Council for Responsible Genetics

Human Genetic Engineering
Current Science and Ethical Implications

Fact Sheet

I. Introduction

It may seem like the stuff of science fiction, but genetic engineering has now entered the realm of human possibility. For some, the term brings to mind hopes of futuristic therapy and fantastic human enhancement; for others, it generates fears of a dystopian world where eugenics is commonplace and the human genome is corrupted. Often, the reality of genetic engineering is eclipsed by the media storm and wild expectations. But what does our science actually allow us to do today, and what could it realistically achieve in the future? What are the true potential benefits and risks of this powerful technology? And is genetic engineering something we should endeavor to pursue at all?

This fact sheet will discuss the practical benefits and dangers, the ethical concerns, and the social implications of genetic engineering. We will focus on two specific techniques: mitochondrial DNA transfer and use of somatic-cell nuclear transfer (SCNT) to create embryonic stem cells. Mitochondrial DNA transfer has been promoted as a way for people with mitochondrial disease to have healthy children with their own nuclear DNA, and SCNT-produced stem cells have been promoted as a technique that could potentially lead to innovative therapies that will treat various diseases and injuries.

These two techniques are in the research and development phase at the moment and are therefore particularly ripe for evaluation, as they raise some important concerns that will need to be addressed before any decision can be made on whether they should be pursued more thoroughly. It is vital to engage a public and transparent discussion and debate about the potential benefits and risks of these genetic engineering techniques now, before the first attempted application. We must proceed cautiously and in full appreciation of the risks involved.

II. The Science

Before we can consider the ethical and social implications of new genetic engineering technology, we must explore the practical realities of the science that is currently available and its potential applications.

Mitochondrial Disease

Mitochondrial DNA transfer is a technique designed for the purpose of eliminating mitochondrial disease. Mitochondria, organelles in the cell that produce ATP and power metabolic pathways, are an essential component of a functioning cell.[1] They are crucial to the cell's ability to form new DNA and RNA molecules, and their primary function is to provide 90% of the energy the human body needs to function. Mitochondria are produced from special "mitochondrial DNA" (mtDNA) that is separate from the primary nuclear DNA (the DNA that is responsible for most everything else). Only a

[1]http://www.umdf.org/site/c.8qKOJ0MvF7LUG/b.7934627/k.3711/What_is_Mitochondrial_Disease.htm

small portion of the genome is mtDNA, less than 1%, which are only 37 genes (out of a total 20,000-25,000 in the human genome).[2] Mitochondrial DNA is passed directly from the mother to the offspring; the father's mitochondrial DNA plays no role in the process. Mutations in mitochondrial DNA appear ten times more often than mutations in nuclear DNA.[3] When the mitochondria are damaged, the individual incurs devastating, and often fatal, consequences.

Mitochondrial disease is a genetic disorder that can cause a variety of malfunctions throughout the body, including stunted growth, an increased risk of infection, diabetes, disease of the heart, liver, and kidneys, visual and auditory deficits, and loss of coordination and muscle weakness, various neurological problems, and seizures. Most symptoms affect children before the age of 10, though mitochondrial malfunctions can play a role in age-related diseases as well, such as multiple sclerosis and Parkinson's disease.[4,5] Approximately 1 in 10,000 people suffer from some form of mitochondrial disease today, and as many as 1 in 200 are carriers.[6]

There is no known cure for mitochondrial disease once it develops, so if a woman is identified to be a sufferer or carrier of mitochondrial disease, she must currently refrain from having children with her own eggs.[7] Two courses of action are available if she wishes to have children: she can use a donated egg, or adopt. She may not give her own

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[2] http://mda.org/publications/facts-about-genetics-and-NMDs/genes-outside-cells-nucleus
[3] http://blogs.nature.com/stepwise/2012/11/12/following-science-lead-to-reflect-on-the-ethics-of-mitochondrial-transfer
[4] http://www.mitoaction.org/mito-faq#whatare
[5] http://www.scientificamerican.com/article.cfm?id=dna-swap-technology-almost-ready-fertility-clinic
[6] http://www.eurekalert.org/pub_releases/2012-12/nysc-nac121712.php
[7] http://blogs.nature.com/stepwise/2012/11/12/following-science-lead-to-reflect-on-the-ethics-of-mitochondrial-transfer

genetic material to her offspring without passing on her disease as well. Once a woman has a child who displays mitochondrial disease, there is nearly a 100% chance that any future children will be affected by the disorder as well.

The Science of Mitochondrial DNA Transfer

Mitochondrial DNA transfer has been developed to offer a woman suffering from mitochondrial disease the option of having her own, healthy biological children. Using this technique, the donor nuclear DNA is extracted from the donor egg, leaving only the donor mitochondrial DNA. Then, the fertilized nuclear DNA from the mother's egg is extracted and placed into the donor egg. The end result is a donor egg, containing donor mitochondrial DNA and the nuclear DNA of the intended parents. Developers of this technique claim the child produced would express the genetic traits from her intended parents, but possess the donor's mitochondria. Many women place deep value in passing their own DNA to their children, so mitochondrial DNA transfer could provide a great service to them and help halt the spread of mitochondrial disease that results when affected women attempt to have their own children despite their condition.

Limits of the Current Science

As promising as mitochondrial DNA transfer technology may seem, however, there are many challenges to overcome, and the science is not yet at a stage where technicians can be sure that there are no hidden complications. So far, there have been no official clinical trials in humans; federal funding for such trials is illegal in the United States, and private funding is scarce. The use of mitochondrial DNA transfer is currently

banned in the United Kingdom, though in March 2013 the Human Fertilisation and Embryology Authority (HFEA) officially recommended that the practice be allowed, and the issue is currently under review. Back in the late 90s and early 2000s, before the FDA banned the technology in the US in 2001, there was a slightly unofficial experimental trial at the Institute for Reproductive Medicine and Science of St. Barnabas in New Jersey, in which ooplasmic transfer was used to produce approximately fifteen human babies. Whether all these babies were entirely healthy, however, remains unclear, and no follow up experiments have been completed to verify the results.

Two different groups have used the technology, apparently successfully, in rhesus monkeys: one in 2009 and another in 2010.[8,9] The offspring produced appeared to be healthy, with no complications. Experiments with human oocytes have also been done, with mixed results. In one study published in *Nature* by Masahito Tachibana et al, fertilization anomalies occurred (their pronuclei numbers were off) though once fertilized, the zygotes seemed to be healthy and could produce normal stem cells. The group declared that "mtDNA can be efficiently replaced in human oocytes."[10] According to Shoukhrat Mitalipov, a reproductive biologist who led the group in 2009, the technique could be ready to use within three years.[11] These studies appear to indicate that the technology would be largely successful if implemented in human subjects. However, such studies tracked the effects of MR only to the age of three, whereas studies in mice

[8] http://blogs.nature.com/stepwise/2012/11/12/following-science-lead-to-reflect-on-the-ethics-of-mitochondrial-transfer
[9] http://www.nature.com/nature/journal/v461/n7262/full/nature08368.html
[10] http://www.nature.com/nature/journal/vaop/ncurrent/full/nature11647.html
[11] http://www.scientificamerican.com/article.cfm?id=dna-swap-technology-almost-ready-fertility-clinic

and other animals have suggested that harmful effects may not become apparent until adulthood and that problems from swapping mitochondria show up disproportionately in males and often affect fertility. Longer-term effects on health and fertility in non-human primates born from MR must be followed at least until their sexual maturity before such conclusions should be formulated. Moreover, since no conclusive human studies have been completed, it is impossible to predict exactly what complications may arise in human applications. And as with all types of genetic engineering, mistakes could have staggering consequences—not just for the current individual, but for generations down the line as well.

Stem Cells and Research

The prospect of using stem cells for cell-based therapy, called regenerative medicine, has long been a medical dream. Stem cells are unspecialized cells that can differentiate into a multitude of different cell types. They can fall into two categories: embryonic stem cells (ESCs), which are found in the developing embryo and become the varied tissues of the body, and somatic (adult) stem cells, which act as a repair mechanism for specific tissues.[12] Stem cells also have the ability to replicate themselves through cell division for great lengths of time, though embryonic stem cells can do so for much longer than somatic stem cells—often for more than a year.[13]

Because of their ability to specialize into nearly any type of cell and renew themselves so consistently, embryonic stem cells are of particular interest to scientists,

[12] http://stemcells.nih.gov/info/basics/pages/basics1.aspx
[13] http://stemcells.nih.gov/info/basics/pages/basics2.aspx

who hope to be able to use them in the future to create new organs, repair tissue damage, and treat illnesses. Studying the mechanism through which these cells replicate and specialize may also lead to a greater understanding the of the development process and of diseases such as cancer and Alzheimer's. In addition, stem cells could be used to test experimental drugs.[14] With further research, even more new possibilities could arise.

Embryonic stem cell research has been complicated by a lack of stem cell availability, however; there are many ethical issues associated with using embryos to harvest stem cells, which will be discussed in the Ethics section of this fact sheet. Because of this, federal funding in the US is banned, and the research progress has been greatly stymied. A method of producing stem cells that does not become entangled in embryo ethics has been a "holy grail" of biology for years.[15]

One such a technique was devised in 2007, called cellular reprogramming.[16] This method consists of manipulating a somatic cell so that it reverts back to an unspecialized, stem cell-like state, producing what is called an "induced pluripotent stem cell" or iPSC. The term "pluripotent" refers to the cell's ability to form many different types of tissues in the body. iPSCs are not identical to embryonic stem cells, though, and researchers are still investigating exactly how they differ. [17] Whether iPSCs are sufficient or if a better method for producing embryonic stem cells is needed is still under debate in the scientific

[14] http://stemcells.nih.gov/info/basics/pages/basics6.aspx
[15] http://wap.npr.org/news/Health/183916891?start=0
[16] http://www.geneticliteracyproject.org/2013/05/20/confusion-scientific-and-ethical-reigns-in-the-wake-of-stem-cell-cloning-landmark/
[17] http://www.isscr.org/home/resources/learn-about-stem-cells/stem-cell-faq

community, though no one can deny the impact of the discovery—for which its developers won the Nobel Prize in 2012.[18]

The Science of Somatic Cell Nuclear Transfer Using Adult Skin Cells

One alternative technique was recently completed successfully, published in the May 2013 issue of the journal *Cell*. Using somatic cell nuclear transfer (SCNT) and adult stem cells to create embryonic stem cells is a genetic engineering technique that biologists have been attempting for decades without success. Somatic cell nuclear transfer, a form of cloning, involves removing the DNA from an unfertilized egg and replacing it with a somatic cell. The unfertilized egg then begins to divide after it is exposed to various chemicals and an electric pulse.[19] Eventually, a blastocyst is created (the size of approximately 150 cells), and embryonic stem cells can be obtained. The cells gleaned are genetically identical to the individual from whom the original somatic cell was derived.[20,21]

For years, the SCNT method failed to produce a good result.[22] Recently, a team at Oregon Health and Science University was able to produce viable stem cells by adjusting the process, which involved adding caffeine to the mix of chemicals used to stimulate the cell division. The team demonstrated that with their method, the embryo can develop to a stage where embryonic stem cells with the genetics of the skin cell can be extracted, and

[18] http://www.geneticliteracyproject.org/2013/05/20/confusion-scientific-and-ethical-reigns-in-the-wake-of-stem-cell-cloning-landmark/
[19] wap.npr.org/news/Health/183916891?start=0
[20] http://www.standardmedia.co.ke/?articleID=2000083787&story_title=scientists-create-human-stem-cells-through-cloning&pageNo=2
[21] http://www.isscr.org/home/resources/learn-about-stem-cells/stem-cell-faq
[22] http://www.cell.com/abstract/S0092-8674%2813%2900571-0

that the ESCs produced are able to specialize into differentiated cells such as beating heart cells.[23]

This is a similar technique to the one that created the famous cloned sheep Dolly in 1996, with one major difference: the embryo produced would not implant in a uterus if it were to be inserted, according to Shoukhrat Mitalipov, the head of the Oregon team.[24,] [25] Some have questioned his assertion that the embryo could not implant, however. The technique has been heralded as the first step into the realm of human cloning, though some argue that there is no evidence that the cloning method Mitalipov used could be extended to create a true healthy, human cloned baby. [26]

Limits of Current Science

Despite its potential, SCNT genetic engineering has several roadblocks to overcome. It is very difficult to acquire donor eggs for the procedure, and many people are not comfortable with the idea of creating embryos just to be destroyed after their stem cells are extracted. These issues lead to lack of support and funding. Though SCNT is scientifically promising, it is still in its very early stages, and would require at least years, and perhaps decades of further research before we can determine whether it could be truly useful in medicine. Some researchers have questioned even its potential for clinical relevance, saying that although Mitalipov and his team's success is a scientific triumph, it is unclear whether it will be medically useful at all—especially in light of the previous

[23] wap.npr.org/news/Health/183916891?start=0
[24] http://www.reuters.com/article/2013/05/15/us-science-stemcells-idUSBRE94E0V220130515
[25] http://online.wsj.com/article/SB10001424127887324082604578485064174222502.html
[26] http://www.geneticliteracyproject.org/2013/05/20/confusion-scientific-and-ethical-reigns-in-the-wake-of-stem-cell-cloning-landmark/

discovery of cellular reprogramming.[27] It remains to be seen whether the benefits of this technology outweigh the many ethical issues associated with it, which will be covered in the following Ethics section of this paper.

III. Ethics

With new technology comes new ethical questions. The field of genetic engineering is particularly rife with ethical concerns, because it involves tampering with some of the basic mechanisms of human biology. There are a number of significant ethical issues that are associated with mitochondrial DNA transfer, SCNT technology, and the practice of genetic engineering as a whole.

The Ethics of Mitochondrial DNA Transfer

Though some biologists have high hopes for mitochondrial DNA transfer, critics have voiced many concerns about the ethics of the technology since its conception. These ethical issues tend to fall into two categories: concerns around the safety of the technology, and worries about the effects it will have if it is successful.

Perhaps the most common concern is the untested nature of mitochondrial DNA transfer technology. Though trials have been conducted in animal subjects (primarily monkeys, by the team in Oregon), human biology is distinctly different, and it is impossible to know exactly what effect the procedure will have on a human baby.[28] Some

[27] http://www.geneticliteracyproject.org/2013/05/20/confusion-scientific-and-ethical-reigns-in-the-wake-of-stem-cell-cloning-landmark/
[28] http://www.hfea.gov.uk/docs/2011-06-08_-_Ethical_issues_of_new_techniques_to_avoid_mitochondrial_disease.pdf

scientists and ethicists fear that new, unexpected problems could be introduced. They claim that since there is no way to predict the intricacies of how the technology will work in humans, proceeding with mitochondrial DNA transfer would be in effect using human babies as lab experiments.[29,30] These critics argue that because the risks are so unknown and potentially great it is unethical to proceed—especially when there are alternatives such as adoption and egg donation. They say the parents' wish for children who carry their own genetics should not trump the potential harm to the future children.[31]

Another similar concern is the potential for any health issues introduced by the donor mitochondria to be passed down to future generations.[32] Mitochondrial DNA is passed from the maternal parent to the offspring, so if the child resulting from the mitochondrial DNA transfer procedure is female, she will give her donated mitochondrial DNA to her own future children; her germ-line is forever altered. Though some people can accept genetic engineering when it affects only the current individual, it is often viewed as unethical to make modifications to genetic material that will be passed on to future generations. Germ-line alternations are concerning because of the possibility of serious and debilitating health issues continuing through future generations.[33,34]

Even if mitochondrial transfer can be proven safe, critics have voiced apprehensions about the idea of modifying whole genetic lines of human beings. They

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[29] http://www.geneticsandsociety.org/article.php?id=6916
[30] http://www.dailymail.co.uk/health/article-1365287/Babies-THREE-parents-born-years-controversial-IVF-technique-gets-ahead.html
[31] http://www.geneticsandsociety.org/article.php?id=6916
[32] http://www.nuffieldbioethics.org/mitochondrial-donation/mitochondrial-donation-background-ethical-questions-arising
[33] http://www.hfea.gov.uk/docs/2011-06-08_-_Ethical_issues_of_new_techniques_to_avoid_mitochondrial_disease.pdf
[34] http://www.nuffieldbioethics.org/mitochondrial-donation/mitochondrial-donation-background-ethical-questions-arising

say that future individuals have the right to an unmodified human genome, and to use mitochondrial DNA transfer technology would be essentially changing their genome without their consent. [35,36] Also, since the technology is so new and untested, it would be most prudent for resulting children to participate in follow-up studies years after their conception, and possibly the entirety of their lives—both to monitor their own health, and to provide information about the technique that can be used to ensure greater safety of users in the future. Since their participation would clearly need to be voluntary, there is no guarantee that such follow-up studies would be successful, which would add to the danger of the procedure.[37]

A related issue is the fact that the unborn child has no say in whether he or she wishes to participate in this experimental procedure and work with the accompanying complications.[38] These complications include the obligation to participate in research studies, any abnormalities that may occur as a result of the mitochondrial DNA transfer (both medical and others), and any societal implications that may result. Someone else must make the decision for the child, without her direct consent, which is problematic.[39]

In addition, some argue that the child's very identity is altered. They argue that the simple fact that the child is not ill will change their identity. [40] To make such a drastic change in the child's genome and self, the argument goes, is a violation of the child's

[35] http://www.geneticsandsociety.org/article.php?id=6916
[36] http://www.edinethics.co.uk/mitochondria.htm
[37] http://www.nuffieldbioethics.org/mitochondrial-donation/mitochondrial-donation-background-ethical-questions-arising
[38] http://www.edinethics.co.uk/mitochondria.htm
[39] http://www.edinethics.co.uk/mitochondria.htm
[40] http://www.ncbi.nlm.nih.gov/pubmed/21071569

right to "an open future."[41] Also, the child will know that he or she is different, and that there might be unforeseen consequences that could affect him/her or their future decedents. The individual will realize that she is essentially a test subject—knowledge that might be disturbing. According to some, this knowledge will become a part of the individual's identity, and it is unethical to place such a burden on him or her.[42]

Furthermore, some scientists argue that there is evidence to support that mitochondria do influence important qualities that participate in the identity of a person—in addition to the nuclear DNA that is traditionally thought to be the source. They are therefore concerned about altering the mitochondrial DNA, because they say it could lead to unforeseen changes in the child's identity without his or her permission.[43]

A secondary line of criticism is the fear that genetic engineering techniques like mitochondrial DNA transfer will lead to genetic engineering for enhancement purposes rather than purely medical ones, acting as a "gateway" genetic engineering technique that could lead to eugenic applications. Some critics of mitochondrial DNA transfer also feel that interfering with something as powerful as mitochondrial DNA would be essentially "playing God."[44] They believe that once we take the first step into modifying the genome, it will be a slippery slope to continue along this path and begin allowing parents to choose "desirable" traits for their children—such as high intelligence, height, and specific hair colors.[45] This first foray into genetic engineering could therefore lead to a world

[41] http://www.ncbi.nlm.nih.gov/pubmed/21071569
[42] http://www.geneticsandsociety.org/article.php?id=6527#3b
[43] http://www.ncbi.nlm.nih.gov/pubmed/21071569
[44] http://www.geneticsandsociety.org/article.php?id=6916
[45] http://uk.reuters.com/article/2013/06/27/uk-mitochondria-britain-idUKBRE95Q1IW20130627

where designer babies are commonplace.[46] It is important to note that in most cases genomic science has not developed to a point where scientists are able to identify the components of the genome responsible for particular traits, because biological systems too interconnected and the mechanisms are as of yet unknown.

The Ethics of SCNT Using Adult Stem Cells

Somatic cell nuclear transfer technology also comes with ethical issues. The most common concern is centered around SCNT's connection to cloning. Since the SCNT technique is the same technology that scientists used to famously clone the sheep Dolly in 1996, there is concern that SCNT could be used to clone a human as well.[47] Shoukhrat Mitalipov (the head of the Oregon team who successfully gleaned embryonic stem cells using the SCNT technique) claims that the technology could not be used to create a viable cloned human embryo in its current state; scientists have attempted to do so with animals, and the technique has failed every time. Even so, there is still concern that it will be employed for human cloning purposes in the future.[48, 49 ,50] Others believe that what has been accomplished using SCNT is the equivalent of human cloning and should be considered as such.[51] The use of cloning on humans has long been taboo in the scientific community, as well as the general public. One main reason for this view is that cloning

[46] http://uk.reuters.com/article/2013/06/27/uk-mitochondria-britain-idUKBRE95Q1IW20130627
[47] http://www.pbs.org/newshour/bb/science/jan-june13/stemcells_05-16.html
[48] http://www.reuters.com/article/2013/05/15/us-science-stemcells-idUSBRE94E0V220130515
[49] http://online.wsj.com/article/SB10001424127887324082604578485064174222502.html
[50] http://www.pbs.org/newshour/bb/science/jan-june13/stemcells_05-16.html
[51] http://www.lifenews.com/2013/05/19/somatic-cell-nuclear-transfer-is-human-cloning/

is widely believed to be unsafe.[52] There are also many social concerns, such as how cloned individuals would be perceived and whether cloning devalues human life.

Another ethical concern regarding SCNT is the use of embryos in the process. Many people believe it is unethical to create embryos and then destroy them in order to harvest the stem cells. A philosophical difference arises between people who believe that embryos are human beings and as such have the full moral right of an individual, and those who view embryos as something that is not yet a human. For those who believe that embryos are people, the idea of destroying them for medical research is very disturbing.[53] However, Mitalipov denies that the embryos should be seen as human beings, arguing that since they were not "fertilized naturally," and most likely do not have the potential to grow into humans, they should not be viewed as true people. Others agree.[54]

An additional issue that surfaces in the SCNT ethical debate is the technique's need for donated eggs. The issue of egg donation is relevant to multiple genetic engineering techniques; mitochondrial DNA transfer, for example, also requires an egg donor, and the debate as to whether egg donation is ethical applies to it as well. However, egg donation comes up particularly frequently in discussions about the ethics of SCNT, so we will discuss it here.

There are several aspects of egg donation that have been questioned for their ethics. First, there are medical risks for women who donate eggs. This by itself is a problem, but when women are financially compensated for donating, there is concern that they may be persuaded (and exploited) to undertake risks out of financial desperation.

[52] http://www.scu.edu/ethics/publications/cloning.html
[53] http://www.pbs.org/newshour/bb/science/jan-june13/stemcells_05-16.html
[54] http://m.npr.org/story/183916891

Another source of ethical unease is that women may participate in egg donation without a true appreciation for the risks involved, leading to a lack of informed consent. Even if researchers give participants the requisite information, they may still fail to understand the implications of what they are undertaking.[55]

Finally, some people hold an opposing ethical view to those described above: they believe that there is a wealth of medical potential behind SCNT technology, which could (they argue) lead to therapy that would relieve significant amounts of suffering. To pursue this therapy, in this view, would thus be a very moral undertaking.[56]

IV. Social Implications

In addition to ethical concerns, genetic engineering technologies can have powerful social implications as well. It is important to consider how use of mitochondrial DNA transfer and SCNT will affect society and the individuals they influence within the societal context. Below we will explore the various social issues that have been raised in association with these techniques.

Social Implications of Mitochondrial DNA Transfer

Mitochondrial DNA transfer technology presents a thus far unprecedented situation: a child resulting from the technique would glean its DNA from three sources. As described earlier, the child would inherit its nuclear DNA from her intended parents,

[55] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2726839/
[56] http://m.npr.org/story/183916891

but would also receive its mitochondrial DNA from a donor woman (less than 1% of the total DNA the child will have). People have questioned whether this mitochondrial DNA donation would have an effect on the child's parental situation. Would the child essentially have three parents? Would he or she need to have a relationship with the donor?[57] Would the donor have any parental rights?[58] Or would it simply be like donating an organ—which, some scientists have argued, results in the transference of more DNA than mitochondrial DNA transfer does.[59]

Another point of interest is how peoples' opinions on the child's parentage might differ. While one family might believe that the father and mother, who have contributed most of the child's DNA, are the true parents, another person might think that the donor should have involvement in the child's life.[60] Would confusion and disagreement arise? Would there need to be a legal agreement made beforehand between the specific adults involved, or would it require a universal law? And what say does the child get in the matter? Some believe that the child might have a desire to meet the person who has contributed to their existence, and may feel some connection to her.[61] Some have argued that the answers to these questions could have important impacts on society.

In addition to issues of parentage, questions have been raised about whether knowledge that an individual was conceived using mitochondrial DNA transfer

[57] http://www.nuffieldbioethics.org/mitochondrial-donation/mitochondrial-donation-background-ethical-questions-arising
[58] http://www.dailymail.co.uk/health/article-1365287/Babies-THREE-parents-born-years-controversial-IVF-technique-gets-ahead.html
[59] http://www.nuffieldbioethics.org/mitochondrial-donation/mitochondrial-donation-background-ethical-questions-arising
[60] http://www.nuffieldbioethics.org/mitochondrial-donation/mitochondrial-donation-background-ethical-questions-arising
[61] http://www.geneticsandsociety.org/article.php?id=6527#3b

technology would itself raise implications worth considering. Would the perception of the individual be influenced by the fact that they were conceived through genetic engineering?[62]

One further objection that has been raised comes at the issue from a different angle: are the resources required to move forward with mitochondrial DNA transfer really available? Many people believe that there are more important medical areas in which we as a society should invest.[63] These critics often cite the alternative options that are available to women who suffer from mitochondrial disease and want to have a child: adoption and egg donation. They argue that women's desire to have their own biological children should not trump other more pressing areas of medical research, and that our society should tackle these more important priority areas.

There is also concern about what this entrance into genetic engineering will do to our society as a whole. Some fear that society will become used to the idea of genetic engineering, which will make it easier for more dangerous technology to become accepted in the future.[64] For those of this point of view, taking this first step into genetic engineering is a mistake, and we should refrain from stepping over a line that we might not be able to come back from.

[62] http://www.nuffieldbioethics.org/mitochondrial-donation/mitochondrial-donation-background-ethical-questions-arising
[63] http://www.geneticsandsociety.org/article.php?id=6916
[64] http://www.cnn.com/2013/06/28/health/uk-health-dna-ivf

V. Conclusion

Techniques that have implications for human genetic engineering are advancing rapidly and such techniques raise serious health and safety issues that have yet to be resolved. Before any approval can even be considered such techniques must be proven safe. But equally compelling is the need for significant, public and transparent legal and policy discussions and debate about the science of human genetic engineering and its ethical guidelines. The time for such discussions is now upon us.