Cytologia Focus:

Planimal Cells: Artificial Photosynthetic Animal Cells
Inspired by Endosymbiosis and Photosynthetic Animals

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Summary

I propose a new concept of artificial photosynthetic animal cells as planimal cells. Secondary endosymbiosis, symbiotic algae in animal cells and kleptoplasty evoke algae as the most fascinating autotrophic organisms for the creation of planimal cells. Strategies for the generation of planimal cells include three approaches, cell fusion between algae and animal cells, microinjection of algae into the cytoplasm of a host animal cell and creation of synthetic chimeric chromosomes with both algae and animal genomes. Planimal cells will contribute to overcoming global food problems by reducing energy consumption. Combining planimal cells with medical regeneration techniques will enable photosynthetic therapies. In the future, heterotrophs with planimal cells will support migration to other planets under the harsh conditions through long-distance space travel.

Key words

Planimal cell, Photosynthetic animal, Endosymbiosis, Kleptoplasty, Chimeric chromosome, Photosynthetic therapy.

Algae are the most important contributors to the environment because they perform 40% of photosynthesis on earth (Andersen 1992). Algae are also the most diverse organisms with over 0.2 million species (Guarnieri 2013) and varied morphologies (Camaya et al. 2016, Higuchi et al. 2016, Kuroiwa et al. 2014, Kuroiwa et al. 2015, Kuroiwa et al. 2016, Miyamura and Nagumo 2016, Ota et al. 2014, Sugawara et al. 2015, Suzuki et al. 2014, Takahashi et al. 2014, Takeshita et al. 2015, Yagisawa et al. 2016, Yamamoto et al. 2016). About 1 to 2 billion years ago, a primitive eukaryotic cell took up a cyanobacterium in the first endosymbiosis and evolved into algae with plastids derived from the endosymbiotic cyanobacterium (McFadden 2014). Several algae have become nested within secondary host cells through secondary endosymbiosis (Timmis et al. 2004). Secondary endosymbiosis has occurred individually and horizontally at different times in different lineages in the animal, fungi and plant kingdoms, resulting in a great diversity of eukaryotes. Thus, secondary endosymbiosis is a powerful system by which heterotrophs acquire photosynthetic capability and becomes autotrophs. *Hatena* can convert to an autotrophic species.

Photosynthetic animals are found in different phyla, including Acoelomorpha, Chordata, Cnidaria, Mollusca and Porifera (Venn et al. 2008). Their heterotrophic lifestyles are partially supported by oxygen and energy supplied by photobionts, i.e., symbiotic algae and cyanobacteria. Symbiotic green algae in the cytoplasm of a salamander embryo supply oxygen and photosynthates for embryo development as a quid pro quo for the benefit of nitrogenous wastes from the embryo (Kerney et al. 2011, Small et al. 2014, Burns et al. 2017). Kleptoplasty is a unique symbiotic association in which sea slugs intracellularly retain functional chloroplasts extracted from predated algae (Rumpho et al. 2011).

Evolutional insights from secondary endosymbiosis and extant photosynthetic animals imply that heterotrophic organisms have the potential to uptake algae and convert to autotrophic organisms. Inspired by such endosymbioses and photosynthetic animals, researchers have attempted to experimentally create photosynthetic animals. I propose here that artificial photosynthetic animal cells should be called “planimal cells.” Strategies for the construction of planimal cells include three main approaches. One is to generate plant–animal hybrid cells by cell fusion techniques. Hybrid cells between human and tobacco were generated by cell fusion with polyethylene glycol (PEG) (Jones et al. 1976). However, the first plant–animal hybrid cells survived only 6 days. Recently, human and *Arabidopsis* hybrid cells were generated by PEG cell fusion (Wada et al. 2017).
Although these hybrid cell lines were proliferative, they harbored only a partial *Arabidopsis* genome and lacked chloroplasts. Chromosome elimination possibly occurs immediately after cell fusion as can be seen in plant hybrids (Ishii et al. 2016). The second approach is microinjection of algae or photosynthetic bacteria into animal cells (Agapakis et al. 2011). Recently, the green alga *Chlamydomonas reinhardtii* was microinjected into zebrafish eggs and survived in embryos and larvae for a few days (Alvarez et al. 2015). The main problem in maintaining microinjected algae is preventing exclusion of the algae based on allore cognition including autophagy and the ubiquitin–proteasome system. Compartmentalization of microinjected algae using a synthetic nucleus (Kobayashi et al. 2015) or synthetic vesicles (Schmitt et al. 2016) will be a useful countermeasure against degradation. Similar compartmentalization of symbiotic algae can be observed in symbiosomes in cnidarians (Rumpho et al. 2011).

The third approach is the generation of chimeric chromosomes derived from the genomes of both algae and animals. Synthetic genomics research on artificial chromosomes is accelerating (Fujimoto and Matsunaga 2016) and a project to synthesize all 16 chromosomes in *Saccharomyces cerevisiae* is underway (Mitchell et al. 2017). Because a 770 kb-chromosome of yeast has already been completely synthesized (Shen et al. 2017), plastid genomes, which generally range in size from 120 to 170 kb (Shaw et al. 2007), could now be completely synthesized. However, the integration of synthesized plastid genomes into animal genomes is not sufficient to achieve chloroplast proliferation and photosynthesis in planimal cells because the majority of gene sequences responsible for chloroplast division and photosynthesis have been transferred to the nuclear genome. Thus, a synthetic genome should include both nuclear and plastid genomes with an efficient design to reduce functional redundancy compared with the animal genome. Such a down-sized genome design should be possible because mRNAs from plant genes integrated into the human genome were detected in human cells, suggesting that plant genes can be transcribed using the human transcription system (Wada et al. 2017). Molecular analyses of planimal cells using transcriptomic, proteomic, metabolomic and epigenetic analyses will give us new insights into the universality and specificity of molecular mechanisms between plants and animals. Future synthetic genomic techniques for DNA sequences of dozens of Mb based on the down-sized genome design will allow us to synthesize a minimal genome for planimal cells that can maintain chloroplasts through cell proliferation and photosynthesize efficiently.

The future success of planimal cells based on iPS and ES cells will bring about photosynthetic tissues and organs, e.g. transplantable photosynthetic skin that can use sunlight. Combining photosynthetic tissues with a photon-supply micro device embedded in the body will allow photosynthetic therapy. Moreover, microinjection or transplantation of planimal cells may ameliorate hypoxic conditions, which are induced by cancer cells.

Fig. 1. Endosymbiosis, photosynthetic animals and planimal cells. Algae contribute to secondary endosymbiosis and photosynthetic animals. The approaches for generation of planimal cells are cell fusion, microinjection and synthetic genome with the mixture of algal and animal cells.
(Brown and Wilson 2004). In fact, when photosynthetic bacteria were microinjected into the blood of mice with heart disease and the mice’s hearts were irradiated with light, the CO₂ concentration in the blood was reduced and the low oxygen concentration causing the heart disease was improved (Cohen et al. 2017).

The techniques and knowledge required to realize planimal cells are being steadily established. Planimal cells have the potential to induce an energy revolution and solve the global food problem by reducing energy consumption by heterotrophic species including humans. Because heterotrophs with planimal cells can survive in inhospitable environments with scarce food, they will be able to migrate to extra-terrestrial planets through long-distance space travel.

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References


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