Health Security
Volume 17, Number 1, 2019 © Mary Ann Liebert, Inc.
DOI: 10.1089/hs.2018.0087

COMMENTARY

AEROSOLIZED NANOBOTS: PARSING FACT FROM FICTION FOR HEALTH SECURITY—A DIALECTICAL VIEW

Jennifer Snow and James Giordano

IT WAS RECENTLY REPORTED that nanobot sensors could be aerosolized and deployed for the detection of various airborne chemicals.[1] Such capabilities are of evident utility in and benefit to medicine, as well as to detect toxins in the environment (functioning as a nanoscalar "canary" to warn of hazardous contamination in industrial sites) and/or as a threat awareness system that could be employed in both public and military settings.[2]

Nanoscalar robotics can be used as both sensors and receiver-delivery devices, and the controllability of these technologies enable their directed activity in biological organisms. Such devices—either operating in tandem as distinct sense-and-engage systems, or as single devices with both sense and delivery modes—could be employed to assess, respond to, or modify molecular and chemical characteristics of a biological target. As recent studies have indicated, these approaches can be used in clinical care to more precisely monitor tissue, organ, and overall bodily states and to alter the structure and function of biological tissues and systems at a variety of scales, from the subcellular to the systemic and organismic. To be sure, there is significant value in this technology's current and near-term capabilities in affording more granular methods and tools of evaluating and treating disease and injury.[1-3]

However, we posit that the development of aerosolizable nanomaterials and devices also poses defined risks to public health and biosecurity that warrant consideration, address, and constraint. Aerosolized nanobots could be used to sidestep extant proscriptions of the current Biological and Toxin Weapons Convention (BWC) or Chemical Weapons Convention (CWC).[4,5] The properties of these devices that allow their stable aerosolization also confer ability to remain suspended for longer periods of time in a variety of environments. They can be partially or fully autonomous and are capable of storing information with potential to identify or affect specific biological targets. They possess the ability to move independently and up to 2 feet multidirectionally in a closed space, and they can be disseminated much further when dispersed via a spray mechanism or other propellant. Their size (and "programmability") allows them to easily enter unprotected bodily spaces and to penetrate protective gear. A key limiting factor is the energetics required for nanobots' operations. If the nanobot was to rely on stored energy (eg, that when assembled or released), then energy demand would constrain functional durability, as current nanobotic systems do not have extensive energy-storing capacity.

Jennifer Snow, MS, is a lieutenant colonel in the US Air Force, assigned as the US Special Operations Command Donovan Group Innovation Officer, and USSOCOM J5 Future Plans and Strategy Team Air Force Representative at MacDill AFB; she is the Technology Liaison Officer for SOFWERX, Tampa, FL. James Giordano, PhD, is Professor, Departments of Neurology and Biochemistry, and Chief, Neuroethics Studies Program, Georgetown University Medical Center, Washington, DC, and is Donovan Group Senior Fellow, Biowarfare and Biodefense, USSOCOM 2019.

However, a nanobotic system capable of collecting energy from either its environment (eg, via thermal transfer or conversion), or through interaction with non-robotic nanomaterials, could effectively decrease such constraints. As well, the convergence of nanotechnology with synthetic biology (eg, CRISPR-Cas9 gene editing,[6,7] use of information about synthesizing viruses[8,9]) could lead to a more effective capability to deliver new, and increasingly potent, morbid or lethal synthetic microbes or chem-bio hybrids. These could be customized to create novel agents that could be weaponized and, given their novelty, are not surveilled or recognized by existing regulatory bodies or anticipated by public health and biosecurity operations.

To be sure, many of the capabilities incurred by weaponized nanobots (eg, motion, information collection and storage, programmability, aerosolized dissemination, ability to enter unprotected bodily cavities, and ability to penetrate protective gear) are already possible with currently existing biological agents. However, certain aspects of nanotechnology confer additional capabilities. A prime example is that nanotechnologies involve chemistries (eg, silicon, elemental metals, long-chain, and branched polymers) and mechanisms (eg, electromechanical and optical information and energy handling) that are radically different from biologicals. Biological systems are not evolved to recognize and interfere with (many) nanotechnological functions and capabilities. Thus, nanodevices could pose an emerging threat as either stand-alone weapons or as force multipliers for extant biochemical agents. This potential to create such new weaponry is not likely to escape the notice of adversaries intent on subtly influencing specific events or, more broadly, providing overmatch capabilities to gain advantage during major conflict or gray zone actions. A nation-state or independent nonstate laboratory with capabilities similar to those employed to aerosolize nanomaterials could reproduce the results of this research with relative ease.

Of course, it could be argued that although nanotechnology, unlike biological systems, is human-designed and therefore perhaps more programmable, it will, like any other highly distributed information system, nonetheless suffer from unpredictable dynamics. But such unpredictability may confer benefit if and when a range of effects is desired. Moreover, testing the technology in a variety of environmental conditions can decrease both uncertainty and variability of such devices' functional behavior(s). As well, given that nanodevices cannot self-replicate (at least at present), even a modest rate of their destruction could negate their viability. But this may be moot; if the effective potency of the nanodevices to incur a disruptive or destructive effect is sufficiently high, it may be that only "a little" is required to do "a lot," and if a great enough number of nanodevices is delivered, then this could account for relative attrition and still leave enough to "do the job."

Perhaps nanodevices are not (yet) ready for "prime time" use as weaponized agents.[10,11] Yet, it is important to note that the aforementioned constraints can be viewed as challenges to overcome, so that opportunities for creating novel weapons can be exploited. Such possible trajectories should be recognized and regarded. Thus, as have others,[4,5,7] we too reiterate a call for the review, redress, and in some cases revision or reformulation of key guidelines, surveillance, control, restrictions, and enforceable penalties to prevent nefarious development and use of these technological advancements.

In his 2002 science fiction novel, *Prey*, author Michael Crichton depicted a terrifying view of runaway effects of convergent nanotechnology and genetic engineering.[12] While it is cavalier to look to science fiction scenarios to portend scientific fact, it must be acknowledged that such stories can serve to convey ideas, insights, and cautions, both about science and, perhaps, even more about the ways that individuals and societies view scientific and technological advancement and what such stances reveal.[13] In our view, caution—and preparedness—need not focus on the ease of nanobots going rogue, but on the relative ease and ardor with which nations and rogue actors could go "nano" in creating weapons that threaten public safety and biosecurity.

Acknowledgments

This work was supported in part by federal funds UL1TR001409 from the National Center for Advancing Translational Sciences (NCATS), National Institutes of Health, through the Clinical and Translational Science Awards Program (CTSA), a trademark of the US Department of Health and Human Services, part of the Roadmap Initiative, "Re-Engineering the Clinical Research Enterprise" (JG); the European Union's Horizon 2020 Research and Innovation Programme under grant agreement 720270: HBP SGA1 (JG); and funding from CSCI (Biosciences and Biotechnology Sub-Program), Springfield VA, USA (JG). The authors declare that they do not have any conflict(s) of interest, and that the views and opinions presented in this essay are their own and do not necessarily represent those of the funding organizations that support their work.

References

1. Koman VB, Liu P, Kozawa D, et al. Colloidal nanoelectronic state machines based on 2D materials for aerosolizable electronics. *Nat Nanotechnol* 2018;13(9):819-827.
2. Ahmad J, Akhter S, Rizwanullah M, et al. Nanotechnology-based inhalation treatments for lung cancer: state of the art. *Nanotechnol Sci Appl* 2015;8:55-66.
3. Giordano J, Akhouri R, McBride D. Implantable nano-neurotechnological devices: consideration of ethical, legal, and social issues and implications. *J Long Term Eff Med Implants* 2009;19(1):83-93.

4. Wallach E. A tiny problem with huge implications—nanotech agents as enablers or substitutes for banned chemical weapons: is a new treaty needed? *Fordham Int Law J* 2009;33(3):858-956.
5. Gerstein D, Giordano J. Re-thinking the Biological and Toxin Weapons Convention? *Health Secur* 2017;15(6):638-641.
6. DiEuliis D, Giordano J. Why gene editors like CRISPR/Cas may be a game-changer for neuroweapons. *Health Secur* 2017;15(3):296-302.
7. DiEuliis D, Giordano J. Gene editing using CRISPR/Cas9: implications for dual-use and biosecurity. *Protein Cell* 2018; 9(3):239-240.
8. Soucheray S. Step-by-step horsepox study stokes dual-use controversy. *CIDRAP News* January 23, 2018. http://www.cidrap.umn.edu/news-perspective/2018/01/step-step-horsepox-study-stokes-dual-use-controversy. Accessed January 9, 2019.
9. Snow JJ, Giordano J. Public safety and national security implications of the horsepox study. *Health Secur* 2018;16(2): 140-142.
10. Ramsden J. Nanotechnology for military applications. *Nanotechnol Percept* 2012;8(2):99-131.
11. Nichols G. Nanotechnology and the new arms race. *HDIAC J* 2017;4(2):1-6.
12. Crichton M. *Prey*. New York: Harper-Collins; 2002.
13. Wurzman R, Yaden D, Giordano J. Neuroscience fiction as eidolá: social reflection and neuroethical obligations in depictions of neuroscience in film. *Camb Q Health Care Ethics* 2017;26(2):292-312.

Manuscript received September 1, 2018;
revision returned December 18, 2018;
accepted for publication December 18, 2018.

Address correspondence to:
James Giordano, PhD
Professor, Departments of Neurology and Biochemistry
Chief, Neuroethics Studies Program
Pellegrino Center for Clinical Bioethics
Georgetown University Medical Center
4000 Reservoir Road
Washington, DC 20057

Email: james.giordano@georgetown.edu