Symbiosis between Non-Related Bacteria in Phototrophic Consortia

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1 Introduction

Consortia are defined as close associations of microbial cells in which two or more different microorganisms maintain a permanent cell-to-cell contact and form an organized structure (Schink 1991). Currently, 19 different morphological types of bacterial consortia are recognized based on the taxonomy and the arrangement of the participating bacteria (Overmann 2001a,b; Huber et al. 2002; Glaeser and Overmann 2004). The habitats of consortia range from the human oral cavity, which is colonized by the so-called corn-cob bacterial formations, to deep sea sediments which harbor anaerobic methane-oxidizing consortia. Even more frequently observed are irregular aggregates, biofilms, and patches of free-living bacterial cells containing non-related prokaryotes (e.g., Jacobi et al. 1997; Rudolph et al. 2001).

In contrast to monospecific associations like those of autoinducer-producing bacteria (Bassler 2002) or myxobacteria (Reichenbach and Dworkin 1992), only little is known about the significance, specificity, and the evolutionary origin of bacterial interactions in heterogeneous assemblages. To date, syntrophic associations represent the only type of heterogenous assemblage investigated in sufficient detail to permit a functional understanding of the interaction. Metabolites like H_2, formate, acetate, or sulfur are transferred from one partner to the other (Chap. 1), with the efficiency of metabolite transfer depending on the diffusion distance (Schink 1991). Considerable evidence has accumulated that a close juxtaposition of the metabolite-producing and -consuming bacteria occurs, leading to flocs densely populated by the intermixed bacteria (Conrad et al. 1985; Schink 1991). Another type of interaction is an interspecies signal exchange based on AI-2 type autoinducers, which has been proposed to occur in mixed bacterial communities as a type of universal interspecies chemical language (Bassler et al. 1997). The physiological and genetic interactions in other heterogeneous associations, particularly in the most highly structured bacterial consortia, are still largely unknown. This is mostly due to the lack of a suitable laboratory model system.

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Among all consortia, phototrophic consortia probably represent the highest degree of mutual interdependence between non-related bacteria. Phototrophic consortia consist of green- or brown-colored cells, which are associated with colorless bacteria. The cells are tightly packed and arranged in a highly regular fashion (Fig. 1A, Fig. 2). In the free water column of stratified freshwater lakes, the biomass of phototrophic consortia can amount to as much as two-thirds of the total bacterial biomass (Gasol et al. 1995). Although phototrophic consortia had already been discovered at the beginning of the last century (Lauterborn 1906), they could not be cultivated until more than 90 years later (Fröstl and Overmann 1998). In the recently established enrichment cultures, phototrophic consortia have become amenable to detailed investigations of the phylogenetic composition, physiology and morphology of the cells and, more recently, to molecular studies of the functional basis of the symbiosis.

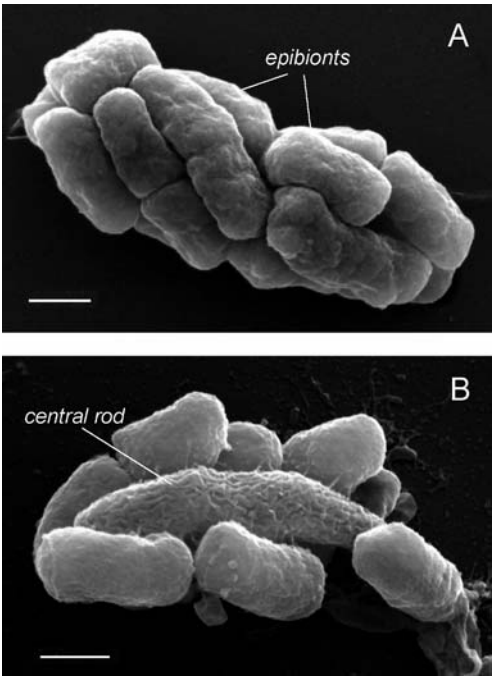

Fig. 1. Transmission electron photomicrographs of "*Chlorochromatium aggregatum*". **A** Intact consortium after fixation in 2% glutardialdehyde. The outer layer of epibionts covers the central rod entirely (courtesy of Martina Schlickenrieder and Gerhard Wanner). **B** "*C. aggregatum*" without glutardialdehyde fixation and after exposure to air and a rinse with distilled water (courtesy of Kajetan Vogl and Gerhard Wanner). Partial disaggregation of the phototrophic consortia result in exposure of the single central rod-shaped bacterium. Note the rough cell surface structure of the latter as compared to the epibionts. *Bars*, 0.5 μm