Research Article

Where Will We Draw the Line? Public Opinions of Human Gene Editing

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Abstract

The application of gene editing technologies to prevent or mitigate genetic disease in humans is considered one of its most promising applications. However, as the technology advances, it is imperative to understand the views of the broader public on how it should be used. We conducted focus groups to understand public views on the ethical permissibility and governance of gene editing technologies in humans. A total of 50 urban and semirural residents in the upper Midwest took part in six focus groups. Participants expressed multiple concerns about nonmedical uses of gene editing and its potential for unknown harms to human health, and were divided as to whether the individual patient or "medical experts" should be charged with overseeing the scope of its application. As potential stakeholders, the perspectives from the general public are critical to assess as genome editing technologies advance toward the clinic.

Keywords

ethics; moral perspectives; genetics; health; qualitative research; North America

Introduction

Recent advances in gene editing technologies have led some observers to predict a revolution in genomic medicine for the rescue or prevention of serious genetic conditions. Although several methods of gene editing exist (zinc-fingers [ZFNs] and transcription activator–like effector nucleases [TALENs]), the discovery the CRISPR/Cas9 system has been a particularly promising development. Because of its simplicity and cost-effectiveness, CRISPR/Cas9 has quickly been adopted by researchers, although the potential for off-target effects and varying efficiencies remain serious limitations to its clinical translation (Dai et al., 2016; Dunbar et al., 2018). Nevertheless, several clinical trials using CRISPR/Cas9 nucleases for somatic modifications are ongoing or planned in China, the United States, and Europe (Dunbar et al., 2018; Knapton, 2018; Lipschultz & Spalding, 2018; Rana, Marcus, & Fan, 2018).

In 2015, as a proof-of-principle study, scientists in China used CRISPR/Cas9 in nonviable human embryos to cleave the hemoglobin gene, reporting low efficiency and off-target effects (Liang et al., 2015). Several other labs in China followed suit (Kang et al., 2016; Tang et al., 2017) along with labs in Sweden (Callaway, 2016) and the United Kingdom (Fogarty et al., 2017). In 2017, the Oregon-based Mitalipov lab became the first group to correct a disease-related mutation using CRISPR/Cas9, correcting the *MYBPC3* mutation that causes hypertrophic cardiomyopathy. This experiment differed from other published studies, in that the embryos were first created using healthy donor eggs and a sperm donor heterozygous for the *MYBPC3* mutation and for the low mosaicism and high efficiency they reportedly achieved (Ma et al., 2017). Research up to this point had been in nonviable or viable embryos not intended for reproduction. However, in November 2018, the live birth of twin girls from genetically edited embryos was announced by a Chinese scientist, He Jiankui. This report has yet to be independently verified (Marchione, 2018; Regalado, 2018b). Ostensibly, the embryos were edited for HIV resistance through disabling the *CCR5* gene; one embryo had two edited alleles, but was mosaic with an off-target effect, and one embryo was heterozygous for the modification. A second pregnancy using a third genetically edited embryo is reported to be in its early stages (Begley, 2018). China has since suspended He's research activity saying it was in violation of Chinese laws and regulations.

Many national and international professional societies have proposed guidelines on human gene editing in embryos out of concern for ethical, safety, and legal ramifications of germline modifications (Brokowski, 2018). Although responses have ranged from calls for a complete moratorium on human embryo research and/or the gestation of genetically modified human embryos to

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term, to those who argued this research should cautiously proceed toward clinical application, the majority agreed that clinical application of human germline genome editing was premature without further characterization of the safety and efficacy of CRISPR/Cas9 (de Wert et al., 2018; Friedmann et al., 2015; Ishii, 2015; McCarthy, 2015; National Academies of Sciences, Engineering, and Medicine, 2017; Ormond et al., 2017). Following the announcement of the implantation and subsequent birth of genetically edited embryos, many researchers and bioethicists renewed calls for caution or have argued for a temporary moratorium on gene editing for reproductive purposes, given the secrecy and lack of transparency by the researcher on the nature of his work, the lack of institutional or government oversight, and the premature application of this technology prior to a full vetting of the possible health consequences of introducing novel genome variations of uncertain significance (Center for Genetics and Society, 2018; Regalado, 2018a).

Scholars of the public understanding of science and science and technology studies have long stressed the importance of more robust and systematic attention to public views of medical technology and translation (Baltimore et al., 2015; Hough & Ajetunmobi, 2017; Ishii, 2015; Jasanoff, Hurlbut, & Saha, 2015; Scheufele et al., 2017). Although several surveys have been conducted to elicit general public opinion and attitudes on germline and somatic gene editing (McCaughey et al., 2016; STAT & Harvard T.H. Chan School of Public Health, 2016; Scheufele et al., 2017), these instruments are limited in their ability to assess participant comprehension, viewpoints on the ethical acceptability of this technology, and the circumstances in which members of the public would consider using gene editing to any meaningful depth. Given that members of the general public are potential stakeholders in the use of somatic and germline gene editing, it is important to identify the social and moral perspectives that individuals use to construct their beliefs and attitudes about the acceptability of genome modification. In light of the recent live birth, a more in-depth exploration of the concerns and aspirations of the broader public with regard to the potential implications of this technology is even more vital (Hasson & Darnovsky, 2018). This study sought to understand opinions of members of the public on gene editing in humans and the circumstances, if any, under which it would be morally acceptable for use in humans.

Method

Recruitment

We conducted focus groups with members of the general public to understand how they engaged with scenarios on possible applications of gene editing in humans. All study methods were approved by the Mayo Clinic Institutional Review Board. A local contract research organization invited both urban and semirural residents in the upper Midwest to participate in a prescheduled focus group. Inclusion criteria included local residence, conversant in English, and age 18 or older. All participants provided written informed consent.

Data Collection

Six focus groups of six to 10 participants each were conducted between March 1 and 22, 2017, and lasted 2 hours each. Sixty individuals were invited to participate; a total of 50 participants took part in the focus groups. As participants chose which of the prescheduled focus groups they would attend, each group differed in composition with regard to the age, gender, and employment status of individual participants. Focus groups were moderated by three members of the institution's qualitative research core, and were semi-structured following a moderator guide that described two scenarios of germline and somatic gene editing for the treatment of disease in humans, with follow-up questions asked by the moderators for clarity and depth (see Supplemental Table B for sample follow-up questions). Participants completed a brief survey of biographical information before being presented with the two scenarios. To gauge participants' native understanding of genetic interventions and to prevent undue influence on participant responses, an education brief on the techniques and risks/benefits of gene editing or gene therapy was not provided.

The germline scenario described the alteration of human embryos to prevent heritable diseases. It also stated that some people see gene editing as wrong or that it might be used to pick the attributes of children, and that gene editing may cause unintended side effects. The somatic scenario stated that gene therapy has been used to treat certain diseases by delivering new genes into a patient's cells. It also noted that gene therapy is still experimental, requiring Food and Drug Administration (FDA) approval that may not be approved in time for terminal patients to access the therapy, and some people argue that it should be up to doctors and families to decide whether a treatment is acceptable for an individual patient rather than a government agency. Participants were invited to discuss their understandings of the technology and its abilities along with their opinions of appropriate contexts for the technology's application. After each focus group, the qualitative research staff met to discuss how the session went, and to propose potential changes and additions to the moderators' guide. The focus groups' audio recordings were submitted to an external transcription service for verbatim transcription, returned to the project team, and reviewed for accuracy.

Data Analysis

The central methodological approach for reviewing focus group transcripts consisted of an iterative qualitative thematic analysis based on principles of grounded theory (Donovan, 1995; Strauss & Corbin, 1990). As transcripts were completed, two coding analysts (A.K., J.E.) independently reviewed the content for potential themes and patterns, whereas another prepared a summary of recruitment and observational notes (D.F.). When all six transcripts were complete, the two coders met to formulate a preliminary codebook to present to the full project team. The codebook was developed using an iterative parsing mechanism that grouped concurrent themes by thematic content according to the principles of grounded theory (Donovan, 1995; Strauss & Corbin, 1990). Two transcripts were independently coded by each coder using the preliminary codebook. After feedback from the full project team and refinement of the codebook based on early application, a final codebook was applied to all transcripts (Supplemental Table B for sample coding analysis). The early inductive coding, combined with the project team's a priori deductive requirements, resulted in a comprehensive coding schema, applied to the full data set. When all data were independently coded by two analysts, they met to arrive at consensus for all material. The reconciliation was then applied using NVivo 11 software, where consensus documents were stored and further analyzed.

Results

Participant Demographics

Table 1 displays participant demographics. A total of 50 individuals participated in six focus groups. The majority of participants were slightly older with an average age of 51 years (56% were above 50 years) and had completed some level of higher education (90% with some college education or advanced degree). Illustrative quotes for each of the inductively derived themes are presented below. Quotes have been minimally edited for readability.

Table 1. Participant Demographics.

	$n = 50$ (%)
Female	25 (50.0)
Male	25 (50.0)
Average age	51
20–30	2 (4.0)
31–40	9 (18.0)
41–50	12 (24.0)
51–60	13 (26.0)
61–70	10 (20.0)
71–80	2 (4.0)
80+	2 (4.0)
Employment	
Decline to state	2 (4.0)
Education	5 (10.0)
Finance	1 (2.0)
Food service/hospitality	1 (2.0)
Health care	13 (36.0)
Retail	5 (10.0)
Retired	12 (24.0)
Self-employed	2 (4.0)
Technology	1 (2.0)
Unemployed	3 (6.0)
Education	
Some high school	1 (2.0)
High school diploma	3 (6.0)
Some college	4 (8.0)
Two-year college degree	8 (16.0)
Four-year college degree	16 (32.0)
Master's degree	11 (22.0)
Graduate degree	6 (12.0)
Decline to state	1 (2.0)

Participant Knowledge and Support of Gene Editing

In response to a general prompt and the two scenarios presented on germline and somatic gene editing, participants discussed their familiarity with genetics and gene editing. Varying levels of knowledge of genetics and gene editing were evident among participants. Most conceived of genetics as "DNA," "what you get from your parents," "inherited diseases," or "personal makeup." The majority of participants were less specific in their discussions of germline or somatic gene editing with frequent cross talk among participants discussing the definition of an embryo or genetic material. Few participants were knowledgeable about the process of gene editing in a human embryo; many expressed confusion as to the timeline and methodology of gene editing.

Many participants expressed strong support for applications of gene editing for disease prevention, especially for serious chronic, progressive, or life-threatening diseases:

> Yeah, exactly. I mean, ideally, if what you say is precisely what would happen, who would argue with that? Oh, we could take away your blindness, we could take away your deafness, we could take away your tendency to get tendonitis, we could take away your tendency to perhaps have diabetes, or heart disease, and that type of thing. I mean, you'd be an idiot to say no we don't want to fix this.

The benefits of gene editing were often considered in light of participant's own medical histories or were hypothesized as a potential medical treatment for themselves, their families, or future offspring:

> I think if I were a young parent wanting to have children and I knew that in my family line there was some serious disease that could be prevented for my children, or maybe if somebody carried this they wouldn't be viable to come to term, if there was something that I could do to prevent that I think I would be interested as a parent to have the embryo checked and to have that line taken care of to give my family a chance to have a child or to have a healthy child.

Many participants were hopeful that gene editing technologies could be used to improve human health. Although participants offered nuanced views on the acceptability of gene editing, no participant was opposed to gene editing as a medical therapy or thought research into this technique should be prohibited outright.

Who Should Oversee Human Gene Editing?

Participants were invited to reflect upon the regulation of gene editing technologies as described in the somatic gene therapy scenario. Participants were divided over who should oversee the use of gene editing technologies.

Gene editing should be individually governed. Some participants argued that it should be left up to the individual to use the therapy, even if that therapy is still in the experimental or preclinical stage of development. This group believed that it should not be left to the "medical elites" to limit the use of this technology, but that patients should be able to request gene therapy for their own self-directed purposes:

> Okay, and I'm saying it should be up to the individual whether they want to accept that potential. I shouldn't have to have FDA approval, necessarily, to potentially get the treatment.

Participants expressing individual governance of gene editing did so, however, with the understanding that this technology was subject to some level of safety and efficacy testing, even if immediate side effects and long-term effects were unknown in human participants:

> So, they probably had some preliminary testing and such that says this, in theory, should work. I don't see why you would necessarily have to worry what the government says about it. You know, if the person that has the affliction wants it, and the doctors think this is the way to go, then do it.

Even if participants accepted that gene therapy should only be initiated following a shared decision-making process with their provider, rather than as a result of their individual request, many were opposed to higher levels of oversight, citing the difficulty of accessing medications that are in use in other countries. These participants typically viewed FDA or government oversight as a hindrance to beneficial therapies rather than as an important safeguard of therapeutic safety and efficacy:

> I don't like the idea of the government telling me I can't do something that might save my life. I understand that there might be risks involved. Ethically, should we have them determine who should get this treatment and when they should get this treatment? As long you go in fully aware that this may not work, this may not be what you expect, and there may be side effects, I don't see why the government should be able to stop you from doing it.

Gene editing should be collectively governed. In contrast, another group of participants advocated for some level of regulation at either an institutional or federal level, with some arguing that experts should be involved in the oversight process. Those participants in favor of expert involvement stressed the limited knowledge of the general public about these technologies:

> But really, don't you think the general public, we know really nothing compared to an educated person that is in research and that are doing that as a business . . . for the most part, the education gap is monstrous.

Participants favoring collective governance stressed their potential for misuse and the possibility that vulnerable patients could be exploited as this technique is adapted for clinical use:

> There needs to be some oversight. I mean, currently there are places where there are unscrupulous doctors who will offer stem cell therapy, which is nothing more than just a sham . . . but you're desperate and you'll go for anything and so I think you do need be concerned about and have some sort of safeguards so you don't have people taking advantage of people that are desperate.

In particular, several participants commented on the financial and professional pressures physicians and researchers may face in applying this technology:

> I think most [researchers] are honorable, but when you get up into where they're doing, hey, where are the bucks coming from? . . . Now that's not a researcher when you're up there, that's a bureaucrat. He ain't a technician. The only thing he's technical on is who I'm going to squeeze the next buck out of. And I can't, I won't speak for his morals.

Many participants felt that the input of individual patients and doctors should be solicited and used to determine how these technologies are used. They indicated that as stakeholders, their input should be valued and considered, referencing the medical profession's history of paternalism or dismissal of nonexpert opinions:

> I kind of think it should be parents, doctors, and some ethics advisor . . . As parents, as just as people and patients, we are so much informed, we want to be more informed, and we want to make informed decisions. I think we're a little bit past the era of, okay doctor, whatever you say. We're a little more informed, but we also need to know from somebody who's more educated, is this the right thing? What's the next step about?

This group of participants was supportive of a more egalitarian approach to oversight, with regulatory power spread more equally between patients, health care providers, institutions, and government stakeholders:

> And so, I think wherever it is, if it's on the hospital level or the government or wherever it's at, that we need some sort of ethical balance with equal power between the doctors and the families.

Other participants questioned whether expert consultation with the wider public would be truly genuine, suggesting that exercises in public dialogue are often more symbolic gestures in support of democratized science rather than authentic attempts at broadening stakeholder input:

> I mean, what it sounds to me is you're looking to me for a possible answer to a potential public relations problem. I mean, that's the way I'm looking at it, because if you're a researcher, why would you care what the community thinks?

In general, the division between those who favored individual or collective governance was reflected in the positive or negative attitudes expressed about government regulation. Personal or family histories with disease and/or ease or difficulty in accessing treatments were frequently used as personal anecdotes when expressing their thoughts on the level of regulation most appropriate for gene editing technologies.

Should There Be Limits to Human Gene Editing?

Participants were asked to reflect upon whether gene editing should be limited to certain diseases or circumstances, as well as whether potential future consequences of gene editing should influence the use of this technology to correct disease or improve human health.

Therapeutic versus nonmedical uses. There were high levels of consensus among focus group participants that it was acceptable to use gene editing to prevent or correct serious diseases, with cystic fibrosis, muscular dystrophy, Parkinson's disease, and multiple sclerosis being referenced by participants:

> In my mind, number one, start with these diseases that we can see, I mean, again, MS, and Parkinson's, and those things. Get on the ball with those things because there are other countries that are farther advanced than we are.

There was less agreement about whether genetic interventions should be permitted for multifactorial diseases such as Type 2 diabetes, which might be prevented or mitigated with changes to diet or lifestyle:

> Oh, you could argue that having genetics to give people a more muscular build helps medically because it prevents obesity, which prevents type 2 diabetes and other conditions like joint problems. And that starts leading into the whole cosmetic more than the medical.

Many participants voiced concern that allowing human gene editing could lead to a "slippery slope," wherein parents are eventually allowed to choose desired characteristics for their children. Many expressed alarm that gene editing technologies could be used for enhancement purposes or to select nonmedical traits such as eye or hair color:

> And the fact that it's a disease today, but tomorrow it's going to be creating the next Hulk Hogan, or whatever it is, there's no limit to what they can do with it. It starts out with something that's going to be good to help mankind and something's going to destroy other aspects of it and people are going to take it to another edge.

There was general consensus among participants that altering embryos to create a "designer baby" would be an inappropriate use of gene editing. In this context, participants referenced eugenic histories (e.g., Nazi Germany) in support of their positions:

> I had slippery slope on my card as well . . . this makes me uncomfortable . . . it can go down the road where you get the preferential gene engineering, and then let's go the road of the blue eyes, blond hair and we've done that in history already . . . The moral guidelines for this are going to be extremely hard.

Unforeseen consequences of gene editing. A number of participants remarked that gene editing could have unintended and unforeseen consequences. They stressed the limited knowledge and fallibility of humans, emphasizing that it is only a matter of time before a mistake is made with this technology:

> The embryo is . . . I think we're tinkering with something we clearly do not know enough about. I mean, we couldn't come up with some genetic organism to help an adult through diabetes, and you want to go tinkering with something that's not born yet? That has many ways, exponential ways, of doing things that might turn out slightly

> different than the way our test models indicate that it should happen. I think that's nice to look into, but I'd be leery about somebody messing with it.

A few participants stated that we may not know all the functions of a given gene, which if altered, may have significant societal or environmental ramifications:

> During times of famine, that fat gene was probably responsible for the survivors who had the fat gene. I mean, there are reasons sometimes for those genes. We think now, oh, we need to get rid of that and that might not be the best thing. I think we have to look at each case. I'm not sure exactly where we should draw that line, but I would say life threatening diseases. It's worth the risk. And the thing to remember is, if you're modifying an embryo, it might be 30 or 40 years before you realize all the consequences of that modification.

Although the potential for negative effect to human health or the environment was raised by many participants, this did not seem to drive participants to reject gene editing as a medical–scientific endeavor. However, some participants argued genomic research should proceed with caution, given this potential for harm, and should be limited to severe genetic disease, given the uncertain long-term impact to human health.

How Will Human Gene Editing Affect Society?

Focus groups participants extemporaneously reflected on the larger social impact of gene editing technologies as part of their discussion on somatic and germline editing. Participants were apprehensive about how the implementation of genetic interventions will affect society.

Impact to social diversity. Concerns were raised that gene editing could promote genetic conformity to the detriment of social diversity and the collective functioning of society:

> I've got the quiet gene. I've got three kids and they're all totally different. They're all people, they all have their own gifts that they can give to the world and they're just so different. I think if everyone was the same, it would be pretty boring and we wouldn't be able to function because we need people for all different kinds of jobs.

Many participants also expressed alarm that gene editing could, intentionally or not, eliminate individuals who uniquely contribute to society. This was largely viewed as an undesirable outcome with unknown consequences:

> And there have been people throughout history who have had some really bizarre and strange disease processes, and yet they've ended up being probably some of the brightest in the world.

Impact to the disability community. Several participants also expressed concern as to how this technology will affect the disability community and how it may affect the societal value of individuals with particular genetic conditions:

> I watch science fiction, too, and another concern is that if you start eliminating disease and someone had the disease, how would they be viewed in society? Is that kind of like, well, if we're willing to eliminate the disease and somebody has the disease do we eliminate the person with the disease? I mean, it's a little scary to think about the ramifications that might come from that, too. Does society look down on them because they did have the choice to get rid of the disease?

Participants worried that the refusal of gene therapies for the prevention of disability of disease by individuals or parents might negatively affect insurance coverage or access to social services:

> But I think that does beg the question of if I chose not to and my child needs services, is it going to . . . well, you had the option of preventing these so why should the school pay for these services and this service, because you had the option of . . . I mean, you just never know, that could be someone's argument. You made a choice to not do this.

Some participants stressed the contributions of the disabled to their families and society more broadly. These participants postulated how society might be affected if gene editing prevented their existence, as they felt the less abled had a unique role in helping others to become more tolerant and inclusive.

What Ethical Principles Should Guide Gene Editing Technologies?

In the course of their discussion, participants indicated it was important to consider the larger ethical ramifications of gene editing technologies, beyond the immediate concerns of safety and appropriate uses of this technology. Participants emphasized that society should not lose sight that this technology is used on humans and, as such, should be treated with caution and guided by certain moral standards:

> I think helping us define that slippery slope, where that slope gets too slippery . . . And then also what Ricky said, it's making sure that the right people are informed and we never get too laissez-faire about well, it's just this little test or it's just this little tweak. Understanding that that's not just a gene, that's a human and a human life and you don't just get to make that decision.

Many stressed the importance of autonomy and stated that no individual should be forced to use this technology.

A few participants noted the lack of consent from offspring subjected to germline modification and/or the right of the embryo/fetus to an open future:

> Is it ethical to change someone's DNA without their permission? I'm not sure where I fall on this yet, but just thinking about it does bring up some questions. I'd love to see kids grow up without genetic diseases, but at the same time do we have the right to go in and change them like that?

Others noted the responsibility of researchers to use beneficence in applying genetic interventions, arguing that it should only be used for diseases that are severe or life-threatening and should not be used to select traits that suggest that some characteristics are more inherently valuable than others or for their own personal gain:

> And you get to a point where you start saying that certain traits are better than other traits. That maybe being 6′2″ is better than being 5′8″, or 5′1″ in my case. Or blond hair is better than red hair or whatever, and when you start getting over in that line, I don't see where that is a positive. You're marginalizing people. You're not improving, truly improving, the human race. That's strictly a cosmetic change. It's not truly a useful change like correcting a medical condition or a potentially life-threatening condition or something.

Some participants noted that the path to effective clinical treatments will likely be marked by significant failure. These participants stressed the importance of transparency in the research process, with clear accounting of any adverse outcomes. Some expressed concern that profit-driven companies may push this technology toward the market before long-term safety is known:

> I think you have to open the books. You have to show us your qualifications. What you have done, what you have succeeded at, what your failures were, and what you learned from your failures so that, okay, we're making progress and we're not the all-know-it-all.

More generally, participants in each focus group expressed their concerns about unethical uses of gene editing by stressing the "slippery slope" of gene editing, where it will be used to fulfill lower order desires for improved appearance, intelligence, and strength by the wealthy and privileged. A few of these participants postulated that it could lead to further separation between the wealthy and poor as society is divided between the genetic "haves" and "have-nots."

Discussion

Although the potential clinical applications of gene editing technologies have been heralded as one of the most promising means of improving human health through the reduction of disease, considerable social and ethical concerns persist. These parallel narratives of promise and peril were evident in the perspectives of our study participants, many of whom saw significant potential for benefit while expressing concern about potential misuse.

As gene editing enters the clinic, members of the general public will be affected by this technology, either as recipients or family and friends of target patient groups. Understanding their viewpoints will be helpful in determining public acceptance of future research as well as evaluating the most appropriate means of regulation and oversight of genetic technologies; this is especially true because the majority of this research is taxpayer funded and subject to laws and regulations enacted by democratically elected representatives. Broad public support is needed for effective clinical translation of gene editing. Indeed, one criticism of the recent announcement of the birth of twins from genetically edited embryos is that this technique was applied prior to public acceptance and support of germline gene editing. Furthermore, assessing the general public's knowledge of and attitudes toward gene therapies may be helpful in public engagement and education on this issue.

Participant Understanding of Gene Editing

Participant viewpoints were shaped by their situational contexts; many participants referenced their own individual or family medical histories, their genetic risk of certain conditions (hereditary cancer, heart disease), their hopes for their offspring, and relationships with disabled family members or friends. Although many expressed concerns about the safety and efficacy of gene editing, most participants spoke positively about how gene editing could be used to reduce the burden of human disease. It is unclear whether participants understood the specific health risks of gene editing, including off-target effects, although many suspected long-term safety, given the nascent nature of this technology.

Many participants appeared to overestimate what is possible with human gene editing, especially the possibility that the technology might be used to create "designer babies." Given that traits such as eye and hair color, physical strength, and intelligence are polygenic and shaped by dozens to hundreds of genes with varying epistatic relationships and penetrance, it is extremely speculative that gene editing could be used to generate a specific phenotype "to order" (Belluck, 2017; Yong, 2015). Nonetheless, many participants seemed to believe that this prospect was near, and voiced concerns about a dystopian future in which children are designed to particular specifications. Other comments seemed to imply a commitment to some form of genetic determinism, especially for complex polygenic

traits such as intelligence, which may have influenced participants' views about germline editing.

Acceptable Applications

Many participants voiced sincere moral and ethical concerns about human germline editing. Participants agreed that the prevention or correction of serious chronic or terminal conditions was an appropriate and beneficent use of gene editing, but expressed concerns that widespread implementation of this technology may lead to the eugenic selection of children or promote nonmedical human enhancement. The majority of participants approached the question of what traits or disorders were appropriate to target in black and white terms; only a few comments appeared to highlight nuance in the distinction between therapies and enhancements. This is an area that needs more exploration, especially given the widely publicized birth of twins with genome modifications for HIV resistance, because this action was widely condemned as medically unnecessary with little health benefit.

These findings are consistent with recent surveys suggesting that the U.S. public is less accepting of gene editing for nonmedical traits such as intelligence or physical characteristics, with 72% of 2,537 surveyed U.S. adults agreeing that gene editing for a serious congenital disease is appropriate, and 80% agreeing altering genes to increase intelligence is an inappropriate use of medical technology (Pew Research Center, 2018). Similarly, almost two thirds of 1,600 U.S. adults expressed some support for therapeutic genome editing and only one third supporting genome editing for enhancement (Scheufele et al., 2017). More than two thirds of 1,489 U.S. adults surveyed in a 2016 STAT-Harvard survey believe it should be illegal to edit a human embryo for disease prevention and 83% agreed that it should be illegal for nonmedical enhancement (STAT & Harvard T.H. Chan School of Public Health, 2016).

Although qualitative research into stakeholder perspectives is currently ongoing, less qualitative data exist on attitudes of the general public on genetic interventions. One pilot study in Wales found participants were supportive of somatic gene therapy, but were generally more ambivalent toward the use of germline gene therapy to prevent disease (Iredale, Dolan, McDonald, & Kirk, 2003). Similar to the views expressed by focus group participants in the present study, a 2005 mixed-methods study by the Wellcome Trust found that group discussion participants were supportive of somatic gene therapy for serious and life-threatening diseases, even if gene therapy carried some risk. Some participants were supportive of germline therapy to correct for conditions such as Down syndrome, autism, alpha thalassemia, or cystic fibrosis. However, these participants were opposed to the use of gene therapy for nonmedical or enhancement purposes (Wellcome Trust, 2005).

Focus group participants were also concerned that human gene editing may promote biological uniformity, potentially to the detriment of societal diversity. Some participants emphasized the further stigmatization of disabled persons as a possible outcome of gene editing. These participants expressed concern that a universal moral imperative for "procreative beneficence" (Savulescu, 2001) may emerge causing undue coercive influence or violations of individual reproductive autonomy. Indeed, the ethical concerns expressed by focus group participants are paralleled in discussions of bioethicists, researchers, and public commentators (Baltimore et al., 2015; Ishii, 2015, 2017; Lander, 2015; Lanphier, Urnov, Haecker, Werner, & Smolenski, 2015; Nuffield Council on Bioethics, 2016).

Participants also raised the possibility that gene editing may have unintended effects, especially in relation to the unknown functions of a given gene and the generational effects of germline gene editing. Some participants cited made-up hypothetical examples that reflect the real-life effects of modifying genes with pleiotropic effects. Recent scientific studies, for example, demonstrate that genetically modifying p53 not only protected mice against cancer but also induced a phenotype associated with early aging (Tyner et al., 2002). Similarly, genetic variants have been identified that decrease risk of some diseases but increase the risk of others (Stanford & Bottini, 2014).

Although lacking in specifics, many participants seemed to share the concern that it is premature to introduce germline editing in the clinic, given the unknowns surrounding its safety and efficacy. The safety profile of CRISPR/Cas9 has yet to be fully characterized; safety concerns include the potential for off-target effects, embryo mosaicism, and human adaptive immunity to Cas9 proteins, which may trigger an inflammatory attack or prevent the genetic correction (Charlesworth et al., 2018; Wagner et al., 2018). Two recent reports also suggest that genetically edited cells may be at increased risk to become oncogenic (Haapaniemi, Botla, Persson, Schmierer, & Taipale, 2018; Ihry et al., 2018). Moreover, many generations will need to be observed before it is exactly known how modifications to endogenous DNA will affect the health of future generations (Cwik, 2017; Friedmann et al., 2015; National Academies of Science, Engineering, and Medicine, 2017). Participants agreed that the safety of human genome editing needs to be more fully established before it is attempted in human embryos intended for gestation. This is consistent with the concerns of many research scientists, bioethicists, and other stakeholders in response to the birth of the genetically edited twin girls, who argue that the biological outcomes

of both on-target complexities and off-target effects following CRISPR/Cas9 genome edits are largely unknown and need to be more thoroughly researched before any future reproductive attempts are made (Begley, 2018; Weintraub, 2018).

Sources of Authority

Focus group discussions revealed a tension between viewing human genome editing as an individual pursuit versus viewing it as an activity that should be guided by some form of collective governance. Some participants advocated for the individual self-directed use of gene editing, while acknowledging its potential for misuse and harm. This group was vocally opposed to any form of institutional or governmental regulation, preferring instead that individual choices (with possible consultation from a medical professional) be allowed to determine uses of gene editing. Their opinions appeared to be shaped by their preexisting support of allowing terminally ill patients the "right to try" experimental therapies that have not been approved by the FDA, and a skepticism that government bureaucracy was preventing effective treatments used in other countries from reaching patients in the United States.

Other participants recognized the general public's limited knowledge of this genetic technology and preferred that decisions regarding the application and scope of gene editing rest with medical and scientific experts. These participants supported some form of regulation, whether at a government or institutional level, to ensure human gene editing is implemented in a safe and ethical manner. Although these participants assigned the primary oversight of these technologies to a group of medical and scientific "elites," they still felt that patients and physicians should contribute to these discussions. In general, participants who argued expert input was necessary for sensible regulation were supportive of a collective or democratic approach to the regulation of genome editing technologies.

This debate over regulatory scope is not unexpected, given the lack of consensus among the broader U.S. public. In a prior study, when asked to choose between whether "scientists, physicians, and other technological experts" or "government officials and policy makers" should have decision-making authority over germline engineering (therapeutic or enhancement), the majority (53%) chose the "experts," 9% chose "government officials," with 31% selecting "other/neither" (STAT & Harvard T.H. Chan School of Public Health, 2016). U.S. public opinion surveys also routinely rank medical doctors and scientists as trustworthy (Gallup, 2017; Pew Research Center, 2016a). This high trust may be why some study participants believed medical and scientific experts were the most appropriate authorities to regulate genome editing. Interestingly, focus group participants landing on either side of this regulatory divide generally agreed that self-regulation by researchers or biotechnology corporations should not be permitted, given the potential influence of financial motivations and the unique vulnerabilities of patients who may be in search of a miracle cure.

A literature search revealed only two qualitative studies that discussed participant attitudes on the regulation of genetic intervention. Most participants in group discussions in the United Kingdom thought government should be involved in the regulation of gene therapy, although some participants thought doctors and patients should be involved as well (Wellcome Trust, 2005). In a smaller study, participants were supportive of regulation to prevent abuse, but were generally trusting of scientists and their efforts to develop therapies to improve human health (Iredale et al., 2003). The tension between individualism versus collective governance has been observed in other recent debates over therapies with dubious clinical safety and efficacy, including the use of stem cell therapies, "expanded access" or "compassionate use" of non–FDA-approved therapies, and "right-to-try" legislation more broadly (Charo, 2016; Scharf & Dzeng, 2017; Walker, Rogers, & Entwistle, 2014). This tension is not limited to an American context, as citizens of European countries also express dubious trust in government authority and cite concerns over improper industry influence on matters related to health (Bergman, Eli, Osowski, Lövestam, & Nowicka, 2019; Fournier & Poulain, 2018). Given that these issues are prominently debated in the public square, it is essential to understand how this dualistic approach to governance may inform debates about the implementation of future therapies that may be desired by patients, but will be subject to a lengthy trial process before they are offered in the clinic, including gene editing technologies.

Limitations

Despite the fact that the study population scored slightly higher than national averages in terms of educational achievement and that one third of our participants were employed in the health care sector, participants demonstrated low scientific literacy about gene editing technologies and genetics more generally. This appears to be in line with the general public's lack of knowledge about this area of research. A recent Pew Research Center study (2016b) found that 42% of Americans have not heard anything about gene editing, whereas 48% have heard a little. The same study found that respondents with at least a little knowledge were more inclined to want gene editing to reduce serious diseases in their child (57%) as

compared with those who had not heard of this technology (37%). Similarly, a STAT-Harvard survey found that 69% of Americans had not heard much about germline editing, and those who had heard or read about therapeutic germline editing were twice as likely to agree that it should be legal to change the genes of unborn babies to reduce their risk of developing certain diseases (STAT & Harvard T.H. Chan School of Public Health, 2016).

It is unclear whether most participants were able to make a meaningful distinction between somatic and germline gene editing. Participants' lack of familiarity with somatic or germline genome editing may have influenced their responses, either positively or negatively. Although this might have been ameliorated by a brief educational summary at the beginning of each focus group, it may have influenced participants' free and open responses. Participants may also have been reluctant to provide contrarian opinions to avoid disrupting group cohesion or consensus, or due to lack of familiarity with the subject matter. In addition, individual group composition or dynamics may have influenced participant responses.

Focus groups were conducted in English, were relatively heterogeneous, and took place within a geographically limited range in the upper Midwest in a city that contains a large academic medical center. As such, the educational achievement and health literacy of the study population is higher than the national average. Participants were also more likely to have health care coverage and access to tertiary care. More research with geographically and demographically diverse populations is needed to fully understand the public's reaction to this emerging technology.

It should also be noted that this study took place prior to the public announcement and considerable media attention of the birth of twin girls from genetically edited embryos in China. The shift from the hypothetical possibility of germline editing of human embryos to its reality in this controversial study may increase public attention and scrutiny of the ethics and appropriate regulatory oversight of germline genome editing. Much opportunity remains to more fully explore the reaction of the public to this announcement and how it may influence stakeholder views of genome editing as a scientific enterprise.

Conclusion

Advances in genome editing raise serious questions about its potential applications in humans. The voices of our focus group participants offer a window into how human gene editing may be viewed by the general public. Although focus group participants expressed optimism about the use of genome editing in medicine, they also voiced multiple ethical concerns. These concerns focused largely on nonmedical uses of gene editing, its implementation prior to a comprehensive understanding of its safety and efficacy, the possibility of unknown health and environmental consequences, and worries that gene editing may affect how society views those with disabilities of genetic origin. The difference of opinion that we observed regarding the oversight of human gene editing suggests that additional public engagement is needed between the medical and scientific community, government regulators, and the general public, including educational outreach. Such engagement can not only help to determine the scope of appropriate regulations but also help build trust in the bodies charged with that oversight. As the discussions we observed here frequently paralleled the conversations by academic, industry, and government stakeholders on the ethical applications and limitations of gene editing, it is critical that the views of the public are not discounted, but rather occupy a central place in the democratic pursuit of scientific advancement.

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References

Baltimore, D., Berg, P., Botchan, M., Carroll, D., Charo, R. A., Church, G., . . . Yamamoto, K. R. (2015). A prudent path forward for genomic engineering and germline gene modification. *Science*, *348*, 36–38. doi:10.1126/science.aab1028

Begley, S. (2018, November). Amid uproar, Chinese scientist defends creating gene-edited babies. *STAT News*. Retrieved from https://www.statnews.com/2018/11/28/chinese-scientist-defends-creating-gene-edited-babies/

Belluck, P. (2017, August). Gene editing for "designer babies?" Highly unlikely, scientists say. *The New York Times*. Retrieved from https://www.nytimes.com/2017/08/04/science/gene-editing-embryos-designer-babies.html

Bergman, K., Eli, K., Osowski, C. P., Lövestam, E., & Nowicka, P. (2019). Public expressions of trust and distrust in governmental dietary advice in Sweden. *Qualitative Health Research*. Advance online publication. doi:10.1177/1049732318825153

Brokowski, C. (2018). Do CRISPR germline ethics statements cut it. *The CRISPR Journal*, *1*, 115–125. Retrieved from https://www.liebertpub.com/doi/abs/10.1089/crispr.2017.0024

Callaway, E. (2016). Gene-editing research in human embryos gains momentum. *Nature*, *532*, 289–290. doi:10.1038/532289a

Center for Genetics and Society. (2018). *Civil society statement to the organizers of the "second international summit on human genome editing."* Retrieved from https://www.geneticsandsociety.org/internal-content/civil-society-statement-organizers-second-international-summit-human-genome

Charlesworth, C. T., Deshpande, P. S., Dever, D. P., Dejene, B., Gomez-Ospina, N., Mantri, S., . . . Porteus, M. H. (2018). *Identification of pre-existing adaptive immunity to Cas9 proteins in humans*. BioRxiv. Retrieved from https://www.biorxiv.org/content/biorxiv/early/2018/01/05/243345.full.pdf

Charo, R. A. (2016). On the road (to a cure?)—Stem-cell tourism and lessons for gene editing. *The New England Journal of Medicine*, *374*, 901–903. doi:10.1056/NEJMp1600891

Cwik, B. (2017). Designing ethical trials of germline gene editing. *The New England Journal of Medicine*, *377*, 1911–1913. doi:10.1056/NEJMp1711000

Dai, W.-J., Zhu, L.-Y., Yan, Z.-Y., Xu, Y., Wang, Q.-L., & Lu, X.-J. (2016). CRISPR-Cas9 for in *vivo* gene therapy: Promise and hurdles. *Molecular Therapy—Nucleic Acids*, *5*, e349. Retrieved from https://www.sciencedirect.com/science/article/pii/S2162253117300586

de Wert, G., Pennings, G., Clarke, A., Eichenlaub-Ritter, U., van El, C. G., Forzano, F., . . . Cornel, M. C. (2018). Human germline gene editing: Recommendations of ESHG and ESHRE. *European Journal of Human Genetics*, *26*, 445–449. doi:10.1038/s41431-017-0076-0

Donovan, J. (1995). The process of analysis during a grounded theory study of men during their partners' pregnancies. *Journal of Advanced Nursing*, *21*, 708–715. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/7797707

Dunbar, C. E., High, K. A., Joung, J. K., Kohn, D. B., Ozawa, K., & Sadelain, M. (2018). Gene therapy comes of age. *Science, 359*, eaan4672. doi:10.1126/science.aan4672

Fogarty, N. M. E., McCarthy, A., Snijders, K. E., Powell, B. E., Kubikova, N., Blakeley, P., . . . Niakan, K. K. (2017). Genome editing reveals a role for OCT4 in human embryogenesis. *Nature*, *550*, 67–73. doi:10.1038/nature24033

Fournier, T., & Poulain, J.-P. (2018). Eating according to one's genes? Exploring the French public's understanding of and reactions to personalized nutrition. *Qualitative Health Research*, *28*, 2195–2207. doi:10.1177/1049732318793417

Friedmann, T., Jonlin, E. C., King, N. M. P., Torbett, B. E., Wivel, N. A., Kaneda, Y., & Sadelain, M. (2015). ASGCT and JSGT joint position statement on human genomic editing. *Molecular Therapy*, *23*(8), 1282. doi:10.1038/mt.2015.118

Gallup. (2017, December). 2017 Honesty/ethics in professions. Retrieved from https://news.gallup.com/poll/1654/honesty-ethics-professions.aspx

Haapaniemi, E., Botla, S., Persson, J., Schmierer, B., & Taipale, J. (2018). CRISPR-Cas9 genome editing induces a p53-mediated DNA damage response. *Nature Medicine*, *24*, 927–930. doi:10.1038/s41591-018-0049-z

Hasson, K., & Darnovsky, M. (2018, November). Gene-edited babies: No one has the moral warrant to go it alone. *The Guardian*. Retrieved from https://www.theguardian.com/science/2018/nov/27/gene-edited-babies-no-one-has-moral-warrant-go-it-alone

Hough, S. H., & Ajetunmobi, A. (2017). The future of CRISPR applications in the lab, the clinic and society. *Advances in Experimental Medicine and Biology*, *1016*, 157–178. doi:10.1007/978-3-319-63904-8_9

Ihry, R. J., Worringer, K. A., Salick, M. R., Frias, E., Ho, D., Theriault, K., . . . Kaykas, A. (2018). p53 inhibits CRISPR-Cas9 engineering in human pluripotent stem cells. *Nature Medicine*, *24*, 939–946. doi:10.1038/s41591-018-0050-6

Iredale, R., Dolan, G., McDonald, K., & Kirk, M. (2003). Public attitudes to human gene therapy: A pilot study in Wales. *Community Genetics*, *6*, 139–146. doi:10.1159/000078161

Ishii, T. (2015). Germline genome-editing research and its socioethical implications. *Trends in Molecular Medicine*, *21*, 473–481. doi:10.1016/j.molmed.2015.05.006

Ishii, T. (2017). The ethics of creating genetically modified children using genome editing. *Current Opinion in Endocrinology, Diabetes and Obesity*, *24*, 418–423. doi:10.1097/MED.0000000000000369

Jasanoff, S., Hurlbut, J. B., & Saha, K. (2015). CRISPR democracy: Gene editing and the need for inclusive deliberation. *Issues in Science and Technology*, *32*, 25–32. Retrieved from http://www.ask-force.org/web/Genomics/Jasanoff-CRISPR-Democracy-Gene-Editing-2015.pdf

Kang, X., He, W., Huang, Y., Yu, Q., Chen, Y., Gao, X., . . . Fan, Y. (2016). Introducing precise genetic modifications into human 3PN embryos by CRISPR/Cas-mediated genome editing. *Journal of Assisted Reproduction and Genetics*, *33*, 581–588. doi:10.1007/s10815-016-0710-8

Knapton, S. (2018, April). Humans to be genetically-modified in Europe for the first time this year using gene-splicing therapy. *The Telegraph*. Retrieved from https://www.telegraph.co.uk/science/2018/04/15/europe-see-first-genetically-engineered-patients-using-gene/

Lander, E. S. (2015). Brave new genome. *The New England Journal of Medicine*, *373*, 5–8. doi:10.1056/NEJMp1506446

Lanphier, E., Urnov, F., Haecker, S. E., Werner, M., & Smolenski, J. (2015). Don't edit the human germ line. *Nature*, *519*, 410–411. doi:10.1038/519410a

Liang, P., Xu, Y., Zhang, X., Ding, C., Huang, R., Zhang, Z., . . . Huang, J. (2015). CRISPR/Cas9-mediated gene editing in human tripronuclear zygotes. *Protein Cell*, *6*, 363–372. doi:10.1007/s13238-015-0153-5

Lipschultz, B., & Spalding, R. (2018, May). Gene-therapy company Crispr drops as FDA puts trial on hold. *Bloomberg*. Retrieved from https://www.bloomberg.com/news/articles/2018-05-30/gene-therapy-company-crispr-drops-after-fda-puts-hold-on-trial

Ma, H., Marti-Gutierrez, N., Park, S. W., Wu, J., Lee, Y., Suzuki, K., . . . Mitalipov, S. (2017). Correction of a pathogenic gene mutation in human embryos. *Nature*, *548*, 413–419. doi:10.1038/nature23305

Marchione, M. (2018, November). Chinese researcher claims first gene-edited babies. *AP*. Retrieved from https://www.apnews.com/4997bb7aa36c45449b488e19ac83e86d

McCarthy, M. (2015). Scientists call for moratorium on clinical use of human germline editing. *British Medical Journal*, *351*, Article h6603. doi:10.1136/bmj.h6603

McCaughey, T., Sanfilippo, P. G., Gooden, G. E., Budden, D. M., Fan, L., Fenwick, E., . . . Hewitt, A. W. (2016). A global social media survey of attitudes to human genome editing. *Cell Stem Cell*, *18*, 569–572. doi:10.1016/j.stem.2016.04.011

National Academies of Sciences, Engineering, and Medicine. (2017). *Human genome editing: Science, ethics, and governance*. The National Academies Press. Retrieved from https://www.amazon.com/Human-Genome-Editing-Science-Governance/dp/0309452880

Nuffield Council on Bioethics. (2016). *Genome editing: An ethical review*. Retrieved from http://nuffieldbioethics.org/project/genome-editing/ethical-review-published-september-2016

Ormond, K. E., Mortlock, D. P., Scholes, D. T., Bombard, Y., Brody, L. C., Faucett, W. A., . . . Young, C. E. (2017). Human germline genome editing. *American Journal of Human Genetics*, *101*, 167–176. doi:10.1016/j.ajhg.2017.06.012

Pew Research Center. (2016a). *The politics of climate*. Retrieved from http://www.pewinternet.org/wp-content/uploads/sites/9/2016/10/PS_2016.10.04_Politics-of-Climate_FINAL.pdf

Pew Research Center. (2016b). *U.S. public wary of biomedical technologies to "enhance" human abilities*. Retrieved from http://www.pewinternet.org/wp-content/uploads/sites/9/2016/07/PS_2016.07.26_Human-Enhancement-Survey_FINAL.pdf

Pew Research Center. (2018). *Public views of gene editing for babies depend on how it would be used*. Retrieved from http://www.pewresearch.org/science/2018/07/26/public-views-of-gene-editing-for-babies-depend-on-how-it-would-be-used/

Rana, P., Marcus, A. D., & Fan, W. (2018, January). China, unhampered by rules, races ahead in gene-editing trials. *Wall Street Journal*. Retrieved from https://www.wsj.com/articles/china-unhampered-by-rules-races-ahead-in-gene-editing-trials-1516562360

Regalado, A. (2018a, November). CRISPR inventor Feng Zhang calls for moratorium on gene-edited babies. *MIT Technology Review*. Retrieved from https://www.technologyreview.com/s/612465/crispr-inventor-feng-zhang-calls-for-moratorium-on-baby-making/

Regalado, A. (2018b, November). Exclusive: Chinese scientists are creating CRISPR babies. *MIT Technology Review*. Retrieved from https://www.technologyreview.com/s/612458/exclusive-chinese-scientists-are-creating-crispr-babies/

Savulescu, J. (2001). Procreative beneficence: Why we should select the best children. *Bioethics*, *15*, 413–426. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/12058767

Scharf, A., & Dzeng, E. (2017, March). "I'm willing to try anything": Compassionate use access to experimental drugs and the misguided mission of right-to-try laws. Retrieved from https://www.healthaffairs.org/do/10.1377/hblog20170327.059378/full/

Scheufele, D. A., Xenos, M. A., Howell, E. L., Rose, K. M., Brossard, D., & Hardy, B. W. (2017). U.S. attitudes on human genome editing. *Science*, *357*, 553–554. doi:10.1126/science.aan3708

Stanford, S. M., & Bottini, N. (2014). PTPN22: The archetypal non-HLA autoimmunity gene. *Nature Reviews Rheumatology*, *10*, 602–611. doi:10.1038/nrrheum.2014.109

STAT & Harvard T.H. Chan School of Public Health. (2016). *The public and genetic editing, testing, and therapy*. Boston: Harvard T.H. Chan School of Public Health.

Strauss, A., & Corbin, J. (1990). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. London: SAGE.

Tang, L., Zeng, Y., Du, H., Gong, M., Peng, J., Zhang, B., . . . Liu, J. (2017). CRISPR/Cas9-mediated gene editing in human zygotes using Cas9 protein. *Molecular Genetics and Genomics*, *292*, 525–533. doi:10.1007/s00438-017-1299-z

Tyner, S. D., Venkatachalam, S., Choi, J., Jones, S., Ghebranious, N., Igelmann, H., . . . Donehower, L. A. (2002). p53 mutant mice that display early ageing-associated phenotypes. *Nature*, *415*, 45–53. doi:10.1038/415045a

Wagner, D. L., Amani, L., Wendering, D. J., Reinke, P., Volk, H.-D., & Schmueck-Henneresse, M. (2018). *High prevalence of S. pyogenes Cas9-specific T cell sensitization within the adult human population—A balanced effector/regulatory T cell response*. BioRxiv. Retrieved from https://www.biorxiv.org/content/biorxiv/early/2018/04/04/295139.full.pdf

Walker, M. J., Rogers, W. A., & Entwistle, V. (2014). Ethical justifications for access to unapproved medical interventions: An argument for (limited) patient obligations. *The American Journal of Bioethics*, *14*(11), 3–15. doi:10.1080/15265161.2014.957416

Weintraub, K. (2018, November). Scientist who edited babies' genomes faces widespread criticism. *Scientific American*. Retrieved from https://www.scientificamerican.com/article/scientist-who-edited-babies-genomes-faces-widespread-criticism/

Wellcome Trust. (2005). *What do people think about gene therapy?* Retrieved from https://wellcome.ac.uk/sites/default/files/wtx026421_0.pdf

Yong, E. (2015, December). What can you actually do with your fancy gene-editing technology? *The Atlantic*. Retrieved from https://www.theatlantic.com/science/archive/2015/12/what-can-you-actually-do-with-your-fancy-gene-editing-technology/418377/

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