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Mycelial Networks as Bioelectrical Conduction Systems: Mechanisms, Evidence, and Theoretical Limits of Energy Transfer in Fungal Hyphal Architecture

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Abstract

Filamentous fungi develop extensive mycelial networks whose hyphae are increasingly recognised not only as conduits for nutrients and signalling molecules but also as substrates for the propagation of electrical activity. This memorandum reviews the physical basis for energy conduction in mycelium, distinguishing three phenomena often conflated in popular literature: (1) metabolic energy transport via cytoplasmic streaming, (2) ionic and bioelectric signal propagation along hyphal membranes, and (3) passive electrical conductivity of the hyphal matrix under applied potential. We argue that while mycelium exhibits measurable, structured electrical behaviour, claims of efficient long-range energy *transmission* in the engineering sense remain unsupported. [redacted] We propose testable boundaries for what fungal networks can and cannot do.

1. Introduction

The mycelial network—a branching mass of tubular hyphae—has drawn attention as a candidate biological information and transport system [1]. Reports of spike-like electrical potentials in *Pleurotus* and other genera have prompted speculation about 'fungal computing' and energy-conducting webs [2, 3]. To evaluate these claims rigorously, energy conduction must be defined precisely. Here we treat 'energy' in three operational senses: chemical potential (metabolites), electrochemical potential (ion gradients), and electrical power (charge flow under voltage). Figure 1 summarises the three modes.

2. Metabolic Energy Transport

Within hyphae, cytoplasmic streaming and vesicular trafficking move ATP-bearing metabolites, sugars and organelles along microtubule and actin tracks [4]. Septal pores in many species permit cytoplasmic continuity, allowing translocation of carbon and phosphorus across centimetres to metres, as demonstrated in mycorrhizal carbon-sharing experiments [5, 6]. [redacted] This is genuine energy transport, but its rate is governed by diffusion and active streaming (micrometres to millimetres per second), not by field propagation. It is a plumbing system, not a wire.

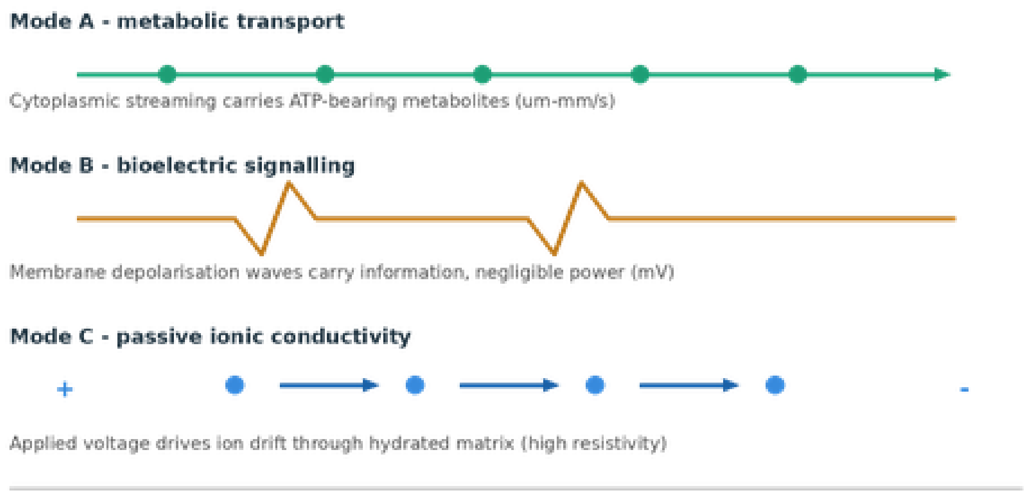

Fig. 1 Same hypha, three phenomena. Only Mode A moves meaningful energy; Mode C is highly lossy.

3. Bioelectric Signal Propagation

Hyphal membranes maintain transmembrane potentials via proton-pumping ATPases [7]. Localised depolarisations can propagate as slow waves, producing the oscillatory and spike-train extracellular potentials recorded with inserted electrodes [2, 8]. These signals carry *information* (and may coordinate growth or stress responses) but transmit negligible *power*. [redacted] Their amplitude (millivolts) and the high resistance of the medium mean the energy involved is minute—comparable to the bioelectric signalling of plant tissue rather than to a conductor [9].

4. Passive Electrical Conductivity

When an external voltage is applied across a mycelial mat, current flows—largely through the hydrated, ion-rich extracellular matrix and the cytoplasm [10]. Conductivity depends strongly on moisture content, ionic concentration and network density; dried mycelium is effectively insulating [10, 11]. Measured conductivities place fungal tissue in the range of moist biological materials, orders of magnitude below metallic conductors and below most engineered ionic conductors [11]. [redacted] The network's branching topology produces complex, frequency-dependent impedance rather than ohmic conduction [12].

5. Theoretical Limits

We can bound the system. Long-range power transmission is constrained by (a) the high resistivity of aqueous, weakly ionic cytoplasm, (b) capacitive losses across abundant membranes and septa, and (c) [redacted] the absence of any low-loss charge-carrier pathway analogous to delocalised electrons in metals or conjugated polymers [12, 13]. Consequently, mycelium cannot serve as an efficient power conductor. Its strengths lie in *transport* (mass flow of energy-rich molecules) and *signalling* (low-power bioelectric coordination).

6. Conclusion

Mycelial networks conduct energy in biologically meaningful but physically modest ways: as moving matter and as faint electrochemical signals. The romantic image of a forest-spanning 'electrical web' overstates the physics. Future work should quantify per-hypha impedance under controlled hydration, map the relationship between network topology and signal-propagation velocity, and [redacted] test whether engineered ionic doping could meaningfully raise conductivity without killing the organism [14].

Keywords: mycelium, hyphae, bioelectricity, cytoplasmic streaming, ionic conductivity, mycorrhizal networks

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