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An Ancient Symbiont of Auchenorrhyncha from the Bacterial Phylum *Bacteriodetes*

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Several insect groups have obligate, vertically transmitted bacterial symbionts that provision hosts with nutrients limiting in the diet (Buchner 1965). Some of these bacteria have been shown to descend from ancient infections of ancestral hosts. Many groups within the Auchenorrhyncha including representatives of Cicadidae, several subfamilies of Cicadellidae, Membracidae, Cercopoidea, and Fulgoroidea are hosts to a distinct clade of bacterial symbionts, which inhabit specialized bacteriomes of their hosts (Moran et al., in press). This newly described symbiont lineage belongs to the phylum Bacteroidetes. It corresponds to the "a-symbiont" of Mueller (1962), Buchner (1965) and other authors, although some confusion is associated with that designation in the literature. Among previously studied bacteria, this new taxon is most closely related to the genus *Blattabacterium* consisting of symbionts of cockroaches. Analyses of 16S rRNA genes indicate that the phylogeny of the Bacteroidetes symbiont is completely congruent with the phylogeny of insect hosts as currently resolved, based on published studies. Certain groups, such as Delphacidae and Flatidae and some leafhoppers, lack the symbiont, probably due to secondary loss, as first proposed by Mueller (1962). Two species of Peloridiidae (Coleorrhyncha) were found to lack this symbiont taxon, although other bacterial sequences, probably representing symbionts, were obtained.

The distribution and phylogenetics of this symbiont taxon are most readily interpreted as supporting the ancient acquisition of a symbiont by a shared ancestor of these insects. Thus, the results are consistent with a monophyletic Auchenorrhyncha. Alternative interpretations of current evidence are that some or all Fulgoroidea acquired a closely related symbiont independently or that a single colonization occurred in the ancestor of all Hemiptera followed by loss of the symbiont in the hemipteran sister group of Fulgoroidea. As visualized in a species of spittlebug (Cercopidae), the symbionts have extraordinarily large cells with elongate shape, often more than 50 microns in length; *in situ* hybridizations verified that these correspond to the phylum Bacteroidetes. All of the host insects also harbor at least one additional obligate symbiont, the phylogenetic affiliation of which varies among insect host groups. For example, in most Cicadellinae the second symbiont is *Baumannia cicadellicola*, a member of the *Gammaproteobacteria* (Moran et al. 2003).

Limited genomic sequencing of this symbiont from *Homalodisca coagulata* indicate that it has a small genome and retains a number of pathways for the biosynthesis of essential amino acids (N. A. Moran, DongYing Wu, J. Eisen, unpublished data). Thus, this symbiont is mostly likely involved in host nutrition and may have been an important element in the evolution of the sap-feeding lifestyles of auchenorrhynchan groups.

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Why Do We Study Auchenorrhynchan Feeding Processes?

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The Symposium on Feeding Processes and Their Role in Hopper-Plant-Microbe Interactions will highlight the multi-facetted role of feeding in the life of Auchenorrhynchans, a topic that is a bridge across many disciplines in the study of these insects. The speakers in this Symposium will provide their diverse discipline's insights, both empirical and theoretical, from many points of view, into the many aspects of feeding. The Symposium will emphasize holistic blends of modern techniques, often presented by interdisciplinary teams of researchers in the field. It also will emphasize interactions between Auchenorrhynchan feeding and other organisms such as microbes (both vectored and non-vectored) and plants. This preview of the Symposium will give an overview of Auchenorrhynchan feeding, provide some additional information that will not be covered in the Symposium, explain why these studies are important, and introduce the major topics and speakers.

The very earliest natural history studies of Auchenorrhyncha noted their highly specialized, piercing-sucking mouth parts. It has always been recognized that understanding the anatomy, or "plumbing", of the feeding structures informs our understanding their function. It wasn't until the late 1800's that detailed, empirical studies began, culminating eventually in the major works of (Snodgrass 1935) and (Goodchild 1966). In the Symposium's first paper, Wayadande and Ammar will review modern work on the anatomy of the alimentary canal and salivary glands, discussing how understanding functional anatomy is crucial for explaining the mechanisms of pathogen transmission by vectors. This preview talk will complement their talk by providing some extra information on the sensory systems that control feeding.

The insect arrives at the plant armed with an array of anatomical devices to penetrate the plant tissues and propel the tips of the stylets into position to ingest from only certain cell types within the plant. This selection is highly specialized within the Auchenorrhyncha, uniquely among all animals on Earth. Depending upon the taxonomic family or subfamily, different insects normally prefer to ingest from either vascular tissues (usually phloem or xylem, seldom both) or parenchyma/mesophyll tissues. They do so utilizing different strategies or sub-strategies (tactics) of feeding behavior that also differ by taxonomic group (Miles 1972, Backus et al. 2005). This preview talk will introduce the feeding strategies and stylet penetration tactics as well as the Auchenorrhynchan taxa that use each. Three presentations will elaborate on these very specialized stylet penetration behaviors. Bextine and Walker will provide an overview of stylet penetration by sheath-feeding leafhoppers, and how such details can aid in management of glassy-winged sharpshooter. Reynaud will discuss sheath-feeding planthoppers. Ranger will discuss cell rupturing leafhoppers and the behaviors that cause their direct feeding damage. These wide-ranging talks will also examine methods for how we study stylet penetration, examples of how such intricate feeding behaviors facilitate exploitation of the host plant, ways the host plant can resist that exploitation, and also how feeding behavior controls transmission of plant pathogens by vectors. One of the most rigorous and informative methods used to study feeding is the electrical penetration graph (EPG). All of the speakers in this section will discuss findings from EPG studies, as well as other types of studies. My introductory talk for the afternoon session will be a quick overview of the principles and applications of EPG, and the talk by Reynaud in the Symposium will describe some of the latest methods used for automated, computerized analysis of EPG waveforms.

Feeding behavior allows the insect to consume (sometimes very large) quantities of fluid from its host plants. Coudron, Hunter and Labavitch will blend their expertises in insect nutritional biochemistry and molecular genetics as well as plant biochemistry for their presentation. They will discuss both existing results and testable theories about the interplay among feeding (including extra-oral digestion by saliva), midgut digestion, and nutrition. Finally, Mizell (an entomologist) and Anderson (a plant chemist) present an integrated picture of the complex interactions among vector feeding and nutrition, plant chemistry, and natural enemies, using the glassy-winged sharpshooter as a model system.

Finally, we will bridge from this Symposium on the functions of feeding across to Chris Dietrich's symposium on the evolution and phylogeny of Auchenorrhyncha, by examining fossil evidence for piercing-sucking feeding. This preview