Application of Nanomaterials and Nanotechnology in Addressing Covid-19 Challenges – Review

Sunday A. Afolalu, Ayodeji A, Noiki, Abiodun A. Abioye and Moses E. Emetere; Osise Okwilagwe
Department of Mechanical Engineering, Department of Physics
Covenant University
Ota, Nigeria
sunday.afolalu@covenantuniversity.edu.ng
dejjynoiky@gmail.com

Olabisi Omolola
Department of Microbiology
Obafemi Awolowo University
Ile-Ife, Nigeria

Olusegun D. Samuel
Department of Mechanical Engineering
Federal University of Petroleum Resources
Effurun, Delta –State. Nigeria

Abstract
The current outbreak of the Coronavirus diseases that have constituted a global issue with its adverse effects upon the world economy, healthcare systems, human lifestyle, and educational system. Several thousands of lives have was; numerous business establishments have folded up. This disease outbreak has been accompanied by a high mortality rate and loss of employment across the nations of the world. Several challenges have arisen from the recent epidemic of coronavirus pandemic. Over the years, nanomaterial has been used considerably in address the numerous clinical and health system challenges. This paper aims to carry out a comprehensive and systematic review of existing literature, investigates how nanomaterial and nanotechnology can aid in addressing the challenges of this outbreak and the current mitigation approaches. In this study, we explore the role of nanomaterial in addressing the challenges: supply of personal protective equipment, reliable clinical diagnostic, vaccine development, and therapeutic drugs. Covid-19 trial affords nanomaterial with the vast opportunity to exhibit their vital contribution to the healthcare system at this time of great need.

Keywords
Nanotechnology; Nanoparticles; Nanomaterials; COVID-19; Pandemic

1. Introduction
The current outbreak of the Coronavirus disease has constituted a global issue with its adverse effect upon the world economy, healthcare systems, human lifestyle, and educational system. Several thousands of lives have been lost; numerous business establishments have folded up. This disease outbreak has been accompanied by a high mortality rate and loss of employment across the nations of the world (Tsatsakis et al., 2020). As established via various researches, the transmission of this virus is through airborne droplets and from surface and skin contamination of airborne droplets. Besides, it's essential to note that it can as well be transmitted through direct inhalation, from hand to the nasal area and surface- to-hand to nasal area and other visual exposure channels (Semple & Cherrie, 2020).

The Covid-19 disease infection often attacks the immune system and affect the aged and persons suffering from life-threatening diseases such as hypertension, kidney-failure cancer, heart failure. Hence, a daily increase in the number of people that are infected and died by Covid-19. This has necessitated the need not only for prevention but also for the control of the spread of this disease and, above all, to save human lives (Aydemir & Ulusu, 2020). Several years of research have shown that nanomaterials have been applied in the detection, prevention, and

treatment of some critical diseases such as cancer. The fast growth of nanomaterial is unraveling an enormous world of favorable potentials in healthcare, which has necessitated the increase in the study of the safety of nanoparticles on public health and the environment (Marques et al., 2019; Sengupta & Sasisekharan, 2020).

Various fields of endeavor have engaged the use of nanomaterial to develop numerous products or devices, of which the healthcare system is not an exception. Mostly, substance or end products with dimensions in the range between 1 and 100-nm are regarded as nanomaterials. There are specific requirements for the manufacture, control, distribution, and labeling of nano products. It is rather challenging to define the appropriate classification of methods and assays of such products due to toxicity, occupational health, and safety considerations (Marques et al., 2019). The current pandemic outbreak has its challenges, ranging from high demand and short supply of personal protective equipment, test kits, time-consuming and ineffective clinical diagnostics tools, need for the development of effective antivirals and vaccines, and need for therapeutic drugs for the treatment of this infectious disease. Currently, the focus of several researchers is to explore the use of nanomaterial to address the challenges of Covid-19.

2. Review of Existing Literature

Salata (2004), reported nanomaterial as the cutting edge of the fast-growing field of nanotechnology owing to its distinctive size-qualities that make them better quality and vital to numerous areas of human interest, most of the commercial Nano based applications are engaged towards the delivery of drugs. More so, in biological sciences, the nanomaterial is gradually substituting organic dyes in a form where multiplexing capacities and photo-stability are required. Nanomaterials are being further developed to perform multiple functions and controlled via outward signals and the environment, thereby transforming them into Nano-devices. Ever since the advent of nanomaterial, intense studies have been carried out on nanomaterial for both medical and biomedical applications. Nanomaterials are anticipated to proffer solutions to several health challenges via nano-bio sensors, nano-based agents, and nano-based targeted drug channels that can convey antimicrobial or antitumoral agents. Safe handling and usage of nanomaterial have become a significant area of concern in medical applications. It is rather unfortunate that the long term effects of these materials are yet to be determined, though some nanomaterials are already exhibiting adverse effects in the human health system (Andronescu et al., 2016).

Chen et al., (2013), in their study established that the prospect of nanomedicine lies on the fabrication of nanomaterials and nanoproducts founded upon an in-depth understanding of biomedical processes such as therapeutic drug design and targeting techniques which could vary relative to the nature, developmental stage, and site of the disease. Also, there are specific nanomaterials that are multifunctional and have the capacity of targeting, imaging, and therapy. However, issues of toxicity are of great concern; to achieve the successful application of these techniques, primary research needs to be carried out due to the interdisciplinary nature of this field. It is essential to train and equip a new generation of researchers who are grounded in the various interdisciplinary. Liu et al., (2018), proposed the use of magnetic nanomaterial for tissue regeneration to facilitate the growth of regenerative medicine. Tissue generation is a technique founded upon repair and replacement of diseased tissue to recondition the lost, impaired, aging cell, particularly in the human body. This technique explores the exceptional properties and specific dimensions of the magnetic nanomaterial, which make them prospective components adept for advancing tissue regeneration. However, this application requires a broad-based understanding of complex structures and interactions; it will also require further optimization.

Mohana et al., (2020), investigated the role of nanomaterial application in the area of agriculture poultry and food production. The study suggested that Nano based preparations could be used for fertilizers, nutrients, pesticides in conjunction with the protection of crops. It envisaged the detection of pathogens, prolongs shelf life, and improved sensory taste in the food sector. Also, Nano based strategies could be engaged in addressing pathogen-related contamination with poultry farming and the growth of livestock. The applicable physiochemical properties of nanomaterial have made them suitable tools for improving pharmacodynamics, pharmacokinetics, bio-distribution, and biocompatibility as well as therapeutic drug delivery and targeting. The lack of vital data on toxicology remains a significant challenge. However, the need for a comprehensive evaluation of the biocompatibility and biosafety of nonmedical devices is pertinent (Genchi et al., 2017). Gholizadeh & Aziz, (2019), reported the symbiosis between nanomaterial and cell culture, which is fast growing with prospects for improvement of the healthcare system. The application of nanomaterial is 3D culture seems to draw a new phase in stem cell studies bringing about changes in tissue engineering methodology, tracking and imaging of stem cell,

vaccine, and drug targeting. Remarkably findings from this discovery have been used for therapeutic and prevention in specific health issues. Also, nanomaterial has considerably contributed to the fabrication of composite or reinforced 3D scaffolds.it is evident that significant progress has been made in advancing the potentials of nanomaterials. However, nano-toxicity remains a considerable challenge that has existed over the years, which has impeded the approval of relevant bodies. Thereby truncating the shift of various accomplishments to clinical stage, further studies are to be carried out to understand the toxic effects and potential bio complications of these materials.

Priyadarsini et al., (2018). examined nanomaterial scaffolds of graphene and graphene-oxide for stem cell culture implementation due to its physicochemical properties. Graphene-based nanomaterials are also employed in micro molecular and gene-drug delivery. Furthermore, nanomaterial can be used for teeth implantation act as anticancer therapy and antimicrobial. The biocompatibility property of nanomaterial enhances its applications in biomedical.

.

3. Challenges

Several challenges have arisen from the recent outbreak of coronavirus pandemic. Nanomaterial can considerably address the numerous clinical and health system challenges. This study investigates how nanomaterial and nanotechnology can aid in addressing the challenges of this outbreak and the current mitigation approaches. Nanomaterial based products are presently being built and utilized for the prevention, diagnosis, and treatment of the disease. The challenges are as follows: supply of personal protective equipment, reliable clinical diagnostic, vaccine development, and therapeutic drugs.

3.1. Shortages of Personal Protective Equipment

Due to the exponential growth rate of the persons affected by the current pandemic Covid-19 and the death toll of over hundreds of thousands, which has led to a shortage in the supply of personal protective equipment(PPE) such as face shields, N95/P2respirator mask, and disposable waterproof gown, etc. Transmission from patients to other patients and health workers were essential features of this outbreak. Adequate production and distribution of PPE during this outbreak has become an issue of concern. To address this issue, thus, the need to explore the role of nanomaterial in the production of PPE.Covid-19 challenge affords nanomaterial with the vast opportunity to exhibit their vital contribution to the healthcare system at this time of great need (Ishack & Lipner, 2020; Paxton et al., 2020; While, 2020). The viability of severe acute respiratory syndrome (SARS-CoV-2) was tested under different environmental conditions; however, the plastic surfaces and stainless steel show the longest feasibility. The copper environment was found to be the most effective in inactivating the virus in a short period. The inactivation of coronavirus by copper and copper alloy surfaces was due to the release of copper ion and reactive oxygen species generation (S. Afolalu et al., 2015). Sportelli et al., (2020) suggested that well known antimicrobial characteristics of preparations and nanostructures that contain metals like copper, silver, and zinc particles can be employed to combat COVID-19, most notably in the area of prevention and to curb both contaminations and spread of the virus.

Precisely, copper salt nanomaterial solutions are known for antiviral effectiveness, which could be of help in the manufacturing of PPE with better shielding properties. Such as the treatment of respirators, face shields, and masks, surgical gowns. Abbasinia et al., (2018), in their comparative study, asserted that nano-based protective respirators possess increase efficiency, better performance of air filtration in conjunction with antimicrobial properties compare with regular masks. However, there is a need to investigate the skin reaction and other unknown effects of this nanostructure of these protective respirators. An improved facemask was developed using nanoparticles coating as protection against infectious diseases. The solution of colloidal silver nanoparticles was synthesized using biodegradable reagent at room temperature. The nano-based product was tested for antimicrobial activity. The result shows that enhanced antibacterial properties of face mask with a minimal amount of silver nanoparticles emphasize their capacity for biomedical applications (Hiragond et al., 2018). Konda et al., (2020), in their study established that nano-hybrid combinations of cloths(chiffon, silk offer a wide filtration range across a nanoscale and microscale which is probably due to the combination of both physical filtering and electrostatic effects. Also, the performance of the mask will be affected by the gaps and opening between the edge of the mask and the facial contours. Furthermore, cloth masks have the prospect to provide essential protection against the transmission particles in the size range of aerosol.

3.2. Clinical Diagnosis

The urge to understand the mechanism of the current COVID 19 pandemic with a strong point of care diagnostics require much advanced biomedical analysis. However, modern tools, in combination with nanomaterial and nano techniques, possess the ability to address these present challenges. Nano solution can be built via numerous nanomaterial for detection and diagnostics owing to the unique physicochemical properties that permit viruses and bacterial to be detected even at minimal concentrations. Silver nanoparticles have become a potential tool for point of care diagnostics, and it has been employed for the detection of cancer cells. There is a high demand for a simple, reliable, effective, efficient, and friendly method for the discovery of the coronavirus.to address this challenge, several nanoparticles are being developed for diagnostics (Parveen et al., 2012). Zhang et al., (2020), developed a loop-mediated isothermal amplification, which offers a fast and straightforward technique for the coronavirus ribonucleic acid RNA detection. This is a quick sample preparation technique with a simple detection process that may permit the development of useful, field detection, and screening test applications—thus serving as a model for impending outbreaks. Though genome sequences of coronavirus have been fully discovered and numerous reverse transcription-polymerase chain reaction RT-PCR detection kits have been proposed. Yet, the timely diagnosis of coronavirus is still a significant challenge owing to the scarcity of RNA extraction techniques. A carboxyl polymer-coated magnetic nanoparticles were developed with an effective extraction system for the detection of coronavirus. This has several advantages compared to the traditional method of extraction, due to its outstanding performances, thus providing an alternative solution to the time-consuming extraction processes, and reveals a great prospect in the molecular diagnosis of the virus.

3.3. Vaccine Development

Several ongoing research on vaccine development, which includes recombinant protein unit, viruses, and nucleic acids that, on the long, may offer prospective vaccines against coronavirus. Moreover, these vaccines may involve further developmental steps and comprehensive toxicity testing before regulatory agencies' approval as well as clinical trials to determine the safety and the immunogenicity. The urgent need for new vaccines is paramount. However, the challenge persists; we must acknowledge the reality of the novel coronavirus pandemic. Therefore, it is expedient to advance, build up COVID-19 vaccines, and to find means of funding research to support their development and production (W. Chen, 2020). Prompetchara & Chutitorn Ketloy, (2020), in their study, affirmed the use of lipid nanoparticles in enhancing the delivery of messenger ribonucleic acid (mRNA) vaccines for intermuscular and intradermal administration. Since deoxyribonucleic acid DNA vaccine administration via electroporation and its likely genomic addition and persistence are still a challenge. Numerous pharmaceutical companies or academic sector are optimizing the lipids nanoparticles for delivery systems using various platforms, including adenoviral vector, nucleic acids, and recombinant proteins for the development of prophylactic vaccines. Nevertheless, before the clinical trials, regulatory bodies must evaluate the production techniques and preclinical details to guarantee safety (Afolalu et al., 2019; Chan, 2020). In an attempt to improve vaccine efficacy, nanomaterial can be used as nano-carriers, which should protect antigens from proteolytic degradation and also enhance antigen uptake via antigen cells, control release, and safe human use. These nano-carriers comprise of proteins, lipids, and polymers that have been used to attain some features. In determining the efficacy of vaccines, physiochemical properties of nanoparticles play a vital role in other to stimulate the immunity of the host against the infection (Pati et al., 2018).

3.4. Therapeutic Drugs

Coronavirus is a new virus, having no emergency therapy available for the treatment of this disease, which has resulted in widespread infection and has also created social issues for the infected people. There are several ongoing kinds of research for the possible development of drugs founded upon the viral activities and life cycle. Numerous herbal formulas are being reviewed, lack of complete characteristics and life cycle of the virus, and has caused a delay in the development of therapeutic drugs. Some of the existing prescriptions have been assessed for the treatment of the disease and proved promising in clinical trials (Chhikara et al., 2020; Nadeem et al., 2020). Uncontrolled inflammatory process has been the root cause of various pathologies. A recent investigation carried out cases of coronavirus have shown that the mortality rate might be due to hyper inflammation induced by the virus. Nano based multidrug has being developed to mitigate the hyper inflammation. These serve as immunomodulatory, antioxidant, and therapeutic agents for the treatment of infections (Dormont et al., 2020). Stocum (2018), Investigated drug discovery using dispersion since emulsifying agents are expected to be more soluble in the aqueous phase. Emulsifying the drug delivery system is a prospective technique towards drug delivery, and nano emulsification techniques can be explored for drug delivery against the coronavirus. However,

external factors are required due to the nano range size of the diameter. The nano-size offer kinetic stability and thermodynamic instability, though it is a slow process and complicated to an extent. Dynamic light scattering is employed in estimating the sample size of the distribution through the drug delivery system (Khan et al., 2012).

4. Justification

Nanomaterials have found applications in various disciplines such as healthcare, biomedical, physics, electronics, and energy. Several diseases (such for instance Cancer, Tuberculosis, Parkinson and Alzheimer's diseases) and neuro disorders have been treated through the application of nanomaterial and nanotechnology, for instance. The unique properties of nanomaterial have led to the fast growth of nanotechnology in developing Nano based products and devices. The current pandemic of Covid-19 presents numerous challenges to humanity. In addressing these challenges, some preventive measures have been recommended. Yet to be explored is the role of nanomaterial and its applications in mitigating the spread of Covid-19. These materials offer numerous advantages, owing to its exceptional properties (surface-volume ratio, effective virus inhibition, molecular interaction, and particle size). The future of medicine lies in the multi-functionality and dimensionality of nanomaterials. There are several ongoing Nano based research geared towards addressing the challenges of Covid-19.

4. Conclusion

The synergy between nanomaterial and Covid-19 has revealed prospective results for an improved healthcare system. Nanomaterial applications in health care delivery seem to be drawing the attention of several researchers and forming changes in approach in addressing the current pandemic challenges. Remarkably, some of these materials are utilized for clinical, prevention, therapeutic interventions in the treatment of viral infections. Nanomaterials have considerably enhanced the fabrication of personal protective equipment such as face shield and mask respirators, gloves, surgical gowns, and test kits. Furthermore, due to their physicochemical properties, these materials are used for clinical diagnostics, therapeutic purposes, and vaccine development. However, significant progress has been achieved in furthering the prospect of nanomaterials in healthcare delivery. This recent pandemic affords nanomaterials vast opportunities in addressing its challenges. Nevertheless, the issue of toxicity remains a significant concern over the years, thus impeding the approval of relevant regulatory agencies. Additional studies are required to understand fully the toxicity impact and likely biomedical complications of these materials with a notion to address this issue.

Acknowledgements

We acknowledge the financial support offered by Covenant University in actualization of this research work for publication.

References

Abbasinia, M., Karimie, S., Haghighat, M., & Mohammadfam, I. (2018). *Application of Nanomaterials in Personal Respiratory Protection Equipment : A Literature Review*. 1–12. https://doi.org/10.3390/safety4040047

Afolalu, S. A., Oladipupo, S., Bose, M. E., Abioye, A. A., Adejuyigbe, S. B., Ajayi, O. O., & Ongbali, S. O. (2019). Agro Waste A Sustainable Source For Steel Reinforcement-Review. *Journal of Physics: Conference Series*, *1378*, 32032. https://doi.org/10.1088/1742-6596/1378/3/032032

Afolalu, S., Adejuyigbe, S., & Adetunji, O. (2015). Impacts of Carburizing Temperature and Holding Time on Wear of High Speed Steel Cutting Tools. *International Journal of Scientific & Engineering Research*, *6*(5), 905–909.

Andronescu, E., Brown, J. M., Oktar, F. N., Agathopoulos, S., Chou, J., & Obata, A. (2016). Nanomaterials for Medical Applications : Benefits and Risks. *Journal of Nanomaterials*, 2–4. https://doi.org/http://dx.doi.org/10.1155/2016/8284319

Aydemir, D., & Ulusu, N. N. (2020). Correspondence_ Angiotensin-converting enzyme 2 coated nanoparticles containing respiratory masks, chewing gums and nasal filters may be used for protection against COVID-19 infection. *Travel Medicine and Infectious Disease*, *April*, 101697. https://doi.org/10.1016/j.tmaid.2020.101697

Chan, W. C. W. (2020). Nano Research for COVID-19 [Editorial]. *ACS Nano*. https://doi.org/10.1021/acsnano.0c02540

Chen, S., Zhang, Q., Hou, Y., Zhang, J., & Liang, X. (2013). *Nanomaterials in medicine and pharmaceuticals : nanoscale materials developed with less toxicity and more efficacy*. *5*(2), 61–79. https://doi.org/10.1515/ejnm-2013-0003

Chen, W. (2020). *The SARS-CoV-2 Vaccine Pipeline : an Overview*. 1–4.

Chhikara, B. S., Rathi, B., & Singh, J. (2020). *Corona virus SARS-CoV-2 disease COVID-19 : Infection , prevention and clinical advances of the prospective chemical drug therapeutics*. *7*(1), 63–72.

Dormont, F., Brusini, R., Cailleau, C., Reynaud, F., Reynaud, F., Peramo, A., Gendron, A., Mougin, J., Gaudin, F., Gaudin, F., Varna, M., & Couvreur, P. (2020). Squalene-based multidrug nanoparticles for improved mitigation of uncontrolled inflammation in rodents. *Science Advances*, *6*(23), 1–12. https://doi.org/10.1126/sciadv.aaz5466

Genchi, G. G., Marino, A., Grillone, A., Pezzini, I., & Ciofani, G. (2017). *Remote Control of Cellular Functions : The Role of Smart Nanomaterials in the Medicine of the Future*. https://doi.org/10.1002/adhm.201700002

Gholizadeh, S., & Aziz, G. (2019). *Application of nanomaterials in three - dimensional stem cell culture*. *November 2018*, 1–9. https://doi.org/10.1002/jcb.29133

Hiragond, C. B., Kshirsagar, A. S., Dhapte, V. V, Khanna, T., Joshi, P., & More, P. V. (2018). Enhanced anti-microbial response of commercial face mask using colloidal silver nanoparticles. *Vacuum*, *May*, 0–1. https://doi.org/10.1016/j.vacuum.2018.08.007

Ishack, S., & Lipner, S. R. (2020). Applications of 3D Printing Technology to Address COVID-19 Related Supply Shortages. *The American Journal of Medicine*. https://doi.org/10.1016/j.amjmed.2020.04.002

Khan, A. W., Kotta, S., Ansari, S. H., Sharma, R. K., & Ali, J. (2012). Potentials and challenges in self-nanoemulsifying drug delivery systems. *Expert Opinion on Drug Delivery*, *9*(10), 1305–1317. https://doi.org/10.1517/17425247.2012.719870

Konda, A., Prakash, A., Moss, G. A., Schmoldt, M., Grant, G. D., & Guha, S. (2020). Aerosol Filtration Efficiency of Common Fabrics Used in Respiratory Cloth Masks. *ACS Nano*, *14*(5), 6339–6347. https://doi.org/10.1021/acsnano.0c03252

Liu, X., Chen, S., Zhang, H., Zhou, J., Fan, H., & Liang, X. (2018). *Magnetic Nanomaterials for Advanced Regenerative Medicine : The Promise and Challenges* (Vol. 1804922). https://doi.org/10.1002/adma.201804922

Marques, M. R. C., Choo, Q., Ashtikar, M., Rocha, T. C., Bremer-Hoffmann, S., & Wacker, M. G. (2019). Nanomedicines - Tiny particles and big challenges. *Advanced Drug Delivery Reviews*, *151–152*(June 2017), 23–43. https://doi.org/10.1016/j.addr.2019.06.003

Mohana, N. C., Mithun, R., Rao, H. C. Y., Mahendra, C., & Satish, S. (2020). Chapter 16. Nanoparticle applications in sustainable agriculture, poultry, and food: trends and perspective. In *Nanotoxicity*. INC. https://doi.org/10.1016/B978-0-12-819943-5.00016-6

Nadeem, M. S., Zamzami, M. A., Choudhry, H., Murtaza, B. N., Kazmi, I., Ahmad, H., & Shakoori, A. R. (2020). Origin , Potential Therapeutic Targets and Treatment for Coronavirus Disease (COVID-19). *Multidisciplinary Digital Publishing Institute*, 1–13.

Parvathy, S. T. (2020). Engineering Plants as Platforms for Production of Vaccines. *American Journal of Plant Sciences,* 707–735. https://doi.org/10.4236/ajps.2020.115052

Parveen, S., Misra, R., & Sahoo, S. K. (2012). Nanoparticles : a boon to drug delivery , therapeutics , diagnostics and imaging. *Nanomedicine: Nanotechnology, Biology, and Medicine*, *8*(2), 147–166. https://doi.org/10.1016/j.nano.2011.05.016

Pati, R., Shevtsov, M., & Sonawane, A. (2018). *Nanoparticle Vaccines Against Infectious Diseases*. *9*(October). https://doi.org/10.3389/fimmu.2018.02224

Paxton, N. C., Forrestal, D. P., Desselle, M., Kirrane, M., Sullivan, C., Powell, S. K., & Woodruff, M. A. (2020). *N95 Respiratory Masks for COVID-19 : A Review of the Literature to Inform Local Responses to Global Shortages* . 1–26.

Priyadarsini, S., Mohanty, S., Mukherjee, S., Basu, S., & Mishra, M. (2018). Graphene and graphene oxide as nanomaterials for medicine and biology application. *Journal of Nanostructure in Chemistry*, *8*(2), 123–137. https://doi.org/10.1007/s40097-018-0265-6

Prompetchara, E., & Chutitorn Ketloy, T. P. (2020). Allergy and Immunology Immune responses in COVID-19 and potential vaccines : Lessons learned from SARS and MERS epidemic. *Asian Pacific Journal of Allergy and Immunology REVIEW ARTICLE Immune*. https://doi.org/10.12932/AP-200220-0772

Salata, O. V. (2004). Applications of nanoparticles in biology and medicine. *Journal of Nanobiotechnology*, *6*, 1–6.

Semple, S., & Cherrie, J. W. (2020). Covid-19: Protecting Worker Health. *Annals of Work Exposures and Health*, *64*(5), 461–464. https://doi.org/10.1093/annweh/wxaa033

Sengupta, S., & Sasisekharan, R. (2020). Exploiting nanotechnology to target cancer. *Journal of Nanotechnology and Nanomaterials*, *96*(9), 1315–1319. https://doi.org/10.1038/sj.bjc.6603707

Sportelli, M. C., Izzi, M., Kukushkina, E. A., Hossain, S. I., Picca, R. A., Ditaranto, N., & Cio, N. (2020). *Can Nanotechnology and Materials Science Help the Fight against SARS-CoV-2 ? 19*(April), 1–12.

Stocum, D. L. (2018). *Foundations of Regenerative Biology and Medicine*. IOP Publishing. https://doi.org/10.1088/978-0-7503-1626-2

Tsatsakis, A., Petrakis, D., Nikolouzakis, T. K., Docea, A. O., Calina, D., Vinceti, M., Goumenou, M., Kostoff, R. N., Mamoulakis, C., Aschner, M., & Hernández, A. F. (2020). COVID-19, an opportunity to reevaluate the correlation between long-term effects of anthropogenic pollutants on viral epidemic/pandemic events and prevalence. *Food and Chemical Toxicology*, *141*, 111418. https://doi.org/https://doi.org/10.1016/j.fct.2020.111418

van Doremalen, N., Bushmaker, T., Morris, D. H., Holbrook, M. G., Gamble, A., Williamson, B. N., Tamin, A., Harcourt, J. L., Thornburg, N. J., Gerber, S. I., Lloyd-Smith, J. O., de Wit, E., & Munster, V. J. (2020). Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1. *New England Journal of Medicine*, *382*(16), 1564–1567. https://doi.org/10.1056/NEJMc2004973

While, A. (2020). *The COVID-19 challenge*. 19.

Zhang, Y., Odiwuor, N., Xiong, J., Sun, L., Nyaruaba, R. O., Wei, H., & Tanner, N. A. (2020). *Rapid Molecular Detection of SARS-CoV-2 (COVID-19) Virus RNA*. *2*.