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Combination of chemistry and material science to overcome health problems

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ABSTRACT

Since its outbreak, the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has strongly influenced the life of the general public around the world. Based on its fast spread and high mortality, there is a need for novel therapeutic treatments to overcome this global health crisis. While medicinal chemistry is focused on the development of highly selective and affine inhibitors toward a specific target enzyme, material science is focused on the development of nanomaterials for selective drug delivery. Based on the individual strengths, these disciplines could synergistically act together and help overcome the limitations of the respective approach. Herein, the combination of medicinal chemistry with material science to overcome health problems with the example of SARS-CoV-2 is critically discussed.

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The severe acute respiratory syndrome—coronavirus 2 (SARS-CoV-2), whose infections are typically referred to as coronavirus disease 2019 (COVID-19), has spread across the world. To date, more than 430 million cases and 5.9 million deaths worldwide have been reported. On 11 March 2020, the World Health Organization has announced this disease as a global pandemic. Capitalizing on this, much research efforts have been devoted towards the development of novel antiviral agents and drug delivery systems to overcome this biosafety issue for the general public. Various governmental institutions and pharmaceutical companies around the world have invested huge financial resources into the drug development of novel compounds/drug formulations [1–4].

Medicinal chemistry is aiming toward the use of molecular therapeutic compounds. These chemical compounds typically intervene in specific cellular processes by inhibiting a specific enzyme. Exemplary, the only clinically approved molecular compound for emergency use Remdesivir is able to bind to the RNA-Dependent RNA Polymerase of SARS-CoV-2, causing an inhibition of the RNA synthesis of the virus [5]. As a promising therapeutic drug that is currently studied in clinical trials, the company Pfizer has developed the compound Nirmatrelvir (PF-07321332) which is a potent inhibitor of the SARS-CoV-2 main protease, a crucial enzyme for the cleavage of the viral polyprotein [6]. The modulation of one of these processes, presents a disruption in the viral life cycle and could therefore present an opportunity for therapeutic intervention. Despite these promising properties, many studied compounds which show good activity in an enzymatic evalua-

tion are associated with poor pharmacological and pharmacokinetic properties, rendering the application of such compounds. Notably, chemical sciences could also be applied to overcome biosafety problems exemplary through the development of novel disinfectants or preservatives for biological samples.

Among other methods, increasing research efforts have been devoted towards the development of new materials. Nanomaterials could encapsulate promising drug candidates and allow for an efficient cellular uptake as well as accumulation at the target site. Capitalizing on this, these biosafety materials could overcome some of the limitations of molecular compounds. With regard to the treatment of COVID-19, scientists have used nanotechnology for the delivery of the therapeutic RNA strand for the vaccination of individuals. In particular, the RNA strand was encapsulated with lipid nanoparticles to ensure efficient cellular uptake and ensure the intact transportation and survival of the RNA strand in the cell [7,8]. Besides nanomaterials, other types of materials could also find applications to overcome biosafety problems exemplary for the detecting of microorganisms, disinfection of surfaces, supplements in therapeutic formulations, or preservation of biological materials.

Based on the individual strengths of each approach, medicinal chemistry and material science could also synergistically act together and help overcome the limitations of the respective disciplines. To date, the detection of infection with SARS-CoV-2 is heavily dependent on the use of reverse transcription-polymerase chain reaction (RT-PCR). Despite its enormous success, this method is limited by the necessity of expensive equipment and skilled analysts, which could render the application in less developed countries, and the time constraint within the range of several hours until a result is obtained. As these drawbacks could result in the infection of even more individuals,

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there is a need for a fast and user-friendly method for the detection of SARS-CoV-2 infections by the general population. While antigen tests are globally distributed, these typically show poor accuracy, resulting in various false positive or false negative results. As an alternative approach, Liu and Li have proposed the combination of polystyrene nanoparticles, a commonly applied nanomaterial for biomedical applications, an aggregation-induced emission dye, a commonly used luminescent molecular compound for the detection of biological processes, and a SARS-CoV-2 antigen for selective detection. The authors could show that the functionalized nanomaterial was able to detect SARS-CoV-2 infections in the same range as an enzyme-linked immunosorbent assay (ELISA). Based on the easy use as a lateral flow test and the high selectivity and affinity of this assay, this functionalized nanomaterial could find application as an alternative for the detection of SARS-CoV-2 infections [9]. Besides the detection, nanomaterials could also be applied in personal protective equipment (PPE) for the protection of individuals from infections with SARS-CoV-2. As SARS-CoV-2 is transmitted through the air, the wearing of protective masks presents a crucial step to avoid infections. To date, surgical and antibacterial/antiviral masks such as FFP2 or KN95 masks are distributed and used around the world. Despite their effectiveness to protect individuals from SARS-CoV-2 infections, this equipment is designed only for single usage. Capitalizing on this, there is a high demand for the production of masks, presenting also an environmental issue for the disposal of this single-use equipment. To overcome this limitation, Forró has demonstrated the incorporation of titanium dioxide nanowires into a mask to enable the disinfection and re-using of masks. The nanomaterial could be easily synthesized on a big scale and incorporated into the mask. The mask could be exposed to UV irradiation (365 nm, 16 mW cm⁻²) and the incorporated titanium dioxide nanowires could generate various types of reactive oxygen species (ROS) which are able to cause oxidative stress and kill microorganisms. Promisingly, the nanomaterial showed to completely eradicate microorganisms within several minutes of irradiation, presenting a method for the recycling of masks. These masks could present an alternative for commonly applied single-usage masks [10].

Combined these examples illustrate that chemical and material sciences could act synergistically together and could overcome the limitations of the respective disciplines. In this context, Wu and Xiao have proposed the development of a new field termed biosafety chemistry and biosafety materials [11,12]. This field of research could become a new discipline within the chemical sciences and could present novel solutions exemplary for the rapid and early detection of new pathogens, the disinfection of surfaces, the preparation of protective equipment, or the treatment of patients with antimicrobial (bacterial, fungal, viral, parasitic) drug formulations. Importantly, this field of research requires expertise from various types of natural science

including molecular chemistry, biology, and material science, and therefore presents a multidisciplinary discipline with influences from various resources. Undergraduate students with a focus on this newly developed field of science could have a unique perspective on the development of novel materials to fight diseases. As such, these studies could pave the way for the discovery of therapeutic agents of the future as well as could help prevent pandemics or other global medical disease outbreaks.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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