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Existential Risk of Synthetic Biology: How Biological Engineering Can Help the World or Destroy It

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ABSTRACT

In the early 2010s, the discovery of the CAS-9 protein thrust genetic editing into the public spotlight. All of a sudden, humans had the power to rapidly and accurately edit DNA, giving us control over the code for life itself. Now, just over a decade later, gene editing and biological engineering have given rise to entirely new industries and fields of research, each with its own possibilities and risks. From synthetic viruses made to target certain types of cancer, to 3D-printed materials that can repair themselves like living tissue, to diseases that have been augmented to carry all of the most dangerous attributes, biological engineering offers some of the most promising, and deadly, technologies of the future. With designer babies, man-made pandemics, and much more on the horizon, it is critical that the global community comes to a consensus about how to properly utilize these technologies without causing our own destruction. This article addresses the promises and dangers of these emerging industries/technologies and offers foresight into the challenges that will arise from biological engineering in the near future. Aside from this, we examine what the international community is doing in terms of oversight for the field, and the steps that we as a species need to take to mitigate the risks of these technologies. Biological engineering offers a future without famine, disease, or maybe even death, but if we are not prepared to guide the technology in the right direction, it also has the potential to be our species' undoing.

Introduction

One of humanity’s greatest collaborative feats was the eradication of smallpox. During the 20th century, the global community bound together to wipe out a disease that had killed hundreds of millions over the course of history. Today, kids are not even vaccinated against smallpox, because it simply doesn’t exist anymore. Except, it does.

Atlanta, Georgia, is home to around 500,000 people. A relatively small, naturally integrated city, Atlanta seems like a great place to live compared to other major cities. However, beneath the surface of the Center for Disease Control and Prevention, a relatively unassuming building on 1600 Clifton Road, smallpox is alive and well. Kept for research purposes and the possibility of fighting against “biological warfare,”, smallpox samples are stored in frozen vials deep inside the CDC biocontainment lab. There is one other “smallpox site” in Koltsovo, Russia, because if America has a live sample of the deadliest disease in human history, Russia must as well.

Of course, holding “eradicated” diseases is not the only thing that biocontainment labs are used for. Many of them are used to perform gain-of-function research, a field of synthetic biology in which scientists enhance certain traits of diseases in order to study possible mutations before they naturally occur. Synthetic biology in general is defined as “a new interdisciplinary area that involves the application of engineering principles to biology,” (Bio.org). Essentially, whether it is creating hybrid organisms, synthesizing new species, or augmenting existing ones, synthetic biology is anything in biology that, in the past, people would have referred to as “playing God”. Synthetic biology also includes certain areas of research such as 3D bioprinting, which aims to use living cells in “bioinks” to generate living, functional structures such as self-repairing building materials or entirely new organs.

Since synthetic biology is more of a general subject than a singular specific field, it is hard to quantify everything that the term covers. However, there are certain key areas that are leading the way in terms of continued innovation and impact on humanity as a species: synthetic viruses, 3D bioprinting, gain-of-function research, and CRISPR.

This emerging technology has the potential to redefine our world or destroy it. As with most new technologies, government regulation is lagging far behind what the industry needs, especially in the most dangerous field: synthetic viruses. While it is important to continue developing in these fields, international cooperation and governmental oversight are needed to ensure that this technology does not lead to our extinction. Each sector of synthetic biology has its own possibilities and its own risks. Biocontainment labs are necessary to safely conduct biological research, but are they safe enough that we can feel protected from the pathogens they contain? Gain-of-function research allows us to stay ahead of the curve when it comes to mutating diseases, but is creating superbugs really the best way to do that? Synthetic viruses have medical capabilities beyond our wildest imaginations, but what happens when the same people who commit mass shootings have access to the technology to create designer diseases? Finally, CRISPR has the potential to eliminate genetic diseases and essentially all undesired traits in general, but do we have the right, or the ability, to ethically edit the human genome? All these questions are things that need to be addressed, and until they are, synthetic biology will remain one of the greatest threats to humanity, especially when most people remain ignorant of what it is.

Biocontainment Labs

To start, it is important to understand the facilities where a large portion of synthetic biology research occurs. Biocontainment labs hold many of the deadliest diseases in human history; smallpox, anthrax, ebola, you name it. The most dangerous of the diseases are kept in level 3 or 4 biocontainment labs, with the main difference between the two levels being that level 4 diseases generally do not have a standard treatment or cure. In New York State, there are at least 13 such biocontainment labs with 6 in NYC alone, (USA Today 2021).

To give a brief overview of the different biocontainment levels and the procedures that accompany them, bio-safety Level 1 labs work with organisms that pose little to zero threat in making healthy adults sick, if they can even infect humans at all. Safety procedures for these labs are minimal, basically following a checklist for basic hygiene: wash your hands, do not ingest samples, avoid aerosols and splashing liquid, and do not bring food into the lab when working with samples. At BSL-2, you have viruses that cause basic human diseases, such as HIV and staph viruses. Additional protections include PPE, lockable doors, biohazard signs, and safety cabinets for experiments that involve aerosols. BSL-3 involves potentially dangerous diseases such as yellow fever, tuberculosis, etc. Researchers often require full scrubs/coveralls, and experiments are conducted in locked rooms with non-recirculating airflow. Finally, BSL-4 labs involve diseases such as Ebola, Marburg, and Anthrax, and they require fully pressurized containment suits, decontamination chambers, Class III safety cabinets, and their own separate air supply. (Trapotsis 2022). There are at least 42 known BSL-4 labs in the world, with 17 others planned or currently under construction.

So what do biocontainment labs do? Well, as can be expected, they contain biological material. Sometimes it is simply storing samples of dangerous diseases in case they are ever needed, while other times they are actively being used for research, whether it is gain-of-function research, drug testing, or anything else that might require live samples. Biocontainment labs are definitely necessary to have, especially with the number of new diseases, antibiotic-resistant infections, and of course the increasing threat of synthetic viruses and biological warfare. However, many people question whether the current protocols and restrictions are enough when compared to the destructive capacity of the diseases they host.

A good biocontainment facility has multiple layers of protection, a maze within a maze within a maze that makes it essentially impossible for diseases to escape. Many of the well-known ones, such as the labs at the CDC in Atlanta, do seem to follow the strictest possible guidelines to prevent lab leaks. However, Rocco Casagrande, a former United Nations weapons inspector states, “because transparency is not required of all of them, they remain ‘a big black box,’” (Gertner 2021). Indeed, the main concern with biocontainment labs is that many operate in secret, especially in more authoritarian parts of the world. Even in the US, these facilities rarely report accidents, preferring to keep the public in the dark. According to USA Today, over 100 labs have had major security breaches: from samples that go missing to cattle infected with human-transmissible diseases being sent to slaughterhouses that sold the meat for human consumption, (Young, Penzenstadler 2015). A biocontainment lab in the UK sent out live anthrax samples by mistake, and in 2014, FDA employees discovered 6 vials of viable smallpox from the 1950s on one of their campuses. The reality is that no matter how secure your facility is, when dealing with microscopic organisms and lots of human involvement, accidents are going to happen.

The problem with biocontainment labs is a lack of governmental oversight, or rather, a lack of public oversight. A majority of labs are run in secret by governmental organizations, so while major issues by necessity get reported to the public, there are no doubt countless small instances that go ignored because people simply do not know about them. If history has proven anything, it is that governments and businesses are unlikely to change risky practices without a strong public push for them to do so. Even airlines have anonymous "minor" problem reporting that allows the public and workers to demand improved performance when small issues build up, so why do not we have the same thing with labs that hold diseases capable of killing millions?

Gain-of-Function Research

Perhaps the most contentious area of synthetic biology is gain-of-function research. Back in 2014, amid widespread public outcry against the technology, the NIH banned funding for gain-of-function (GOF) experiments involving influenza, SARS, and other pandemic-potential viruses, (Collins 2017). This ban was lifted at the end of 2017, but when the coronavirus hit, many people pointed to an NIH-funded GOF research lab in Wuhan, China, the birthplace of the virus. The claim wasn't baseless, as a researcher from the lab was one of the first individuals to test positive for the disease. However, regardless of whether coronavirus was man-made or not, the fact remains that while lab leaks are bad, gain-of-function viruses escaping could be catastrophic.

Gain-of-function research, or GOF, refers to the process of augmenting existing diseases, in order to develop countermeasures for possible future variations of the pathogen. For example, in 2015, researchers at UNC Chapel Hill combined the coronavirus variant responsible for SARS and used proteins from another variant to make it more transmissible in humans. The study concluded that coronaviruses posed a large risk to public health, with extremely high pandemic potential compared to other diseases, (Bojanowska 2021). Looking back on it, they were spot on.

The main problem with gain-of-function research is that lawmakers do not really know how to determine when the risks inherent in a new disease outweigh the benefits of studying it. The largest public outcry against a gain-of-function experiment occurred when scientists took a strain of avian flu and made it transmissible among ferrets, which made many concerned that it could easily be adapted to infect humans, (Kozlov 2022). Today, scientists can adapt pretty much any disease to effectively infect mammalian cells, opening the door for any virus or bacteria in the animal kingdom to be easily turned into a human pathogen.

Most gain-of-function research is conducted in BSL-3 or BSL-4 containment labs, which as discussed earlier, are not perfect. However, a lot of the research is also conducted at universities, or in other locations that have even greater breach risk than governmental facilities. Princeton University unbanned funding for gain-of-function research on its campus in 2018, and many other top universities have done the same. The reality of the situation is, GOF regulation is simply nowhere near what it needs to be in terms of controlling when and how it is performed.

So, GOF can give us insight into new variants of diseases before they even exist, or it could create a superbug that wipes out human civilization. Sounds like a good trade right? But what is the real risk of one of these diseases escaping? Well, according to epidemiologists Marc Lipsitch and Alison P. Galvani, "if 10 American laboratories ran these types of experiments for a decade, there would be a 20 percent chance that a lab worker would become infected with one of these new super-flus and potentially pass it on to others," (Khazan 2014). Seems pretty high for GOF to be worth it. However, many still argue that GOF is essential for predicting pandemics and staying ahead of the curve on new viral mutations. If Covid-19 showed us anything, it is that a sudden deadly pandemic has the capacity to rattle the global health system, if not shut it down entirely. Imagine if Covid had a death rate of just 5%; the results would be catastrophic. However, critics point out that a single team creating a new variation of a disease is unlikely to collect adequate data to be of any use in the case of an actual pandemic. The team that created a Covid-like pathogen didn't help prevent the pandemic, and these sorts of projects are unlikely to get the level of funding they need to be useful until it is far too late.

So, what has the government done to curtail the possible negatives that come with GOF research? Well, during the pause in funding for GOF research, they created numerous new committees and policies to help manage the emerging field. The National Research Council Institute of Medicine (2015), and National Science Advisory Board for Biosecurity (2016) were tasked with coming up with new ways to monitor experiments using the technology, (Evans 2018). The problem is, all these groups were really able to come up with in terms of regulations was "it depends". As of right now, the only projects that get investigated or halted are ones considered to be "dual-purpose research," meaning that it might possibly be used for biological weapons or other forms of bioterrorism. Some pandemic potential pathogen (PPP) experiments are stopped as well, but only a fraction of experiments that have high risk are investigated by these groups.

The reality is, it is nigh on impossible for the government to regulate GOF research on a case-by-case basis. If the government is going to do anything to lessen the cataclysmic potential of the technology, the policies need to be broad, general, and easily enforceable for every experiment on potentially dangerous pathogens. Special attention can be paid to especially risky trials, but every experiment needs some sort of guidelines, especially when most BSL-4 facilities do not even have separate guidelines for GOF research.

3D Bioprinting and Synthetic Viruses

Even though GOF research has its risks, if humanity is ever wiped out by "synthetic biology", it will almost certainly come at the hands of synthetic viruses and 3D bioprinting. Studying the world's deadliest diseases and even augmenting their characteristics sounds dangerous, but it is nothing compared to the sheer destructive power of a 3D printer. 3D bioprinting is defined as "technology where bioinks, mixed with living cells, are printed in 3D to construct natural tissue-like three-dimensional structures," (UPM Biomedicals). Given this definition, it is hard to imagine why this technology might pose the greatest threat to humanity compared to leaky biocontainment labs and unregulated gain of function research facilities. Indeed, the vast majority of its functionality will be for benign medical research and patient care. However, the concerning part of this technology, which some consider to be another field entirely, is the creation of new microbial life.

3D bioprinting has innumerable applications. From creating biofilms that can detect radioactive materials via quorum sensing, to creating building materials that repair themselves, to printing new organs for patients with organ failure, its practical uses for improving our society are endless.

In 2021, Lawrence Livermore National Laboratory students discovered a new method for printing biological materials in more structured and stable formations. Using this new technology, researchers at LLNL were able to create "biosensors for a variety of natural and man-made chemicals ... bacterium *Caulobacter crescentus* was genetically modified to extract rare-earth metals and detect uranium deposits," (LLNL 2021). As 3D printing technology continues to develop, these biofilms will only improve, offering massive industrial benefits in terms of finding raw materials and rare metals. These sensors will also be able to detect various radioactive materials, making them useful in radiation detection and finding specific radioactive fuel for nuclear processes.

Aside from creating biosensors, it will eventually be possible to produce cheap, self-repairing, sustainable building materials using 3D bioprinting. In the human body, our cells can repair environmental damage by dividing to replace the damaged cells. However, when there is no significant damage to be repaired, cells use various strategies such as contact inhibition to prevent over-replication, which could lead to tumors. By using this same process in building materials, we may eventually be able to create structures that can repair themselves on a much larger scale than current "self-repairing" materials. To point once again to LLNL, researchers are currently working on "materials that are autonomously patterned and can self-repair or sense/respond to their environment," (LLNL 2021). Given the exponential growth of cell populations, this technology would offer essentially limitless construction capabilities using the most high-tech building materials in history, all with zero actual technology in the materials themselves. Everything would be autonomous, with each material acting as an organism that can monitor and repair itself, excluding sudden catastrophic damage of course.

Finally, there are the countless medical applications of 3D bioprinting, which include things such as tissue repair, organ replacements, and impactless drug testing. According to the Wyss Institute at Harvard, they are close to being able to "create various vascularized 3D tissues for regenerative medicine and drug testing endeavors," (Wyss 2022). With access to limitless and impactless drug testing on live human tissue, how much further could we take medical research? Furthermore, as technology develops, we might be able to replace patients' tissues with 3D-printed ones made with their own cells, making regenerative healing an easy and affordable process for everyone. Of course, the final step for 3D bioprinting in medicine is to be able to construct entirely new organs. Within a couple of decades, we will be able to construct new hearts, livers, kidneys, and other commonly donated organs entirely from scratch, eliminating donation waitlists and saving thousands of lives. We may also be able to extend our lifespan by a number of years, as this technology would essentially eliminate progressive organ failure as a cause of death for a majority of the population.

Whether it is in industry, construction, or medicine, it seems like 3D bioprinting can do no harm. Using existing cells as the raw material for 3D printed structures poses little existential threat to humanity, but that is only part of what "bioprinting" will be able to do in the future. The far more impactful, and dangerous, part of bioprinting is the creation of new life. Perhaps not complex organisms, but we are already at the point where we can essentially construct new microbes from scratch. Within a few decades, anyone with a basic knowledge of virology will be able to construct a virus capable of wiping out humanity.

Of course, creating microbial organisms is not all bad. In 2014, Andrew Hessel created 3D-printed oncolytic viruses that could fight cancer by tearing mutated cells apart. According to Hessel, he is confident, "he will be able to 3D print customized viruses which will attack the cancer cells specific to each individual," (O'Neal 2014). Of course, technology is nowhere near making this treatment affordable or even effective at this point, but the idea that we could one day eliminate cancer by designing our own viruses to fight it is quite incredible. Creating new microbes could also be used to improve gain-of-function research, as scientists could create whatever wild imaginative disease comes to mind, rather than simply augmenting existing ones.

Although designer viruses are cool, it is not hard to imagine why they might become extremely dangerous if used incorrectly. As the technology for creating new viruses becomes more and more accessible to the general public, there is an increasing risk that someone will try to use it to create the deadliest disease in human history. With the recent Covid pandemic overwhelming hospitals across the globe in a matter of months, one can only imagine the catastrophic consequences of a disease designed specifically to kill as many people as possible. Imagine a disease with the fatality rate of ebola, the transmissibility of Covid, and the incubation length of Polio. It could sweep across the globe in a matter of months, destroying entire nations and wreaking havoc on a scale not seen since the Bubonic Plague in Middle Ages Europe. The technology to create such a disease is not centuries, but rather mere years, away. In fact, it is pretty much already here.

In 2019, Rob Reid gave a Ted Talk on the catastrophic risks of synthetic biology. During his presentation, Reid gives perhaps the best quote for explaining why bioprinting and viral synthesis could spell the end for humanity: "when suicidal mass murderers go all in, tech is the force multiplier," (Reid 2019). According to the WHO, there are at least 300,000,000 people who suffer from depression. 800,000 people commit suicide each year, and while most do it in a very personal way, some decide to take as many others with them as they can. In 2021, there were 330 "mass shootings" that resulted in at least one death. We do not know how many of these people would have kept going if they had the chance, but we do know that their death toll was limited by the technology they had at hand. A maniac with a knife can kill dozens of people, but with a gun, they can kill hundreds. By hijacking a plane, they may be able to get a thousand, but with the ability to create designer viruses, they can kill millions. That is why this technology is so dangerous. Imagine if every mass shooting was instead a unique pandemic that ravaged communities and shut down the global economy similar to how Covid did. Even if it never happens, that is a possibility that can not be allowed to exist.

So how close are we to a reality where this can happen? Well, as shown with the work of Andrew Hessel, 3D printing viruses is already possible. Recently there was a lot of concern over the artificially synthesized "horsepox" virus, which scientists believed would create "a workflow that allows for the generation of any infectious poxvirus, including smallpox virus, from synthesized DNA," (Coyne 2018). While it is not quite equivalent to 3D printing viruses, this technology could be used to inject viral DNA into cells and use their natural processes to create new viruses. Obviously, in this case, the main concern is that someone will recreate smallpox DNA and use this technology to recreate the virus, but as genetic technology gets more advanced, people will be able to synthesize entirely new diseases. Maybe only a couple of people can create new viruses now, but as it gets more and more accessible to researchers, it is only a matter of time till one of those people Rob Reid was talking about gets their hands on the technology to create their own pandemic.

So what is being done to stop this apocalyptic scenario from playing out? Well, like with most dangerous new technology, not much. In 2011, virologist Ron Fouchier developed a new virus based on H1N1, except it would be able to be carried by a wider variety of animals, thus providing higher transmission to humans. After discussions about censoring his findings, the World Health Organization decided in 2012 to release the unredacted report because of "the difficulty of rapidly creating and regulating such a mechanism in light of the complexity of international and national legislation," (Mechanic 2012). Essentially, the World Health Organization decided that it would not be possible to reach a global consensus on the restriction of this new technology, and as such, it was not even worth trying. This outlook is reflected in pretty much all areas of synthetic biology, as a concerning lack of regulation continues to be a major issue in the sector. In order to properly control the use of synthetic viruses, we would need global cooperation on a scale rarely seen in human history. It would have to be something akin to the global effort to eliminate ozone-depleting aerosols, but it is unlikely that will happen until the negative effects are extremely apparent, at which point it will be far too late. Even in the US, the synthetic biology industry is essentially developing without governmental oversight, with scientific ethics being the main force of restraint. While each newly created disease raises concern and oftentimes pushback, it is not enough to try to mediate the damage after the fact. Regulation doesn't mean that we shouldn't explore this technology, but there have to be rules about who can do it and to what degree, lest it gets out of control and leads to millions of deaths.

So, synthetic viruses might cause the end of human civilization. However, aside from that, what are the possibilities for their use in other settings, such as biological weapons in warfare? In March 2022, an AI drug creation software was tasked with the creation of new biological weapons. In just six hours, it created 40,000 new potential weapons, and while most of them were chemical agents such as nerve toxins and gasses, many of them included biological agents similar to anthrax and other virus-related weapons, (Calma 2022). With AI only increasing in complexity and efficiency, it is quite likely that as the technology to create synthetic viruses progresses, it may be used to come up with new and increasingly potent diseases.

Of course, biological weapons are banned for a reason. For one, they are horrific, with lifelong effects for survivors and debilitating damage being done by invisible chemical agents. However, the other reason is the fear that if a disease is used as a biological weapon, it may spread and turn into a global pandemic. Because of this, synthetic viruses would be pretty impractical to use as biological weapons, at least if we are talking about a disease that spreads from person to person. A country could use a non-person-to-person transmissible disease and give it to enemy soldiers through spore releases or infected animals. However, if they are able to get close enough to do this, they could probably just hit the enemy with more rapid methods of killing, making synthetic viruses extremely impractical as a biological weapon. Of course, if a country is losing a war and they no longer care about morality or even self-preservation, it may turn to synthetic viruses as a self-destructive method of defense, making man-made viruses another weapon of mass destruction that humanity has to worry about. Generally though, if man-made viruses cause a global pandemic, it will almost certainly be at the hands of a crazed individual, rather than a country using it as a weapon of war.

CRISPR

CRISPR, or Clustered Regularly Interspaced Short Palindromic Repeats, are DNA segments found in prokaryotic organisms that help them fight specific viral infections. In the ocean, viruses called bacteriophages kill around 40% of oceanic bacteria every day, (UC San Diego 2022). In the rare case that a bacteria survives being infected by a bacteriophage, it stores a portion of the viral DNA in its own genetic makeup. When the same virus returns, the CAS9 protein is used to cut viral DNA that matches the stored segment, essentially making the bacteria immune to that virus. In the late 2000s, scientists discovered that this process could be programmed, allowing gene editing at a speed and precision magnitudes above the current techniques. Today, CRISPR is the foremost technology used for nearly every genetic experiment, and it has the potential to not only redefine microbial studies but change the very state of humanity forever.

The most obvious use for CRISPR is eliminating genetic diseases. Thousands of conditions are caused by a single point mutation, insertion, or deletion, and CRISPR could easily be used to fix these disorders. With this singular protein, we have the potential to cure sickle cell anemia, muscular dystrophy, Huntington's disease, and even cancer, (Khatri 2022). We even have the potential to cure previously incurable diseases such as retroviruses like HIV, or other conditions such as cystic fibrosis, (Fernández 2021). The possibilities are limitless. CRISPR gives us hope for a future in which thousands of ailments that affect humanity are no more. Millions of lives will be saved, and billions of hours of human suffering will be avoided. CRISPR is the miracle technology of the future, and curing diseases is just the tip of the iceberg.

So, curing most known diseases? Cool, whatever. CRISPR can do so much more than that. This technology gives us the ability to edit our own genome, and design ourselves to be whatever we want. More specifically, CRISPR can create designer babies.

Currently, there are only a select few traits that we know how to control. Most characteristics are controlled by hundreds or even thousands of genes, with each one acting as a small input toward a greater whole. For example, there's no "tallness gene". Rather, there's an entire host of genes that each produce a protein, which collectively determine how tall you will be, contingent upon environmental factors. The most significant genes affect your height by maybe an inch, (Cyranoski 2019). Even with traits that we know how to change, we cannot be sure that switching a gene may not come with unwanted side effects. However, as genetic editing technology continues to progress, it is highly likely that we will one day be able to isolate and alter specific traits in babies. Do you want your kid to have blue eyes? Easy. Incredibly intelligent? Done. Grow a tail and wings that they can use to fly? Why not?

Of course, it is not really that simple. The first ethical concern is cost. Individuals in more wealthy socioeconomic classes already enjoy a higher quality of life, but what happens when parents can pay to make their kids objectively superior as well? The outcome is not hard to parse; a rigid social order, determined by whether your parents could afford to optimize your traits or whether you were an inferior "natural-born". Doesn't seem particularly fair, does it? The other concern is the same with any aspect of biological engineering: do we have the right to mess with nature like this? Whether you are religious or not, it is undeniably off-putting to tamper with the natural order to the point where we can essentially make ourselves into different species, which leads us to the final concern. What if we take CRISPR one step further, and start using animal genes in human embryos? Scientists are already looking into it, whether it is trying to utilize the regenerative properties of zebrafish or isolate the genes that give hawks near-perfect eyesight. Aside from the unbelievable physical advantages, which go back to the previous points, there is the possibility of splintering humanity into different groups that are hardly even the same species anymore. If you think nobody would be crazy enough to give their kids gills or maybe wings, just look at what celebrities use plastic surgery for; if it is possible, it will happen. There's also the risk of super soldiers and CRISPR being used for warfare, but honestly, if it gets to that point, genetically modified soldiers will likely be the least of our concerns.

So how far away are we from this reality? Well, it is hard to say, but if you think that moral guidelines will stop human experimentation, it is already begun. In 2018, He Jiankui announced that he had produced two genetically modified babies, with a third on the way. While he was heavily criticized and his work was quickly halted, he proved that CRISPR could in fact be implemented into viable human embryos. Since then, numerous studies in China, the US, and other countries have started doing research on viable human embryos, and although there have been no more babies born from this research, “many ethicists saw only one possible outcome: a clinical application not unlike what He has claimed to have done,” (Cyranoski 2019). While there was a strong push for international consensus on the topic, countries remain split on whether working with viable embryos is ethical. China and Mexico allow it, while countries like Canada and Australia ban it completely. Mitochondrial replacement therapy, a procedure that switches out mitochondria to correct defects and/or increase pregnancy success rates, is offered in Russia, Ukraine, Spain, Albania, and Israel. The question is not if CRISPR will become a mainstream technology for editing human embryos, but when.

Conclusion

So, what can we do to make sure we get the best parts of each of these technologies and avoid the rest? Well, as with every other aspect of synthetic biology, the answer is complicated. Generally, regulation, education, and international cooperation.

Biosecurity labs are necessary for the safe execution of research and storage of dangerous pathogen samples. However, a lack of regulation, transparency, and differences in guidelines between countries undermines their usefulness. These diseases have to be stored somewhere, but that doesn’t mean that we should accept anything less than perfect containment from places whose only purpose is to keep diseases inside. As such, there needs to be more public involvement in these facilities, like the airline mishap reporting system mentioned earlier. Governments won’t spend the time and money improving these facilities if they do not consider the reward to outweigh the risk. However, if the public is up in arms over every breach in containment, the facilities will inherently be improved until they are virtually perfect, and therefore almost completely safe. This policy needs to be replicated across the international community, and regulations about the construction of these facilities need to be in the form of laws from the government, not suggestions written by a 3rd party ethics committee.

Next, gain-of-function research. While technology is fascinating, and it certainly does have its uses, there is not nearly enough oversight for something that essentially takes the problems with biocontainment labs, and makes them worse. Research with pandemic potential pathogens should always be conducted in BSL-4 labs, and there must be special regulations for this kind of research as opposed to standard experiments. Like with the biocontainment labs, there needs to be international consensus on these regulations, as a chain is only as strong as its weakest link. While the most well-made biocontainment facilities may be safe enough to warrant the risk, there are many that are definitely not.

3D bioprinting is fine as it is. Standard scientific practices and medicinal trials before implementing anything should obviously be used, but this is the only aspect discussed in this paper that doesn’t have the potential to destroy the human race. Synthetic viruses, on the other hand, are another story. If you thought biocontainment labs were bad, what happens when people can create their own super pathogens, from scratch, in an unregulated and unprotected environments? Rob Reid said it the best when he called technology the force multiplier of egotistical maniacs. If we let the group of people with access to this technology get large enough that it overlaps with the kinds of people who commit mass shootings, we have a serious problem. All it takes is one person to want to destroy society, and millions will die. So, what do we do? Well, synthetic viruses have medical uses, such as the oncolytic viruses designed to fight cancer mentioned earlier. However, there need to be severe restrictions on how the technology to synthesize new viruses is spread and taught, and all projects should be approved and supervised before they take place. This is perhaps the most dangerous area of synthetic biology, and we cannot allow for the free advancement of a technology that can easily kill us all.

Finally, we have CRISPR. CRISPR is the most promising of the new technologies, offering the opportunity to cure innumerable diseases and rewrite the very fundamental nature of human reality. However, it also has the possibility to divide us in a way that nothing else has before, whether it be by the nature of its cost or its ability to create humans that are basically different species. So, while this technology should certainly continue to be pursued, the global community should continue to keep its wariness of CRISPR, and only permit its use on human embryos in ways that remove suffering and save lives, not augmenting people's traits.

By combining engineering and biology, synthetic biology allows us to design life in the way we have been designing our world for decades. Whether it is GOF research being performed via modifying microorganisms, CRISPR allowing us to reprogram our own DNA, or synthetic viruses providing a doorway into the creation of man-made life, synthetic biology offers innumerable possibilities that decades ago would have been considered science fiction. The field is so much larger than just what was discussed in this paper, and it is constantly expanding in new directions as well. With technology this new, the possibilities are limitless, but so are the risks. With great power comes great responsibility, and is humanity ready for the responsibility of having control over life itself? Well, that remains to be seen.

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