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An antiviral trap made of protein nanofibrils and iron oxyhydroxide nanoparticles

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Minimizing the spread of viruses in the environment is the first defence line when fighting outbreaks and pandemics, but the current COVID-19 pandemic demonstrates how difficult this is on a global scale, particularly in a sustainable and environmentally friendly way. Here we introduce and develop a sustainable and biodegradable antiviral filtration membrane composed of amyloid nanofibrils made from food-grade milk proteins and iron oxyhydroxide nanoparticles synthesized in situ from iron salts by simple pH tuning. Thus, all the membrane components are made of environmentally friendly, non-toxic and widely available materials. The membrane has outstanding efficacy against a broad range of viruses, which include enveloped, non-enveloped, airborne and waterborne viruses, such as SARS-CoV-2, H1N1 (the influenza A virus strain responsible for the swine flu pandemic in 2009) and enterovirus 71 (a non-enveloped virus resistant to harsh conditions, such as highly acidic pH), which highlights a possible role in fighting the current and future viral outbreaks and pandemics.

The current ongoing COVID-19 pandemic illustrates the importance of valid therapeutic tools[1], but also the notable lack of technologies capable of fighting the spread of viruses in the environment. Many viruses diffuse and transmit in the environment in water, some in their bulk form (waterborne viruses)[2–4] and others in small droplets suspended in the air (airborne viruses)[5–9]. A key defence strategy against infectious diseases is always the prevention of pathogen transmission from an infected person to an uninfected one. This is achieved by using masks, gloves, physical barriers and disinfection, which introduces other challenges on a global scale, such as achieving the goal in a fully sustainable and environmentally friendly way[10–12].

In particular, the COVID-19 pandemic revealed the paradox that, although both technological and scientific knowledge are available to develop a vaccine within the record time of less than a year[13,14], there is still a lack of preparedness to fight the rapid spread of new viruses until such vaccines are developed and a substantial portion of the population is vaccinated[15]. Without the appropriate readiness, viruses spread widely and rapidly and, eventually, new virus strains emerge via mutations[16,17], which could potentially confer resistance to vaccines that target the original strain or increase the virulence of the virus, and possibly lead to an endless vicious cycle. Viruses can spread through many different routes, but mostly through fomites[18], small water droplets[5–9] and bulk water bodies (which include wastewater)[2–4]. Proper hand hygiene serves as a very effective practice against the spread of infections through fomites[19]. In all the other cases, however, virus inactivation must be tackled in the hosting fluid, and the overarching strategy is then to target the virus in its surrounding aqueous environment, may this be in the form of microscopic suspended water droplets or bulk waters. For airborne viruses, suitable face masks, although effective, pose the risk of further dissemination of the viruses when improperly handled[20] and/or disposed[21,22]. Additionally, the generated plastic waste eventually emerges as a parallel environmental problem, especially in times of pandemics[10–12]. For waterborne viruses, and despite decades-long technological developments, contaminated drinking water is still responsible for 500,000 annual deaths, of which more than half occur in children under five years of age[23]. Non-enveloped enteric viruses, such as enteroviruses, adenoviruses and rotaviruses, can cause gastrointestinal infections with diseases such as diarrhoea and dysentery. It is estimated that ~40% of often-fatal childhood diarrhoea in developing countries is connected to viral agents[24]. Non-enveloped viruses can persist in water bodies for long periods of time[25] and can resist even some of the harshest treatments[26,27]. This challenge is not only exclusive to unfavoured communities, but extends also to countries with state-of-the-art water and wastewater treatment facilities[2]. Furthermore, even enveloped viruses, such as influenza viruses and coronaviruses, which were often regarded as unstable in water environments, have now been shown to remain highly infective for long times in bulk water bodies[28,29]: SARS-CoV-2, for example, can retain its infectivity for longer than seven days in tap water and wastewater at room temperature[30].

Therefore, the development of efficient barriers against the spread of viruses via diffusing environmental fluids becomes crucial if global contamination is to be prevented. In spite of decades of scientific and technological development, no existing technology can universally eliminate viruses from water, unless it is extremely energy intensive (for example, reverse osmosis)[31] or starts to pose the risk of toxicity towards humans and the environment (for example, silver-based technologies)[32,33]. All these limitations

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