins in the diet, suggesting some intestinal synthesis and absorption of these vitamins. In most animals, vitamin K appears to be a microbial product absorbed from the intestine and colon, since germ-free rodents require supplementation of this vitamin and normally raised animals do not.

COMMENSALISM

By convention, most of the gastrointestinal microorganisms are viewed as commensal. These microbes establish niches and benefit from the host environment, but appear to contribute little to the host. However, this view may be in error. As our understanding of biology and its complexities changes, so does our understanding of biological interactions and the assessment of commensal bacteria. Establishment of the commensal population is affected by host factors and the population typically recovers after a perturbation (i.e., antibiotic treatment).

Numerous studies with simple-stomach animals such as swine and rats reared in germ-free environments (without the gastrointestinal microflora) suggest that microorganisms are not essential for the animal's survival, but they are beneficial. In laboratory rats as a model, animals raised germ-free need to consume significantly more calories than conventionally raised animals to maintain their body weight.[6] Mutualistic bacteria can contribute some energy, amino acids, and/or vitamins (discussed earlier), but the commensal bacteria appear to stimulate development of the gastrointestinal capillary system and intestinal villi.[7]

A healthy commensal population colonizes the gastrointestinal tract and, as a result, competitively excludes transient pathogens. The presence of commensal bacteria helps fortify the gastrointestinal barrier, regulate postnatal maturation, affect nutrient uptake and metabolism, and aid in the processing of xenobiotics.[8] More important, commensal bacteria appear to communicate with specialized cells (Paneth cells) in the intestine to elicit the production by the host of antimicrobial factors called angiogenins, which that can help shape the microflora composition.[9]

Not all examples of commensal bacterial interactions are advantageous to the host. Some *Clostridium* species can transform secreted bile acids to form secondary products that may impact nutrient digestion and absorption. Metabolism of feedstuff components can generate toxic products that affect animal performance and health.

CONCLUSIONS

Bacteria are ubiquitous in nature and have an impact on animal health, growth, and development. Within the gastrointestinal system, animals have established relationships with bacteria that appear to benefit both in many cases. Scientists are just starting to understand the complexities of these relationships and their implications. In the future, better formulation of animal diets and supplementation may enhance these relationships.

ARTICLES OF FURTHER INTEREST

Digestion and Absorption of Nutrients, p. 285
Digesta Processing and Fermentation, p. 282
GI-Tract: Anatomical and Functional Comparisons, p. 445
Immune System: Nutrition Effects, p. 541
Lower Digestive Tract Microbiology, p. 585
Molecular Biology: Microbial, p. 657
Rumen Microbiology, p. 773

REFERENCES

1. Hungate, R.E. *The Rumen and Its Microbes*; Academic Press: New York, NY, 1966.
2. Mims, C.A.; Playfair, J.H.L.; Roitt, I.M.; Wakelin, D.; Williams, R. *Medical Microbiology*; Mosby: London, 1993.
3. Swartz, M.N. Human diseases caused by foodborne

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pathogens of animal origin. Clin. Infect. Dis. **2002**, *34* (Suppl. 3), S111–S122.
4. Torrallardona, D.; Harris, C.I.; Fuller, M.F. Pigs' gastrointestinal microflora provide them with essential amino acids. J. Nutr. **2003**, *133*, 1127–1131.
5. Hooper, L.V.; Midtvedt, T.; Gordon, J.I. How host microbial interactions shape the nutrient environment of the mammalian intestine. Annu. Rev. Nutr. **2002**, *22*, 283–307.
6. Wostmann, B.S.; Larkin, C.; Moriarty, A.; Bruckner-Kardoss, E. Dietary intake, energy metabolism, and excretory losses of adult male germfree Wistar rats. Lab. Anim. Sci. **1983**, *33*, 46–50.
7. Stappenbeck, T.S.; Hooper, L.V.; Gordon, J.I. Developmental regulation of intestinal angiogenesis by indigenous microbes via Paneth cells. Proc. Natl. Acad. Sci. U. S. A. **2002**, *A99*, 15451–15455.
8. Hooper, L.V.; Wong, M.H.; Thelin, A.; Hansson, L.; Falk, P.F.; Gordon, J.I. Molecular analysis of commensal host-microbial relationships in the intestine. Science **2001**, *291*, 881–884.
9. Hooper, L.V.; Stappenbeck, T.S.; Hong, C.V.; Gordon, J.I. Angiogenins: A new class of microbicidal proteins involved in innate immunity. Nat. Immun. **2003**, *4*, 269–273.

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