NYU SCHOOL OF MEDICINE
HIGH SCHOOL BIOETHICS PROJECT

THE ETHICS OF ORGAN FARMING AND INTERSPECIES CHIMERAS

OVERVIEW

This module examines the ethical issues surrounding human-animal chimeras and their use in the production of organs for transplantation. Currently, there is a prodigious backlog of transplants in the United States. The median wait time for an organ transplant is almost 5 years, and about 20 people die waiting on the transplant list every day. This crisis has necessitated the development of new strategies to acquire organs for transplantation. Among these advances is the prospect of growing a custom organ for a recipient using chimeras. Chimeras are organisms made up of two genetically distinct types of cells. Chimerization can occur within a single species or between two different species. The latter type has garnered interest among scientists as a possible method for generating organs suitable for human transplantation. The proposed strategy is to create a chimera from a non-human animal embryo, usually a pig, and human stem cells. Eventually, after the chimera reaches adulthood, the stem cell donor will receive a transplant with a new, humanoid organ from the chimera. Naturally, crossing species and sacrificing animal lives for organ farming comes with some ethical baggage, but chimera research has been prominent for several decades and foretells a bright future. The goal of this module is to educate students in the subject of chimera research, particularly how it pertains to organ transplantation, and spark healthy debate surrounding the ethics of this medical advance.

CONTENTS

LEARNING OUTCOMES

1. Understand what an interspecies chimera is and its potential importance in organ transplantation.
2. Examine multiple ethical perspectives on chimeric organ farming.
3. Understand the importance of regulating animal research as well as the nuance inherent in chimera research.

PROCEDURES AND ACTIVITIES

This unit uses a student-centered and interactive approach to teaching. Activities are designed to allow for student participation and are marked as an individual, partner or group activity.

1. INTRODUCTION

A. Organ Transplantation: A Broad Overview

There is a chronic organ shortage in the United States. Every 10 minutes, someone is added to the transplant list, and the median wait time for an organ transplant is about 5 years. Simply put, there are far too few viable, transplantable organs and far too many desperate people in need of a lifesaving transplant. Many factors contribute to this deficit: among them is that only 0.3% of people die in such a way that their organs can be transplanted. This is because few deaths occur in a way that the body's key structures and functions, especially maintaining blood flow to organs, are preserved. Only organs that are still healthy and functional can be transplanted. This crisis cannot be fixed merely by encouraging the public to enlist as organ donors, since there are far too many people in need of transplants for this to be the only solution. One current strategy to alleviate this problem is to obtain organs from living people through living donation. Usually, the donor will opt to give an organ to a specific person, but others will donate with no specified recipient (altruistic donation). Still, very few people choose to donate an organ while alive, and further solutions are needed to satisfy organ demand. To address this issue, scientists have proposed strategies for generating more organs and have begun research on a number of these new tactics.

Key Terms:

Organogenesis means to the growth of organs in plants or animals. In this module, organogenesis will be used mainly to refer to the creation of organs to be transplanted into humans.

Organ farming refers to animal husbandry conducted for the purpose of harvesting the animals' organs so that they can be transplanted into humans. Organ farming is not yet practiced.

Xenotransplantation refers to the transplantation of an organ from an individual of one species to an individual of a different species. Usually, humans are the proposed recipients of xenotransplantation. Xenotransplants that have been previously been attempted have involved chimpanzee kidneys, chimpanzee livers, chimpanzee hearts, baboon livers, baboon hearts, pig corneas, pig pancreases, and more. However, xenotransplant recipients rarely survive long-term following their procedures.

B. Stem Cells and Chimeras

An **embryo** describes one of the earliest phases of plant and animal development. During the embryonic stage, organisms are unborn and multicellular.

A **stem cell** is an unspecialized cell that can differentiate into any one of many different cell types. For example, a single stem cell can become a skin cell, a white blood cell, or a nerve cell, just to name a few. Stem cells are incredibly important to human development and are found largely in early phases of embryonic growth. Adults still have some stem cells, but they are not as versatile as these early cells.

There are several classifications of stem cell based on their ability to specialize. **Totipotent** stem cells can differentiate into any type of body cell including placental cells. Only very early embryonic cells are totipotent. Next are **pluripotent** stem cells, which can also develop into any type of body cell except for placental cells. Lastly, **multipotent** stem cells are much more limited than the other two varieties; they can differentiate into one of multiple cell types.

A **chimera** is an organism composed of tissue and genetic information from two distinct individuals who did not sexually reproduce. These individuals can be of the same species or of two different species. The latter type of chimera is referred to as **interspecies**. Single-species chimeras can occur naturally, but interspecies chimeras cannot. One of the species that most frequently forms chimeras in nature is cats. Sometimes a human fetus can become a chimera if it absorbs its fraternal twin in the womb, which is known as the **vanishing twin phenomenon**. Chimeras are named after the eponymous ancient Greek mythological beast with the head of a goat, the body of a lion, and the tail of a snake.

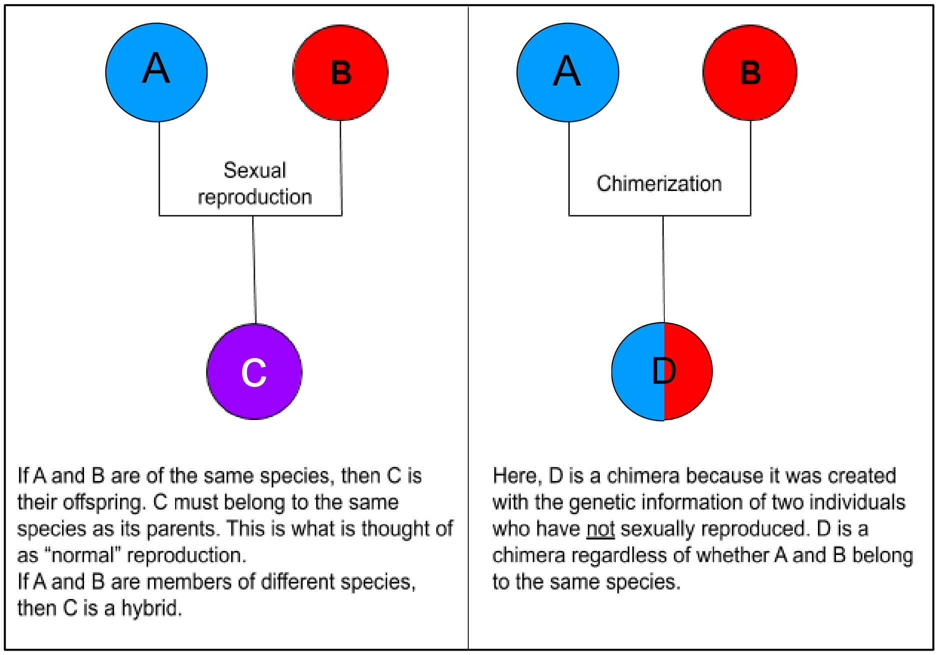

Image credit: Heather Thaler

It is important not to confuse chimeras with **hybrids**, which are born from the mating (sexual reproduction) of individuals from different species. The resulting organism is ostensibly an equal mix of its parents' species. Unlike a chimera, a hybrid has genetic information from only one individual. Some examples of hybrids are mules, ligers, and zorses. None of these animals are inherently chimeric.

Regenerative medicine is a burgeoning field of study that seeks to solve medical issues, from dementia to limb loss, by regenerating or replacing the body's tissues in order to restore normal function. Stem cell research often falls under the umbrella of regenerative medicine, meaning that work involving chimeras would, as well.

A chimera cat. Image credit: Flickr

C. Animal Research Ethics

Because chimera research involves studying and experimenting on live animals, it must abide by animal research standards and regulations. Some of the core guidelines of animal research ethics that must always be considered are known as the **Three Rs: replacement, reduction, and refinement**.

- **Replacement:** Researchers should always try to avoid the use of animals in science. Some of the common practices that fall into this category are replacing an animal research subject with a computer simulation or a less sentient animal (i.e. using a rat instead of a chimpanzee).
- **Reduction:** Researchers should seek to use the lowest possible number of animals to accomplish their goals. For example, if a certain experiment requires a minimum of 15 mice, researchers should strive to use 15 only.
- **Refinement:** Researchers should try to improve their animal subjects' quality of life, both in bettering their living conditions before being used in experimentation and reducing the amount of pain they must suffer during experiments.

Additionally, all institutions that partake in animal experimentation must have an **Institutional Animal Care and Use Committee (IACUC)**. The IACUC must perform regular internal reviews to ensure that their institution's labs are treating their animal subjects ethically. If a lab wants to start using animals for a new purpose or project, it must pass inspection by the IACUC.

Individual Activity

Have students jot down and discuss responses to the following questions. Make sure they save their answers, as they will be used again at the end of the unit.

1. If you need an organ transplant, would you want to receive a "custom" organ grown specifically for you inside a non-human animal? Why or why not?
2. To what extent is an animal with some human cells a person?
3. Should animals with some human cells have more rights than completely non-human animals?
4. Is it ethical to experiment on animals, given that it is impossible for them to agree to being research subjects? If not, is animal research necessary despite its ethical lapses?

2. Why and How Interspecies Chimeras are Created

To produce an interspecies chimera, cells from two individuals from different species must work in tandem, as its name implies. Usually, this is achieved through injecting cells from one animal into the embryo of another. In order to increase the chance that the donor cells 'take' to the host, some safeguards are put in place. First, the donor cells are implanted into the host embryo by researchers very early in embryonic development. At this stage, the embryo is referred to as a **blastocyst**. The inside of a blastocyst contains pluripotent stem cells. As such, it is preferable that the donor cells are also pluripotent stem cells. Next, the blastocyst is inserted into the womb of a female (of the same species as the host embryo). If all goes according to plan, the young chimera will be carried to term and born. After birth, researchers usually conduct tests to check that the animal contains genetic information from the donor cells. It is important to note that the genetic information of the host and the donor do not actually mix; rather, the chimera contains some cells with the host's genes and some cells with those of the donor. Also, chimeras have significantly more genetic information from their host than their donor. For example, a rat-mouse* chimera would be mostly made up of mouse cells, but its heart might be rat-derived.

Interspecies chimeras have great potential in modern medical research. This module will focus on organ transplantation, but among the other proposed uses for chimeras are medication testing, disease modeling, and vaccine research. Lots of scientific research studies use non-human animals in order to glean some insight as to how certain conditions would affect humans. While these model organisms are certainly useful, a chimera made with human cells might be more accurate. Similarly, it has been proposed that the human body may be more likely to accept a chimeric organ than a completely non-human organ, which raises myriad possibilities for the future of xenotransplantation. Hopefully, chimeric organ transplants will eventually be adopted into standard medical treatment, and this would expand access to live-saving procedures for people across the globe.

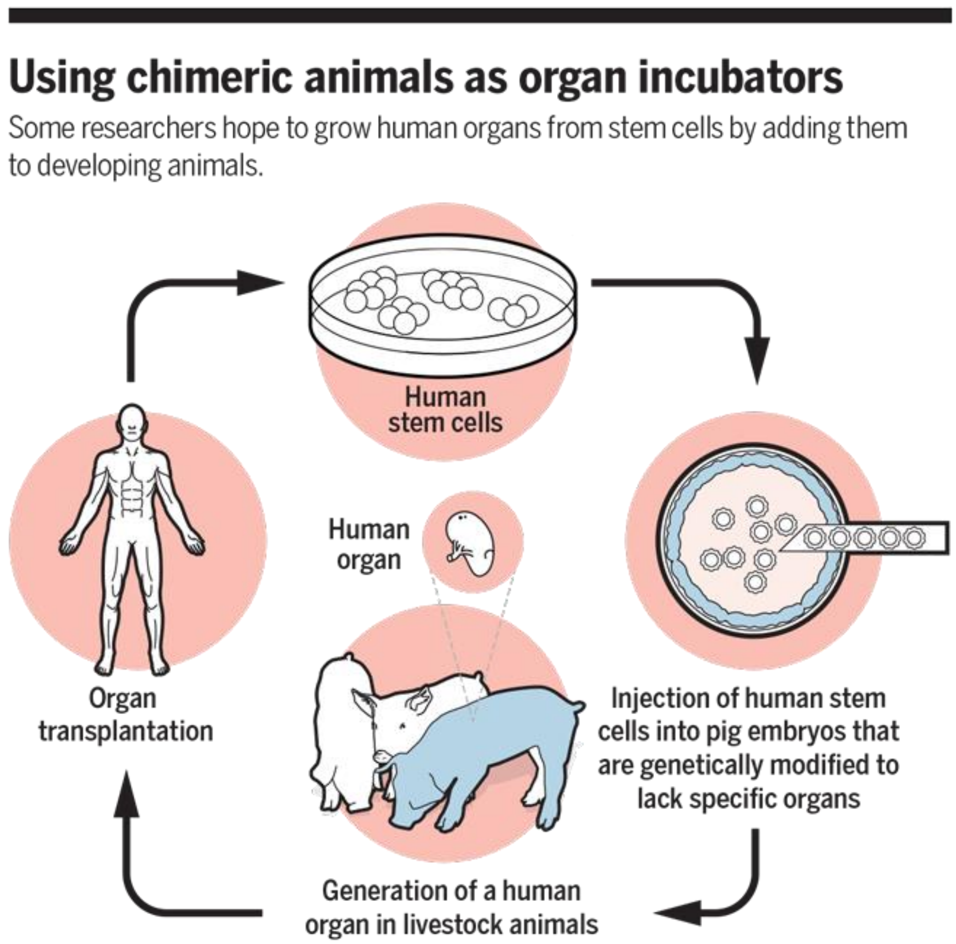

Image credit: Science

*When naming the species that form a chimera, the donor is typically listed before the host. So, in this example, the mouse is the host animal, and the rat donates stem cells.

3. The Usage of Pigs in Chimera Production

Teacher-Directed Class Discussion

Is it more or less ethical to sacrifice a pig (or any other animal) for an organ transplant than for its meat? Make sure to note that only one usable organ could be produced per animal.

Which animals should be used as hosts for human stem cells? In order to create viable chimeras, the two species must be similar in body size, anatomy, physiology, disease progression, and development. Additionally, they should be relatively close in terms of evolutionary distance. For example, a human and a shark most likely would not produce viable chimeras because they diverged hundreds of millions of years ago.

Furthermore, if chimeras are to play a part in public health, the host animal must satisfy certain logistical guidelines as well (A Brief History of Cross-Species Organ Transplantation). These include:

- Availability– Are there already large populations of this animal? Can we access them readily?
- Cost to raise and maintain– How expensive is it to care for this animal? Would we need to create new infrastructure to sustain it?
- Time until adult size is reached– How long do we need to wait until the animal's organs can be harvested?
- Reproductive viability– Are this species' pregnancies generally successful? How many offspring are generally produced per pregnancy?
- Scientific knowledge– Is there broad, in-depth understanding of this animal's biology? Have we been studying this species for a long time?
- Public opinion– Are most people comfortable with sacrificing this animal for their own benefit?

Several species have been proposed as hosts, including baboons and pigs. Baboons are much more similar to humans in terms of their biology, but they do not fit the logistical criteria very well; they are not very populous, and they are expensive to maintain. Additionally, there is comparatively little known about them, and they take many years to reach adult size. Pigs, while further away from humans on the evolutionary tree, still share many important biological similarities, including size, anatomy, and physiology. They are also less likely than baboons to pose a risk of infecting human transplant recipients with xenozoonoses (diseases that can be spread from animals to humans). More promising still is their practicality. Pigs are already produced cheaply and efficiently. Because of widespread pork consumption, there are lots of existing infrastructure for farming pigs, and people generally do not object to the slaughter of pigs for medical purposes. Lastly, pigs are polytocous, which means they regularly produce multiple offspring per pregnancy and this makes them efficient incubators. In general, pigs are excellent candidates for chimera research due to their biological and logistical adequacy.

Group Activity

Organize students into small groups and randomly assign each group an animal species. Give students time to develop arguments for why their animal would do best as a host for human stem cells in organ transplant research. Then, set up a rapid-fire debate tournament to determine a winning group/animal.

4. Advantages of Interspecies Chimeras

The dire transplantation shortage is an ethical crisis. Bioethicists grapple constantly with how to best allocate the extremely limited supply of organs among the many people who desperately need transplants. As a result, any potential advance that might alleviate this issue should be ethically scrutinized before being studied further or incorporated into the medical landscape.

One advantage to chimeric transplantation is that it evades the controversies surrounding embryonic stem cells. One of the most hotly debated facets of stem cell research is the use of cells from human embryos, which are sometimes taken from aborted fetuses or leftover embryos donated from fertility clinics. This is especially relevant given the Trump administration's retraction of federal funding for fetal tissue research in June 2019. Some people view the destruction of these embryos as murder. To others, this is a necessary sacrifice for scientific progress and the benefit of the human species as a whole. There is a way, however, to circumvent this discussion entirely. Recently, a technique was developed that can revert adult cells into pluripotent stem cells. These are referred to as **human induced pluripotent stem cells** (hiPSCs). This strategy can be implemented without the loss of human life in any form. Additionally, because the tissue donors for hiPSCs are adults, they can give informed consent. **Informed consent** ensures that a patient or fully understands and agrees to the risks and benefits of a procedure or treatment they will undergo. It is vitally important in complying with ethical guidelines.

While the use of chimeric organs in transplants is still fairly far off, this technique is much more viable than other attempts at artificial organogenesis. Namely, researchers have tried to grow usable solid organs *in vitro*, here meaning in a petri dish, using hiPSCs, but the cells failed to mature and emulate the complex, three-dimensional structures of natural organs. It's likely that interspecies chimeras could fix this particular problem; the stem cells can 'hack' the host body's natural growth processes.

Chimeric organs might also be advantageous in that they are less likely to be rejected by the recipient's body compared to purely alien organs. Xenotransplants have historically been unsuccessful; there has never been a xenotransplant patient who survived long-term. It is hoped that chimeric transplants would be more successful, perhaps acting as a midpoint between xenotransplants and **allotransplants** (transplants within the same species). This has been corroborated by researchers from the University of Tokyo, who in 2017 produced functional mouse-derived pancreases in mouse-rat chimeras that performed well when transplanted into mice.

5. Risks and Complications of Interspecies Chimeras

As stated prior, informed consent is often a key component of scientific research and medical procedures. However, when the subjects or patients in question are non-human animals, it is impossible to obtain informed consent. This is an unfortunate but accepted limitation of animal experimentation, but it may be complicated by the ambiguous status of interspecies chimeras. Because human- animal chimeras are principally "animal" and are not cognitively influenced by their human cells, they would probably be exempt from informed consent policies as well. Still, this issue is indicative of a broader lapse in legal scholarship and policy that currently leaves chimeras and hybrids in an outdated grey area.

There are many challenges to the scientific viability of chimeric organogenesis as well. Interspecies chimeras, especially when used in transplants, are a very new development. Naturally, the technique for production has not yet been perfected and there are even some struggles that could cause longer-term problems. First, implanted stem cells, which are crucial to the creation of chimeras, perform unpredictably in their host embryos. Currently, it is difficult to control exactly *how* the stem cells will contribute to their host, if at all. Some warn that it is dangerous to toy with this concept before it is fully understood, lest we accidentally produce, for example, a pig with a human brain that could hinder regenerative medicine at large. Furthermore, many studies that attempt to produce chimeras report low yield rates. Even in the most promising of trials, only about 25% of blastocysts injected with stem cells actually developed into viable chimeras (Wu et al., 2017),. Another study (Kroon et al., 2008) reports that 33-100% of human-mouse chimeras developed teratomas, a type of tumor that can be either benign or malignant. So, are interspecies chimeras fit for clinical use? Hopefully, as techniques are refined, these challenges will be alleviated, but currently, chimeras may be too unpredictable and inefficient to be marketable.

Another potential limitation of chimeric organ transplants is price. Even though these treatments are far from implementation, early versions would almost certainly be very costly. While an exact price has not yet been pinpointed, it would probably be prohibitively expensive for all but the wealthy. In other words, chimeras, touted for their promise in increasing transplant availability, might not actually help very many people. Others argue that while these transplants would be costly, they would be a more immediate solution, saving a patient from spending years on the transplant list. To that point, a person waiting for an organ usually has to undergo frequent, expensive treatments to sustain their health, meaning that a chimeric organ might not cost that much more than the total price of waiting on the transplant list. Nonetheless, many new technologies are very expensive when they are first released but decrease in price over time. Perhaps chimeric transplants will follow this model, but nothing is certain yet.

Teacher-Directed Class Discussion

Should we continue developing and researching a new technology if it will be prohibitively expensive for most of the population? Is this equitable?

6. The Ethical Implications of Blastocyst Complementation

In recent years, an auspicious development has arisen in the creation of chimeras: **blastocyst complementation**. This technique refers to the genetic editing of a host embryo so that it will fail to grow a particular organ. The donated stem cells, once introduced, are likely to fill this artificial genetic niche. For example, researchers might prevent a pig embryo from developing a pancreas before implanting human stem cells, making it likely that the pig's pancreas would become at least partially human. This is beneficial for a few reasons. First, as previously mentioned, one of the main problems with stem cell therapies is predictability. Although blastocyst complementation is not a perfect solution, it significantly increases the regularity of stem cell behavior. Second, chimeric organ farming would be a useful treatment only if scientists could control *which* organ is grown with donor stem cells. If this doesn't make sense, imagine that you need a new kidney, so your doctor takes some of your stem cells, and in return offers you a liver. So, to make interspecies chimeras a viable treatment option, we need to have control over how human stem cells contribute to the chimera. Blastocyst complementation can aid immensely in achieving this aim.

Still, as with many scientific developments, there are some ethical hang-ups to blastocyst complementation that must be considered. First of all is the use of gene editing technology on embryos. This is done through **CRISPR/Cas9**, a tool that can very precisely change genetic information. CRISPR/Cas9, though developed recently, has opened the door to a wealth of possibilities, many of which are ethically dubious, especially the editing of human embryos. In fact, it has been banned and condemned by many government bodies, including the United States. Additionally, some ethicists and policymakers are concerned about the implications of hindering the development of vital organs in animal embryos (as is necessary for blastocyst complementation). This could put the animal at risk of a painful, unnecessary death, especially if the donor stem cells do not properly form the missing organ. No decision has yet been made with regard to this ethical quandary.

7. The Legal and Moral Status of Chimeras

Because human-animal chimeras are, by definition, partially human and partially animal, they do not fit neatly into current laws regarding the respective rights of these two groups. It is important that there are legal differences between animals and humans. For example, in the United States, it is legal to eat most types of animal meat, but it is illegal to obtain a human corpse for consumption. Most people would agree that this distinction should be upheld. But, should it be legal to consume chimera meat? The answer is unclear. More important are the ambiguities regarding the differences between animal rights and human rights, and where interspecies chimeras should fit.

One important issue is that of informed consent. In order for a human to go through with a medical treatment or participate in a study, they must give informed consent. The same does not apply to animal subjects because they cannot communicate with humans in any sort of reliable, comprehensible way. A human-animal chimera, because it would be predominantly "animal," would also be incapable of giving informed consent. Still, to many people, it seems wrong to give a partially human creature the same disregard as a natural animal.

In general, the status of chimeras is undefined in the law. This is not simply a result of the newness of chimera research. Some legal scholars think that because the law is inherently dependent upon categorization, and chimeras defy this type of grouping, a lapse in legislation is unavoidable. Human-animal chimeras will probably continue to sit in an undefined grey area between human and animal; they will all have at least slightly different amounts of human genetic information. However, this does not mean that *no* advances in policy can be made; rather, solutions may be difficult to formulate, but they are possible for some issues regarding chimeras.

On a similar note, the moral status of chimeras is currently in flux. According to Sebastian Porsdam Mann of the University of Oxford, there are two existing types of moral status: categorical and contingent. **Categorical moral status** is earned simply by virtue of belonging to a particular group; in this case, all humans are afforded rights because they are humans. If something has **contingent moral status**, however, it has rights not because of *what* it is, but because of its relationship to others, in particular, humans. Humans hold categorical moral status, while animals have contingent moral status. By this logic, it is not morally wrong to kill a raccoon in and of itself, but it is wrong to kill a person's pet raccoon because pets hold sentimental value.

Here again, chimeras do not fit cleanly into either category, given that they are neither fully human nor fully animal. An argument presented for both the legal and moral disputes is that because human genes will not contribute to chimeric brain development, the chimera, in its own mind is purely animal. As such, it should be afforded the same or nearly the same status as natural animals. It should be emphasized that there are a number of precautions in place to prevent the genesis of chimeras with human-derived neural tissue. It is severely unlikely that any scientific institution would permit this kind of experimentation without extremely careful consideration. Additionally, if such a creature were to come about accidentally, scientists would be able to tell that it had humanoid neural matter long before it was born. Even so, because this is still a biological possibility, it would be unwise to act as if partially human-brained chimeras are impossible in case the situation arises, whether or not it is intentional.

Teacher-Directed Class Discussion

Separate students into small groups and discuss the following questions
- What happens if human cells contribute to the growth of a chimera brain?
- Should the chimera be considered a person?
- Is there a difference between the killing of a pig with a partially human pancreas and a pig with a partially human brain?

Have each group explore these questions and come to a consensus. Then, each small group should share their views with the class.

8. Religious Perspectives

Individual Activity

If you or a loved one were diagnosed with a life-threatening medical condition whose only treatment violated one of your core beliefs, would you go through with it? Why or why not? Write down your answer.

Because chimeric organ farming might one day be a medical treatment administered to the general public, it is necessary to weigh its sociopolitical ramifications. People of diverse backgrounds can view the same procedure in drastically different ways, and ethicists should consider how these perspectives will affect the public view of a given treatment or therapy. Religion, in particular, is a major contributor to people's ideas with regards to medical practices.

In general, many religions accept or encourage medical research, but they tend to take a less favorable view of xenotransplants and chimeras, often because they are seen as a violation of the natural hierarchy. This section will focus on the views of the Abrahamic faiths (Christianity, Islam, and Judaism) because of their power as drivers of culture and belief in much of the world, including the United States. It is important to note, however, that this is by no means a thorough examination of all religious perspectives, nor does it capture the diversity of thought within individual religions.

A. Christianity

Christian tradition usually supports the practice of medicine on the grounds that people must try to heal others in body, mind, and spirit because Jesus healed all of humanity. Accordingly, Christian leaders and scholars tend to evaluate individual medical practices by judging how it affects the individual as a whole, not merely how well it fixes their ailment. Christians also believe that humans were created in the image of God, who granted them dominion over nature, including the other animal species. This is not to say that humans have free reign over animals; Christian scripture emphasizes the necessity of consideration and kindness towards animals. Because of this regard for both human dignity and animal life, the concept of chimeras has proved challenging for many Christian leaders. Some believe that interspecies chimeras, as a mixture of human and animal matter, would degrade the dignity and stature of humanity as well as causing suffering to animals. In general, just as chimera research itself is new, so too are Christian perspectives regarding their use. There has not yet been a major verdict among the Christian community on this issue.

B. Islam

Islamic law and tradition generally characterize medical treatment as important, especially if the treatment in question is life-saving. However, pigs and anything involving porcine (pig-related) materials are considered taboo. Pigs are *haram*, meaning forbidden, and many Muslims even think that they are *najis*, or inherently impure. Naturally, this has led to conflict regarding the use of pigs in medical care. The argument against pig-related treatments is supported by a quote attributed to the Prophet Muhammad, saying that prohibited substances, including pigs, should never be used for healing. Some scholars counter that medical research involving pigs should be permitted through the concept of *ḍarūrah*, meaning dire necessity, because they have the potential to save lives. It seems that a consensus on this issue has not yet been reached among Muslim leaders, but there is broader support for the idea that humans have a duty to care for animals. One application of this idea is that the slaughter of animals should occur in the least painful way possible. Thus, in order for animal research to be in accordance with this belief, we should better regulate the treatment of animal research subjects.

C. Judaism

Traditionally, Judaism has taken a very favorable view of medical research and development, which stems from an intense focus upon preserving human life. Jewish scholars of antiquity and of modernity tend to agree that physicians should do what they can to save lives, even if this results in the violation of religious law. One important Jewish law is that of *kashrut*, a system that dictates certain cooking and husbandry practices as taboo. As in Islam, among the foods considered taboo is pork. Due to the relevancy of pigs in emerging medical advances, including chimeras, some discourse has arisen within the Jewish community as to whether these practices abide by *kashrut*. It is generally agreed that they do not, though their use is permissible so long as research is conducted with the ultimate goal of saving human lives. With regards to xenotransplantation, some ancient Hebrew scholars felt that the merging of species was immoral, but more modern perspectives tend to support the practice. In 2015, however, at a rabbinical assembly, it was ruled that human-animal chimeras are unacceptable. Perhaps in coming years the Jewish aversion to chimeras may be alleviated if their potential to save lives is sufficiently demonstrated.

Teacher-Directed Class Discussion

If the leaders of these religions condemn the use of pig organs, does this unfairly disadvantage Jews and Muslims on the transplant list?

9. The Future of Chimera Research

Individual Activity

Imagine that you are a lawmaker writing legislation on chimera research. Would you support it? How would you try to prevent the abuse of this technology? If you, as a public servant, had moral or ethical objections to chimeras and/or xenotransplantation, would the potential public health benefits outweigh your aversion?

Though chimera research, and regenerative medicine in general, is a young field, it has been gaining prominence. In January 2017, researchers at the Salk Institute in California successfully created the first human-pig chimera. 1466 pig embryos were initially injected with human stem cells, though many of them did not develop into chimeras, and among those that did, the majority were underdeveloped. Despite its challenges, this experiment was a huge success. Not only did it succeed in its goal of producing human-pig chimeric embryos, it received major media coverage, which can be hugely beneficial for a burgeoning area of research like this one.

Even though chimera-based treatments are still far from coming to market, it is critical to establish legislature regulating their use. Plenty of research is currently being done on chimeras, and even though some applications of this research may sound like science-fiction, they may not be so far-off. As such, it is important to restrict the types of work with chimeras that can be done. Some of the most frequently discussed regulations involve brain experimentation. Because our knowledge of how the brain works is currently so limited, it is probably unwise to explore this territory in a being as unique and unknown as an interspecies chimera. As such, tampering with chimeric brain development will probably be severely restricted, if not banned, for the foreseeable future. Along the same lines, a moratorium on chimeric breeding will likely be put in place because we know so little about what results this might yield. An important idea in bioethics in general is not diving headfirst into a question in which one has not yet dipped their toe; in other words, a lack of caution in science can yield unexpected consequences. Chimera research will continue to be closely monitored by Institutional Review Boards (IRBs), IACUCs, governmental and intergovernmental policy, and other safeguards.

10. CONCLUSION AND DISCUSSION

Group Activity

- Given what you've learned, is it ethical to kill a human-animal chimera for the life of a natural-born human?
  - If so, what does this imply about the value of a life? Does this validate the concept of "an eye for an eye"?
- Is it possible to assign a concrete value to a human life? If so, is this ethical?
- Have students look at their responses to the introductory questions. Encourage them to examine if, how, and why their perspectives have changed.

11. ADDITIONAL RESOURCES

SciShow video on the first human-pig chimera
SciShow video: introduction to chimeras
Vice News video profiling the scientists behind the first human-pig chimera
National Geographic article covering the first human-pig chimera
Go, Go, Stem Cells: a flash game that explains the basics of stem cells

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1. Flickr user 'Miss Insomnia Tulip'. "Im 14 You Know, Don't I Look Good for My Age? It's All the Puss- Te - Pet - Tides!" Digital image. Flickr. January 13, 2007. Accessed July 26, 2019. https://www.flickr.com/photos/22242229@N08/2169903100.

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ACKNOWLEDGEMENTS

This module was developed and written by Heather Thaler. Kelly McBride Folkers supervised the project.