THE DOUBLE-EDGED HELIX: DNA, ARTIFICIAL INTELLIGENCE AND THE BIOSECURITY CHALLENGE[1]

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ABSTRACT

Biotechnology has many beneficial applications, but it can also be used, either maliciously (e.g. for the development of bioweapons) or inadvertently, to cause harm. It is therefore a so-called *dual-use* technology.

For fifty years, the Biological and Toxin Weapons Convention (BWC) has effectively prohibited the development, production, acquisition, transfer, stockpiling, and use of biological and toxin weapons.

During this period, an increasing number of countries have developed significant capacity and expertise in biotechnology research; however not all have adequate regulatory checks and controls in place.

Artificial Intelligence (AI) is another increasingly accessible *dual use* technology that can be applied for beneficial purposes, but also for harm.

Because multilateral (United Nations) agreements often lack binding enforcement mechanisms, rely heavily on voluntary compliance, and cannot easily monitor the rapidly evolving global research landscape, they are insufficient on their own to regulate and oversee possible breaches in biotechnology research norms and regulations.

Ultimately, it is up to *all of us* – through education, training, and a commitment to responsible scientific practices, and the leadership of scientific institutions, such as academies of science, to stand up for what is right and ensure that biological weapons are consigned to history.

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The United Nations Office for Disarmament Affairs defines biological weapons as those weapons that “disseminate disease-causing organisms or toxins to harm or kill not only humans, but also animals or plants”[2]. It further notes that

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[1] Based on the presentation given during the Albanian Academy of Sciences ‘DNA Day Conference’ on 25 April 2025.

[2] United Nations Office for Disarmament Affairs, *Biological Weapons*, available at: https://disarmament.unoda.org/biological-weapons/ (accessed 19 March 2026).

“they can be deadly and highly contagious,” and adds that “diseases caused by such weapons would not confine themselves to national borders and could spread rapidly around the world.”

Historical examples

Biological warfare is not a new or modern phenomenon, although early methods were relatively crude. During sieges, for example, beehives were sometimes catapulted into castles to panic the defenders. When the hives shattered, the enraged insects caused chaos among anyone nearby. Other ‘weapons’ were hurled in this way, as well. During the 1346 Mongol siege of Caffa in Crimea, for example, plague-ridden corpses were reportedly launched into the defendants’ midst. People fleeing the siege carried the plague bacillus with them through the Bosphorus and Dardanelles straits and into the Mediterranean (Zanders, 2022). This event is widely associated with the onset of the *Black Death* epidemic (1346-1353) in Europe and North Africa, which killed an estimated 50 million people.

During the Second World War – before the structure of DNA had been elucidated – many countries maintained active biological weapons programmes. As one example of the kind of experimentation taking place, in 1942, British government scientists detonated bombs containing anthrax spores among a flock of 80 experimental sheep on Gruinard, a 2km long and 1km wide island located off the west coast of Scotland. The sheep began to die within days of exposure.

Anthrax has long been considered a potential biological weapon because it can infect both humans and domestic animals. However, its spores are extremely resistant and can persist in the environment for decades. As a result, Gruinard remained off-limits to livestock for more than 40 years. Decontamination, which, involved the spraying of formaldehyde mixed with seawater, and the removal of contaminated topsoil, began only in 1986. The following year, a test flock of sheep was reintroduced and survived.

More recently, a notorious anthrax attack occurred in the United States in the aftermath of the terrorist attacks of 11 September 2001. In this act of bioterrorism, the US Postal Service unwittingly delivered envelopes containing anthrax spores, resulting in 22 confirmed or suspected cases of infection that included five deaths (Bush and Perez, 2012).

Introducing the Biological and Toxin Weapons Convention (BWC)

Formally titled *The Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction*, the Biological and Toxin Weapons Convention (BWC) entered into force in March 1975. For fifty years it has effectively prohibited the development, production, acquisition, transfer, stockpiling and use of biological and toxin weapons[3].

The Age of Biotechnology

The BWC entered into force almost twenty years after the 1953 elucidation of the DNA double helix structure by Watson, Crick and Franklin – an event often regarded as the beginning of the Age of Biotechnology. Indeed, the Convention was opened for signature in 1972, the same year that the first complete gene sequence (encoding the coat protein of a bacteriophage) was published (Min Jou *et al.* 1972).

Just one year later, in 1973, the first genetically modified organism (GMO) was reported, when DNA from one bacterium was successfully transferred into another (Stanley *et al.* 1973). Progress accelerated further in 1983 with the invention of the Polymerase Chain Reaction (PCR) by Kary Mullis, who received the 1993 Nobel Prize in Chemistry for this work[4]. PCR is a technique for rapidly multiplying specific DNA fragments, even when they are initially present at very low concentrations in a sample. It has since become routine practice in many laboratories worldwide. During the 1990s, the emergence of commercial gene synthesis companies made it possible for researchers to order custom-designed DNA sequences by mail.

Another transformative advance came in 2012 with the discovery by Jennifer Doudna and Emmanuelle Charpentier of the CRISPR-Cas9 gene-editing system – one of several gene-editing platforms now available – for

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[3] United Nations Office for Disarmament Affairs, *Biological Weapons Convention*, available at: https://disarmament.unoda.org/en/our-work/weapons-mass-destruction/biological-weapons/biological-weapons-convention (accessed 19 March 2026).

[4] Nobel Prize Outreach AB, *Kary B. Mullis – Facts*, **Nobel Prize**, available at: https://www.nobelprize.org/prizes/chemistry/1993/mullis/facts/ (accessed 19 March 2026).

which they were awarded the 2020 Nobel Prize in Chemistry[5]. Together, these technologies enable unprecedented precision and flexibility in how DNA can be studied, modified, and utilised. In practical terms, we can do almost anything we want with DNA!

But the crucial question remains: *should we*?

The double-edged helix

The ability to analyze and manipulate DNA has many beneficial applications across science and society.

Vaccines based on mRNA technology, for example, helped protect millions of people during the COVID-19 pandemic (Zheng *et al*. 2022)[6]. The first successful gene-therapy treatment was reported as early as 1990 (Rosenberg *et al*. 1990), while the first clinical use of CRISPR-based therapy to correct a genetic defect came in May 2025 (Ledford, 2025). Beyond medicine, DNA technologies have helped accelerate plant breeding programmes, enabling the development of disease-, pest- or drought-resistant crop varieties. These improvements can be achieved through traditional breeding, now recognized as relatively slow and labor-intensive; through marker-assisted selection, which uses DNA-based technologies to track desirable traits in offspring; or through genetic modification (GM). Most commercially available GM varieties have been modified to resist pest attacks, or are herbicide tolerant (AgBio Investor GM Monitor 2025)[7]. More recently, new varieties developed using CRISPR-based gene editing technology are hitting the market. In May 2023, for example, less bitter mustard greens were introduced in the USA (Mullin, 2023), and in 2024, the Philippines government announced that a reduced-browning banana variety developed using CRISPR technology had been approved for import, propagation and production in the country[8].

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[5] Nobel Prize Outreach AB, *The Nobel Prize in Chemistry 2020*, **Nobel Prize**, available at: https://www.nobelprize.org/prizes/chemistry/2020/summary/ (accessed 19 March 2026).

[6] A meta-analysis of 51 studies that concluded that “COVID-19 vaccines are highly protective against SARS-CoV-2-related diseases in real-world settings.

[7] GM crops are now grown on more than 200 million Ha of land across the world, with soybean, maize and cotton being the most widely grown species.

[8] FreshFruitPortal, “New non-browning bananas in the Philippines,” 3 July 2024, available at: https://www.freshfruitportal.com/news/2024/07/03/new-non-browning-bananas-in-the-philippines/ (accessed 19 March 2026).

These examples are only the first of many improved crop varieties currently under development and field-testing world.

However, DNA manipulation and biotechnology also have harmful or malicious applications.

While the merits, or otherwise, of so-called de-extinction (Jacobs, 2025) remain debated, biological weapons – described in the preamble of the BWC treaty as "repugnant to the conscience of mankind"[1] – and are "universally seen as abhorrent and illegitimate" (UN, 2022).

Although no country is currently known to possess or deploy biological weapons, several recent 'notorious' cases of *bona fide* research projects have raised concerns that legitimate scientific work could aid malicious actors in their bioweapons research.

Why the 'Double-edged' Helix?
Case study 1: Gain of Function (GoF)

Gain of Function (GoF) research is generally defined as research in which an organism is genetically altered in a way that modifies the biological function of one or more of its gene products. For disease-causing organisms, this may include changes in pathogenicity, transmissibility, or host range.

In 2012, two laboratories independently reported experiments involving the H5N1 avian influenza virus. One was led by Yoshihiro Kawaoka at the University of Wisconsin-Madison, USA, (Imai, 2012) and the other by Ron Fouchier at the Erasmus University Medical Centre in the Netherlands (Schrauwen *et al*. 2018). Although H5N1 spreads easily among a number of bird species and can infect mammals, it is not usually transmissible between mammals. Both research teams overcame this limitation by repeatedly passaging the virus from one ferret to another. After several cycles, it was noted that the virus was better able to survive in ferret lungs and, crucially, became capable of being transmitted between ferrets without direct human intervention. In effect, the virus had become airborne, spreading via droplets when infected animals coughed or sneezed.

Because H5N1 can cause severe disease in humans, the evolution of a mammal-to-mammal airborne strain raised profound biosecurity concerns, particularly if such a virus were to escape – even accidentally – from the high-containment laboratories in which the research was conducted. Supporters of the work argued, however, that these experiments could help guide the development of vaccines and antiviral drugs that would target the novel mutations that enabled airborne transmission.

Why the ‘Double-edged’ Helix?
Case study 2: Poxviruses

Poxviruses (family *Poxviridae*) are a group of double-stranded DNA viruses that infect a wide range of vertebrates and arthropods. For much of human history, smallpox was one of the most debilitating and deadly infectious diseases. Following a global vaccination campaign, the World Health Organisation officially declared smallpox to be eradicated in 1980, (WHO, 1980), although a small number of samples remain stored in nominated high security laboratories. Vaccination against smallpox was originally developed using the closely related – but milder in humans – cowpox virus.

Another poxvirus that infects a domesticated animal is horsepox. Although horsepox is not known to cause disease in humans, and is also believed to be extinct in nature, it does have a genome closely related to that of smallpox. In 2017, a team of Canadian researchers ordered a series of horsepox DNA fragments from a commercial supplier. Using standard molecular biology technologies, they assembled these fragments in the laboratory – and successfully recreated fully infectious horsepox virus.

Having demonstrated that this could be done, the concern is that the same approach could be used by others to reconstruct smallpox itself.

Legislation

We therefore return to the central question: We can now do almost anything we want with DNA – but should we?

To explore this, three additional questions must be considered:

- Is all knowledge inherently good?
- What checks and controls exist?
- Who possesses the knowledge and the capacity to conduct such work?

The first question raises deep philosophical issues that will not be addressed here.

With respect to the second question, many countries – particularly those with well-developed research systems – have established layers of oversight. These include legally binding laws and regulations, as well as 'bottom-up' approaches such as best practices guidelines, and research ethics frameworks and codes of conduct.

Following the H5N1 gain-of-function experiments described above, the European Academies' Science Advisory Council (EASAC) conducted a study that concluded that the necessary laws, rules, regulations and research integrity frameworks are in place in several (though not all) European Union (EU) countries, and that, overall, EU-based research in this area was being conducted responsibly (EASAC, 2015).

In the United States, regulatory oversight was comparatively less strict until the second Trump administration, when rules and regulations were tightened through an Executive Order (White House, 2025), although the precise implications – including how non-federally funded research will be regulated – remain unclear (Kupferschmidt, 2025).

To address the third question, it is important to recognise that an increasing number of countries are developing significant scientific capacity, including in biotechnology (CAS-TWAS Centre of Excellence in Biotechnology and Clarivate Analytics, 2016). Following the COVID-19 pandemic, many governments have also invested in high-containment biosecurity laboratories, arguing that such facilities are essential for studying pathogens that affect their populations. At the same time, advances such as PCR and gene-editing techniques have effectively democratised molecular biology. Well-equipped laboratories and a growing workforce of trained scientists now enable advanced biotechnology research to be carried out in a growing number of countries.

At the international level, the BWC has effectively prohibited the development, production, acquisition, transfer, stockpiling and use of biological and toxin weapons for 50 years. It currently has 189 States Parties, with only a number small of mostly minor states yet to sign or ratify the Convention[9]. However, the BWC has no authority over so-called non-state actors, such as terrorist groups or individual bio-terrorists.

[9] United Nations Office for Disarmament Affairs, *Biological Weapons Convention*, available at: https://disarmament.unoda.org/en/our-work/weapons-mass-destruction/biological-weapons/biological-weapons-convention (accessed 19 March 2026).

The BWC is often compared with the Chemical Weapons Convention (CWC), which similarly bans certain an entire class of weapons of mass destruction. The CWC entered into force in 1997 and now has 193 States Parties[10]. Its implementation is supported by a substantial international organisation: the Organization for the Prohibition of Chemical Weapons (OPCW), based in The Hague, Netherlands. By contrast, the BWC's Implementation Support in Geneva, Switzerland, has fewer than ten staff members. Moreover, unlike the CWC, the BWC has no formal verification regime for assessing purported breaches of the Convention, and also has no standing scientific advisory mechanism to assess emerging technologies.

A science advice mechanism

I titled this paper *The Double-edged Helix: DNA, Artificial Intelligence and the Biosecurity Challenge* and have so far examined the dual-use nature of biotechnology – that is, the fact that the manipulation of DNA can be used for beneficial purposes or, alternatively, with malicious intent. So far, however, artificial intelligence (AI) has not been addressed directly.

AI, in its many forms, is beginning to affect almost every aspect of our lives, from scientific research and medical diagnosis to art, music, and even the way football teams are trained to play. As with any powerful technology, however, its impact depends on how it is used. Like biotechnology, AI can be applied for harmful as well as beneficial purposes. In addition, there is growing concern that the combination of AI and biotechnology could provide malicious actors with 'short-cut' pathways to the development of biological weapons.

One illustration of this risk was presented in a recent publication (Urbina *et al*. 2022)[11]. The authors conducted a thought-experiment in which a commercial *de novo* molecular-design AI, normally used to propose new therapeutic drugs, was reconfigured to optimize for toxicity rather than safety. Among the structures proposed by the algorithm were

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[10] The Chemical Weapons Convention www.opcw.org/chemical-weapons-convention (accessed 19 March 2026).

[11] Urbina, F., Lentzos, F., Invernizzi, C. and Ekins, S. (2022). Dual use of Artificial Intelligence-powered drug discovery. *Nat Mach. Intell*. 4(3): 189-191. pmc.ncbi.nlm.nih.gov/articles/PMC9544280/

several compounds resembling the highly toxic nerve agent, VX. Remarkably, within just six hours, the model generated more than 40,000 molecules exceeding the specified toxicity threshold, including compounds with previously unknown mechanisms of toxic action.

Because both biotechnology and AI are fast-moving fields with clear dual-use potential, there is widespread concern about the possible risks of their convergence.

At the same time, it is noted that the BWC currently lacks a formal science advisory mechanism. This raises a fundamental question: how can developments of such significance be assessed and communicated to State Parties in a timely and credible way to support informed decision-making?

Indeed, the BWC has been considering the establishment of a science advisory mechanism for some years. Many States Parties believe the time is ripe to create such a body, and although no country has formally opposed the idea, there is still debate about an appropriate and effective structure.

One proposal being considered favorably puts forward a *hybrid* model: an initial group of unlimited size, open to all, would discuss a topic, and this would be followed by a smaller expert group tasked with focusing on specific technical aspects of the topic. During 2023-2024, the InterAcademy Partnership (IAP)[12] conducted a proof-of-concept exercise to explore whether such a mechanism could function in practice. An open-ended online meeting was held in November 2023, followed by an invitation-only expert meeting in Trieste, Italy, in February 2024.

Between these two events, the question *to be taken under consideration by the smaller expert group was defined as: In the context of the BWC, what are the potential risks and benefits of the use of artificial intelligence*?

Following the exercise, IAP produced two reports: a technical report that analysed this question (IAP 2024a), and a procedural report that evaluated the effectiveness of the hybrid advisory process (IAP 2024b). IAP presented the findings during a webinar organized by the United Nations Institute for Disarmament Research (UNIDIR) and in-person in Geneva during the Fifth Session of the Working Group on Strengthening the BWC in December 2024.

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[12] InterAcademy Partnership (IAP) is the global network of academies of science, medicine and engineering. Its ~150 member academies, working through 4 regional networks, provide access to some 30,000 leading scientists, engineers and health professionals in over 100 countries. www.interacademies.org

As detailed in the technical report, the mock scientific advisory body concluded that AI could provide important benefits, including:

- AI tools can monitor attempts to create a new pathogen, or to build a known high-risk pathogen, allowing controls to be put in place for biotechnology oversight.
- AI tools can test response capabilities, robustness of oversight mechanisms, and safety of biotechnology products and services.

However, the report also identified serious risks, including:

- AI tools may allow masking of illicit biotechnology activities.
- AI tools have raised concerns about enabling the development of novel (and potentially lethal) bioagents that may be difficult to detect without advanced capabilities, and about lowering barriers to access of toxic and/or pathogenic agents by both State and Non-State actors.

Responsible research practices

Given the uneven strength of regulatory frameworks across countries and the limited capacity of the BWC to keep pace with rapidly advancing science, how can the risk of accidental or deliberate misuse of biotechnology be reduced?

Here again, IAP has played an active role. Going back to 2012, it has produced a series of reports promoting responsible and ethical research practices, including:

- *Responsible Conduct in the Global Research Enterprise: A policy report* (IAP 2012)
- *Doing Global Science: A Guide to Responsible Conduct in the Global Research Enterprise* (IAP 2016)
- *The Tianjin Biosecurity Guidelines for Codes of Conduct for Scientists* (Johns Hopkins Center for Health Security *et al*. 2021)

The Tianjin Biosecurity Guidelines, in particular, focus on preventing the intentional misuse of bioscience in line with the objectives of the BWC, while also addressing the prevention of the unintentional harm. They are based on the principle that all scientists share responsibility for strengthening biosecurity and minimising risks. Available in all official UN languages, the Guidelines articulate ten core principle covering:

1) Ethical Standards
2) Laws and Norms

3) Responsible Conduct of Research
4) Respect for Research Participants
5) Research Process Management
6) Education and Training
7) Research Findings Dissemination
8) Public Engagement on Science and Technology
9) Role of Institutions
10) International Cooperation

Together with its partners – the Center for Biosafety Research and Strategy at Tianjin University (China) and the Johns Hopkins Center for Health Security (USA) – IAP has proposed that the BWC formally endorse these principles (Gronvall *et al*. 2022)[13] However, it is clear that multilateral (UN) agreements alone are not sufficient to regulate or oversee all potential breaches of biotechnology governance.

In addition to such 'top down' approaches, therefore, a complementary *bottom-up* approach is also essential. Each new generation of scientists must be educated in biosecurity, ethics and responsible research practice, beginning during the undergraduate and postgraduate training and continuing throughout their careers. As emphasized in the Tianjin Biosecurity Guidelines, universities and research centers should also develop and implement their own institutional codes of conduct. Here, academies of science can play a facilitating role – especially in developing countries – by promoting, harmonizing and disseminating best practices across institutions.

Ultimately, it is up to *all of us* – through education and training, and the leadership of scientific institutions – to stand up for what is right and ensure that biological weapons are consigned to history.

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[13] Gronvall, G.K., Wang, L., McGrath, P.F. *et al* (2022). *Trends in Microbiology*. The Biological Weapons Convention should endorse the Tianjin Biosecurity Guidelines for Codes of Conduct https://www.interacademies.org/publication/biological-weapons-convention-should-endorse-tianjin-biosecurity-guidelines-codes

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REFERENCES

AgBio Investor GM Monitor. 2025. Global GM Crop Area Review https://gm.agbioinvestor.com/downloads/9&ved=2ahUKEwiPjeqIy5eTAxXc3QIHHbNRCjoQFnoECCQQAQ&usg=AOvVaw3mmCFXMeN3hgo7MM0S2abk (accessed 19 March 2026).

Bush LM, Perez MT. 2012. The Anthrax Attacks 10 Years Later. *The Annals of Internal Medicine*, vol. 156. https://doi.org/10.7326/0003-4819-155-12-201112200-00373

CAS-TWAS Centre of Excellence in Biotechnology, Clarivate Analytics. 2016. *Biotechnology in Developing Countries: Growth and competitiveness.* http://english.im.cas.cn/ns/es/201611/W020161115403490152491.pdf.

European Academies' Science Advisory Council (EASAC). 2015. Gain of Function: Experimental applications relating to potentially pandemic pathogens. https://easac.eu/publications/details/gain-of-function-experimental-applications-relating-to-potentially-pandemic-pathogens.

Gronvall GK, Wang L, McGrath PF, Cicero AJ, Yuan Y, Parker MI, Zhang W, Sun Y, Xue Y, Zhang J, Zhang X, Yu L, Song J, Trotochaud M. 2022. The Biological Weapons Convention should endorse the Tianjin Biosecurity Guidelines for Codes of Conduct. *Trends in Microbiology*, 30 (12): 1119-1120. Elsevier. https://doi.org/10.1016/j.tim.2022.09.014.

Imai M, Watanabe T, Hatta M, Das **SC,** Ozawa **M,** Shinya **K,** Zhong **G,** Hanson **A,** Katsura **H,** Watanabe **Sh,** Li **Ch,** Kawakami **E,** Yamada **Sh,** Maki Kiso**,** Yasuo Suzuki**,** Maher **EA,** Neumann **G,** Kawaoka**Y. 2012.** Experimental adaptation of an influenza H5 HA confers respiratory droplet transmission to a reassortant H5 HA/H1N1 virus in ferrets. *Nature,* **486 (7403):** 420-428 https://doi.org/10.1038/nature10831.

InterAcademy Partnership (IAP). 2012. Responsible Conduct in the Global Research. https://www.interacademies.org/publication/responsible-conduct-global-research-enterprise

InterAcademy Partnership (IAP). 2016. Doing Global Science: A Guide to Responsible Conduct in the Global Research Enterprise. *Princeton University Press.* https://www.interacademies.org/publication/doing-global-science-guide-responsible-conduct-global-research-enterprise.

Johns Hopkins Center for Health Security, Tianjin University and the InterAcademy Partnership. 2021. The Tianjin Biosecurity Guidelines for Codes of Conduct for Scientists. https://www.interacademies.org/publication/tianjin-biosecurity-guidelines-codes-conduct-scientists.

InterAcademy Partnership. (IAP). 2024a. Exploring possible impact of AI on Biosecurity and International Cooperation in the BWC https://www.interacademies.org/publication/science-and-technology-advisory-mechanism-biological-weapons-convention-proof-concept.

InterAcademy Partnership (IAP). 2024b. Proof of Concept Meeting on a BWC Scientific Advisory Body: Procedural Report https://www.interacademies.org/publication/bwc-proof-concept-procedural-report.

Jacobs P. 2025. Is the dire wolf back from the dead? Not exactly. *Science* https://www.science.org/content/article/dire-wolf-back-dead-not-exactly

Kupferschmidt K. 2025. Trump moves to tighten rules on risky research on viruses, bacteria, and toxins. https://www.science.org/content/article/trump-moves-tighten-rules-risky-research-viruses-bacteria-and-toxins.

Ledford **H. 2025.** World's first personalized CRISPR therapy given to baby with genetic disease (15 May 2025). *Nature*, https://www.nature.com/articles/d41586-025-01496-z.

Min Jou W, Haegeman G, Ysebaert M, Fiers W. 1972. Nucleotide sequence of the gene coding for the bacteriophage MS2 coat protein. *Nature*, **237(5350):**82-88.

Mullin E. 2023. The first CRISPR-edited salad Is here. *Wired*. https://www.wired.com/story/wired30-crispr-edited-salad-greens/ .

Rosenberg SA, Aebersold P, Cornetta K, Kasid A, Morgan RA, Moen R, **Karson EM, Lotze MT, Yang JC, Topalian SL, Merino MJ, Culver K, Miller AD, Blaese RM, Anderson WF**. (1990). Gene transfer into humans: Immunotherapy of patients with advanced melanoma, using tumor-infiltrating lymphocytes modified by retroviral gene transduction. *The New England Journal of Medicine.* 323 (9): *570*-578. *doi*:*10.1056/NEJM199008303230904*.

Schrauwen EJA, Herfst S, Leijten LM, van Run **P,** Bestebroer **ThM,** Linster **M,** Bodewes **R,** Kreijtz **JHCM,** Rimmelzwaan **GF,** Osterhaus **ADME,** Fouchier **RAM,**Thijs Kuiken **Th,** van Riel **D. 2012.** The multi-basic cleavage site in H5N1 virus is critical for systemic spread along the olfactory and hematogenous routes in ferrets. *Journal of Virology*, **86 (7):** 3975-3984. PMID: 22278228 PMCID: PMC3302532 DOI: 10.1128/JVI.06828-11.

Stanley N, Cohen SN, Chang ACY, Boyer HW, Helling RB. 1973. Construction of Biologically Functional Bacterial Plasmids In Vitro. *PNAS*, **70 (11)**: 3240-3244. https://doi.org/10.1073/pnas.70.11.3240.

United Nations (UN). 2022. UN Press release, 11 March 2022. United Nations Not Aware of Any Biological Weapons Programmes, Disarmament Chief Affirms as Security Council Meets to Address Related Concerns in Ukraine. https://press.un.org/en/2022/sc14827.doc.htm.

Urbina F, Lentzos F, Invernizzi C, Ekins S. 2022. Dual use of Artificial Intelligence-powered drug discovery. *Nature Machine Intelligence*, **4(3):** 189-191. pmc.ncbi.nlm.nih.gov/articles/PMC9544280/. https://doi.org/10.1038/s42256-022-00465-9.

White House (2025). Executive Order: Improving the Safety and Security of Biological Research, 5 May 2025, available at https://www.whitehouse.gov/presidential-actions/2025/05/improving-the-safety-and-security-of-biological-research/ (accessed 19 March 2026).

World health Organization (WHO) 1980. The Global Eradication of Smallpox (1980). https://iris.who.int/bitstream/handle/10665/39253/a41438.pdf .

Zanders JP. 2022. Catapulting Cadavers: A Medieval Practice of Biological Warfare? https://www.the-trench.org/catapulting-cadavers.

Zheng C, Shao W, Chen X, Zhang B, Wang G, Zhang W. 2022. Real-world effectiveness of COVID-19 vaccines: a literature review and meta-analysis. *International Journal of Infectious Diseases*, **114**: 252-260. https://www.sciencedirect.com/science/article/pii/S1201971221008572 .