**Faith & Reason Honors Program**



**SENIOR THESIS**

|  |  |
| --- | --- |
| **Name** | **Erik Cudo** |
| **Thesis Title** | **Medical and Catholic Ethical Concerns in CRISPR Technology** |
| **Thesis Director** | **Dr. Joseph Leese** |
| **Year** | **2018** |

# Abstract

For the past century, modern medicine has studied biology at the molecular level. While technology is continually improving, there is a greater emphasis placed on the cell’s basic blueprint: deoxyribonucleic acid (DNA). The structure of DNA was correctly determined in 1953 by James Watson and Francis Crick, along with the insight of Rosalind Franklin; and after this breakthrough, there have been many attempts to alter DNA in order to treat diseases that would otherwise have no treatment. Although there have been several gene editing tools invented in the last decades, the CRISPR Cas9 system is gaining more attention in the medical field than any other gene editing method. The CRISPR Cas9 system can be used to cure or prevent genetic disease within a human but the process raises ethical concerns in general, and among Catholics raises concerns relating to *in vitro* fertilization and the idea of genetically modified babies. Throughout the course of this paper, research on the CRISPR Cas9 system will be discussed to explain its history and mechanics through a review of recent literature. *In vitro* fertilization is discussed in light of firmly founded Catholic principals that have been

clearly set. Famous scientists’ opinions, such as those of Richard Dawkins, are discussed. The differences between genetic therapy and genetic engineering are also discussed. To explore the ethics of utilizing the new CRISPR Cas9 technology in the light of Catholicism’s ethics and values; the conclusion is that the Catholic Church does not currently have a set position on the ethics of using the CRISPR Cas9 technology. There has, however, been multiple efforts from members in the Catholic Church to research and openly discuss concerns related to the technology.

# Introduction to CRISPR

CRISPR stands for Clustered Regularly Interspaced Short Palindromic Repeats. The CRISPR Cas9 system is a gene editing tool used to edit DNA in organisms. According to Garneau (2010), it has the potential to correct defects in human DNA to cure or prevent genetic based disease. Today, when an average patient presents with a serious condition caused by a

faulty gene or a combination of faulty genes, there is little a physician can do to cure this individual. With the CRISPR Cas9 system, genetic diseases can potentially be wiped from a human’s DNA all together, so that no further course of treatment is needed after repairing the patient’s DNA (Garneau et al., 2010).

According to Makarova (2011), Francisco Mojica was the first person to discover CRISPRs in archaea, then in bacteria. According to Woese and Fox (1977), archaea are organisms distinctly different from bacteria and eukaryotes that typically thrive in extreme environments, such as temperatures above forty-five degrees Celsius. Mojica hypothesized that CRISPRs are a critical component of bacteria’s and archaea’s immune systems. They consist of repeating sequences of genetic code, or strands of base pairs adenine, guanine, thymine and

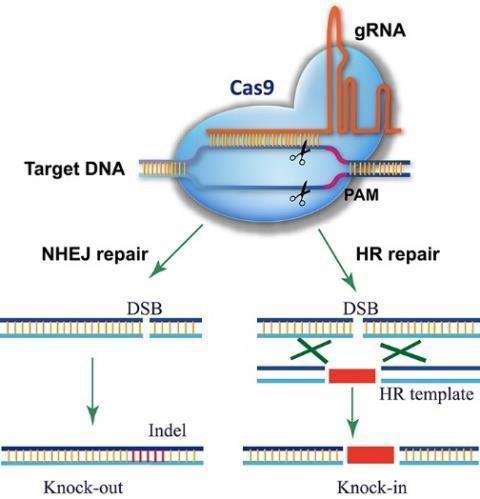
cytosine, with added spacer sequences. The entire system’s purpose is to detect changes in the cell’s local environment and store past information as genetic memory. By storing this information, CRISPRs will signal an immune response when the cell is being attacked. Thus, CRISPRs assist the bacterium in detecting and destroying intruding bacteriophages. There is one important finding to be taken from this study. Just like our body develops immunity to a disease after being infected by it, CRISPRs appear to do the same thing. Even though this study showed a discovery and not a medicinal benefit of the CRISPR Cas9 system, it gave light to the fact that this system can be used in the field of immunology (Makarova et al., 2011).

While researching the functions of CRISPRs in bacteria and archaea, scientists invented a system utilizing harvested CRISPRs called the CRISPR Cas9 system. After Francisco Mojica discovered CRISPRs in archaea, Bolotin (2005) observed an unusual locus, which is a specific location on a chromosome, found inside bacteria. Bolotin was studying bacteria known as *Streptococcus thermophilus*, which were found to contain an unorthodox CRISPR locus, different from those seen in past technologies. The CRISPR Cas9 system showed similar findings to previous gene editing technologies. It did, however, lack several known Cas genes. Cas stands for CRISPR associated protein. The Cas protein attaches to a ribonucleic acid

(RNA) strand to form a complete CRISPR (see Figure 1). Instead, it contained novel Cas genes which included the Cas9. The Cas9 encodes for a large protein which Bolotin predicted to display nuclease activity. Nuclease is an enzyme responsible for breaking bonds between base pairs in DNA or RNA. The spacers shared a common sequence at one end, known as the protospacer adjacent motif, which is required for target recognition. A protospacer adjacent motif is a short DNA sequence following the Cas9 nuclease in bacteria. Once a specific CRISPR gene is under selection, more intensive studies are able to be performed to discover

this method’s potential healing power (Bolotin et al., 2005).

*Figure 1.* CRISPR Cas9 system editing a strand of DNA (modified from Ding et al., 2016).

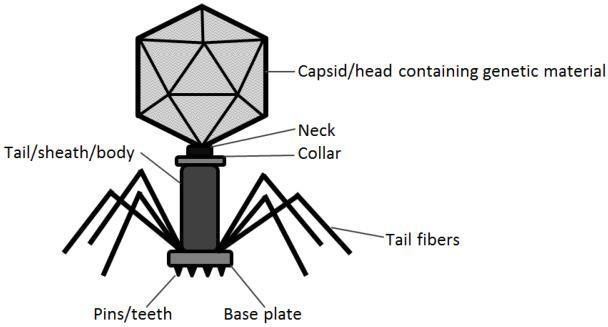


Following the discovery of CRISPR Cas9, a study performed two years later revealed a crucial finding to the field. According to this new study conducted by Philippe Horvath (2007), the bacteria *Streptococcus thermophilus* was studied to observe how bacteria respond to a bacteriophage attack. A bacteriophage attack is the process by which a virus injects its nucleic acid into a bacterium (Figure 2). There, bacteriophages are replicated and cause the cell to lyse, or break open to begin the process again. Phage attacks are commonplace in industrial yogurt making. Horvath and colleagues found a multitude of evidence that CRISPRs are an adaptive immune system because they integrate the DNA of new phages into the existing CRISPR array. This allows the bacteria to respond effectively to future attacking phages and neutralize them effectively. Most importantly, evidence was provided that Cas9 was the only protein that was required for interference. Interference is the process by which the CRISPR system in bacteria or

archaea inactivates the invading phage. Because Cas9 was the only protein needed to deactivate invading phages in this study, the CRISPR Cas9 technology started to become heavily studied in laboratories throughout the entire world (Barrangou et al., 2007).

*Figure 2.* A typical bacteriophage is composed of a capsid (head), a sheath body and tail fibers. The genetic information is stored in the capsid before it flows down the body and into a host cell ((adapted from “A review of phage therapy against bacterial pathogens of aquatic and

terrestrial organisms.” By Doss et al., 2017).



In 2010, Sylvain Moineau was the first to discover that the CRISPR Cas9 system is capable of producing double-stranded breaks in DNA. According to Garneau (2010), his study explains that CRISPR-Cas9 system induces double-stranded breaks to DNA at precise points, specifically, three nucleotides higher up the strand of the protospacer adjacent motif. The study also showed evidence that Cas9 is the only protein necessary for cleavage in the entire CRISPR-Cas9 unit. In this system, interference is mediated by the Cas9 protein along with crRNAs. crRNAs are RNA molecules transcribed from the CRISPR’s locus. It stands for CRISPR RNAs. Creating a double-stranded break is essential for the correction of many genetic diseases that have a defect in both strands of the DNA double helix. If nitrogenous bases on only one of the two strands forming the double helix are incorrect, then this advantage is not needed. There are, however, an enormous quantity of genetic diseases caused by malformation or defectiveness of nitrogenous bases on both strands (Garneau et al., 2010).

In 2011, Virginijus Siksnys tested the adaptably of the CRISPR Cas9 system. He and

his colleagues, cloned the CRISPR-Cas9 locus from the *Streptococcus thermophilus* bacteria and then later expressed it in *Escherichia coli*. The *E. coli* bacteria was shown to provide

plasmid resistance, meaning the bacteria developed an immunity to the foreign pathogen. This is significant because it suggested that CRISPRs are self-contained units, meaning they can function independently and without assistance from other enzymes. It also verified that all of the required components of the CRISPR Type II unit were known. According to Chylinski et al. (2014), the CRISPR Type II system is such that the endonuclease activities are concentrated in a singular Cas9 protein. They are guided by a tracrRNA and crRNA molecule. This finding gave light into the practical potential of the CRISPR Cas9 system. CRISPRs were not destroyed upon entering another cell. They were also able to function in a different species all

together. This made way to Feng Zhang’s enlightening study on the transportation of CRISPRs out of their original cell (Sapranauskas et al., 2011).

Arguably the most fascinating study in the history of the CRISPR Cas9 system took place in 2013. An MIT scientist named Feng Zhang made several discoveries in terms of the CRISPR Cas9 system’s function in eukaryotic cells. In his past career, Zhang had worked on multiple genome editing systems. Eukaryotic cells differ from prokaryotic cells in the sense that eukaryotic cells have organelles, or specialized subcellular components that perform specific functions within the cell. Prokaryotes lack these organelles. Zhang then took his knowledge to the CRISPR Cas9 system where he was the first to adapt the system for specific genomic editing in eukaryotic cells. Zhang took *Streptococcus thermophilus* and *Streptococcus pyogenes* and engineered two different Cas9 orthologs which showed genome cleavage in both human cells and mouse cells. Orthologs are defined as genes in different species that have evolved from a common ancestral gene through speciation events only. Two significant findings were observed during the experiment. The CRISPR Cas9 system can be programmed to target many genomic loci. It could also drive homology-directed repair. Homology directed repair is a mechanism the cell uses to correct defects in both strands of the DNA double helix. To back up Zhang’s findings, researchers from George Church’s lab at Harvard University reported similar observations in the same journal. There are several remarkable findings in this

study. The fact that the CRISPR Cas9 system can successfully edit the genome in eukaryotic cells is a huge breakthrough in the field of medicine because human cells are eukaryotic. Until 2014, the CRISPR Cas9 system was thought to work only in prokaryotes, namely bacteria and archaea. Another crucial finding in this study was that the CRISPR Cas9 system can target multiple genes. Some genetic diseases are caused by a mutation of a single base pair, while others are caused by the malfunction of multiple genes. Because this system can target multiple genes it can essentially erase any genetic disease, no matter the degree of genetic damage, from an organism’s genome. A genome is the cell’s complete set of genetic information. This can potentially allow the individual to have a life free from their original genetic disease (Zhang et al., 2014).

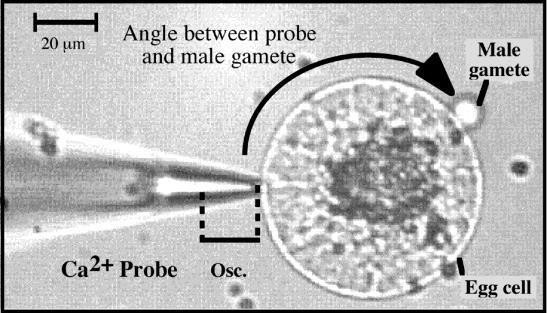
# The CRISPR Cas9 system and *in vitro* fertilization

Before proceeding through this paper, it is important to distinguish what the system does and does not do. Although the CRISPR Cas9 technology can be used during procedures that involve artificial insemination, it is not bound by these parameters. The CRISPR Cas9 system may be utilized in numerous other ways not involving artificial fertilization. Since CRISPRs are real DNA and RNA harvested from cells in either bacteria or archaea, they have the potential to be directly used in the treatment or the cure of a disease.

*In vitro* fertilization (IVF) is described as a medical procedure whereby an egg is fertilized by sperm in a test tube or elsewhere outside the body (Veatch, 1989). According to Robert M. Veatch, IVF is most often proposed when a married couple is not able to conceive due to obstructions in the woman’s reproductive tract or because the man’s sperm count is low (Veatch, 1989, p. 232). Instead of allowing the sperm to attach to the egg in utero, IVF binds the two cells together manually in order to create a zygote (shown in Figure 3), which is a fertilized egg. Veatch explains that the egg cells used in IVF are typically surgically removed from the wife’s ovaries. The semen is then provided by the man. In most cases, no early embryos are frozen, and either one or more developing embryos are transferred to the uterus of

the woman (p. 232). This procedure is done in a laboratory, which is where humans developed the nickname “test tube babies.”

*Figure 3. In vitro* fertilization is taking place. The egg is being fertilized by the male gamete, or sex cell (modified from Antouine et al., 2000).



Multiple CRISPR Cas9 studies have been conducted using IVF. For example, according to Fogarty et al. (2017), a scientist from the Francis Crick Institute in London, fifty-eight viable human embryos were used to complete her study. The term viable human embryo simply means that, given the appropriate pH level, temperature and incubation period, an embryo can potentially grow into a healthy adult. A nonviable human embryo does not have this potential. After her experimentation, the embryos were donated to research. It is important to note that the CRISPR technology does not necessarily require IVF to take place.

Before confronting the ethics of IVF, an important clarification must be made in terms of the donation of embryos for research. Any study, including scientific studies using the CRISPR Cas9 system, must not donate fertilized human embryos for research if that research leads to the death of the embryo. According to the *Manual of Catholic Medical Ethics*, this kind of research on embryos is immoral, because, from the moment the child is conceived, the embryo has the intrinsic finality of a human being and this status must be respected as such (Eijk et al., 2014).

IVF does not come without serious ethical concerns in the medical community. For example, Veatch (1989) states that the major ethical reservation about clinical IVF in cases involving the reproductive cells of the man and the woman is that this technical procedure

separates sexual union from procreation. Medicine also underlies the metaphysical aspects of

this procedure. Veatch states, “The metaphysical problem is what status to ascribe to an undifferentiated human entity that can be preserved for years in a state of suspended animation” (Veatch, 1989, pg. 216). It is important to address these concerns before proceeding with this research.

The Catholic Church makes it clear that IVF is immoral. It not only recognizes possible concerns but outright deems the practice as intolerable. According to the *Manual of Catholic Medical Ethics*, “Techniques of artificial procreation open the way to other aberrations from the God-given order of nature, such as heterologous procreation, the acquisition of a child by homosexual couples and surrogate motherhood” (Eijk et al., 2014). As Veatch mentioned the concern of separating the sexual act from procreation, the *Manual of Catholic Medical Ethics* agrees. It states that “The teaching of the Church on artificial insemination and IVF is based on the principle that marriage is the fulfillment of human sexuality and that the two aspects of the marital act, namely the physical and spiritual unification and procreation, are not to be separated from each other. The separation of the two aspects of the marital act is in conflict with the natural and moral order of human procreation as revealed by God” (as cited in Eijk et al., 2014).

Another reason the Catholic Church is against IFV is that it may lead to an abortion, whether intentional or unintentional, of the embryo. According to Eijk (2014), “During an

attempt at IVF…spontaneous abortion will occur more often than normal” (Eijk et al., 2014). Abortion is considered gravely immoral in the Catholic Church. According to Pope John Paul II’s *Evangelium Vitae*, “The moral gravity of procured abortion is apparent in all its truth if we recognize that we are dealing with murder and, in particular, when we consider the specific

elements involved” (Paul II, 1995). Clearly, the Catholic Church prohibits all CRISPR studies that lead to an abortion.

The Catechism of the Catholic Church also states that techniques which entail the dissociation of husband and wife by the intrusion of a person other than the couple (donation of

sperm or ovum, surrogate uterus), are gravely immoral. These techniques, such as heterologous artificial insemination and fertilization, infringe the child's right to be born of both a father and a mother known to him and bound to each other by marriage. They betray the spouses' “right to become a father and a mother only through each other” (Catechism of the Catholic Church, 2016). In this excerpt from the Catechism, the Catholic Church implies that it is important for couples to beget, not make, children. The word “make” implies something different. It means that something was crafted or produced during an effort of labor. The Catholic Church makes clear that it is important to beget children instead of using artificial insemination because it is in accordance with human dignity and gives both the mother and the father their appropriate roles in the family. In Charles E. Curran’s work *Readings in Moral Theology*, he explains that, “The Roman Catholic church…maintains that the relational and procreational “goods” are not adequately kept together when the openness of the sexual act to procreation is deliberately

impeded.” He goes on to state, “If…the argument in favor of IVF is related to the same basic issue which underlies the argument in argument in favor of responsible contraception, one would expect the Roman Catholic position to have some objections to IVF” (Curran, 1993, p. 177).

Continuing in the Catechism of the Catholic Church, the act that begets the child into existence through artificial means is no longer an act where the two individuals give themselves completely to one another. It is, however, an act that gives doctors and biologists the power to alter the life and identity of the embryo. It goes on to state that a relationship, such as this, is one of domination. It is contrary to the dignity and equality that is common between children and their parents. Procreation is imperfect when the conjugal act is not present. Only respect for the link between the meanings of the conjugal act and also respect for the unity of the human being are morally acceptable in terms of the dignity of the person (Catechism of the Catholic Church, 2016). Dissociating a sexual act from a procreative act is immoral because the two must be complimentary for proper union to form. Charles E. Curran, in his book *Contraception*,

states that, “The procreative and unitive elements of the conjugal act are inseparable, and evinces optimism and confidence that all men of good will can accept this proposition” (Curran, 1969). The Catechism then references the domination of doctors and biologists over embryos that they fertilized, exactly what Niakan’s CRISPR study performed. It implies that it is better for God to take hold of forming the child than for a scientist to act as the creator in the process of forming the child. This is supported in Pope John Paul II’s *The Gospel of Life: Evangelium Vitae*. Pope John Paul II (1995) states that, “Human life is sacred because from its beginning it involves ‘the creative action of God,’ and it remains forever in a special relationship with the Creator, who is its sole end. God alone is the Lord of life from its

beginning until its end” (Paul II, 1995).

Through much research, it can be easily concluded that the Catholic Church would consider any CRISPR Cas9 system study or technology that involves human embryos and IVF immoral because it not only separates the unitive and procreative act involved in consummation, but it also leads to abortion of certain embryos. In any event, the CRISPR Cas9 technology has the potential to solve amazing problems in healthcare. Although this technology seems quite beneficial, there are even more concerns that need to be addressed, including the age of the perspective patient being treated with the CRISPR Cas9 system. Because the Catholic Church has established a rule against IVF, the discussion of ethics on this topic must move to the process of adults using the CRISPR Cas9 system on themselves. For years, grown men and women have utilized medicine for the treatment and cure of disease. There are a variety of medical interventions that humans use each day in the combat against pathogens.

A common argument against using certain medicinal therapies, let alone the CRISPR Cas9 system, is that God orders the human race to respect all human life. While this is true, the Bible states, "Let us make mankind in our image, in our likeness, so that they may rule over the fish in the sea and the birds in the sky, over the livestock and all the wild animals, and over all the creatures that move along the ground." (Genesis 1:26). This passage from Genesis explains

that, while we are to respect all creatures of the earth, God gave us dominion over the animals because we are made in His image and likeness. This gives mankind the right to utilize nonhuman organisms to benefit our human species. Although the Catholic Church frowns upon IVF in human embryos, it does not place that same restriction on nonhuman animals because of our dominion over them.

Referencing both the Bible and the Catechism gives a clear perspective to which the Church has on using nonhuman organisms to our benefit. Thus, it can be fairly easily concluded that the Catholic Church would condone using these organisms for the benefit of human bodies. In this case, the CRISPR Cas9 system would be no different for treating an adult human being than with a conventional medication. However, the Catholic Church makes it clear that

“Neither scientific research nor intervention in procreation may be accompanied by the killing of human beings or the use of techniques that violate the intrinsic dignity of the human person or his integral wellbeing, including human life before birth. The embryo also falls under the norm that human life may never be instrumentalized” (Eijk et al., 2014).

CRISPRs are found in either bacteria or archaea, as stated before. Using these organisms in search of treatments in adults would be considered highly ethical and even favorable by the Catholic Church because it is expressing dominion over the organisms in order to serve human beings. Presumably, if the CRISPR Cas9 system was to be utilized by an adult and thus perform healing, this would be an ultimate good in the eyes of the Church.

There is little debate that the CRISPR Cas9 system may be widely and morally used in adults with conditions that can benefit from this treatment. If the technology can advance to outstanding levels, such as a high yield treatment, it can truly transform medicine as well as serve the human race. The more complex question lies earlier in a human’s ontogeny, namely early childhood, infancy, and even embryonically.

# A Brief Look at Development

Before the argument is made whether it is moral to use the CRISPR Cas9 system on a

juvenile human, it is important to make the point clear that the earlier a deformity in a human’s DNA is corrected, the more substantial the benefits will be. A basic understanding of embryology is needed to comprehend the significance of repairing a gene sooner rather than later in development. Development is the development of the individual during the embryonic stage and, by extension, in all stages of the life cycle. Development begins with the process of fertilization, where many sperm compete to fertilize a specific egg (Figure 4).

*Figure 4.* Many sperm cells are competing to fuse with an egg cell. Although many will bind, only one sperm cell will fuse with the egg to create a zygote.



Later, that one cell divides into two, then four, then eight, until it becomes a cluster of cells. This cluster is called a blastocyst. A blastocyst (shown in Figure 5) is a thin-walled hollow structure in early embryonic development that contains a cluster of cells, called the inner cell mass, from which the embryo begins. The outer layer of cells gives rise to the placenta and other supporting tissues needed for fetal development within the uterus while the inner cell mass cells gives rise to the tissues of the body” (Reece, 2013). From there, cells begin differentiating into specialized cells, such as liver, cardiac, and nervous cells. Each one of the

cells in the blastocyst contains DNA which was replicated semi-conservatively through mitosis. (Sex cells replicate through meiosis, another form of cell replication, but this process is unrelated.)

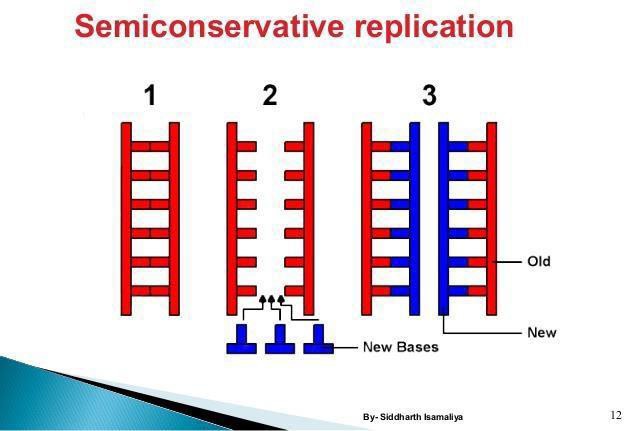
*Figure 5.* A typical blastocyst from day four in development to day twenty-four in a mouse

(modified from Shin et al., 2017).



Semi-conservative replication (as shown in Figure 6) is the process where one DNA strand from the original cell directly is placed in the new cell and the complementary base pairs are added by DNA Polymerase, a biomolecule. According to an article by Meselson and Stahl, the two daughter molecules would contain one strand each from the parent molecule. This is considered a semiconservative replication fashion (Meselson and Stahl, 2004). Because fifty percent of the DNA in the new cell is identical to the old cell, any error in the DNA is carried into the future “generations” of cells. Therefore, correcting the gene as early as possible in development is vital for optimal outcome.

*Figure 6*. Semiconservative replication, which occurs when a new double stranded DNA molecule is formed from one old strand and one newly synthesized strand (modified from

Isamaliya, 2017). 

It is important to consider parameters for this method of research using the CRISPR Cas9 system. Any CRISPR Cas9 system technique that involves “positive or negative selection

of the embryo” (Eijk et al., 2014) is undeniably immoral. However, with a method in which “the result leads to a therapeutic treatment, such as a gene therapy” (p. 330) it can be said that these CRISPR procedures are morally acceptable. This is because the Catholic Church does indeed consider gene therapy morally acceptable.

Humans have demonstrated incredible growth, intellect and innovation in terms of scientific development. Therefore, it is a reasonable question to ask if humans are going “too

far” in order to progress their scientific understanding of the world. This includes changing the DNA within a human being. Considering DNA is the cell’s basic blueprint that, in many cases, leads to the formation of proteins, manipulating it can have dramatic effects on the phenotype of the human. Humans have previously altered DNA in the past, are doing it in the present, and will do it in the future, simply by choosing with whom to reproduce. The difference with utilizing the CRISPR Cas9 system is that humans can target a specific gene and correct it. This is different from taking a chance on a mating partner where genotypic outcome is not one hundred percent known the vast majority of the time.

# Scientists’ Concerns About Utilizing CRISPR Technology

Certain scientists do not agree with using the CRISPR Cas9 system to edit the human genome. For example, a group of scientists publishing in The International Weekly Journal of Science stated that, “In our view, genome editing in human embryos using current technologies could have unpredictable effects on future generations. This makes it dangerous and ethically unacceptable. Such research could be exploited for non-therapeutic modifications. We are concerned that a public outcry about such an ethical breach could hinder a promising area of

therapeutic development, namely making genetic changes that cannot be inherited” (Lanphier et al., 2015). This is a rather strong statement against gene editing tools, such as the CRISPR Cas9 system. It shows the dangers in conducting research used in therapeutic ways.

Another prominent scientist, Richard Dawkins, gave his interpretation of the CRISPR Cas9 system. He stated, “I’m a believer in the precautionary principle as I’ve just said, and I

think we have to worry about possible consequences of things that we do, and the ability to edit our own genomes is one thing we ought to worry about” (Dawkins, 2017). Dr. Goldstein explains the precautionary principle relating to healthcare. He states, “The precautionary principle asserts that the burden of proof for potentially harmful actions by industry or government rests on the assurance of safety and that when there are threats of serious damage, scientific uncertainty must be resolved in favor of prevention” (Goldstein, 2001). Dawkins explained that humans, throughout history, have used artificial selection long before the CRISPR Cas9 system was even a thought. Although this does not modify an individual’s genome, it does modify the descendants of the breeding population. Dawkins implies that he believes that people should not utilize the CRISPR Cas9 system in the human population.

Dawkins then proposes a hypothetical situation if humans used the CRISPR Cas9 system on a frequent basis. He states, “You could imagine a future scenario in which people go to a doctor and say, Doctor, we want our baby to be a musical genius. Please edit the genes so that we have the same genes as the Bach family had or something like that to make them into a musical genius” (Dawkins, 2017). Clearly, a world-renowned scientist such as Richard Dawkins has great concern over the implementation of the CRISPR Cas9 system into modern society because it would encourage a society that picks and chooses their children’s characteristics.

Contrasting Richard Dawkins’s perspective on whether the CRISPR Cas9 system should be utilized is what is known as the technological imperative. The technological imperative is described as the concept that new technologies are inevitable and they must be accepted for the good of society (Hofmann, 2002). While Dawkins would argue against sponsoring a CRISPR Cas9 system therapy for humans, it appears he would therefore argue that the technological imperative should not be utilized for this system.

Stemming from the controversy between whether the precautionary principle or the technological imperative is appropriate for the CRISPR Cas9 system, the issue of “playing

God” must be addressed. There is debate within the religious communities as to what should be

considered “playing God.” It is a term usually used with the connotation of humans overstepping their bounds by creating something that should ultimately be left up to God.

A major question worth asking is: If the CRISPR Cas9 system displayed strong effectiveness in preventing disease in humans at the embryonic level, should humans be utilizing this technology that early in development? A benefit to proceeding with the

technology in light of the Catholic Church’s teachings and priorities would be a hopeful decrease in the abortion rate in children diagnosed with genetic diseases while still in the womb. If correcting the faulty gene *in vivo* leads parents, both Catholic and non-Catholic, to “want” their child at a greater rate than if the child permanently had the disease, the use of the CRISPR Cas9 system will be extremely beneficial in terms of the Catholic Church.

A practical example of a genetic disease the CRISPR Cas9 technology can potentially cure is Cystic Fibrosis (CF). CF is caused by a faulty cystic fibrosis transmembrane conductance regulator (CFTR) gene. The CTFR gene is located on human chromosome seven, and it regulates the chloride ion content of the epithelial cells that line the nasal cavity and lungs, as well as the stomach (Winikates, 2012). Therefore, the CRISPR Cas9 system should, in theory, have the ability to treat, or even cure this disease. The abortion rate in babies diagnosed in the womb with CF is not negligible. According to an article from the American Journal of Public Health, twenty percent of surveyed individuals would support legal abortion for a child diagnosed with CF while still in the womb (Wertz et al., 1991). While this statistic only conveys that a minority of the population would choose to allow legal abortions to take place when a baby is diagnosed with CF, the sinfulness of committing an abortion does not change. Since screening for disease while still *in vivo* is becoming considerably more prevalent, it is likely that more babies will be aborted when the diagnosis of CF is made. If the CRISPR Cas9 system is one day clinically shown to cure CF in babies while still *in vivo*, this will be a great benefit to medicine as well as the lives of the preborn.

Along with the survey participants’ twenty percent abortion preference in babies

diagnosed with CF, the same article depicts that forty percent of the individuals who took the survey would support legalized abortion in the case that a preborn child is afflicted with a genetic disorder that would cause the him or her to die within five years of their birth (Wertz et al., 1991). This abortion preference is double that of the CF scenario. If numerous deadly genetic diseases can be cured utilizing the CRISPR Cas9 system, it is probable that the world’s abortion rate will dramatically decrease.

Another consideration of humans utilizing the CRISPR Cas9 system is if using this technology on unborn children violates their basic rights. In essence, the child never gave consent for the CRISPR system to be enacted on him or her. Earlier in this paper, it was shown that a fully consenting adult can in theory benefit from a genetic modification done by the CRISPR Cas9 system without overstepping any moral boundaries. The question now becomes, is it ethical to use the CRISPR Cas9 system on nonconsenting, preborn babies?

Another thought on the matter concerning the CRISPR Cas9 system is not whether the parents should utilize this technology on their children, but if there should be a consequence for not using the CRISPR Cas9 system to give their children a better life. Direct neglect done by parents by refusing to give their child proper care goes against the Fourth Commandment. This commandment also implies and presupposes the duties of parents and of anyone exercising authority over others (Catechism of the Catholic Church, 2016). The Catechism states, “This commandment includes and presupposes the duties of *parents*, instructors, teachers, leaders, magistrates, those who govern, all who exercise authority over others or over a community of persons” (Catechism of the Catholic Church, 2016). If breaking a commandment is a sin according to the Catholic Church, it can then be concluded that the parents that are unwilling to allow the CRISPR Cas9 system to benefit the health of their child are guilty of sin. This presupposes that all CRISPR Cas9 techniques are perfectly in line with the Catholic Church.

The Fourth Commandment implies that parents have both the physical and financial capabilities to provide adequately for their children. There are, however, mitigating situations

that lessen the gravity of the sin of not properly providing for the children. The first obstacle to not being able to provide well for a family is financial problems. When parents are either in debt or struggling financially, using the CRISPR Cas9 system might not be financially feasible. In this instance, it is assumed that the parents would be under no sin for providing themselves and their children their basic needs of food, water, clothing and shelter instead of sacrificing those necessities to receive the CRISPR Cas9 treatment.

# Parents’ Obligation to Have their Child Baptized

The Catechism of the Catholic Church makes it clear that parents have an important role in the education of their children. While parents are obligated to educate their children, there are times where parental direction is needed in order to make important decisions concerning

the child’s health and wellbeing. To determine whether it is ethical for parents to use the CRISPR Cas9 system on their children, other duties of the parent can be considered. A primary example is baptism. Baptism is the first sacrament of initiation that a child ideally receives. The Catechism of the Catholic Church defines baptism as, “Holy Baptism is the basis of the whole Christian life, the gateway to life in the Spirit and the door which gives access to the other sacraments. Through Baptism we are freed from sin and reborn as sons of God; we become members of Christ, are incorporated into the Church and made sharers in her mission: Baptism is the sacrament of regeneration through water in the word (Catechism of the Catholic Church, 2016). This all-important sacrament is necessary to receive before any of the other sacraments can be received. The Catholic Church heavily advises its members to have any newly born child baptized as soon as possible. According to Cannon Law Made Easy, “It is only logical that Catholic parents should want to have their newborn children baptized as soon as possible, to free them from original sin and make them members of the Church” (Caridi, 2009).

The importance of discussing a parent’s duty to baptize a child relates closely with a parent’s responsibility toward the health of their preborn child. When children are baptized, preferably at a young age, the child does not consent to the baptism. Even without the

consenting of the child, the Catholic Church is promoting baptism for the betterment of the child’s spiritual wellbeing. The same can be said of utilizing the CRISPR Cas9 system on a preborn child. The child did not consent to undergoing CRISPR treatment. However, if

treatment done by the CRISPR Cas 9 system is in the child’s best interest, the parents should make the decision to genetically help the child.

# Parents’ Obligation to Vaccinate Children

Similar to the obligation parents have to properly getting the child baptized in order to benefit their spiritual wellbeing, parents also have the duty to benefit the child’s physical health. An example would be the use of vaccines. It is a parents’ duty, whether or not they choose to do so, to vaccinate their children. The Centers for Disease Control and Prevention (CDC) states that, “When an infant is due to receive vaccines, nothing is more important than making the time to assess the parents’ information needs as well as the role they desire to play in making decisions for their child’s health, and then following up with communication that meets their needs” (CDC, 2017). The CDC then continues to dispel a fallacy addressing the safe quantity of vaccines received in one day. It states that, “There’s no proven danger in getting all the recommended 2-month vaccines today. Any time you delay a vaccine you leave your baby vulnerable to disease. It’s really best to stay on schedule. But if you’re very

uncomfortable, we can give some vaccines today and schedule you to come back in two weeks for the rest, but this is not recommended” (CDC, 2017).

Evidently, parents have the duty and obligation to do what is best for the child regardless of the child’s consent at a young age. The examples of Baptism and vaccinations should stand to reason that parents should ultimately use the CRISPR technology if it cures or prevents a disease in a child. The Catholic Church does not prohibit parental intervention

against the child’s will unless it physically, mentally, or emotionally harms the child. Protective barriers are reasonable measures to ensure physical and spiritual health and wellness to the child. Naturally, the earlier in development the genetic disease is corrected, the better the likely

outcome of the treatment. Therefore, it is unwise to wait until the child is old enough to give consent to this treatment.

# The Meaning of Disease and Genetic Therapy vs Genetic Enhancement

Because humans now have the CRISPR Cas9 technology, there are many concerns as to where to draw the line in utilizing this treatment. CRISPR technology has the potential to treat or even cure many diseases, but what exactly is a disease? There is general disagreement about the definition in the science community. The World Health Organization (WHO) defines health as “a state of complete physical, mental and social well-being, not merely the absence of disease or infirmity” (WHO, 2018). Although this is not a definition of disease, it brings tolight an important concept. By stating that pure health does not contain disease, it can be said that the absence of disease is only one of the requirements to be “healthy.” A historic definition comes from the British Medical Journal. Macilwaine (1900) defines the word disease as “The sum total of the pathological consequences resulting in a patient from the interference with his physiological state disease cause.” Clearly, the word disease describes a roadblock to optimal function. There is also evidence that the criteria for disease has been evolving for years. As Jackie Leach Scully, a senior lecturer in sociology at Newcastle University, states that, “What counts as a disease also changes over historical time, partly as a result of increasing expectations of health, partly due to changes in diagnostic ability, but mostly for a mixture of social and economic reasons” (Scully, 2004).

Scientists using the CRISPR Cas9 technology clearly have the ability to edit DNA and change people’s lives, therefore, the CRISPR system is one form of genetic engineering. As numerous scientists have argued against using CRISPR for genetic engineering purposes, two closely related terms must be differentiated: genetic therapy and genetic enhancement. The two terms overlap in mechanism but differ greatly in their ethical components.

**Genetic therapy –** is defined by Scheller and Krebsbach (2009) as, “the treatment of disease by transfer of genetic material into cells.” Gene therapy is directed towards treating diseases as

its primary purpose. An example of utilizing CRISPR for gene therapy would involve curing a disease like cystic fibrosis. As stated above, CF is caused by a malfunctioning CFTR gene, leading to overly thick mucus. If CF is caused by one faulty gene, utilizing the CRISPR Cas9 system to break into the genome, remove the incorrect base pair, and replace it with the correct base pair would be seen as genetic therapy. This is because the purpose of initiating the procedure on the afflicted human was to cure a particular disease. The purpose was therefore not to transform the human’s genome in order to advance an already healthy part of the human, but to cure a potentially fatal disease.

**Genetic enhancement –** is an effort to make someone not just well, but better than well, by optimizing human attributes or capabilities. This can be done by raising an individual from standard to peak levels of performance (Hanna, 2006). Considering genetic enhancement takes a seemingly healthy individual and takes that individual beyond typical levels, this can be seen as reconstructing the human body. Genetic therapy is more easily defended as ethical.

Suppose there was a human diagnosed with a lethal disease caused by a genetic mutation. It occurred as a result of a point mutation, meaning that a single base pair was damaged. This single mutation, as a result, caused the individual to suffer improper liver function. When the doctors observed this abnormality, they used the CRISPR Cas9 system to correct the damaged base pair, hopefully to renew the patient’s liver to optimal health. The procedure worked correctly and the patient’s liver commenced normal function.

The hypothetical example above would be considered genetic therapy. The doctors did not correct the faulty base pair to give the individual an advantageous liver. They did, however, restore an unhealthy liver to typical function. Thus, the disease was corrected and no enhancement was done.

In another hypothetical situation, a patient presents with a fully functioning muscular system. The individual is in high school and is trying out for the football team in a few months. Although the patient’s muscles are exceptionally healthy and strong, his peers are much

stronger and more athletic. Because he wants a competitive advantage over his teammates during tryouts, he asks his doctor to induce a beneficial mutation that causes significant muscle growth. The doctor agrees and the procedure succeeded as planned. Because he had a competitive advantage during tryouts, he is now the star player on the football team when, without the doctor’s help, he would not have made the team at all.

The above example clearly depicts genetic enhancement. The boy specifically wanted his already healthy muscular system to be “given a boost” so he could compete at a higher level on the field. Because the boy was originally healthy and wanted the procedure to make him stronger than average, this can be explained as genetic enhancement.

The two previous examples have obvious answers as to whether they are examples of genetic therapy or genetic enhancement. The answer to the next two examples is not as clear. A greater level of thought must be provided to determine if the following examples should be considered genetic therapy or genetic enhancement.

Suppose a third grader’s parents bring her into the doctor’s office concerned about her academic performance. The girl’s grades are the lowest in her class, despite the fact that she studies much more than the rest of the students. She has taken an intelligence quotient (IQ) test, and she earned score of seventy-five. A score of a seventy-five is well below the average IQ in her age group. There is hypothetically a gene that, when deficient, is the cause of mental slowness such as in the third grader’s case. The parents elect to have the CRISPR Cas9 system correct their daughter’s mental slowness (assuming the CRISPR Cas9 system is capable of performing this task). The doctor agrees, and the treatment is successful. The third grader returns to school and finishes the year with average grades, directly at the fifty percent mark, and no longer struggles as she did before. Her IQ also improved to an average level.

The above example requires a deeper level of ethical engagement. The example did not demonstrate a particular disease, per se, but it did not show any type of gaining a competitive edge over her classmates in terms of grades. She did receive average grades after the treatment

was finished, so she received a benefit from the technology. It can be inferred that this type of genetic engineering can be classified as genetic therapy because the intent was not to advance the girl’s intelligence to superhuman levels. It simply corrected a faulty gene (or genes) that caused the child to suffer mental slowness. This treatment clearly has a therapeutic benefit. It also does not advance the girl past her “natural” intelligence. Therefore, it can be concluded that the above example depicts a hypothetical situation where genetic therapy, not genetic enhancement, was used.

Suppose there was another situation in which a pregnant woman arrives at the doctor’s office and is informed that her baby girl currently has a defective gene that may hinder her thyroid function slightly. As a result, she would have to take medication twice per day for the rest of her life. The medication the daughter will need is quite potent and has the potential to cause many serious side effects. The mother is quick in her choice to have her daughter undergo the CRISPR Cas9 treatment *in vivo* (supposing this was possible) to correct the thyroid disease. Before she consents to the procedure, the mother learns that the genetic abnormality is actually beneficial in a certain way. The mutated gene would increase her erythrocyte, or red blood cell, function by fifty percent. This would likely make her a superb athlete while competing in aerobic sports. The mother was a star athlete in high school and would be overjoyed to see her daughter win states in the sixteen-hundred-meter dash. At this moment, the mother is conflicted about what decision she is going to make. She would like for her daughter to gain a “natural” competitive edge in athletics. At the same time, however, she does not want her daughter to suffer a thyroid condition that could have otherwise been prevented, along with the potential side effects of the medication. Ultimately, the mother decides that the safety of her child is more important than the competitive athletic advantage gained by her mutated gene.

She decides to allow the doctors to utilize the CRISPR Cas9 system to correct the atypical gene. The doctors oblige, the procedure is successful, and the daughter grows up to be an average athlete as well as a healthy individual without a thyroid condition.

As in the hypothetical situation above, there have been times in the past where certain abnormal genetic alterations have led to a benefit to the individual. A skier named Eero Mäntyranta had a mutation in the erythropoietin receptor, which increased the oxygen carrying capacity of his red blood cells by twenty-five to fifty percent. This allowed him to gain a competitive advantage in cross country skiing, a sport where he won two gold medals.

Evidently, not all genetic mutations are completely harmful to the individual (McCrory, 2003). The hypothetical scenario about the daughter’s genetic defect and the evidence that all genetic mutations are not harmful gives a more thought-provoking puzzle concerning what situations should be treated with the CRISPR Cas9 system. If the daughter’s genes were left alone, she would have developed the minor thyroid issue with the possibility of major health problems due to the medication needed to treat the condition. However, the mother decided to give the daughter a healthier, more typical lifestyle. Because the mutation in the daughter’s genes exceeded normal human functioning, it can be said that she was unintendedly genetically enhanced. This is an example of returning the person to normalcy even when they have a genetic disorder that can be beneficial. It would be illogical to correct genetic mutations that have a natural enhancement quality. In this situation, however, there were compounding factors. Because the daughter might suffer complications from the medicine she would have to take, this example can be referenced as genetic diminishing as well as genetic therapy. This is a complicated situation and these situations must be discussed among bioethicists working in the field of medicine.

Now that several examples have been illustrated, it is time to determine the Catholic Church’s stance on whether it is moral or immoral to use the CRISPR Cas9 system to perform any of these genetic corrections. As of 2018, the Catholic Church does not yet have a specific stance on the utilization of the CRISPR Cas9 technology in the use of human beings to engineer genes. The CRISPR Cas9 system would, of course, be acceptable in a theological sense to use on nonhuman organisms. According to an article written during the Spring of 2017

(about one year earlier than the publication of this paper) by Paul Scherz, an Assistant Professor of Moral Theology and Ethics at the Catholic University of America, there are three major concerns the Catholic Church needs to consider before taking a stance on this issue. The first concern mentioned is, “we must ask how much risk from off-target effects is acceptable in therapeutic uses, a concern that may bar the technology from clinics” (Scherz, 2017). This is a major concern for the health and wellbeing of many patients eager to have the CRISPR Cas9 technology performed on them to correct a disease. If attempting to fix a gene, even if successful, leads to the malfunction of a different vital organ, the results can be devastating to the patient. Therefore, numerous tests should be undergone before the technology is safe to be used in humans.

The second concern presented by Scherz is, “it reintroduces older questions about human power over the next generation and the relationship between technology and human sexuality” (Scherz, 2017). Although the Catholic Church does not have a stance on the CRISPR Cas9 system specifically, this question can be answered by taking a look at the IVF section of this paper. If the CRISPR Cas9 system involves causing an impediment to the natural sexual union, the Catholic Church cannot support this technology.

The third and final concern presented by Scherz is, “gene drives crystallize new concerns about humans’ relationship with the environment” (Scherz, 2017). This is a tricky situation. The Church stance on environmental issues is that, although humans have dominion over animals, humans do have the obligation to protect the environment. If humans use the CRISPR Cas9 system to, for example, induce a gene that eliminates mosquitoes from a section of the earth, that may directly benefit humans by preventing them from suffering from malaria. However, humans must look past the direct benefit and determine whether this procedure will have any harmful long-term effects not just on humans, but on the balance of ecological systems around the planet. It is important to consider Scherz’s concerns and many others before making a judgement on when the CRISPR Cas9 system should and should not be utilized.

# Conclusion

The CRISPR Cas9 system is a new technology that can give humans the opportunity to provide numerous potential benefits to the health and wellbeing of the world. Such a powerful technology does not come without ethical concerns. Accomplished scientists, such as Richard Dawkins, have expressed their opinions and concerns with the new CRISPR Cas9 technology. Because the technology is new, the Catholic Church has not yet taken a hard stance on the usage of the CRISPR Cas9 system. The Catholic Church does, however, deem any usage of the CRISPR Cas9 system gravely immoral when it violates Catholic law. *In vitro* fertilization is always prohibited by the Catholic Church and therefore any experiment or procedure involving CRISPRs that requires IVF to take place has been deemed immoral. Likewise, the Catholic Church requires parents to ensure the physical, mental and spiritual health of their children. If certain procedures using the CRISPR Cas9 system are deemed moral and ethical by the Catholic Church, it is assumed that the Church would require parents to utilize these procedures to cure the diseases of their children. Even though the Catholic Church has not fully concluded on when the usage of the CRISPR Cas9 system is moral, there have been members of the Catholic Church willing to discuss potential issues associated with the technology. In light of Catholic ethics, this technology can save millions of lives and improve the planet. It is important for the Magisterium of the Catholic Church to discuss the potential immoralities involved with the CRISPR Cas9 technology so that the system can one day be utilized ethically to eradicate disease.

References

Antoine, A. F., Faure, J., Cordeiro, S., Dumas, C., Rougier, M., & Feijo, J. A. (2000). A calcium influx is triggered and propagates in the zygote as a wavefront during in vitro fertilization of flowering plants. *Proceedings of the National Academy of Sciences, 97*(19), 10643-10648. doi:10.1073/pnas.180243697

Barrangou, R., Fremaux, C., Deveau, H., Richards, M., Boyaval, P., Moineau, S., . . . Horvath,

P. (2007). CRISPR Provides Acquired Resistance Against Viruses in Prokaryotes.

*Science, 315*(5819), 1709-1712. doi:10.1126/science.1138140

Bolotin, A., Quinquis, B., Sorokin, A., & Ehrlich, S. (2005). Clustered regularly interspaced short palindrome repeats (CRISPRs) have spacers of extrachromosomal origin.

*Microbiology, 151*(8), 2551-2561. doi:10.1099/mic.0.28048-0

*Catechism of the Catholic Church*. (2016). London: Catholic Truth Society.

Caridi, C. (2009, October). How Soon Should a Baby be Baptized? Retrieved March 22, 2018, fr[om http://canonlawmadeeasy.com/2009/10/01/how-soon-should-a-baby-be-baptized/](http://canonlawmadeeasy.com/2009/10/01/how-soon-should-a-baby-be-baptized/)

Centers for Disease Control and Prevention. (2017, April 26). Retrieved March, 2018, from https:/[/www.cdc.gov/](http://www.cdc.gov/)

Chylinski, K., Makarova, K. S., Charpentier, E., & Koonin, E. V. (2014). Classification and evolution of type II CRISPR-Cas systems. *Nucleic Acids Research, 42*(10), 6091-6105. doi:10.1093/nar/gku241

Constitution of WHO: Principles. Retrieved March 21, 2018, from <http://www.who.int/about/mission/en/>

Curran, C. E. (1969). *Contraception: authority and dissent*. Place of publication not identified: Publisher not identified.

Curran, C. E. (1993). *Dialogue about Catholic sexual teaching*. New York: Paulist Press. Dawkins, R. (2017, August 21). How Far Should We Go to Manipulate the Genetic Code of

Human Life? Retrieved March 14, 2018.

Ding, Y., Li, H., Chen, L., & Xie, K. (2016). Recent Advances in Genome Editing Using CRISPR/Cas9. *Frontiers in Plant Science, 7*. doi:10.3389/fpls.2016.00703

"Disease". (n.d.). Retrieved March, 2018, from https://www.biology- online.org/dictionary/Main\_Page

Eijk, W. J., & Regina, V. D. (2014). *Manual of Catholic medical ethics: responsible healthcare from a Catholic perspective*. Ballarat, VC: Connor Court Publishing.

Fang, G., Bhardwaj, N., Robilotto, R., & Gerstein, M. B. (2010). Getting Started in Gene Orthology and Functional Analysis. *PLoS Computational Biology, 6*(3). doi:10.1371/journal.pcbi.1000703

Fogarty, N. M., Mccarthy, A., Snijders, K. E., Powell, B. E., Kubikova, N., Blakeley, P., . . .

Niakan, K. K. (2017). Erratum: Genome editing reveals a role for OCT4 in human embryogenesis. *Nature*. doi:10.1038/nature24292

Gaj, T., Gersbach, C. A., & Barbas, C. F. (2013). ZFN, TALEN, and CRISPR/Cas-based methods for genome engineering. *Trends in Biotechnology, 31*(7), 397-405. doi:10.1016/j.tibtech.2013.04.004

Garneau, J. E., Dupuis, M., Villion, M., Romero, D. A., Barrangou, R., Boyaval, P., . . .

Moineau, S. (2010). The CRISPR/Cas bacterial immune system cleaves bacteriophage and plasmid DNA. *Nature, 468*(7320), 67-71. doi:10.1038/nature09523

Gene editing - What is CRISPR-Cas9? (2017, October 01). Retrieved March 21, 2018, from https:/[/www.clearias.com/g](http://www.clearias.com/gene-editing/)e[ne-editing/](http://www.clearias.com/gene-editing/)

Hanna, K. E. (2006, April). Genetic Engineering. Retrieved April, 2018, from National Human Genome Research Institute.

Hardon, J. A. (1975). *The Catholic Catechism*. Garden-City, Ny: Doubleday.

Hofmann, B. (2002). Is There a Techological Imperative in Health Care? International Journal of Technology Assessment in Health Care. Retrieved April, 2018.

Isamaliya, S. (2017, March 8). DNA Replication. Retrieved March, 2018.

Kritica, J. (2015, August 27). *Fertilization in Human: Process, Events and Significance.*

Retrieved March 21, 201[8, from http://www.biologydiscussion.com/human-](http://www.biologydiscussion.com/human-) development/fertilization-in-human-process-events-and-significance/5135

Krupovic, M., Makarova, K. S., Forterre, P., Prangishvili, D., & Koonin, E. V. (2014).

Casposons: A new superfamily of self-synthesizing DNA transposons at the origin of prokaryotic CRISPR-Cas immunity. *BMC Biology, 12*(1), 36. doi:10.1186/1741-7007- 12-36

Macilwaine, S. W. (1900). What is a Disease? *The British Medical Journal,* 1703. Retrieved May 7, 2018.

Makarova, K. S., Haft, D. H., Barrangou, R., Brouns, S. J., Charpentier, E., Horvath, P., . . .

Koonin, E. V. (2011). Evolution and classification of the CRISPR–Cas systems. *Nature Reviews Microbiology, 9*(6), 467-477. doi:10.1038/nrmicro2577

Mestrovic, Tomislav (2016, January 13). How Does CRISPR Compare to Other Gene-Editing Techniques? Retrieved February 28, 2018, from htt[ps://www.news](http://www.news-medical.net/life-)-[medical.net/life-](http://www.news-medical.net/life-) sciences/How-Does-CRISPR-Compare-to-Other-Gene-Editing-Techniques.aspx

Mojica, F. (2017, June 20). "I'm incredibly proud of having been part of the CRISPR revolution". Retrieved February 28, 2018, from https://redcedarnews.wordpress.com/2017/01/23/francisco-mojica-im-incredibly-proud- of-having-been-part-of-the-crispr-revolution/

Ohtsuki, T., & Sisido, M., The Central Dogma: From DNA to RNA, and to Protein. *Automation in Proteomics and Genomics,* 1-19. doi:10.1002/9780470741191.ch1

Paul, J. (1995). *The Gospel of life: Evangelium vitae: encyclical letter*. Boston: Pauline Books and Media.

Ramoutsaki, I., Haniotakis, S., & Tsatsakis, A. (2000). The snake as the symbol of medicine, toxicology and toxinology. *US National Library of Medicine National Institutes of Health*. Retrieved February, 2018.

Sapranauskas, R., Gasiunas, G., Fremaux, C., Barrangou, R., Horvath, P., & Siksnys, V. (2011). The CRISPR/Cas system provides immunity in *Escherichia coli*. *Nucleic Acids Research, 39*(21), 9275-9282. doi:10.1093/nar/gkr606

Scheller, E., & Krebsbach, P. (2009). Gene Therapy: Design and Prospects for Craniofacial Regeneration. *Journal of Dental Research, 88*(7), 585-596. doi:10.1177/0022034509337480

Scherz, P. (2017). The Mechanism and Applications of CRISPR-Cas9. *The National Catholic Bioethics Quarterly, 17*(1), 29-36. doi:10.5840/ncbq20171713

Scully, J. L. (2004). What is a disease? *EMBO Reports, 5*(7), 650-653. doi:10.1038/sj.embor.7400195

Shin, H., Bang, S., Kim, J., Jun, J. H., Song, H., & Lim, H. J. (2017). Corrigendum: The formation of multivesicular bodies in activated blastocysts is influenced by autophagy and FGF signaling in mice. Scientific Reports, 7, 44973. doi:10.1038/srep44973

Veatch, R. M. (1989). *Medical ethics*. Boston: Jones and Bartlett.

Wertz, D. C., Rosenfield, J. M., Janes, S. R., & Erbe, R. W. (1991). Attitudes Toward Abortion Among Parents of Children with Cystic Fibrosis. *American Journal of Public Health, 81*, 992-996. doi:10.1097/00006254-199204000-00014

Winikates, K. (2012). Cystic Fibrosis Transmembrane Conductance Regulator (CFTR) Gene.

In *The Embryo Project Encyclopedia*. Arizona State University School of Life Sciences. Woese, C. et Fox, G. (1977). “Phylogenetic Structure of the Prokaryotic Domain: The Primary

Kingdoms.” *Proceedings of the Natural Academy of Sciences.* 74(11): 5088-5090.

Zhang, F., Wen, Y., & Guo, X. (2014). CRISPR/Cas9 for genome editing: Progress, implications and challenges. *Human Molecular Genetics, 23*(R1). doi:10.1093/hmg/ddu125

