Journal of Health Ethics

Volume 20 | Issue 1 Article 3

10-2024

Advances in Biomedical Research and Treatments: What is Acceptable?

Michael L. Clancy
Eastern Michigan University, thehawksnest2@gmail.com

Khalid M. Iskandarani
Eastern Michigan University, kiskanda@emich.edu

Mitchell C. McCrea
University of Toledo, mmccrea2022@gmail.com

Recommended Citation
Clancy, M. L., Iskandarani, K. M., & McCrea, M. C. (2024). Advances in Biomedical Research and Treatments: What is Acceptable?. *Journal of Health Ethics, 20*(1). http://dx.doi.org/10.18785/jhe.2001.03

Advances in Biomedical Research: What is Acceptable?

Michael L. Clancy
Eastern Michigan University

Khalid M. Iskandarani
Eastern Michigan University

Mitchell C. McCrea
University of Toledo

ABSTRACT

This study investigated the technology acceptance (TA) of twenty-first century biomedical treatments by adults in the United States. A new TA instrument was created, using five distinct levels: (1) Healing and Prevention, (2) Replacement Organs, (3) Enhancements-Medical, (4) Enhancements-Discretionary, and (5) Transhumans. An on-line survey produced 353 usable responses, which showed distinct patterns for each of five biomedical treatment levels. There was clear support for Levels 1–3, but very strong opposition to Levels 4–5. The TA finding draws the line between which human interventions are acceptable versus others that should be prohibited through public policies and medical guidelines.

Keywords: Biomedical Advances; Medical Ethics; Genetic Engineering; Human Enhancements; Human Replacement Organs

INTRODUCTION

Advances in biomedical research and treatments have exploded in the twenty-first century in the areas of genetic engineering (Kurzgesagt, 2016; Ebrahimkhani, 2020), bioprinting (Murdoch Children's Research Institute, 2020; Haseltine, 2022), and implants (Coxworth, 2021; De La Garza, 2022) to name a few. These advances, however, did not come without concerns related to the misuse of the new capabilities (Gleiser, 2022; Stein, 2023). As a result of this rapid pace of developing new cures and treatments combined with the concerns from the scientific community, society will, at some point, make governance decisions regarding what is acceptable and what is not. Those decisions will be based, at least in part, on public opinion. There has been only limited research dedicated to which new treatments will be acceptable to the American public. Another key question is who can be trusted to make those decisions. Several entities can be entrusted with these decisions including science and the scientists, the government bureaucracy, the medical bureaucracy, and the doctors. In this study we specifically set off to generate initial data to help answer the questions for policy makers and the biomedical community, as well as to serve as a baseline for further research.

In their book, *The 500-Year Delta: What happens after what happens next?* Wacker and Taylor (1997) described the effects of the times when a confluence of new technologies created major societal disruptions. Technologies such as the invention and widespread implementation of nation-wide railroad systems, electrical power for homes and businesses, improvements in steel manufacturing quality, the automobile, and telephone and telegraph systems. These technologies transformed America from an agrarian to a primarily metropolitan society. Jobs and industries, that had previously flourished, disappeared. The Pony Express, for example, went out of business five days after the first transcontinental telegraph was completed.

Wacker and Taylor focused on the transformational aspects of the merger of computing and communication systems (during the 1980s and 1990s) that created a new disruptive societal force: Connectivity. Pointing out that "the World Wide Web came into existence only in 1991" (p. 102), they noted the geometric growth rate of its users, and that was only for the period up to the publication of

their book in 1997. Now personal access to global information through hand-held, multipurpose electronic devices has become routine. This connectivity has fundamentally changed society. "The simple fact is that anyone who has lived through the last forty years has experienced more value dislocation than had occurred collectively in the prior two centuries" (Wacker and Taylor, 1997, p. 68).
A similar confluence of scientific advances is focused on the future of human biological development. First, the advances which are being made in various scientific and medical fields are convergent (Roco and Bainbridge, 2002a, 2002b; Doede, 2009), rapidly creating a potential tipping point in the future of the human race (e.g., Nelson, 2016; Comfort, 2015; Ledford, 2015a; Moreno, 2015; Maron, 2015). Secondly, biomedical advances have been facilitated by enabling technologies that are not cures or treatments in themselves, but, for example, have reduced the cost and duration of genetic experiments. Other benefits realized include the capability to 3-D print biological material (i.e., *bioprinting*), and the use of nanomaterials for new delivery systems for cancer patients (Tran and Wilson, 2011; Wiesing and Clausen, 2014, p. 19; University of Toronto, 2016; Ohta, Glancy, and Chan, 2016; Houser, 2023).

Surgeons have saved children with heart abnormalities (Ghose, 2014), installed the world's first bionic eye implant for macular degeneration (Ho et al., 2015) and enabled a double amputee to control bionic arms with his mind (Ulanoff, 2014). In addition, researchers have successfully demonstrated nerve regeneration (Johnson et al., 2015), created laboratory organoids to facilitate research into the development of human organs and the causes of genetic defects, and are testing human replacement organs grown in pigs and sheep (Iwase, et al., 2015; Regalado, 2015, 2016).
These examples demonstrate an impressive range of work but without knowing exactly what would develop in the future.

Similar to the advances in human biological development Emmanuelle Charpentier and Jennifer Doudna discovered a method of DNA editing (CRISPR-Cas9) that is more accurate, flexible, and much faster than previous methods in 2012. Prior to the discovery of the CRISPR gene editing process, "engineering a mutation into cells was expensive and laborious work. 'It was a student's entire thesis to change one gene,'" (Bruce Conklin, Gladstone Institutes geneticist, quoted in Ledford, 2015). "CRISPR …relies on an enzyme called Cas9 that uses a guide RNA molecule to home in on its target DNA, then edits the DNA to disrupt genes or insert desired sequences" (Ledford, 2015). Since its discovery, the widespread use of CRISPR in labs around the world has resulted in improvements to the process, so that early concerns about off-target effects and unexpected results have been minimized, and its use more widespread. In less than five years, this technique went from laboratory discovery (Doudna and Charpentier, 2014), to widespread research applications (Wadhwa, 2015), to the creation of biotech companies (Ledford, 2015a). As a result of such rapid acceptance and use, "… the CRISPR/Cas9 system of genome editing was named the 2015 Breakthrough of the Year by *Science*" (National Academies of Sciences, Engineering, and Medicine, 2017).

"The fact that these new genome-editing technologies can be used to make precise changes in the genome at a high frequency and with considerable accuracy is driving intense interest in research to develop safe and effective therapies that use these approaches and that offer options beyond simply replacing an entire gene" (National Academies of Sciences, Engineering, and Medicine, 2017). After only eight years from the discovery of the CRISPR gene editing process, Emmanuelle Charpentier and Jennifer Doudna received the 2020 Nobel Prize in Chemistry.

The practically miraculous breakthroughs in biomedical science have also reinforced concerns with how such knowledge could be misused. This is especially true of the ability to make changes to the human genome (Miller, 2014; Begley, 2015; Funk, Kennedy, and Sciupac, 2016; Lent, 2017; Baylis, 2019; National Academy of Sciences 2020; Stein, 2023). Being able to edit someone's DNA to prevent or cure genetic defects has raised hopes for the elimination of certain birth defects, including for example sickle cell anemia, and in utero replacement of genes that control inheritable diseases (Sample, 2015; Columbia University Medical Center, 2016; Noakes, 2016; Regalado, 2017; Weintraub, 2019; Shields, 2020).

Unfortunately, there have already been cases of unauthorized use of this capability. An ex-NASA scientist, with a Ph.D. in biophysics from the University of Chicago, tried to use gene therapy to genetically engineer himself using do-it-yourself kits (Brown, 2017). While this may not be illegal, per se, the FDA has issued a warning against such unauthorized procedures, especially if they involve other people. A more frightening case arose in China in 2018 when a researcher announced that he had altered the genes of three girls prior to their birth. This was done without any authorization and without knowing what effects those genetic modifications might have on the girls. The Chinese government sentenced that researcher (and his colleagues) to prison. But those children will essentially be laboratory specimens for life, and since there is no way to determine what inheritable genetic defects might be present, they may be forbidden from having children of their own.

These examples highlight the ethical and policy questions about where we draw the line, who gets access, what safeguards are in place vis-à-vis ethical research and patient safety, and who will decide between "Could We" and "Should We". Decisions regarding what *should* be done are lagging those of what *can* be done, leaving a social and moral void that may soon result in heated, emotional reactions and government interference. "Even though we're still far from uncloaking all the mysteries of life, the unquestionable acceleration of tech-medicine is already placing our societies in front of difficult moral choices" (Nora, 2015).

RESEARCH MODEL

To answer the ethical and policy questions, we developed a model to guide our research process.
The three specific questions that we hypothesized that our research model needed to answer are:

1. Are there any significant differences in the acceptance responses of different biomedical technology treatment categories (Healing and Prevention, Replacement Organs, Enhancements-Medical, Enhancements-Discretionary, and Transhumans)?
2. What relationships (if any) exists between science awareness and trust in science?
3. Are there any noticeable demographic factors relative to the acceptance of the biomedical technology treatment categories?

The research model utilizes the antecedents of an individual's Science Awareness (SA), Trust in Science (TS), combined with demographics to investigate the relationship with the technology acceptance (TA) of future biomedical advancements. The first step in the development of the research model was to decide how to measure the technology acceptance (TA) of future biomedical advancements. TA is frequently measured using the technology acceptance model (TAM) developed by Davis (1986). TAM uses two measures of respondent perceptions—ease of use and usefulness. But those measures are not applicable in this case, because most of the new biomedical advances are still in development or in very early trials. So, individual decisions regarding such future technologies would typically involve people with no prior experience and very little knowledge of the underlying science, the effectiveness of potential treatments, or of their risks. The TAM approach was therefore excluded. Instead, a format was developed that uses clarifying examples, in five levels of potential treatments to inquire about the acceptability of the potential treatments. The five levels of treatments are (Figure 1):

1. Level 1 (L1): Healing and disease prevention
2. Level 2 (L2): Human replacement organs from non-human sources
3. Level 3 (L3): Enhancements for medical reasons: restoring capabilities
4. Level 4 (L4): Enhancements for discretionary reasons: providing ultra-human capabilities
5. Level 5 (L5): Transhumans (e.g., human brain transplants)

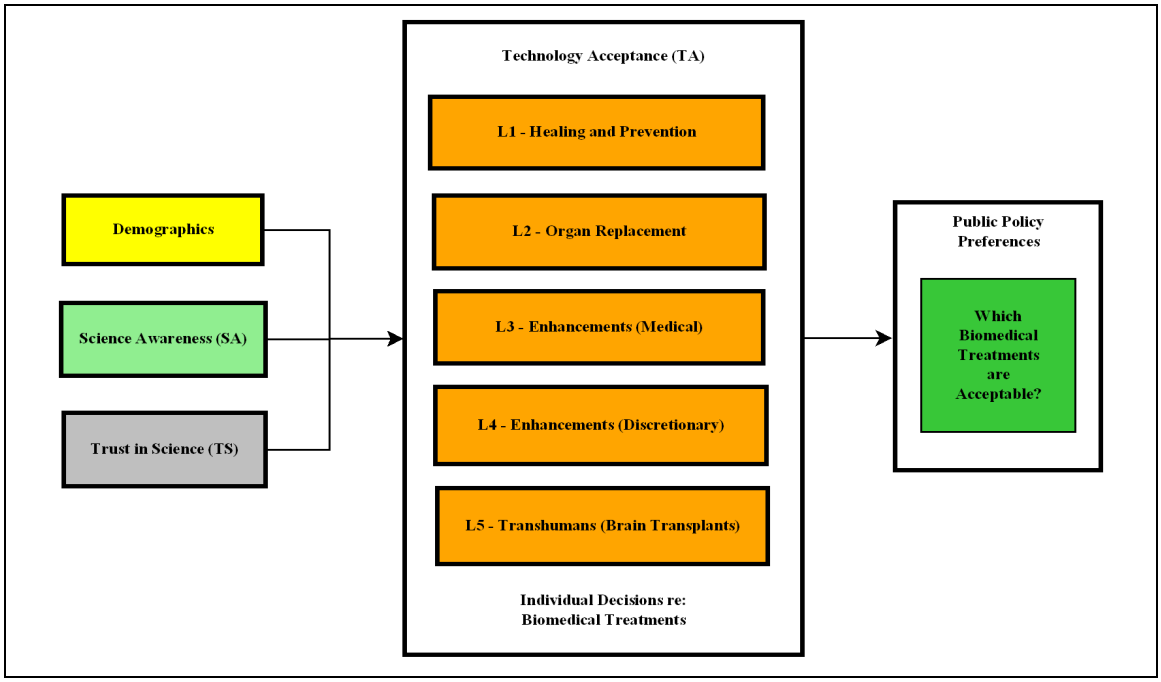

Figure 1. Research Model

Level 1 (L1): Healing and Disease Prevention

The achievements in healing and disease prevention over the last decade have been phenomenal. For example, artificial blood vessels were 3D printed that could become living tissue (Dengler, 2019; Kirkton, et al., 2019); "Scientists engineered an implant that can deliver cancer-fighting meds directly into your body" (De La Garza, 2022; Nash, Jarvis, Aghlara-Fotovat, Mukherjee, and Veiseh, 2022) and an "immunotherapy booster was created that produces 10,000 times more cancer-fighting cells" (Irving, 2022; Kim, Jayasinghe, Devenport, et al., 2022). In addition, research into bio-materials that can be manufactured has made additional advances possible. "Replacement blood vessels may be woven from bio-yarn" (Coxworth, 2020a), and "Lab-grown 3D skin grafts could be applied like biological clothing" (Coxworth, 2023).

Level 2 (L2): Organ Replacement

Human Replacement Organs from Non-Human Sources

There are important reasons that human replacement organs were included in the new acceptance construct:

- In America, at least 17 people a day die waiting for an organ transplant (Woodall, 2021, para. 1) That number was ten patients per day in 2010 (U.S. Food and Drug Administration, para. 2);
- In the United States, nearly 107,000 people are presently waiting for organ transplants, including more than 90,000 awaiting a kidney, according to the United Network for Organ Sharing. Wait times for a kidney average three-to-five years (Lapid, 2021); and
- "While more than 100,000 American who begin dialysis to treat end-stage renal disease each year, one in five will die within a year," (*CMS.gov*, September 18, 2020, para. 3).
- The World Health Organization estimated 10,000 operations involving "black market" organs per year (Kimball, 2017, para. 1).

But what if (instead of waiting for a donor to die) human organs became widely available through new technologies, thus eliminating the chronic world-wide organ shortage? (Woodall, 2021, para. 1). Toward that end, three research and development paths are underway:

- Lab grown organs, typically through stem cell research;
- Manufactured organs, increasingly now through 3D bio-printing; and
- Xenotransplantation (i.e., human organs grown in non-human hosts).

Lab-Grown Organs

Recent progress toward growing human organs in the lab includes: smart biomaterials for tissue engineering (Furth, Atala, and Van Dyke, 2007); artificial, bio-engineered tracheas successfully implanted (Macchiarini, et al., 2008); heart muscle cells regrown by research teams in Israel and Australia (D'Uva et al., 2015); spinal cords grown in a petri dish by German scientists (Meinhardt et al., 2014); and an engineered composite tissue used as a bio-artificial limb graft (Jank et al., 2015). Stem cell research has been the primary driver of the above, as well as producing functional liver cells (e.g., Huch, et al., 2015; Bhatia, Underhill, Zaret, and Fox, 2014; Baptista et al., 2011); working mini-livers (Ebrahimkhani, 2020); and the first lab-grown mini hearts (Irving, 2020a; Israeli, Gabalski, Ball, Wasserman, et al., 2020);

Manufactured Organs

The technology that has had the greatest impact on manufacturing human replacement organs is 3D bio-printing (Naghieh, 2021). It is common knowledge that 3D printers can create complex shapes, but the most significant enhancement for bio-medical research using 3D printers has been the development of printable bio-materials, commonly referred to as bio-ink (Dey and Ozbolat, 2020). The advent of several forms of bio-ink, have enabled the 3D-printing of laboratory organoids to study new medicines and treatments. This process has become known as 3D Bio-Printing (Ozbolat, ed., 2020), and researchers have now 3D bio-printed a functional miniature liver (*Mashable India*, 2019); mini-kidneys" (Murdoch Children's Research Institute, 2020); and human skin (Haseltine, 2022).

While researchers have been working on the applications for 3D bio-printing, advances on the printers and materials have also been realized. A faster 3D printing technique was developed (McGlaun, 2021); a handheld 3D printer was used to grow replacement muscle tissue (Coxworth, 2020b); a robotic system can 3D print cells onto organs inside the body (McClure, 2023); and a new ceramic ink can 3D-print bones directly into a patient's body (Irving, 2020b; Broom, 2021).

Xenotransplantation

Another research path is xenotransplantation—transplants of human organs (grown in genetically-engineered pigs or sheep) into human recipients. The rationale behind this research path is that certain non-primate animals (e.g., pig and cows) have the potential for growing one or more human-compatible organs. If successful, this process could significantly alleviate the world-wide organ shortage. Current research trials entail "injecting human stem cells into days-old animal embryos, then gestating these in female livestock," (Regalado, 2016, para. 5) and these experiments rely on "a cutting-edge fusion of technologies, including recent breakthroughs in stem-cell biology and gene-editing techniques" (Regalado, 2016, para. 8). This approach is an attempt to circumvent the immune system rejection of non-human organs in previous animal-to-human trials dating back to the 1960s (Reardon, 2015; Iwase, et al., 2015).

Xenotranplation has had some preliminary success as demonstrated by the work done at NYU. The NYU Langone Health center transplanted a genetically-altered pig kidney into a human without triggering immediate rejection. The recipient was "a brain-dead patient with signs of kidney dysfunction" and "the kidney was attached to her blood vessels but maintained outside her body." After three days, the transplanted kidney's function was normal, while the "abnormal creatinine level of the recipient – an indicator of poor kidney function – returned to normal after the transplant" (Lapid, 2021).

HUMAN ENHANCEMENTS

Moving the research model a step further, biomedical research also created the potential for human enhancements. "Indeed, science is already making rapid progress in new restorative and therapeutic technologies that could, in theory, have implications for human enhancement" (Masci, 2016, para. 5). But, just what are human enhancements and are there limits beyond which public policies will have to resolve the "Can we? but Should we?" ethical issues?

The literature search identified many discussions of human enhancements as a broad topic, but few that noted that some enhancements may be acceptable, and none that provided a working definition of acceptable vs. unacceptable human enhancements. Thus, these enhancements are differentiated between enhancements for medical reasons versus those which are discretionary.

Level 3 (L3): Enhancements-Medical - Restoring Human Capabilities

Many biomedical enhancements are already available. Artificial hearts, cochlear implants, and hip and knee replacements have almost become routine.

- A bionic suit enabled a paralyzed man [to] "take ~180,000 thousand steps" (Gad, et al., 2015, p. 2), and a "paralyzed man walked again with brain-controlled exoskeleton in 2019" (Kelland, 2019, para. 1),
- A man in the United Kingdom received the "world's first bionic eye implant for macular degeneration" (Ho, et al., 2015), and a bioengineered cornea improved sight in 20 patients who were blind or visually impaired (Koumoundouros, 2022; Rafat, et al., 2023), and
- Brain implants helped a blind woman *see* simple shapes (University of Utah Health, 2021; Fernández, et al., 2021), and for "a paralyzed man to communicate by text" (Rodriguez, 2021, para. 2; Willett, et al., 2021).

Researchers found that neuronal stimulation enabled nine patients "to stand up, walk, and rebuild their muscles." In addition, these improvements continued "after the neurorehabilitation therapy was completed and the electrical stimulation was turned off" (Barraud, 2023, para. 3-5; Kathe, et al., 2023). In another research path, nine patients have received stem cell treatments for three years to reduce the effects of age-related macular degeneration (Schwartz, et al., 2015), with improved vision in ten of the eighteen treated eyes.

Genetic engineering has become the next frontier for Human Enhancements for medical reasons. "Genetic modification of embryos could lead to several health benefits in the long run. It could improve IVF treatment, correct genetic defects such as Huntington's Disease, and create humans with in-built resistance to certain diseases" (Hinxton Group, 2015).

Level 4 (L4): Enhancements-Discretionary: Extending Human Abilities

Enhancements-discretionary: providing ultra-human capabilities. This was the expected bifurcation point in this research: human enhancements that are not medical necessities. The trigger issue in this category is designer babies. Is choosing the hair or eye colors of a baby in utero okay? What about ensuring that more boys will be born in certain cultures? Researchers have recently identified coding variants that alter human adult height (Marouli, et al., 2017). Will specifying the height of an unborn child be allowed? How about gene editing for superintelligence, athletic ability, or sexual prowess?

Concerns regarding potential human enhancements through medical advances goes back several decades, especially regarding editing human genes, especially those that would affect an entire gene pool:

- "Is modern genetics the new eugenics?" (Epstein, 2003)
- "Widespread use of genetic modification in the food chain is currently breaching ancient boundaries: Biological and Man-Made (Hodges, 2010, p. 12);

- "Certain kinds of experiments may have predictable outcomes that demand special scrutiny before they are undertaken and may deserve to be declared unethical and morally forbidden" (Relman, 2014, p. S37); and
- "There is serious concern that genome editing technologies might be used in reproductive contexts (…) before the international community has had the opportunity to weigh the benefits and harms of moving forward" (The Hinxton Group, 2015, p. 1).
- "Should we use genome editing to make better babies?" (Brinkhof, 2022).

There are also ethical concerns that such capabilities would exacerbate have vs. have not issues, which could eventually lead to enhanced vs. non-enhanced children (Allhoff, et al., 2009, p. 21), followed by societal pressure for enhancements despite the beliefs of parents (Colson and Cameron, 2004; Friedersdorf, 2017b), while others argue that "germline modifications could create a level playing field for those whose traits put their children and descendants at a disadvantage" (Buchanan, et al., 2016, in National Academies of Science, 2017, p. 123).

Some biomedical advances may produce discretionary enhancements without involving human DNA manipulations. Recent brain research encompasses how the brain functions and how to prevent or correct brain diseases, along with brain-to-brain (Grau, et al., 2014) and brain-to-machine communications (Gilja, et al., 2015). It is also known, for example, that both the U.S. and China are researching cyborg-type technologies for military purposes (Jacobsen, 2015). One Cyborg activist, Neil Harbisson, found a doctor to implant an antenna in his skull, supposedly to enhance his perception of colors. Is thats acceptable?

But beyond super-soldiers and the occasional "self-enhancers," there are other potential (and current) technologies that provide discretionary enhancements. For instance, some people already have RFID implants (Master & Michael, 2005). You can also have an implanted compass; near-field microchips (NFCs) in one's hand to interact with connected electronic devices, or sound-transmitting magnets in one's ears (Thompson, 2015). How about augmented reality contact lenses that will make you bionic (Kaplan, 2021)? Are these seemingly benign personal implants acceptable—as long as they are voluntary? Where, then, does one draw the line on discretionary enhancements, and how will any guidelines or regulations be enforced?

Level 5 (L5): Transhumans

Finally, the ideas of "The Singularity" (i.e., the point at which artificial intelligence would surpass that of humans) and Transhumanism (the vision of "man remaining man, but transcending himself," Huxley, 1968, p. 76) have been evolving into a scientific and social movement (Bostrom, 2003, p. 4). Transhumanism has been described as:

- "a blanket term given to the school of thought that refuses to accept traditional human limitations such as death, disease and other biological frailties" (McNamee and Edwards, 2006, p. 513);
- "the continuation of evolution by other, more efficient means" (Doede, 2009, p. 47); and
- "a matter of technological inevitability" (Berne, 2001, para. 5).

Since there has been considerable controversy about Transhumanism, as well as opposition to the idea of the Singularity, Transhumanism has been included as the fifth level within the biomedical advances construct. This level also brings into the Research Model the fork-in-the-road question: "Still human?"

SCIENCE AWARENESS (SA) MEASUREMENT

The science awareness (SA) measurement scale was derived from a 2016 Pew Research Center Survey (Funk et al., 2016) that asked about participant's awareness of specific biomedical technologies, Table 1. They found that only 3–9% of respondents said they knew "a lot" about gene editing, synthetic blood

substitutes, or electronic implants for enhanced brain capabilities, while 42–77% reported knowing nothing at all. Building on their approach, Table 1 gives the SA scale used for this research.

Table 1. Awareness of Biomedical Advances

	Not at all	A little	A lot	No Answer
Brain Implants for Enhancements	42%	48%	9%	1%
Synthetic Blood Substitutes	77%	19%	3%	1%
Gene Editing	61%	32%	6%	2%

Note: Adapted from "U.S. public wary of biomedical technologies to 'enhance' human abilities," Funk, Kennedy, & Sciupac (2016), pp. 115, 120, 125

TRUST IN SCIENCE AND SCIENTISTS (TS)

The second STS issue to consider is Trust in Science (TS). When no first-hand knowledge is possible, trust in, and reliance upon, experts very likely has significant influence on personal attitudes and decisions. But how has that idea been addressed relative to scientific advances?

"Those who talk about a crisis in trust should not mistake 'a deep suspicion' of institutions of science for mistrust in science as a whole (Millstone and Van Zwanenberg, 2000, p. 1307).

This suggests that it is not so much science in general that is under attack, but present-day scientific institutions. To investigate that, Achterberg, de Koster, and van der Waal (2015) developed a construct they refer to as a science confidence gap—levels of trust for the scientific method versus trust in scientists and scientific institutions.

They found that "the correlation between trust in scientific methods and trust in scientific institutions is low: $r = .11$ ($p = .001$). Hence, the extent to which someone trusts scientific methods is not a good predictor of their trust in scientific institutions, or vice versa" (Achterberg, et al., 2015, p. 9). This finding brings up the question of who to trust, especially when there are conflicting voices and reports coming from the scientific community. "While people appear to have an appetite for popular science, the paradox is that this is accompanied by increasing scepticism about *the pronouncements of scientists* on science-related policy issues of all types" (House of Lords, 2000, paragraph. 2.2).

Two recent examples have demonstrated how such a division among the general public could be created. The first issue is the debate about the legitimacy of climate science, with scientific armed camps arrayed on the sides of the believers and the non-believers (or heretics who should be burned at the stake, at least according to the self-righteous believers). As of 2023, this conflict among scientists, journalists, and governmental institutions is into its third decade. The second example is the experience of the COVID pandemic. *Masks are necessary and save lives*; *masks are irrelevant*. *Everyone, absolutely everyone must be vaccinated*, notwithstanding that no evidence had been shown that the new vaccines would prevent infection or transference, let alone that the virus put children at risk. In the questionable words of Dr. Fauci, "I *am* science!" and therefore his declarations had to be true and obeyed (Mullen, 2021). Not everyone agreed.

RESULTS

Construct Reliability

Construct analyses, using Cronbach's alpha as the reliability statistic, were done for each of the constructs included in the research model (Table 2). Depending on the type of research (e.g., social science versus medical treatment studies), the general rule of thumb for measurement scale reliability is $\alpha \geq 0.7$ is satisfactory, but $\alpha \geq 0.6$ is frequently deemed acceptable.

Table 2. Construct Reliability Summary

Construct	Variable Codes	N	Cronbach's Alpha	# of Items
Technology Acceptance	TA	355	0.728	10
Science Awareness	SA	344	0.867	5
Trust in Science	TS	345	0.682	3

Technology Acceptance

The most important finding of this research is shown in Figure 2, which highlights the response trends for each of the biomedical treatments categories. Each column shows strong preferences for or against whether that treatment was acceptable. Note the pattern shift between Level 3 (Enhancements-Medical) and Level 4 (Enhancements-Discretionary).

In Treatment Levels 1–3, the agree (41–45%) and strongly agree (24–54%) responses were the most frequent selections. Disagree and strongly disagree were only 1–14% of the column totals. However, that pattern was reversed in Levels 4–5. For Enhancements-Discretionary and Brain Transplants, agree and strongly agree had only 2–15% of the responses, while disagree and strongly disagree together were 77–83% for Level 4 and 51–65% for Level 5. This shift in support demonstrated a distinct level of biomedical treatments that were unacceptable to the majority of respondents. One other observation was that there were also more neutral answers for the Level 5 treatments, which may reflect the uncertainty of those procedures and/or not enough information to be for or against.

Table 3. Technology Acceptance Response Summary – Frequencies

T.A. Frequencies	L1a	L1b	L2a	L2b	L3a	L3b	L4a	L4b	L5a	L5b
Strongly Disagree	5	20	13	13	4	3	175	157	102	140
Disagree	9	44	26	50	2	6	116	113	78	89
Neutral	23	60	23	45	12	19	35	44	99	70
Agree	159	145	151	146	145	146	16	29	52	35
Strongly Agree	157	84	139	99	190	179	10	8	21	19
Total Responses	353	353	352	353	353	353	352	351	352	353

Table 4. Technology Acceptance Response Summary –Percentages

T.A. Percentages	L1a	L1b	L2a	L2b	L3a	L3b	L4a	L4b	L5a	L5b
Strongly Disagree	1.4	5.7	3.7	3.7	1.1	0.8	49.7	44.7	29.0	39.7
Disagree	2.5	12.5	7.4	14.2	0.6	1.7	33.0	32.2	22.2	25.2
Neutral	6.5	17.0	6.5	12.7	3.4	5.4	9.9	12.5	28.1	19.8
Agree	45.0	41.1	42.9	41.4	41.1	41.4	4.5	8.3	14.8	9.9
Strongly Agree	44.5	23.8	39.5	28.0	53.8	50.7	2.8	2.3	6.0	5.4

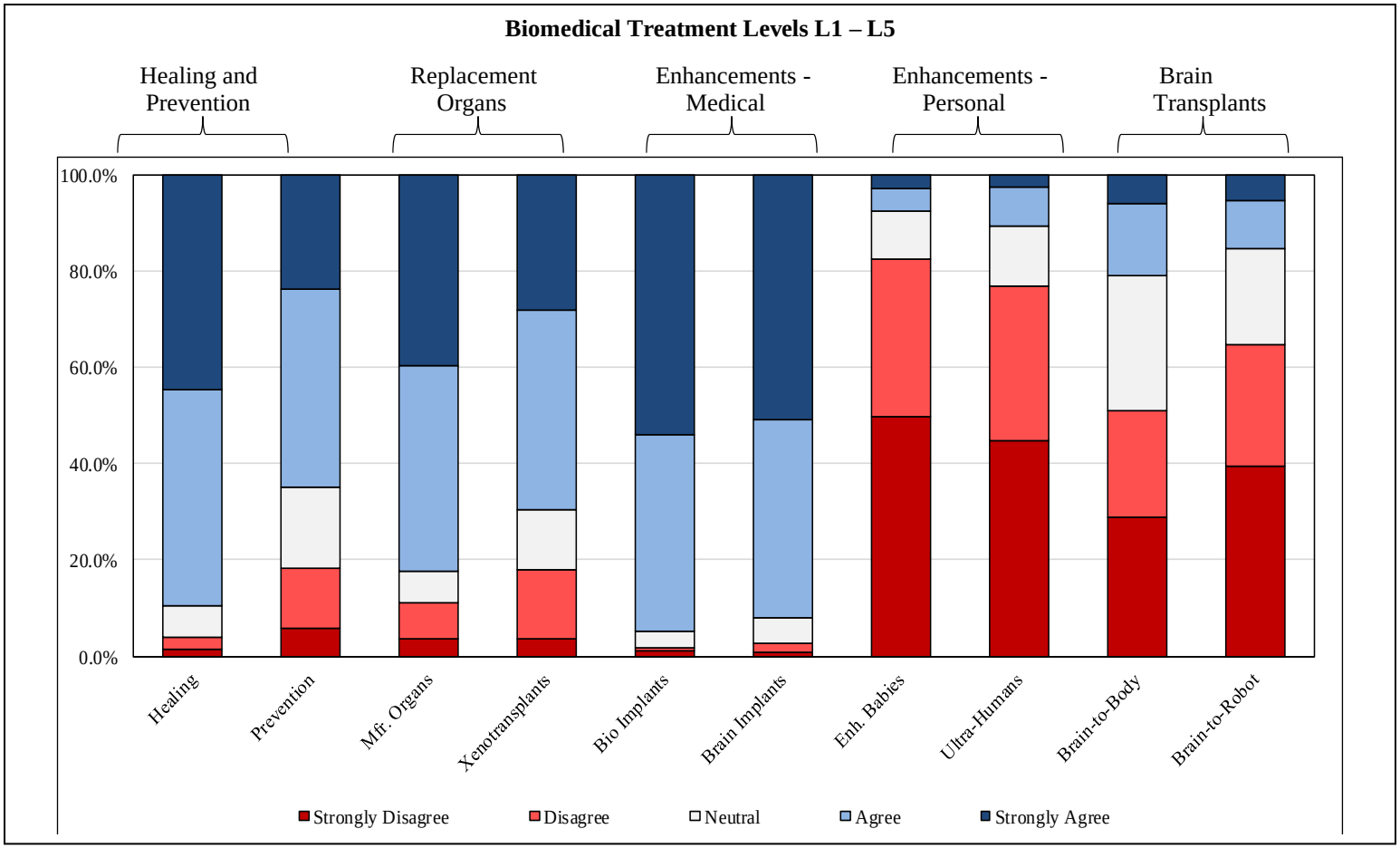

Figure 12. Technology Acceptance Patterns: 10 Items, 5 Levels of Biomedical Treatments

In summary, the TA response patterns in Figure 2 are distinct; the high levels of agree and strongly agree in Levels 1–3 are replaced by similar levels of disagree and strongly disagree in Levels 4–5. This clear demarcation defines where policymakers and the biomedical community could draw the line between "Could we?" versus "Should we?" It also answers Research Question #1: Were there any significant differences in the technology acceptance responses for the five biomedical treatment categories?

Science Awareness

The summary statistics for science awareness (SA) are shown in Figure 3 and Table 5 gives the response percentages for each of the science awareness topics. In designing this research, there was no intent to recruit people familiar with the latest biomedical advances, because the measurement of policy preferences could have been inordinately skewed by such a targeted sample. Accordingly, only 2–6% reported very high science awareness in any of the five categories.

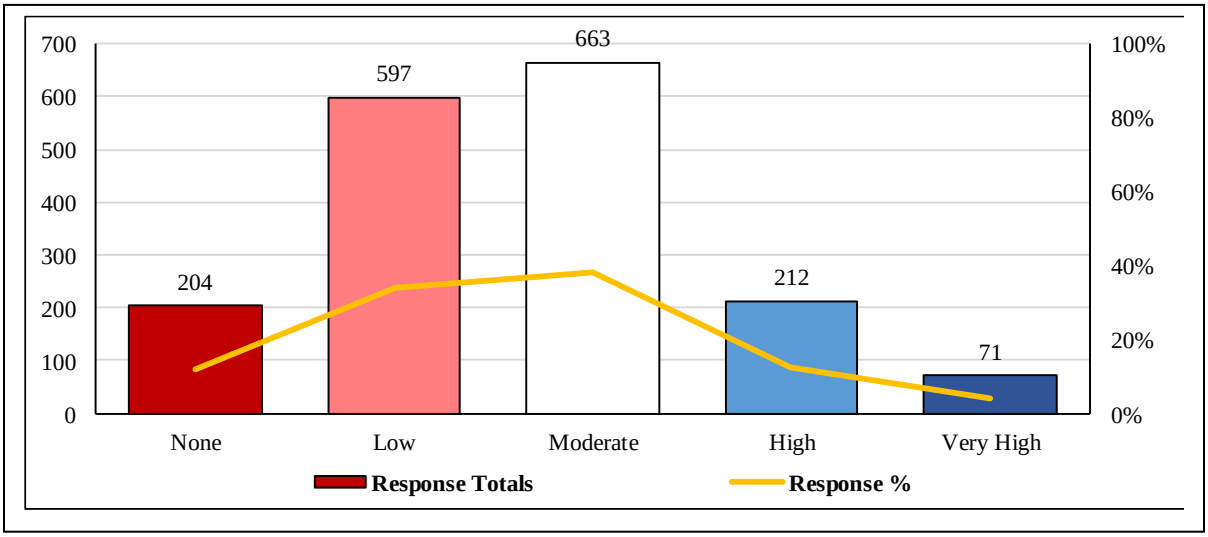

Figure 3. Science Awareness (SA) Responses

Table 5. Science Awareness (SA) Response Summary

	Stem Cell Treatments	Organ Transplants	Gene Editing	Body Implants	Brain Implants	Totals
N =	349	351	348	350	349	1,747
None	2.3%	2.0%	10.9%	8.9%	34.4%	204
Low	30.9%	24.8%	40.2%	34.0%	41.0%	597
Moderate	43.6%	48.4%	37.4%	41.1%	19.2%	663
High	18.3%	18.8%	8.6%	11.4%	3.4%	212
Very High	4.9%	6.0%	2.9%	4.6%	2.0%	71

An overview of the Science Awareness (SA) distribution was obtained by summing the response levels from each returned survey, per Figure 4. SA was used then for the regression analyses vis-à-vis the Technology Acceptance responses.

Trust in Science (TS)

The responses for Trust in Science were scored from 1 (for very low), 3, 5, 7, and 9 (for very high). Summation of the three trust responses produced a TS range of 5-27, with the following distribution (Figure 5).

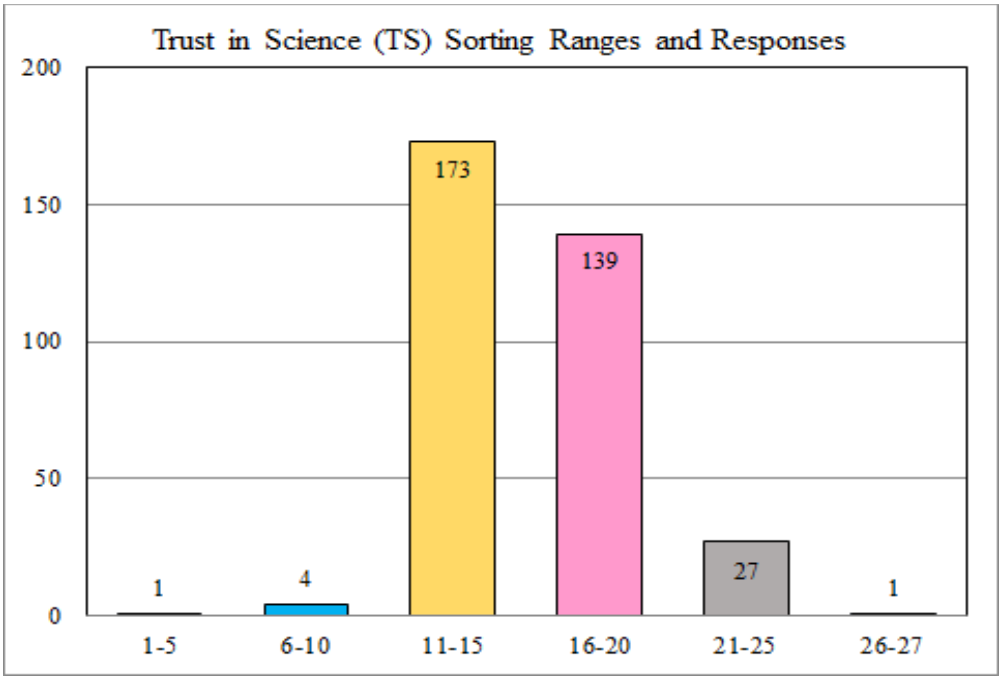

Figure 5. Trust in Science Distribution (TS)

Technology Acceptance as the Dependent Variable

The responses for the two independent variables, Science Awareness and Trust in Science, did not qualify as normal distributions. That also held for most of the Technology Acceptance categories. Accordingly, Box-Cox transforms were used to normalize the data for the regression analyses. Table 6 shows the Lambda values, Box-Cox numbers, and their corresponding approximations. For the regressions calculations, Box-Cox transform equations were used.

Multiple regressions were run (using Microsoft Excel 2010) with Science Awareness and Trust in Science as the independent variables against each of the ten Technology Acceptance elements. As shown in Table 7, nine of these resulted in statistically significant regression equations. Only the analysis for TA4a (Enhanced Babies) was rejected. In the other three Level-4 and -5 variables, the calculations using Science Awareness and Trust in Science produced acceptable p-values for SA, but not TS. Linear regressions were then run for TA4b, TA5a, and TA5b against SA. Given that this was a new model for Technology Acceptance, and allowing for a limited sample population, these results were encouraging and answered Research Question #2: What relationships (if any) existed between the independent variables – science awareness and trust in science – vis-a-vis technology acceptance?

Table 6 – Box-Cox Transforms Summary

Variable Codes	λ	Approx.	Mean
Independent Variables			
SA	0.290	ln(SA)	13.140
TS	2.110	TS^2	20.791
Dependent Variables			
TA1a	2.970	$TA1a^3$	4.180
TA1b	1.722	$TA1b^2$	3.407
TA2a	2.576	$TA2a^3$	3.870
TA2b	1.840	$TA2b^2$	3.524
TA3a	3.658	$TA3a^3$	4.384
TA3b	3.432	$TA3b^3$	4.312
TA4a	-0.894	1 / TA4a	1.557
TA4b	-0.563	1 / $TA4b^2$	1.666
TA5b	0.342	TA5a1 / 3	2.139
TA5b	-0.213	ln(TA5b)	1.854

Table 7. Regression Equations for Technology Acceptance

Technology Acceptance	Regression Equations	R-squared	F stat significance
TA1a	TA1a = 2.4825 - 0.7362(SA) + 0.0423(TS)	0.0608	0.0000
TA1b	TA1b = 3.3714 + 0.4919(SA) + 0.0209(TS)	0.0698	0.0000
TA2a	TA2a = 2.4915 - 1.5297(SA) + 0.0919(TS)	0.1680	0.0000
TA2b	TA2b = 2.8266 - 1.4685(SA) + 0.8289(TS)	0.1011	0.0000
TA3a	TA3a = 1.7262- 0.5199(SA) + 0.0706(TS)	0.1549	0.0000
TA3b	TA3b = 1.9340 - 0.6393(SA) + 0.0659(TS)	0.1274	0.0000
TA4a	TA34a = N/A	0.0093	0.2107
TA4b	TA4b = 2.3697 - 0.8434(SA)	0.0157	0.0220
TA5a	TA4b = 3.2792 - 1.2569(SA)	0.0179	0.0142
TA5b	TA5a = 3.2803 - 1.9178(SA)	0.0528	0.0000

Note: All of the variable codes above represent calculations using their respective Box-Cox values. The original variable codes were used instead of adding "BC" before each one.

Demographics Summary

The goal of the recruitment process was to secure a sample population that was representative of a diverse sector of the American public. There were 413 responses from the on-line survey. Of these, 60 were discarded due to incomplete responses. The final count of usable data was $N = 353$.

The demographic analysis (Table 8) showed a predominantly white and well-educated sample (i.e., 89% white versus 11% for all other racial heritage responses, and 70% with bachelor's degrees or above). The gender mix was 60% female, 40% male, and 0.6% transgender or other, while 30 respondents either left this category blank or chose 'prefer not to answer.' Also, only 2% of respondents indicated Hispanic heritage.

Table 8 – Demographic Analysis

Age Group						Gender			
≤ 25	26-35	36-50	51-65	> 65	No Answer	Male	Female	Transgender or Other	Prefer Not to Answer
70	33	97	84	39	30	139	208	2	4

Education Level							Hispanic, Latino, or Spanish origin?		
No H.S. Diploma or G.E.D.	H.S. Diploma or G.E.D.	Some College	Assoc. Degree	Bachelor's Degree	Master's Degree or Above	Prefer not to answer	Yes	No	Prefer Not to Answer
0	8	72	26	102	144	1	7	337	9

Race							
Asian	Asian Indian	White	Pacific Islander	American Indian or Alaska Native	Middle Eastern, Arabic, or Persian	Black, African, African American	Prefer not to answer
3	8	302	2	5	6	13	14

Figure 6 shows the breakdown of the age ranges and Figure 7 shows the education level distribution. There were zero responses from those who did not finish high school or receive a G.E.D. These graphs show a relatively well-distributed age distribution, but a sample skewed toward higher education levels.

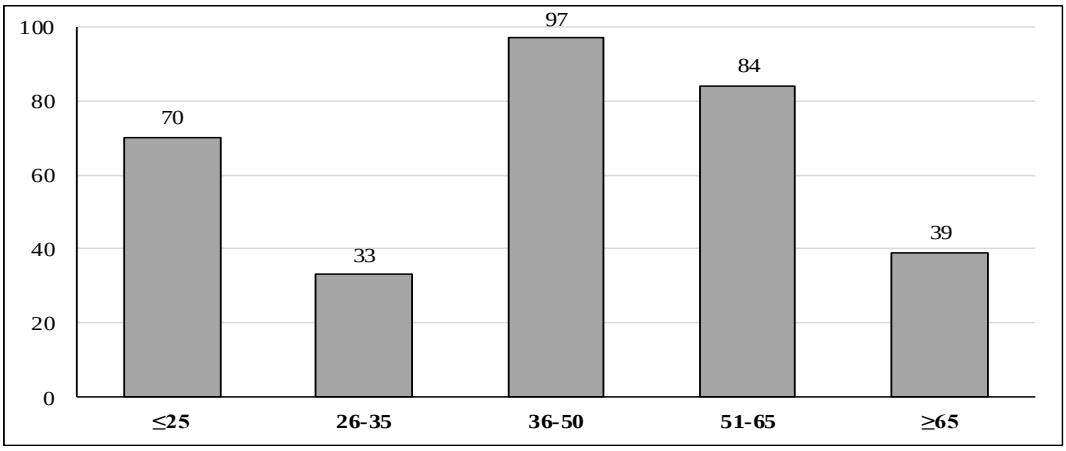

Figure 6. Sample Population by Age Group

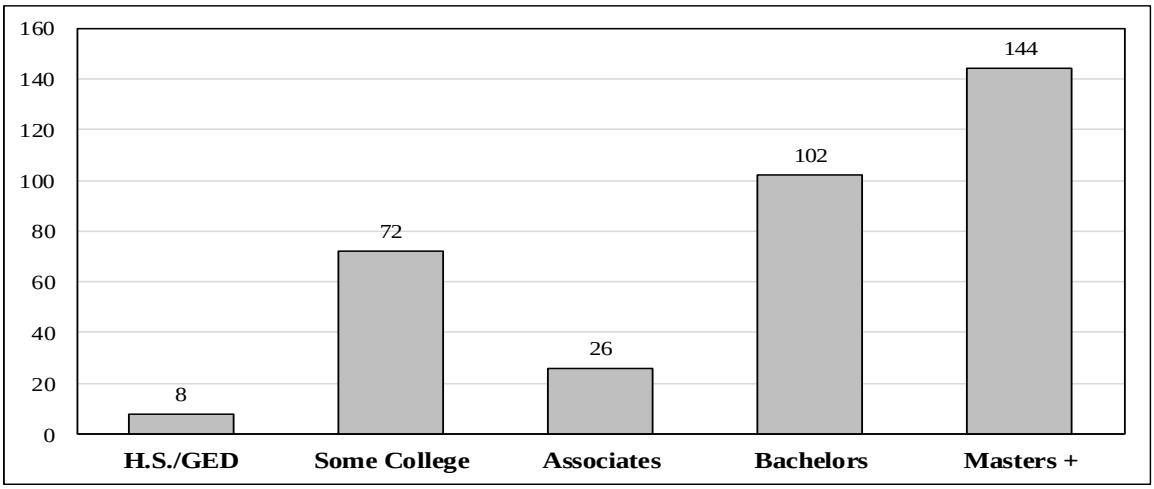

Figure 7. Sample Population by Education Level

The Role of Demographics in the Research Model

The responses for Technology Acceptance were cross-tabulated with the demographics factors: gender, age group, and education level. In Figures 6 – 9, which show the male versus female results, the TA response patterns were similar to those of the overall sample, especially the distinct transition point between Levels 3 and 4. Looking at the individual demographic comparisons, the female responses were less favorable (by 8–20%) than those of the male respondents in seven of the TA categories. This difference was particularly noticeable for the two Enhancement-Discretionary items, Enhanced Babies and Ultra Humans. The corresponding bar charts for TA responses vs. age and education levels were similar to Figures 8-9, but any conclusions from these were limited due to the skews of the sample population. This comparison answers Research Question #3: Were there any noticeable demographic factors relative to the TA responses?

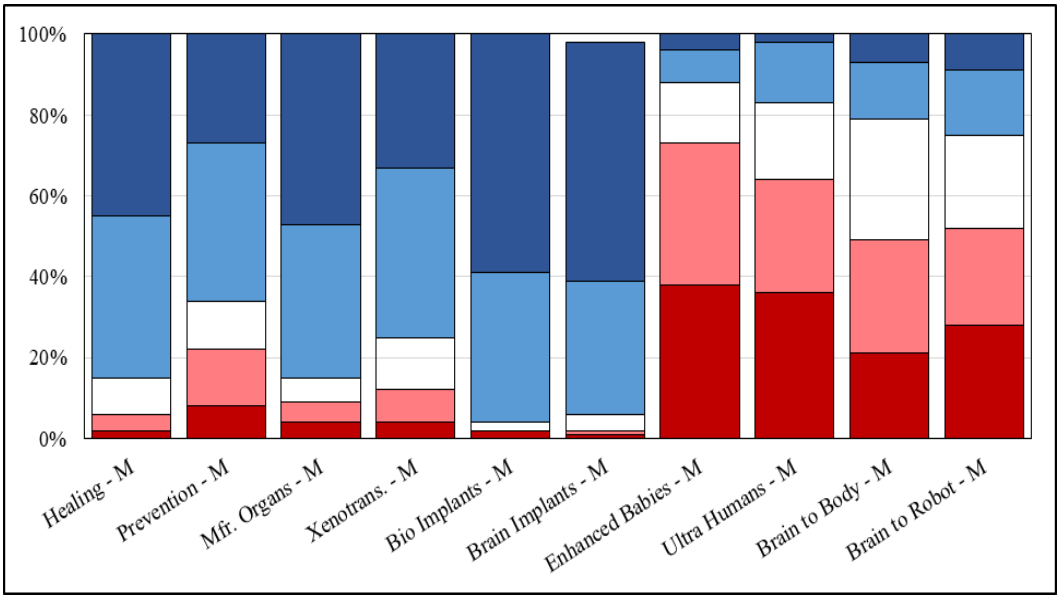

Figure 8. Technology Acceptance vs. Gender (Male)

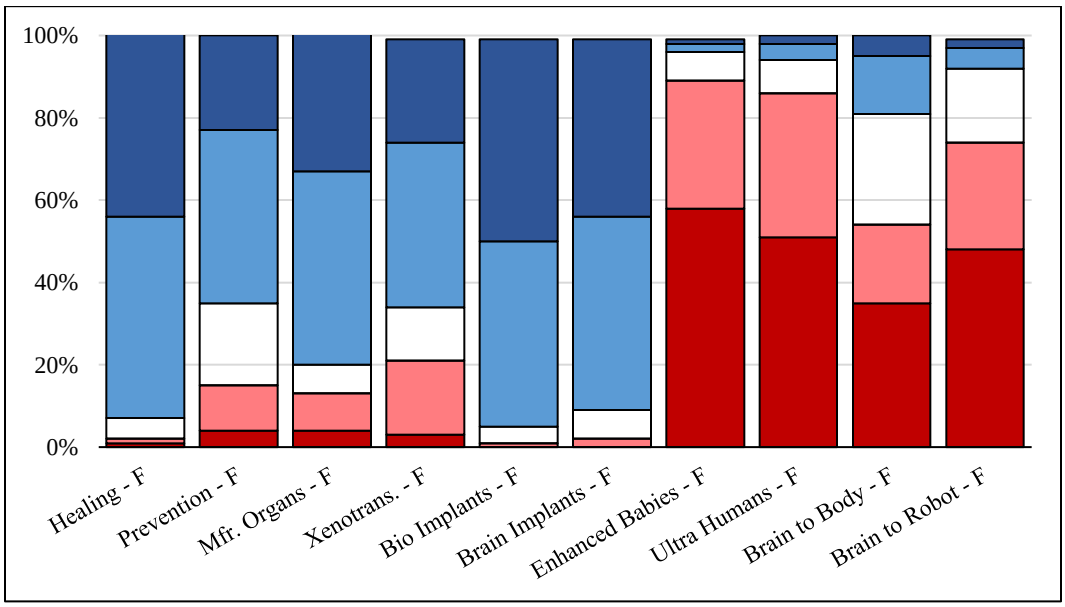

Figure 9. Technology Acceptance vs. Gender (Female)

CONCLUSION

The New Technology Acceptance Scale

A new technology acceptance scale was created for this research. Its intent was to determine which levels of 21st century biomedical treatments Americans would find acceptable and whether there was a line beyond which such treatments were unacceptable. Given a list of biomedical treatments to consider, a clear line between acceptable and unacceptable was revealed. Healing and Prevention Treatments, new Organ Replacement technologies, and Enhancements-Medical were strongly supported; Enhancements-Discretionary and Brain Transplants were rejected.

The new scale was created to provide a hierarchy for future studies that could refine where to draw the lines between "Could we?" and "Should we?" as these questions have already become the focal

point of health policy discussion around the world. So, even with a sample population that was limited in its diversity, clear results were obtained. It is hoped these results will be helpful for future researchers and policy-makers.

The Research Model

Science Awareness and Trust in Science were chosen as the independent variables to assess their relevance vs. the new TA scale. It was encouraging that nine of the ten regression equations were statistically significant. Future studies, especially considering that scientific awareness may have increased in the recent years, may have strengthened its relationship with biomedical technology acceptance. The opposite case might be seen vis-à-vis Trust in Science because of the pandemic and the on-going climate change debates.

"Could We?" but "Should We?"

The popular press term "the miracles of modern medicine" has become increasingly applicable as significant potential benefits of 21st century biomedical research and treatments have been realized. The biomedical world has made breakthroughs at an increasing pace, but concerns about possible misuse by scientists and practitioners are frequently publicized. Consider the titles of the following popular press articles. These are what contribute to public knowledge and influence public trust in science:

- We have the technology to edit babies' genes but no rules for when to do it" (Brueck, 2015);
- "New biological techniques create the potential for catastrophe. The self-control of scientists is not enough to protect us, or to secure public trust" (Lentos, van der Bruggen, and Nixdorff, 2015);
- "Can standards and regulations keep up with health technology?" (Viincent, NIezen, O'Kane, and Tawarz, 2016);
- "Artificial human embryos are coming, and no one knows how to handle them" (Regalado, 2017);
- "Designer babies: An ethical horror waiting to happen?" (Ball, 2017);
- "The U.S. regulations for biotechnology are woefully out of date" (Borel, 2017);
- "We're not prepared for the coming genetic revolution" (Chapman, 2018);
- "Research could eventually lead to new sources of organs for transplant, but ethical and technical hurdles need to be overcome" (Mandelbaum, 2019);
- "3D printing of body parts is coming fast – but regulations are not ready" (Mendis and Rutschman, 2020);
- "Bionics center at MIT may usher in our cyborg future" (Houser, 2021);
- "The Singularity: When will we all become super-humans?" (Thomson, (2021);
- "Genetic Engineering: Is It Ethical?" (Sus, 2022); and
- "Experts weigh medical advances in gene-editing with ethical dilemmas" (Stein, 2023).

The 500-Year Delta of biomedical advances progresses at an increasing pace, augmented by the rapid development of the enabling technologies: 3D bioprinting, stem cell research, nanotechnology, and genetic engineering. Cures for diseases and disabilities are underway, the potential of the CRISPR gene editing process has been proven, people have been at least partially cured of paralysis, sight has been restored through medical therapies and bionic eyes, and human replacement organs from xenotransplantation and/or 3D bioprinted organs are now considered to be a realistic goal this decade. The answer to "Could We?" is increasingly ***Yes***, but "Should We?" is still to be determined.

REFERENCES

Achterberg, P., de Koster, W., and van der Waal, J. 2014. A science confidence gap: Education, trust in scientific methods, and trust in scientific institutions in the United States, 2014. *Public Understanding of Science,* 1-17. doi:10.1177/0963662515617367

Allhoff, F., Lin, P., Moor, J., and Weckert, J. 2009. *Ethics of human enhancement: 25 questions & answers*. U.S. National Science Foundation (August 31, 2009).

Ball, P. 2017. Designer babies: An ethical horror waiting to happen? *The Guardian* (January 8, 2017). Retrieved from https://www.theguardian.com/science/2017/jan/08/designer-babies-ethical-horror-waiting-to-happen

Baptista, P., Siddiqui, M., Lozier, G., Rodriguez, S., Atala, A., and Soker, S. 2011. The use of whole organ decellularization for the generation of a vascularized liver organoid. *Hepatology, 53*(2), 604-617. doi:10.1002/hep.24067

Barraud, E. 2023. First-ever spinal cord implant enables paralyzed people to walk again. *The Brighter Side of News* (January). Retrieved from First-ever spinal cord implant enables paralyzed people to walk again (thebrighterside.news)

Baylis, Françoise. 2019. Altered Inheritance: CRISPR and the ethics of human genome editing. *Harvard University Press* (Cambridge, MA). ISBN 9780674976719

Begley, S. 2015. Dare we edit the human race? Star geneticists wrestle with their power. Retrieved from http://www.statnews.com/2015/12/02/gene-editing-summit-embryos/?s_ campaign=stat:rss

Berne, R. 2001. Robosapiens, transhumanism, and the Kurzweilian utopia: Why the trans in transhumanism? *Iris, 43*(Fall 2001), 36.

Bhatia, S., Underhill, G., Zaret, K., and Fox, I. 2014. Cell and tissue engineering for liver disease. *Science Translational Medicine*, *6*(245), 242sr2. doi:10.1126/scitranslmed.3005975

Blendon, R.J., Gorski, M.T., and Benson, J.M. 2016. The Public and the Gene-Editing Revolution. *The New England Journal of Medicine*, *374*(15), 1406-1411. Cited in National Academies of Science, Human Genome Editing: Science, Ethics, and Governance, 2017, pp. 107-109.

Borel, B. 2017. The U.S. regulations for biotechnology are woefully out of date. Retrieved from https://newsstand.google.com/articles/CAIiECCWXXN-RxPgRgG_UGgSyhUqFQgEKgoIACoGCAowuLUIMNFnMInmAg

Brinkhof, T. 2022. Should we use genome editing to make better babies? Here's what the experts think. *Big Think* (March 23, 2022). Retrieved from: Genome editing debate: if we can make better babies, should we? - Big Think

Broom, D. 2021. This ceramic ink can 3D-print bones directly into a patient's body. Here's how. *World Economic Forum* (April 12, 2021). Retrieved from: https://www.weforum.org/agenda/2021/04/3d-printer-bones-surgery-medicine/

Brown, K. (2017, November). Genetically engineering yourself sounds like a horrible idea—but this guy is doing it anyway. *Gizmodo*. Retrieved from https://gizmodo.com/ genetically-engineering-yourself-sounds-like-a-horrible-1820189351

Brueck, H. 2015. Are you ready for genetically modified babies? *Fortune* (December 2, 2015). Retrieved from http://fortune.com/2015/12/02/genetically-modified-babies/

Buchanan, A., D. W. Brock, N. Daniels, and D. Wikler. 2001. *From chance to choice: Genetics and justice*. New York: Cambridge University Press. Cited in *Human genome editing: Science, ethics, and governance, p. 123*. Washington, DC: The National Academies Press. doi:10.17226/24623.

Centers for Medicare & Medicaid Services. 2020. CMS announces transformative new model of care for Medicare beneficiaries with chronic kidney disease. (Press Release: CMS.gov, September 18, 2020). Retrieved from https://www.cms.gov/newsroom/press-releases/cms-announces-transformative-new-model-care-medicare-beneficiaries-chronic-kidney-disease

Chapman, R. 2018. We're not prepared for the coming genetic revolution. *The Conversation* (May 15, 2018). Retrieved from https://theconversation.com/were-not-prepared-for-the-genetic-revolution-thats-coming-96574

Colson, Charles W. and Cameron, Nigel M. (editors). *Human Dignity in the Biotech Century: A Christian Vision for Public Policy* (Downers Grove, IL: InterVarsity, 2004) cited in *SkyWatch* Editor (2015).

Inhuman: The next and final phase of man is here: Introduction (p. 29). Retrieved from inhuman-exclusive-new-online-series-part-1 (June 7, 2015)

Columbia University Medical Center. 2016. CRISPR used to repair blindness-causing genetic defect in patient-derived stem cells. Retrieved from http://www.eurekalert.org/pub_releases/2016-01/cumc-cut012616.php

Comfort, N. 2015, July 16. Can we cure genetic diseases without slipping into eugenics? *The Nation*. Retrieved from http://www.thenation.com/article/can-we-cure-genetic-diseases-without-slipping-into-eugenics/

Coxworth, B. 2020a. Replacement blood vessels may be woven from bio-yarn. *New Atlas* (February 11, 2020). Retrieved from: https://newatlas.com/medical/replacement-blood-vessels-collagen-yarn/

Coxworth, B. 2020b. Handheld 3D printer used to grow replacement muscle tissue. *New Atlas* (February 28, 2020). Retrieved from: https://newatlas.com/medical/handheld-3d-printer-muscle-tissue/

Coxworth, B. 2021. Brain implant bypasses the eyes to help blind users "see" images. *New Atlas* (October 20, 2021). Retrieved from: https://newatlas.com/medical/blind-brain-implant/

Coxworth, B. 2023, February. Lab-grown 3D skin grafts could be applied like "biological clothing." *New Atlas*. Retrieved from: Lab-grown 3D skin grafts could be applied like "biological clothing" (newatlas.com)

Davis, F. 1986. *A technology acceptance model for empirically testing new end-user information systems: Theory and results*. (Doctoral dissertation: Sloan School of Management, Massachusetts Institute of Technology).

De La Garza, S. 2022. Scientists engineer an implant that can deliver cancer-fighting meds directly into your body. *Dateline Rice* (March 18, 2022). Retrieved from: Dateline Rice for March 18, 2022 | Rice News | News and Media Relations | Rice University

Dengler, R. 2019. Scientists create blood vessels that become living tissue. *Discover* (March 27, 2019). Retrieved from: https://www.discovermagazine.com/health/scientists-create-blood-vessels-that-become-living-tissue

Dey, M. and Ozbolat, I.T. 2020. 3D bioprinting of cells, tissues and organs. *Scientific Reports* 2020; 10: 14023. doi: 10.1038/s41598-020-70086-y

Doede, B. 2009, March. Transhumanism, technology, and the future: Posthumanity emerging or sub-humanity descending? *Appraisal, 7*(3) 1-16.

Doudna, J., & Charpentier, E. 2014, November 28. The new frontier of genome engineering with CRISPR-Cas9. *Science, 346*(6213), 1077. doi:10.1126/science.1258096

D'Uva, G., Aharonov, A., Lauriola, M., Kain, D., [...], and Tzahor, E. 2015. ERBB2 triggers mammalian heart regeneration by promoting cardiomyocyte dedifferentiation and proliferation. *Nature Cell Biology, 17*, 627–638. doi:10.1038/ncb3149

Ebrahimkhani, M. 2020. Genetic engineering transformed stem cells into working mini-livers that extended the life of mice with liver disease. *The Conversation* (December 7, 2020). Retrieved from: https://theconversation.com/genetic-engineering-transformed-stem-cells-into-working-mini-livers-that-extended-the-life-of-mice-with-liver-disease-151089

Epstein, C. 2003. Is modern genetics the new eugenics? *Genetics in Medicine* (5) 469–475. https://doi.org/10.1097/01.GIM.0000093978.77435.17

Faulkner-Jones, A., Greenough, S., King, J., Gardner, J., Courtney, A., & Shu, W. 2010. Bioprinting of human pluripotent stem cells and their directed differentiation into hepatocyte-like cells for the generation of minilivers in 3D. *Biofabrication, 7*, 1-13.

Fernández, E., Alfaro, A., Soto-Sánchez, C., Gonzalez-Lopez, P., [...], and Normann, R.A. 2021. Visual percepts evoked with an intracortical 96-channel microelectrode array inserted in human

occipital cortex. *Journal of Clinical Investigation* (131, 23) e1513311. https://doi.org/10.1172/JCI15133

Friedersdorf, C. 2017. Will Editing Your Baby's Genes Be Mandatory? An ethical dilemma from the near future. *The Atlantic* (April 14, 2017). Retrieved from https://www.theatlantic.com/politics/archive/2017/04/will-editing-your-babys-genes-be-mandatory/522747/

Funk, C., Kennedy, B., & Sciupac, E. 2016, July. U.S. public wary of biomedical technologies to enhance human abilities. *Pew Research Center Report*. Retrieved from http://www.pewinternet.org/2016/07/26/u-s-public-wary-of-biomedical-technologies-to-enhance-human-abilities/

Furth, M., Atala, A., & Van Dyke, M. 2007. Smart biomaterials design for tissue engineering and regenerative medicine. *Biomaterials, 28*(34), 5068-5073. http://dx.doi.org/10.1016/j.biomaterials.2007.07.042

Gad, P., Gerasimenko, Y., Zdunowski, S., Sayenko, D., Haakana, P., Turner, A., ... Edgerton, V. (August 26, 2015). Iron ElectriRx man: Overground stepping in an exoskeleton combined with noninvasive spinal cord stimulation after paralysis. *IEEE Engineering in Medicine and Biology Society*, 1124-1127. doi:10.1109/EMBC.2015.7318563

Gilja, V., Pandarinath C., Blabe, C., Nuyujukian, P., Simeral, J., Sarma, A., ... Henderson, J. 2015. Clinical translation of a high-performance neural prosthesis. PubMed, *10*, 1142-1145. doi:10.1038/nm.3953

Ghose, T. 2014. 3D-printed hearts help surgeons save babies' lives. *Live Science* (November 19, 2014). Retrieved from http://www.livescience.com/48816-3d-printed-hearts-improve-surgery.html

Gleiser, M. 2022. Are some things so taboo that science should never research them? *Big Think* (13.8 – May 18, 2022). Retrieved from: Are some things too taboo for science to research? - Big Think

Goforth, C. 2015. Using and interpreting Cronbach's alpha. University of Virginia Library. Retrieved from http://data.library.virginia.edu/using-and-interpreting-cronbachs-alpha/

Grau, C., Ginhoux, R., Riera, A., Nguyen, T., Chauvat, H., Berg, M., ... Ruffini, G. 2014. Conscious brain-to-brain communication in humans using non-invasive technologies. *PLoS ONE, 9*(8) e105225. doi:10.1371/journal.pone.0105225

Griffith, B.P., Goerlich, C.E., Singh, A.K., Rothblatt, M., [...], and Ayares, D. 2022. Genetically modified porcine-to-human cardiac xenotransplantation. *The New England Journal of Medicine*, 387(1):35-44. PMID: 35731912 doi: 10.1056/NEJMoa2201422.

Haseltine, W.A. 2022. 3D printed skin? Potential new treatment for chronic wounds. *Forbes* (January 4, 2022). Retrieved from: 3D Printed Skin? Potential New Treatment For Chronic Wounds (forbes.com)

The Hinxton Group. (2015, September 3-4). Statement on genome editing technologies and human germline genetic modification. *Hinxton Group Report*. Retrieved from http://www.hinxtongroup.org/Hinxton2015_Statement.pdf

Ho, A., Humayan, M., Dorn, J., da Cruz, L., and Greenberg, R. 2015. Long-term results from an epiretinal prosthesis to restore sight to the blind. *Ophthalmology*, *122*(8), 1547-1554. http://dx.doi.org/10.1016/j.ophtha.2015.04.032

Hodges, J. 2010. Going beyond the limits: Genetic modification of living livestock and dissolution of ancient boundaries. *Livestock Science*, 130, pp. 3-13.

House of Lords, 2000. Science and Technology—Third Report. http://www.publications.parliament.uk/pa/ld199900/ldselect/ldsctech/ 38/3801.htmuk/pa/ld199900/ldselect/ldsctech/38/3801.htm

Houser, K. 2021. Bionics center at MIT may usher in our cyborg future. *Big Think* (October 17, 2021). Retrieved from: Bionics center at MIT may usher in our cyborg future - Big Think

Houser, K. 2023. Hollow "seed" shrinks cancerous tumors from the inside. Freethink (April 26, 2023). Retrieved from: https://www.freethink.com/health/drug-delivery-system

Huch., M., Gehart, H., van Boxtel, R., Hamer, K., Blokzijl, F., Verstegen, M., and Clevers, H. 2015. Long-term culture of genome-stable bipotent stem cells from adult human liver. *Cell, 160*(1-2), 299-312. https://doi.org/10.1016/j.cell.2014.11.050

Huxley, J. 1968. Transhumanism. *Journal of Humanistic Psychology, 8*(73), 73-76.

Irving, M. 2020a. First functioning mini human hearts grown from stem cells. *New Atlas* (August 20, 2020). Retrieved from: First functioning mini human hearts grown from stem cells (newatlas.com)

Irving, M. 2020b. Hybrid 3D-printing bioinks help repair damaged knee cartilage. *New Atlas* (November 9, 2020). Retrieved from: https://newatlas.com/medical/hybrid-bioinks-knee-cartilage/

Irving, Ml. 2022. Immunotherapy booster produces 10,000 times more cancer-fighting cells. *New Atlas* (June 16, 2022). Retrieved from: Immunotherapy booster produces 10,000 times more cancer-fighting cells (newatlas.com)

Israeli, Y., Gabalski, M., Ball, K., Wasserman, A., and Zhou, C. 2020. Generation of heart organoids modeling early human cardiac development under defined conditions. Preprint article retrieved from: Generation of Heart Organoids Modeling Early Human Cardiac Development Under Defined Conditions | bioRxiv. https://doi.org/10.1101/2020.06.25.171611

Iwase, H., Liu, H., Wijkstrom, M., Zhou, H., Singh, and Cooper, D. 2015. Pig kidney graft survival in a baboon for 136 days: Longest life-supporting organ graft survival to date. *Xenotransplantation, 22*(4), 302-309. doi: 10.1111/xen.12174

Jacobsen, A. 2015, September 28. Engineering humans for war. *The Atlantic*. Retrieved from http://www.defenseone.com/technology/2015/09/engineering-humans-war/122189/?oref=DefenseOneTCO

Jank, B., Xiong, L., Moser, P., Guyette, J., Ren, X., Cetrulo, C., and Ott, H. 2015. Engineered composite tissue as a bioartificial limb graft. *Biomaterials, 61*, 246-256. https://doi.org/10.1016/j.biomaterials.2015.04.051

Johnson, B., Lancaster, K., Zhen, G., He, J., Gupta, M., Kong, Y., and McAlpine, M. 2015. 3D printed anatomical nerve regeneration pathways. *Advanced Functional Materials, 25*(39), 6205-6217. doi:10.1002/adfm.201501760

Kamaly, N., He, J., Ausiello, D., and Farokhzad, O. 2016. Nanomedicines for renal disease: Current status and future applications. *Nature Reviews Nephrology, 12*, 738-753. doi:10.1038/nrneph.2016.156

Kaplan, J. 2021. The Future of Vision: Augmented reality contact lenses will make you bionic. *Digital Trends* (March 2, 2021). Retrieved from: https://www.digitaltrends.com/cool-tech/augmented-reality-contact-lenses-vision/

Kathe, C., Skinnider, M.A., Hutson, T.H., Regazzi, N., and Courtine, G. 2022.The neurons that restore walking after paralysis. *Nature* 611, 540–547 https://doi.org/10.1038/s41586-022-05385-7

Kelland, K. 2019. Paralyzed man walks again with brain-controlled exoskeleton. *Reuters* (October 3, 2019). Retrieved from: https://www.reuters.com/article/us-health-exoskeleton-idUSKBN1WI2HQ

Kim, M.Y., Jayasinghe, R., Devenport, J.M. et al. 2022. A long-acting interleukin-7, rhIL-7-hyFc, enhances CAR T cell expansion, persistence, and anti-tumor activity. *Nature Communications* (13, 3296). https://doi.org/10.1038/s41467-022-30860-0

Kimball, W. 2017, October 9. Should you be allowed to sell your kidney? *Gizmodo*. Retrieved from https://gizmodo.com/should-you-be-allowed-to-sell-your-kidney-1819108521

Kirkton, R.D., Santiago-Mayosonet, M., Lawson, J.H., Tente, W.E., and Prichard, H.I. 2019. Bioengineered human acellular vessels recellularize and evolve into living blood vessels after human implantation. *Science Translational Medicine* (11, 485) DOI: 10.1126/scitranslmed.aau6934

Kotz, D. 2022. University of Maryland School of Medicine faculty scientists and clinicians perform historic first successful transplant of porcine heart into adult human with end-stage heart disease. University of Maryland School of Medicine news release (January 10, 2022). Retrieved from https://www.medschool.umaryland.edu/news/2022/University-of-Maryland-School-of-Medicine-Faculty-Scientists-and-Clinicians-Perform-Historic-First-Successful-Transplant-of-Porcine-Heart-into-Adult-Human-with-End-Stage-Heart-Disease.html

Koumoundouros, T. 2022. Clinical Trial Restored Sight to 20 People With Corneas Made From An Unlikely Source. *Science alert* (August 14, 2022). Retrieved from Clinical Trial Restored Sight to 20 People With Corneas Made From An Unlikely Source : ScienceAlert

Kurzgesagt 2016. Genetic engineering will change everything forever – CRISPR (Video). *Genius.com* (August 10, 2016). Retrieved from: Kurzgesagt – Genetic Engineering Will Change Everything Forever – CRISPR | Genius

Lapid, N. 2021. US surgeons successfully test pig kidney transplant in human patient. *Reuters* (October 20, 2021). Retrieved from: U.S. surgeons successfully test pig kidney transplant in human patient | Reuters

Lawlor, K.T., Vanslambrouck, J.M., Higgins, J.W., Chambon, A., and Little, M.H. 2020. Cellular extrusion bioprinting improves kidney organoid reproducibility and conformation. *Nature Materials* (20) 260-271. https://doi.org/10.1038/s41563-020-00853-9

Ledford, H. 2015, June 4. CRISPR, the disruptor. *Nature, 522*, 20-24.

Lent, J. 2017. Technosplit: The bifurcation of humanity. *Salon* (June 2, 2017). Retrieved from http://www.salon.com/2017/06/02/technosplit-the-bifurcation-of-humanity_partner/

Lentzos, F., van der Bruggen, K., and Nixdorff, K. 2015. Can we trust scientists' self-control? *The Guardian* (April 26, 2015). Retrieved from http://www.theguardian.com/science/political-science/2015/apr/26/can-we-trust-scientists-self-control

Macchiarini, P., Jungebluth, P., Go, T., Asnaghi, M., Rees, L., Cogan, T., and Birchall, M. 2008. Clinical transplantation of a tissue-engineered airway. *The Lancet, 372*(9655), 2023-2030. https://doi.org/10.1016/S0140-6736(08)61598-6

Mandelbaum, R.F., 2019. Japan approves scientist's plan to create world's first humanimals. *Gizmodo* (July 30, 2019). Retrieved from: https://gizmodo.com/japan-approves-scientists-plan-to-create-worlds-first-h-1836823089

Maron, D. 2015, December 3. All gene-editing should proceed cautiously, scientists conclude. *Scientific American*. Retrieved from http://www.scientificamerican.com/ article/all-gene-editing-research-should-proceed-cautiously-scientists-conclude1/

Masci, D. 2016, July 26. Human enhancement: The scientific and ethical dimensions of striving for perfection. *Pew Research Center Report*. Retrieved from http://www.pewinternet.org/2016/07/26/human-enhancement-the-scientific-and-ethical-dimensions-of-striving-for-perfection/

Mashable.com. 2019. Researchers have 3D-printed a functional miniature liver. *Mashable India* (December 19, 2019). Retrieved from: https://in.mashable.com/science/9625/researchers-have-3d-printed-a-functional-miniature-liver

Master, A., and Michael, K. 2005, July 19. Humancentric applications of RFID implants: The usability contexts of control, convenience and care. *IEEE International Workshop on Mobile Commerce and Services*. doi:10.1109/WMCS.2005.11

McClure, Paul. 2023, February. Novel robotic system can 3D print cells onto organs inside the body. *New Atlas*. Retrieved from: Novel robotic system can 3D print cells onto organs inside the body (newatlas.com)

McGlaun, S. 2021. Researchers develop a rapid 3D printing technique that could be used for organs. *Slash Gear dot com* (March 11, 2021). Retrieved from: https://www.slashgear.com/researchers-develop-a-rapid-3d-printing-technique-that-could-be-used-for-organs-11663232

McNamee, M., and Edwards, S. 2006. Transhumanism, medical technology and slippery slopes. *Journal of Medical Ethics, 32*, 513-518. doi:10.1136/jme.2005.013789

MCRI (2020). Researchers use cutting edge technology to bioprint mini-kidneys. *Murdoch Children's Research Institute* (November 23, 2020). Retrieved from: https://www.mcri.edu.au/news-stories/researchers-use-cutting-edge-technology-bioprint-mini-kidneys

Meinhardt, A., Eberle, D., Tazaki, A., Ranga, A., Niesche, M., Wilsch-Bräuninger, and Tanaka, E. 2014, December 30. 3D reconstitution of the patterned neural tube from embryonic stem cells, *Stem Cell Reports, 3*(6), 987-999. https://doi.org/10.1016/.stemcr.2014.09.020

Mendis, D. and Rutschman, A.S. 2020. 3D printing of body parts is coming fast – but regulations are not ready. *The Conversation* (January 10, 2020). Retrieved from: https://theconversation.com/3d-printing-of-body-parts-is-coming-fast-but-regulations-are-not-ready-128691

Miller, L. 2014. We now control our evolution: Circumventing ethical and logical cul-de-sacs of an anticipated engineering revolution. *Science & Engineering Ethics, 20*(4), 1011-1025. https://doi.org/10.1007/s11948-013-9493-9

Millstone, E. and Van Zwanenberg, P. 2000. A crisis of trust: For science, scientists or for institutions? *Nature Medicine* 6(12): 1307–1308.

Moakes, R.J.A., Senior, J.J., Robinson, T.E., Chipara, M., Atanasov, A., and Grover, L.M. 2021. A suspended layer additive manufacturing approach to the bioprinting of tri-layered skin equivalents. *APL Bioengineering* (5) 046103. https://doi.org/10.1063/5.0061361

Moreno, J. 2015, December 5. Why the new gene editing technology matters. *Huffington Post*. Retrieved from http://www.huffingtonpost.com/jonathan-d-moreno/why-the-new-gene-editing_b_8697416.html

Mullen, T. 2021. The author who warned us against blindly trusting "the Science." FEE Stories (December 12, 2021). Retrieved from: https://fee.org/articles/the-author-who-warned-us-against-blindly-trusting-the-science/

Naghieh, S. 2021. 3D-printed organs could save lives by addressing the transplant shortage. *The Conversation* (April 6, 2021). Retrieved from: https://theconversation.com/3d-printed-organs-could-save-lives-by-addressing-the-transplant-shortage-132491

Nash, A.M., Jarvis, M.I., Aghlara-Fotovat, S., Mukherjee, S., and Veiseh, O. 2022. Clinically translatable cytokine delivery platform for eradication of intraperitoneal tumors. *Science Advances* (8,9). DOI: 10.1126/sciadv.abm1032

National Academies of Sciences, Engineering, and Medicine. 2016, October 13. *Exploring the state of the science in the field of regenerative medicine: Challenges of and opportunities for cellular therapies*. Washington, DC: The National Academies Press. doi:10.17226/24671

National Academies of Sciences, Engineering, and Medicine. 2017. *Human genome editing: Science, ethics, and governance.* Washington, DC: The National Academies Press. doi:10.17226/24623.

National Academy of Sciences 2020. *Heritable Human Genome Editing*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25665

Nelson, F. 2016, April 2. The return of eugenics. *The Spectator*. Retrieved from http://www.spectator.co.uk/2016/04/the-return-of-eugenics/

Noakes, S. 2016. CRISPR gene editing heads to human trial as cancer treatment. CBC News (June 26, 2016). Retrieved from http://www.cbc.ca/news/health/human-trial-crispr-1.3651755

Nora, D. 2015, August 15. The pitfalls and pioneers of transhumanism. *Worldcruch/L'Obs*. Retrieved from https://www.worldcrunch.com/tech-science/the-pitfalls-and-pioneers-of-transhumanism

Normile, D. 2019. Chinese scientist who produced genetically altered babies sentenced to 3 years in jail. *Science* (December 30, 2019). doi: 10.1126/science.aba7347. Retrieved from: https://www.science.org/content/article/chinese-scientist-who-produced-genetically-altered-babies-sentenced-3-years-jail

Ohta, S., Glancy, and D., Chan, W.C.W. 2016. DNA-controlled dynamic colloidal nanoparticle systems for mediating cellular interaction. *Science*; 351 (6275): 841 doi: 10.1126/science.aad4925

Ozbolat, I. ed. 2020. 3D bioprinting of cells, tissues and organs. *Scientific Reports* (August 18, 2020). Retrieved from: https://www.nature.com/collections/fejgfaihei

Rafat, M., Jabbarvand, M., Sharma, N. Xeroudaki, M., and Lagali, N. 2023. Bioengineered corneal tissue for minimally invasive vision restoration in advanced keratoconus in two clinical cohorts. Nature Biotechnology (41) 70–81. https://doi.org/10.1038/s41587-022-01408-w

Reardon, S. 2015. New life for pig-to-human transplants. *Nature, 527*(7577), 152–154. doi:10.1038/527152a

Regalado, A. 2015, August 12. Surgeons smash records with pig-to-primate organ transplants. *MIT Technology Review* (August 12, 2015). Retrieved from http://www.technologyreview.com/news/540076/surgeons-smash-records-with-pig-to-primate-organ-transplants/?amp&amp

Regalado, A. 2016. Human-animal chimeras are gestating on U.S. research farms. *MIT Technology Review* (January 6, 2016). Retrieved from http://www.technologyreview.com/ news/545106/human-animal-chimeras-are-gestating-on-us-research-farms/

Regalado, A. 2017. U.S. panel endorses designer babies to avoid serious disease. *Technology Review* (February 14, 2017). Retrieved from https://www.technologyreview.com/s/ 603633/us-panel-endorses-designer-babies-to-avoid-serious-disease/

Relman, D. 2014. Biological engineering, risk, and uncertainty—Synthetic future: Can we create what we want out of synthetic biology? *Hastings Center Report*, *44*(6), S36-S37. doi:10.1002/hast.397

Roco, M., & Bainbridge, W. 2002a. Converging technologies for improving human performance: Integrating from the nanoscale. *Journal of Nanoparticle Research, 4*, 281-295.

Roco, M., & Bainbridge, W. 2002b. Converging technologies for improving human performance: Nanotechnology, biotechnology, information technology and cognitive science. *NSF/DOC-sponsored report*.

Rodriguez, A. 2021. After researchers implanted microchips into his brain, a paralyzed man was able to write with his mind. *USA TODAY* (May 13, 2021). Retrieved from: https://www.usatoday.com/story/news/health/2021/05/13/stanford-researchers-implant-microchip-paralyzed-man-communicate/5070495001/

Sample, I. 2015. Baby girl is first in the world to be treated with 'designer immune cells'. The Guardian (November 5, 2015). Retrieved from http://www.msn.com/en-us/news/world/baby-girl-is-first-in-the-world-to-be-treated-with-designer-immune-cells/ar-BBmSnyc?ocid=spartandhp

Schubert, C., Langeveld, M., & Donoso, L. 2014. Innovations in 3D printing: A 3D overview from optics to organs. *British Journal of Ophthalmology, 98*(2), 159-161. http://dx.doi.org/10.1136/bjophthalmol-2013-304446

Schwartz, S., Regillo, C., Lam, B., Elliott, D., Rosenfeld, P., Gregori, N., and Lanza, R. 2015. Human embryonic stem cell-derived retinal pigment epithelium in patients with age-related macular degeneration and Stargardt's macular dystrophy: Follow-up of two open-label phase 1/2 studies. *The Lancet, 385*(9967), 509-516. doi:http://dx.doi.org/10.1016/S0140-6736(14)61376-3

Servick, K. 2019. Eyeing organs for human transplants, companies unveil the most extensively gene-edited pigs yet. *Science* (December 19, 2019). Retrieved from: https://www.science.org/content/article/eyeing-organs-human-transplants-companies-unveil-most-extensively-gene-edited-pigs-yet

Shields, B. 2020. Once experimental, Ste-Justine's Hospital prepares for 1,000th stem cell transplant. *CTV News* (March 7, 2020). Retrieved from: https://montreal.ctvnews.ca/once-experimental-ste-justine-s-hospital-prepares-for-1-000th-stem-cell-transplant-1.4843316

Stein, Rob. 2023. Experts weigh medical advances in gene-editing with ethical dilemmas. *NPR* (March 6, 2023). Retrieved from: Genome summit to weigh pros and cons of gene-editing : Shots - Health News : NPR

Sus, V. 2022. Genetic Engineering: Is It Ethical? *The Collector* (December 10, 2022). Retrieved from: https://www.thecollector.com/pros-and-cons-genetic-engineering/?utm_source=flipboard&utm_content=other

Thomson, J. 2021. The Singularity: When will we all become super-humans? *Big Think* (November 16, 2021). Retrieved from: The Singularity: When will we all become super-humans? - Big Think

Thompson, C. 2015, June. Move beyond differences. *Nature;* London, *522*, 415.

Tran, L. & Wilson, L. 2011. Nanomedicine: Making controllable magnetic drug delivery possible for the treatment of breast cancer. *Breast Cancer Research, 13*, 303. doi:10.1186/bcr2830

Ulanoff, L. 2014. Double amputee controls bionic arms with his mind. *Mashable.com* (December 18, 2014). Retrieved from http://mashable.com/2014/12/18/double-amputee-bionic-arms/

University of Toronto Faculty of Applied Science & Engineering. 2016, February 19. Shape-shifting engineered nanoparticles for delivering cancer drugs to tumors: Modular nanoparticles attached to strands of DNA can change shape to gain access to diseased tissue. *ScienceDaily*. Retrieved from www.sciencedaily.com/releases/2016/02/ 160219100318.htm

University of Utah Health (2021). Scientists enable blind woman to see simple shapes using brain implant. [Press Release, October 20, 2021]. Retrieved frm: healthcare.utah.edu

U.S. Food and Drug Administration. (2010, February 4). Definition of xenotransplantation. *U.S. Food and Drug Administration*. Retrieved from http://www.fda.gov/ BiologicsBloodVaccines/ Xenotransplantation/

Van der Waal J, Achterberg P and De Koster W. 2014. *Residential Preferences, Institutional Trust, Fear of Crime, Value Orientations, and Voting Behavior in the United States*. Dataset. Washington / Palo Alto: GfK Custom Research.

Vincent, C., Niezen, G., O'Kane, A., and Tawarz, K. 2016. Can standards and regulations keep up with health technology? *JMIR Mhealth Uhealth*. 2015 Apr-Jun; 3(2): e64. doi: 10.2196/mhealth.3918. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4526895/

Wacker, W. and Taylor, J. 1997. *The 500-year delta*. New York, NY: HarperCollins.

Wadhwa V. (2015, September 8). Why there's an urgent need for a moratorium on gene editing. *Washington Post*. Retrieved from http://www.washingtonpost.com/news/ innovations/wp/2015/09/08/why-theres-an-urgent-need-for-a-moratorium-on-gene-editing/

Weintraub, K. 2019. Despite controversy, human studies of CRISPR move forward in the U.S. Scientific American (August 13, 2019). Retrieved from: https://www.scientificamerican.com/article/despite-controversy-human-studies-of-crispr-move-forward-in-the-u-s/

Wiesing, U. and Clausen, J. 2014. The clinical research of nanomedicine: A new ethical challenge? *Nanoethics, 8*, 19-28. doi:10.1007/s11569-014-0191-0

Willett, F.R., Avansino, D.T., Hochberg, L.R., Henderson, J.M., and Shenoy, K.V. 2021. High-performance brain-to-text communication via handwriting. *Nature* (593) 249-254. https://doe.org/10.1038/s41586-021-93506-2

Woodall, T. 2021. NASA inches closer to printing artificial organs in space. *MIT Technology Review* (June 18, 2021). Retrieved from: https://www.technologyreview.com/2021/06/18/1026556/nasa-bioprinting-artificial-organs-space/