Definition: genetic engineering from Processing Water, Wastewater, Residuals, and Excreta for Health and Environmental Protection: An Encyclopedic Dictionary

The process of inserting new genetic information into existing cells in order to modify an organism for the purpose of changing one of its characteristics.

Summary Article: Genetic Engineering from International Encyclopedia of Public Health

The potential public health benefits of genetic engineering are considerable, but so too are the potential harms. Genetic engineering may help to promote health and prevent illness by increasing the quality and quantity of food, by cleaning up toxic environments, and by alleviating human health problems for existing and subsequent generations. Genetic engineering may also threaten human health, however, in producing unsafe foods, polluting our environment, and otherwise undermining or compromising our health status. But the ethics of genetic engineering is not reducible to a risk-benefit assessment, for issues of equity, control of the research agenda, and the possible misuse of the technology come into play, as do ethical concerns about human eugenics and enhancement, animal welfare, undermining the sanctity of nature, and playing God.

Keywords

- Assisted reproductive techniques
- Biodegradation
- Bioethics
- Bioterrorism
- Communicable diseases
- Ethics
- Gene transfer techniques
- Genetic engineering
- Genetically modified animals
- Genetically modified organisms
- Genetically modified plants
- Protein engineering

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Introduction

Genetic engineering comprises multiple techniques for the intentional manipulation of genetic material (primarily deoxyribonucleic acid, or DNA) to alter, repair, or enhance form or function. Recombinant DNA technologies, developed in the latter half of the twentieth century, include the chemical splicing (recombination) of different strands of DNA generally using either bacteria (such as *Escherichia coli*) or bacteriophages (viruses that infect bacteria, such as λ phage), or by direct microinjection. In recent years, these traditional tools have been supplemented by new techniques to design and build - literally, to engineer - novel life forms, generally referred to as synthetic biology.

Genetic engineering, writ large, raises a number of significant ethical issues. In agriculture, for instance, ethicists have highlighted potential human health hazards associated with genetically modified crops and livestock, as well as normative concerns about the treatment of animals and the ecological consequences of genetic engineering. In medicine, there has been significant ethical controversy about the putative distinction between protocols meant to restore function and those meant to enhance function beyond species-typical norms. Additionally, ethicists have attended to the potential human health risks associated with germ-line genetic engineering, as distinct from somatic genetic engineering. Finally, in the context of reproduction, ethicists have argued that genetic engineering raises ethical issues involving the screening and manipulation of embryos to eliminate or introduce various medical and/or cosmetic characteristics.

In relation to public health specifically, genetic engineering raises additional ethical issues concerning not only the potential societal consequences of genetic engineering, but also the wisdom of genetic manipulation of plants, animals, and humans. In pursuit of the goals of health promotion and illness prevention, public health initiatives have traditionally sought to improve sanitation, ensure the availability of clean water, and identify the source of, and develop vaccines for, infectious disease. But with the development of genetic engineering techniques and the sequencing of the genomes of plants and animals (including humans), the scope of possible public health interventions has increased dramatically — but so too have the threats to public health.

Applications of Genetic Engineering

Genetically engineered DNA may come from any source (e.g., bacteria, plants, animals) or be synthesized *de novo*, and may be put to use in a variety of domains, such as agriculture, medical science, and environmental management. While these domains are not entirely discrete, they are useful for identifying the ethical and public health dimensions of genetic engineering.

Agriculture

The most familiar form of genetic engineering is in agriculture, where scientists have attempted to improve upon selective breeding as a means to predict and control the characteristics of generations of crops and animals. Classic examples include the development of pesticide-resistant cotton crops and higher-yield dairy cows. As well, crops and animals may be genetically engineered to make other socially and industrially useful products, such as rice that produces beta-carotene (which enables those

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who consume it to generate vitamin A, as vitamin A deficiency is a serious global health concern), and transgenic goats who produce spider silk in their milk. Public acceptance of agricultural biotechnology varies on a global scale, and there is persistent controversy in some jurisdictions (especially the European Union) over the introduction of genetically modified crops and animals. The central ethical issues concern the potential for environmental and human harm should genetically engineered crops or livestock not be properly controlled or contained, as well as worries about animal welfare and the integrity or sanctity of nature.

Environmental Management

One of the first patents on a biological life form was filed by Ananda M. Chakrabarty in 1972 and upheld in 1980 by the United States Supreme Court. Chakrabarty used basic gene transfer techniques to create a microorganism with the capacity to break down crude oil; at the time, it was thought that such a genetically modified microorganism might be useful in eating up oil spills (to date, however, engineering microbes to this end has not produced widespread results). More recently, scientists have developed plants for bioremediation (sometimes referred to as phytoremediation). Phytoremediation is a strategy for eliminating or neutralizing environmental pollutants, whether by exploiting plants’ natural properties in environmental management regimes, or by breeding or engineering plants with enhanced or novel properties. For instance, plants may be engineered to function as magnets for heavy metals in soil and water, or with enzymes that increase the capacity for biodegradation. Though these genetic engineering strategies to achieve public health aims are possibly beneficial (in providing for a healthy environment capable of sustaining healthy lives), they do not address the persistent concern that genetic engineering may be environmentally toxic and so hazardous to the health of populations (Davison, 2005).

Medical Science

There are multiple medical applications of genetic engineering. In drug discovery, for example, genetic engineering is useful for the synthesis of new therapeutic agents, as well as the development and refinement of novel techniques to reliably produce those agents. Examples of the latter include the use of plants as mini-factories for producing pharmaceuticals and vaccines. Another route to health-related outcomes may be the purposeful alteration or addition of DNA in patients with genetic disease, using gene transfer technology. Gene transfer involves the isolation and packaging of normal DNA and its insertion into target cells in order for these cells to produce a protein that is missing because of a gene defect (where the missing protein is responsible for the disease process). The public health impact of somatic cell gene transfer comes with the survival, health, and potential reproductive ability of patients who would otherwise have died, have lived seriously disabled lives, and perhaps never have reproduced. More dramatic public health impacts are imagined with intentional (as contrasted with inadvertent) germ line gene transfer where the genetic manipulation/intervention is heritable (and so not limited to the patient who receives gene transfer). The prospect of controlling the germ line is both tantalizing and fearful, and some would argue inevitable - given current, relatively crude, widely endorsed practices in reproductive medicine, where prospective parents are encouraged to make reproductive choices to control for genetic contributions to disease and disability by creating healthy embryos. This may involve choices about the use of gamete donors (ova or sperm from persons without genetic disease), the selection of embryos for transfer following preimplantation genetic diagnosis, and (eventually) even the genetic or environmental manipulation of embryos to correct for mutations or to enhance normal capacities. In addition to concerns about eugenics and enhancement, ethical issues regarding fairness

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(equitable access) and equality of opportunity abound, particularly if we imagine that only the privileged among us will be able to enhance their immune system, their memory, or their physical prowess, and thereby secure certain competitive and positional advantages (Buchanan et al., 2000).

**Public Health Ethics**

There are many potential public health benefits of genetic engineering. Consider, for example, the use of phytoremediation to facilitate environmental clean-up, and the production and distribution of plant-made vaccines to improve resistance to such infectious diseases as measles, mumps, and hepatitis B that remain endemic in the developing world. Given the health burden imposed by toxic environments and the persistence of infectious diseases, such feats of genetic engineering would be important to advancing public health both locally and globally. And yet even in these domains where public health is the goal of genetic engineering, ethical concerns remain. In particular, there are worries about the just distribution of the benefits of these technologies so as to reduce (or, at least, so as not to increase) health inequities within and between societies, and also about the risk that genetic engineering will draw attention away from tried-and-true public health interventions that may yield more important and lasting benefits for the health of populations (such as clean water and improved sanitation).

An additional ethical issue concerns the potential malevolent use of technologies developed for positive or benign purposes. Consider that knowledge of influenza genome sequences may be used to tailor perfectly adapted vaccines, but may also be used to engineer more virulent strains of influenza. Each of these possible scenarios would have a significant impact on the health of whole populations. Moreover, the use of chemical and biological weapons (such as the release of sarin gas in the Tokyo subway in 1995 and the circulation of anthrax-laced packages via the United States Postal Service in 2001) has raised significant biosecurity concerns that may be exacerbated by genetic engineering. Just as genetic engineering may be used to promote public health and safety in the face of bioterror threats, it may also be used to synthesize new biowarfare agents or even to weaponize zoonotic infections.

In addition to concerns about health inequities and the dual-use of genetic engineering, there are a number of serious health and safety concerns (summarized in Table 1). Beginning with the recombinant DNA controversy in the 1970s, which culminated with a temporary moratorium on this research negotiated at Asilomar (Krimsky, 1982), health and safety issues have been of central concern in ongoing public debates about genetic engineering: Will it be possible to contain genetically engineered bacteria and viruses in the laboratory? Will it be possible to precisely control the behavior of genetically modified materials *in vivo*? While appropriate regulations may manage the threat of containment breaches (as with biohazardous research in general), it will always be difficult to fully control DNA in development, especially in humans and other complex animals. From a public health perspective, since the results of human genetic engineering protocols may be more or less permanent, either restricted to a single generation or intended to be intergenerationally heritable, there may be long-term risks for human health that are difficult to quantify and assess. Additionally, there is considerable concern about the prospect of zoonosis, whereby a disease is transmitted to a human from a nonhuman animal. Given the evidence that human immunodeficiency virus (HIV) began as a zoonotic infection, and given contemporary worries about avian influenza, the prospect of introducing or promoting zoonotic infections is decidedly unwelcome.
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<th>Ethical Concern</th>
<th>Description</th>
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<td>Equitable access to benefits</td>
<td>Genetic engineering risks widening the gap between haves and have-nots both within the developed world and between the developed and developing worlds.</td>
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<td>Research priorities and opportunity costs</td>
<td>Genetic engineering research is expensive, is often driven by a corporate or military agenda, and in some cases may yield health benefits out of proportion to global health needs. The goals and priorities of such research must be subjected to ethical evaluation, especially given the likelihood that other public health interventions may yield more important and lasting alterations in social and physical determinants of the health of populations.</td>
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<td>Dual-use of genetic engineering</td>
<td>Genetic engineering technologies designed for beneficial or benign purposes may be perverted toward malignant ends, such as the development of new biowarfare agents.</td>
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<td>Health and safety risks</td>
<td><strong>Environmental impact (containment, biodiversity)</strong>: Genetically engineered organisms may negatively impact the environment in the event of an uncontrolled spread; genetic engineering may also represent a potential threat to biodiversity resultant from intentional direct manipulation of genetic material.</td>
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<td><strong>Health impact (unpredictability)</strong>: Genetic engineering of complex organisms may be unpredictable owing to the intricacies of organismal development; hence, it may be difficult to control the behavior of DNA constructs. Moreover, experience with direct genetic modification is relatively recent, and long-term risks cannot as yet be assessed.</td>
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<td><strong>Zoonosis</strong>: Genetic engineering that involves crossing species boundaries generates the risk of zoonotic infection: The transmission of a disease from a nonhuman animal to a human host.</td>
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<td>Other ethical concerns</td>
<td><strong>Human eugenics and enhancement</strong>: Genetic engineering is inherently directed toward particular goals, including the elimination of certain phenotypes and the promotion of others. There is a disability rights critique of such research on the grounds that it embodies able-ism - eugenic discrimination based on physical or mental capacities. Additionally, there are concerns about enhancement of humans beyond species-typical norms, potentially resulting in fundamental changes in human nature.</td>
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<td><strong>Animal welfare</strong>: Genetic engineering technologies are often initially tested in nonhuman animals, from mice to nonhuman primates. Generic animal welfare considerations apply, as do new concerns about the significance of possible changes wrought by genetic engineering. The latter would include concerns about the humanization of nonhuman animals.</td>
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<td><strong>Sanctity/integrity of nature</strong>: Genetic engineering, whether by modifying the DNA of extant creatures or by designing novel creatures, is in violation of a religious world view according to which all of nature consists in God’s creatures, each worthy of reverence in its own right. From a secular perspective, similar concerns abound regarding transgressing the intactness or continuity of the natural world.</td>
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<td><strong>Playing God</strong>: Genetic engineering, according to some, is literally God’s work. From a religious perspective, the objection is to usurping God’s authority. From a secular perspective, the concern is with hubris: humans are limited beings and do not have the requisite capacity to engineer wisely.</td>
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Health and safety concerns often warrant a precautionary approach, whereby the development of a technology is slowed until the risk issues are resolved one way or the other. But attention to the potential risks of a technology fails to acknowledge a wide range of other ethical and societal considerations that cannot be addressed by a precautionary approach. Table 1 summarizes additional ethical concerns associated with genetic engineering, including concerns about hubris, the integrity of...
nature, animal welfare, and human eugenics and enhancement.

**Conclusion**

In summary, genetic engineering poses both potential benefits as well as potential risks to public health. In the domains of agriculture, environmental management, and medicine, the public health implications of genetic engineering are complex, both scientifically and ethically. While genetic engineering may help to promote health and prevent illness by increasing the quality and quantity of food, by cleaning up toxic environments, and by alleviating human health problems into the future, it may also threaten human health by compromising the food supply, by negatively affecting other aspects of local and more global ecosystems, or by introducing new health problems as a function of genetic manipulation of humans and other organisms. These risk and benefit issues are important, but so too are less consequentialist ethical considerations that focus on equity and justice, research priority setting and opportunity costs, dual use of beneficial technologies, the social implications of human eugenics and enhancement, animal welfare, the sanctity of nature, and scientific hubris.

**See also**

Ethics of Screening; Foundations in Public Health Law; New Technologies: Ethics of Genomics; Reproductive Ethics: New Reproductive Technologies; Resource Allocation: Justice and Resource Allocation in Public Health; Vaccines, Historical

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Citations


Further Reading


- L. Carter Re-interpreting some common objections to three transgenic applications: GM foods, xenotransplantation and germ line gene modification (GLGM). Transgenic Research, 13, (2004). 583-


Relevant Websites

http://www.cdc.gov - Centers for Disease Control and Prevention


http://www.hc-sc.gc.ca/sr-sr/biotech/index_e.html - Health Canada - Biotechnology

http://www.phac-aspc.gc.ca/new_e.html - Public Health Agency of Canada


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