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Subaquatic Fly Locomotion – Principles

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Abstract

The theoretical criteria essential for underwater superhydrophobicity follow from the analysis on the conditions of heterogeneous wetting. Such surfaces, when immersed in water are not wetted – a layer of air is trapped between them and the surrounding water. Here we provide an observational evidence that house flies can survive under water by exploiting underwater superhydrophobicity in association with underwater adhesion. The adhesion – resisting updraft – is probably mediated by a glue-like interfacial water layer formed on the top of the pathogens collected on the terminal setae.

Keywords: subaquatic, fly locomotion, superhydrophobicity, biomimetic, ultrastructures

1 Introduction

By immersing a house fly (*Musca domestica*) into water, we observed the spontaneous formation of an integral air bag separating the body of the insect from the surrounding water. The protective bubble, approximately twice the body size of the insect (Fig. 1, left panel) seems to represent a central element in the fly locomotion, facilitating its underwater mobility and probably permitting it to breathe. The theory explaining the stability of the air bag – the basic principle of underwater superhydrophobicity – was formulated in 2006[1]. Supercavitating[2] torpedoes realize their subaquatic performance via an air envelope, which reduces dissipative components between water and torpedo. Immersed house flies attached themselves to smooth hydrophobic surfaces, resisted updraft under a 2 cm column of water and presented no immediate effort to resurface. Instead they started exploring their underwater environment for a half minute. What can we learn from a house fly? Focusing on the physical and chemical parameters that are involved in the spectacular subaquatic locomotion of the house fly (chemistry, microstructure, nanostructure and interfacial water layers) – elements of the biomimetic triangle[3], which describe the medium and short term contact between a biomaterial and a biosystem, we formulate here the basic principles of low-irritation contact lenses, non-adhesive bandages and miniature drag-reducing biomimetic submarines.

Fig. 1 Left: Photograph of immersed house fly in polystyrene container allowing discrimination between insect and air bag enveloping its body. Legs are free, permitting the fly to stick to the surface, thereby resisting uplift, and walk around. Right: Water repellency of lady mantle leaf – an interplay of chemistry and ultrastructure.

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2 Ultrastructure, chemistry and interfacial water layers in biology

The dual interplay chemistry microstructure has already been used to explain the water repellency of the lady mantle (*Alchemilla vulgaris*) (Fig. 1, right panel) and the self-cleaning of the lotus flower, natural manifestations of the superhydrophobic effect[4,5]. The triple interplay chemistry, microstructure and nanostructure attracted recently considerable attention. By explaining the extraordinary ability of water striders (*Gerris remigis*) to rest and move quickly on water[6–8], it inspired biomimetic thinking[9]. The biological functions of interfacial water layers were predicted in 1971[10], but their physicochemical properties (e.g., molecular organization, thickness, density, viscosity, elasticity and light absorbance) were only recently accessed experimentally[11–16] – at least partly.

3 Subaquatic superhydrophobicity (body) and subaquatic adhesion (feet)

The exceptional dual subaquatic performance of the house fly can be traced back to the functional interplay of the same parameters, which permit water striders to walk on water – plus adhesion. For an explanation of the subaquatic water repellency it is instructive to examine its exoskeleton and focus on the hydrophobicity and ultrastructure. Clearly, hydrophobicity alone, i.e., a superficial waxy layer, can neither explain the establishment of an integral air bag, nor its remarkable form stability. In general, waxy layers can prevent the formation of extended wetting layers and supply some insects with drinking water. For example, distinct waxy layers on the back of desert beetles (*Stenocara* sp.) are implicated by which the beetles collect fog droplets to survive in extremely dry deserts[17]. However, larger drops, i.e., raindrops, could be dangerous for a number of insects if they are bombarded successively by a series of sufficiently large raindrops without additional self-protective strategies and covering their spiracles for extended periods. Recently it was demonstrated that the outstanding water repellency of the water striders legs can be understood from the functional interplay of hydrophobicity (waxy layer), ultrastructure (microsetae and nanogrooves) and air trapped in the interspaces between microsetae and nanogrooves[6,7]. Initially, the phenomenon was interpreted as a classical surface tension effect, attributed to the action of a waxy layer on the insect's legs[18]. A closer inspection of representative high resolution scanning electron microscopy images of water strider legs[7] and different exoskeletal zones of house fly reveals some ultrastructural parallels, including both the micro- and nanostructures enveloping various parts of house fly's body[19]. So far the functions of their exoskeletal ultrastructures (a multitude of 10 μm to 60 μm long setae with diameters on the order of 200 nm, separated at a distance of 2 μm to 3 μm)[6,20] have been exclusively restricted to bioadhesive tasks, comprising both their attachment to surfaces, and the attachment of pathogens to them[20–22]. Our observation suggests that this catalogue has to be extended by a novel feature: The house flies, presumably a very large number of related insects, potentially exploit the cooperative effect of hydrophobicity, ultrastructures and a trapped air layer (Fig. 2) to survive for the period of oxygen deprivation. Theoretically, the air bag should make them unsinkable. Practically, it might help them to survive violent rainstorms and escape from rushing currents.

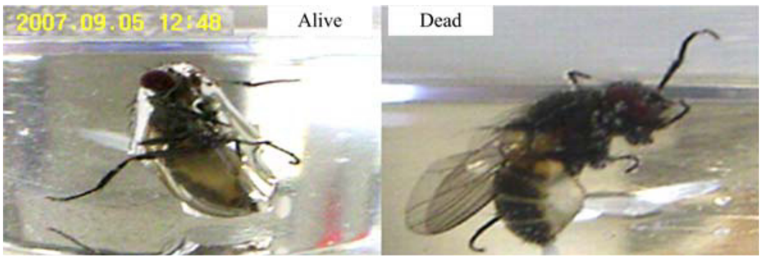

Fig. 2 Left: House fly immersed in water survives by an air bag enveloping its body. Right: A small amount of alcohol was added to the water to destroy the air bag, simultaneously the fly died. The air bubble eliminating function of alcohol was practically exploited in the method of wet medium transfer (Body building on diamonds, Sommer A P, Zhu D, Scharnweber T, Fecht H J. submitted to ICBE).