ABSTRACT

The plasmodium of Physarum polycephalum is a large single cell visible with the naked eye. When inoculated on a substrate with attractants and repellents the plasmodium develops optimal networks of protoplasmic tubes which span sites of attractants (i.e. nutrients) yet avoid domains with a high nutrient concentration. It should therefore be possible to program the plasmodium towards deterministic adaptive transformation of internalised nano- and micro-scale materials. In laboratory experiments with magnetite nanoparticles and glass micro-spheres coated with silver metal the authors demonstrate that the plasmodium of P. polycephalum can propagate the nano-scale objects using a number of distinct mechanisms including endocytosis, transcytosis and dragging. The results of the authors’ experiments could be used in the development of novel techniques targeted towards the growth of metallised biological wires and hybrid nano- and micro-circuits.

Keywords: Endocytosis, Mineralisation, Nanoparticle-Transportation, Physarum polycephalum, Plasmodium

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INTRODUCTION

The plasmodium of *Physarum polycephalum* (Order *Physarales*, class *Myxomecetes*, subclass *Myxogastromycetidae*) is a single macroscopic cell which can grow to tens of centimetres in length (Stephenson and Stempen, 1994). The plasmodium feeds on bacteria and microscopic food particles by endocytosis; when placed in an environment with distributed sources of nutrients, the plasmodium migrates between each source via contraction of muscle proteins (Stephenson and Stempen, 1994), forming a network of interconnected protoplasmic tubes. Nakagaki *et al.* (2001) demonstrated that the topology of the plasmodium’s protoplasmic network optimizes resource harvesting and increases the efficiency of intraplasmodial transport from the nutrient source to the rest of the plasmodium. In Adamatzky (2010a), we have shown how to construct specialised and general purpose massively-parallel amorphous computers from the plasmodium of *P. polycephalum* that are capable of solving problems of computational geometry, graph-theory and logic.

When the slime mould develops a network of protoplasmic tubes spanning sources of nutrients, the cell maintains its integrity by pumping nutrients and metabolites between remote parts of its body via cytoplasmic streaming (Allen *et al.*, 1963; Bykov *et al.*, 2009; Gawlitta *et al.*, 1980; Hulsmann and Wohlfarth-Bottermann, 1978; Newton *et al.*, 1977; Stewart & Stewart, 1959). This cytoplasmic streaming may be manipulated experimentally and employed for the transportation of exogenous bio-compatible substances inside the protoplasmic network: in Adamatzky (2010b) we demonstrated that the plasmodium of *P. polycephalum* consumes various coloured dyes and distributes them throughout its protoplasmic network. By specifically arranging a configuration of attractive (sources of nutrients) and repelling (sodium chloride crystals) fields, it is possible to program the plasmodium to implement the following operations: to take in specific coloured dyes from the closest coloured oat flake; to mix two different colours to produce a third colour; and, to transport colour to a specified locus of an experimental substrate. Transportation of colourings per se is of little interest but shows the potential of *P. polycephalum* as a programmable transport medium.

We propose that *P. polycephalum*’s potential for internalisation and re-distribution of foreign particles may be employed for the development of self-growing electronic circuits and/or hybrid slime mould-artificial computing devices, providing that the plasmodium may be manipulated to internalise and propagate suitable artificial circuit components. Inspired by our previous results (Adamatzky, 2010b) and studies on cellular endocytosis of magnetic nano-beads (Li *et al.*, 2005) and fluorescent nano-beads (Bandmann *et al.*, 2012), nanowire scaffolding for living tissue (Tian *et al.*, 2012) and intake of latex beads by the amoeba’s endocytotic mechanisms (Goodall & Thompson, 1971), we chose to focus on two types of materials: magnetic magnetite nanoparticles—because they can be used for in situ construction of basic nano-scale electronic devices—and glass microspheres coated with silver, because they have been used to grow conductive pathways, i.e. hybrid bio-artificial wires.

METHODS

Culture and Nanoparticle Intake

Plasmodium of *P. polycephalum* was cultivated in plastic containers, on paper towels sprinkled with distilled water and fed with oat flakes (Asda’s Smart Price Porridge Oats, UK). *P. polycephalum* was cultured experimentally upon 2% non-nutrient agar gel (Select agar, Sigma Aldrich, UK) poured in 9 cm plastic Petri dishes. In each experiment, an oat flake colonised by plasmodium was placed in the centre of the Petri dish and 200μl of nanoparticle suspension was dispensed onto the colony. A circle with a radius of 1-1.5cm was cut around the inoculation site to prevent the suspension diffusing into the surrounding gel. The following two types of nanoparticles were used:
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