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INNOVATIONS IN TRANSPLANTOLOGY: XENOTRANSPLANTATION AND ITS IMPACT ON THE HEALTHCARE SYSTEM AND SOCIETY

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ABSTRACT

According to statistics collected by organisations such as Eurotransplant and OPTN Transplant, there is a shortage of organs available for transplantation. The highest demand is for kidneys, with over 100 000 people on the waiting list. Xenotransplantation – inter-species transplantation – may be a solution to this problem. The initial attempts at transfusing animal blood date back to the 17th century. Scientists showed interest in this field not until early 20th century. To perform a pig-to-human kidney transplant while reducing the risk of complications, it is necessary to genetically modify the pig's DNA. Microinjections, viral vectors, or specialised proteins are used to remove animal-specific antigens, eliminate endogenous viruses, and make the animals' cells more similar to human's. The chances of success can be increased by administering immunosuppressive drug, preventing rejection. Animal tissues, such as pig's corneas, are routinely used in medicine. Biological heart valves are also extracted from animals, strictly prepared and then implanted into hearts of individuals whose physiological valves have failed. Coming years may change the clinical implications of animals, as studies have already been published in which humans received complete animal organs such as kidneys, hearts, and livers. This subject, however, sparks a debate in society and raises ethical and religious dilemmas. The main concerns include zoonotic diseases and unequal access to xenotransplantation. Representatives of the world's major religions have not shown opposition, which, coupled with increasing public acceptance, may allow scientists to improve genetic modification techniques and standardise procedures to save lives in the future.

KEYWORDS

Xenotransplantation, Transplantation, Pig's Kidney, Animal-to-Human Transplantation, Xenograft

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1. Introduction

According to statistics compiled by Eurotransplant.org, which gather data from countries such as Austria, Belgium, Croatia, Germany, Hungary, Italy, the Netherlands, and Slovenia, in October 2025, 598 patients were waiting for new lungs, 1 060 were in line for heart transplants, 1 562 patients required a liver transplant, and 9 867 people needed a new kidney [1]. Meanwhile, in the United States, 46 630 patients were waiting for a transplant in 2023, a very low number compared to the demand in October 2025, when the transplant waiting list exceeded 119 948 patients, of whom 102 297 were waiting for a new kidney [2]. Advances in medical technology enable earlier detection of patients who require a transplant, which could lead to increased organ demand in the coming years. It is impossible to ignore that a significant percentage of people on the waiting list are newly registered, and some will not survive to receive a transplant. The solution to this situation appears to be xenotransplantation – that is, inter-species transplantation, such as from a pig-to-baboon, or, most intriguingly for us, the implantation of an animal organ into a human, such as a pig's heart. The greatest scientific hope lies in using genetically modified pigs for "organ farming" [3]. Xenotransplantation, although still in its early stages, raises ethical, religious, and social concerns. Common issues include patient exposure to zoonotic diseases that can develop from microorganisms in animal organs, the ongoing lack of extensive clinical trials demonstrating its efficacy, and unequal access to alternative treatments within society [4]. The use of animals in this procedure is unavoidable. Increasing transplant success requires keeping animals in controlled conditions and feeding them a specially formulated diet. This sterile environment differs significantly from their natural habitat. The scientific community also raises concerns about the extent of human interference in the genotype of animals used for organ cultivation. Certain modifications are necessary to reduce the risk of transplant rejection, making the molecules on the surface of pig organs more similar to those of humans' and to lower the risk of infection with endemic pig's diseases, but isn't this "Playing God" [5]?

1.1 History of xenotransplantation

The topic of animal tissue transplantation, is not only actual in recent years. As early as the 17th century, Jean-Baptiste Denis attempted to use rabbits' blood to supplement patients, a practice that was banned few years later in 1670 after the deaths of his patients [6]. The 20th century brought renewed interest in cross-species transplantation, as demonstrated by Serge Voronoff in the 1920s and 1930s, who transplanted non-human primate testicles into elderly men. Four decades later, in 1964, Keith Reemtsma attempted to transplant a chimpanzee kidney into a human. Of the 13 xenotransplants, one woman lived with a non-human primate kidney for nine months. Twenty years later, Leonard Bailey caused public outrage with his operation of transplanting a baboon heart into a newborn with a lethal heart defect. "Baby Fae," as the tiny patient with a functioning animal heart was called, lived for 20 days. Since the 1990s, the biotechnology company Revivicor has been researching xenotransplantation, focusing on the main immunogenic factor in pig tissue cells and adding human molecules to inhibit the immune system's response. Recognising the risk of zoonotic diseases, eGenesis began its research in 1997, attempting to inactivate pig-specific viruses that could infect humans. In 2021, organs from genetically modified animals from Revivicor farms were submitted to clinical experiments, where they were implanted into bodies of brain-dead patients, and the responses of both the transplant recipients and the organs were analysed. In addition to the companies already mentioned, XTransplant and ClonOrgan also produce xenogeneic organs [7]. The latest research aims to transplant entire organs, but the use of animal tissue fragments remains a clinical practice. A prime example is a biological heart valve extracted from a pig heart, which was already implanted during research in 1962 and became available for general use only 8 years later in 1970 [8].

2. Materials and methods

A scoping literature review was performed in PubMed, Web of Science, Scopus, and Google Scholar. Search terms included combinations of words: „xenotransplantation," „animal to human transplantation," „heart xenotransplantation", „kidney xenotransplantation", „liver xenotransplantation", „xenotransplantation ethical aspect", „xenotransplantation ethical problem", „xenotransplantation social opinion", „religion on xenotransplantation". In this review, publications written in English, published between 2020 and 2025, observational studies, case reports, meta-analyses, literature reviews, reports, and publications from health institutions were included. Papers deemed unreliable, irrelevant, or of low methodological quality were excluded. Selected publications were subjected to qualitative and thematic analysis to provide a multidimensional perspective on xenotransplantation.

3. Clinical aspect

The most significant progress in recent years has been made in xenogeneic kidney transplantation, which is why we will devote most of this section covering it. Heart and liver will also be mentioned, as few research teams conducted clinical experiments using porcine grafts. Despite the intuitive choosing of non-human primates as suitable donors, scientists prefers pigs for their research due to their anatomical, physiological, and immunological similarities.

3.1 Mechanism of graft rejection

Our immune system recognises molecules present on foreign cells, allowing it to effectively defend us against bacterial infections, the onset of cancer, recognise properly functioning body cells, and respond with activation to foreign tissues, such as transplants – not only those from animals but also from humans, which leads to a failure even with allogenic transplantation [9]. The two main problems researchers face are hyperacute and acute humoral rejection, which can lead to organ destruction within the first few hours [10]. Antibodies and the adaptive immune response are elements of the immunological barrier to xenotransplantation. The human body contains so-called xenoreactive natural antibodies (XNAs) that target animal cell antigens even when immune cells did not have contact with them. Native antibodies circulating in human's vessel are directed against characteristic animals antigens: galactose-α1,3-galactose, β-1,4 N-acetylgalactosaminyltransferase, and N-glycolylneuraminic acid. Their attachment to the transplanted cell leads to complement activation, antibody-dependent cytotoxicity, and inflammatory responses. Mechanisms embracing direct lymphocyte cytotoxicity and cellular responses are also important in rejection mechanism [11]. Regardless of the route our body takes, its primary goal is to destroy cells it does not recognise as unharmful.

3.2 Genetic modifications

To modify the immune system's response, scientists alter the types of antigens present on the surface of pig tissues, replacing for example, galactose-α1,3-galactose with CD47 which is human molecule intended to inhibit immune reaction. They use methods such as microinjections into the cell nucleus or cytoplasm containing specially prepared DNA or mRNA. Modified virus vectors can also be introduced into the cell, which, by attaching to pig's DNA, introduce the desired changes. Scientists have also developed special CRISPR/Cas9 proteins that cut out targeted gene fragments, inactivating them. These proteins are most often used to remove endogenous for pigs viruses to prevent the development of zoonotic diseases in the recipient [10]. It is possible to "create" a triple negative pig, characterised by removal of genes responsible for the production of the three main antigens (galactose-α1,3-galactose, β-1,4N-acetylgalactosaminyltransferase, N-glycolylneuraminic acid) against which the previously mentioned XNAs are circulating in the human body [12]

3.3 Immunosuppression

It is important to note that, in addition to modifying the transplanted organ, immune system function can also be influenced using various immunosuppressive drugs. The goal is to block few pathways at once using multiple drugs alternating the chain reactions. Wang L. and his team explored combining specially modified kidneys with new drugs that inhibit the immune response. In an animal model, transplanting pig kidneys into non-human primates (like baboons) and administering drugs that block the CD40/CD154 pathway as well as those that reduce the inflammatory response by blocking interleukin-6 enabled them to maintain normal pig kidney function for over a year. They also announced that they would initiate clinical trials in humans who have exhausted other treatment options and expressed their belief that xenotransplantation could change the face of transplantology in the near future [13].

3.4 Studies of the body's response in brain-dead individuals

To better understand these processes, research teams have been implanting organs from genetically modified pigs into brain-dead individuals since 2021. They maintain organ function and analyse blood samples to understand better the processes occurring in the body. One such study, published in November 2025, was conducted by a team led by E. Schmauch. He and his colleagues noticed that between days 10 and 28, plasma cells, NK cells, and dendritic cells showed significant increase, leading to graft rejection on day 33 via an antibody-dependent mechanism. The number of T lymphocytes raised from day 21 and peaked between days 33 and 49. They point out that the exact T lymphocyte clone (TRBV2/J1) was present in both circulating blood and graft tissues, suggesting that cellular response overlay with antibody-dependent one resulting in porcine kidney destruction. This study confirmed that multiple simultaneous processes are responsible for rejection and highlighted the need to block various pathways simultaneously to increase the chances of organ acceptance [14].

3.5 Kidney - living transplant recipients

The first well-described patient with a xenogeneic kidney was 62-year-old Richard Slayman with end-stage renal disease. After obtaining Food and Drug Administration (FDA) approval and the patient's consent, a team of surgeons from Massachusetts General Hospital began implanting a porcine kidney from eGenesis farms on March 16, 2024. The transplanted organ had undergone 69 genomic modifications, including the removal of the three major antigens mentioned earlier, inactivation of endogenous porcine retrovirus fragments, and addition of DNA fragments encoding human immune system regulatory molecules onto cell surfaces. Immediately after implantation, the organ began functioning. On the eighth day, the risk of T-cell-mediated rejection occurred, but intensified immunosuppressive therapy saved the graft. The patient survived for 52 days with a functioning kidney. A post-mortem autopsy revealed the cause of death was a chronic heart failure, which led to circulatory disorders and ultimately Richard's death [15]. The next recipient of a porcine kidney was 54-year-old Lisa Pisano. She not only suffered from end-stage renal disease requiring haemodialysis, but also an advanced heart failure. Unfortunately, due to her condition, she was not qualified for a heart and kidney transplant. The team from NYU Grossman School of Medicine offered her an LVAD (left ventricular assist device) implantation, followed by a xenogeneic kidney transplant. Afters acquiring necessary approvals, he first procedure was successfully performed on April 4, 2024, and eight days later on April 12, 2024 a porcine kidney was implanted. Unfortunately, on May 29, 2024, after 47 days, the kidney needed to be resected due to insufficient blood supplementation by the LVAD. Lisa died on July 7 of the same year from cardiovascular causes, as the team from NYU Grossman School of Medicine sadly announced [16]. The following xenogeneic transplant functioned for longer, reaching a 130 day mark, in case of Towana Looney, a 52-year-old woman

which is still alive at the time of preparing this article. The Alabama woman underwent surgery on November 25, 2024, during which surgeons implanted a kidney from a pig breeded at the Revivicor farm. Unfortunately, the functioning porcine kidney stopped filtering blood properly and had to be removed on April 4, 2025, leaving Towana once again on haemodialysis to cleanse her body [17]. Tim Andrew, a 67-year-old patient, underwent surgery on January 25, 2025, to receive a kidney developed by eGenesis. "Wilma" (that's how Tim named his new kidney after the name of donor pig) filtered his blood properly for 271 days – a record at the time of preparing this text. Surgeons at Massachusetts General Hospital had to remove it on October 23, 2025, due to impairment in graft function, and Tim returned to the dialysis centre three to four times a week. The research team announced that they would attempt another xenotransplantation of porcine kidney at the end of the same year (2025) [18]. A breakthrough for xenotransplantation, and especially kidneys, was the FDA's decision in February 2025, which allowed Revivicor to conduct a clinical trial involving the implantation of its modified kidneys in six patients, with the possibility of expanding this number to an additional 44 patients if the kidneys continued to function properly six months after transplantation [19]. eGenesis also applied and received such approval in September 2025, but xenotransplantation is limited to patients with end-stage renal disease requiring dialysis and aged 50 or older. This study is considered an Investigational New Drug (IND) to test the functioning of EGEN-2784 (the temporary name of the genetically modified kidney at the time of the study) [20].

3.6 Heart - living transplant recipients

Two years before the first attempt to transplant porcine kidney, scientists from the University of Maryland Medical Centre in Baltimore tried to transplant a pig heart from Revivicor into 57-year-old David Bennet chest. The surgery was successfully performed on January 7, 2022. The heart had undergone 10 genetic modifications, primarily involving the removal of pig antigens and the addition of human molecules to its cell surfaces. Drugs blocking the CD40/CD40L signalling pathway were also administrated to prevent rejection, allowing David to wake up with a functioning pig heart pumping his blood. Unfortunately, Bennet died on March 8, 2022. An autopsy revealed the presence of the porcine cytomegalovirus (PCMV) and antibodies directed against heart tissue in the transplanted organ, which led to its deterioration, rejection, and ultimately, the patient's death [21]. In 2023, the same team performed the second and last reported pig-to-human heart transplant. Lawrence Faucette, 58 years old man received his new heart on September 20, 2023. The transplant functioned normally for the first week on immunosuppression. Unfortunately, its parameters started to decrease eight days after the procedure, and a biopsy of myocardium revealed signs of inflammation and blood clots in the heart muscle. Cardiac failure progressed until Lawrence died on the 40th day after the procedure [22]. No further clinical experiments attempting pig-to-human heart transplant were announced and published.

3.7 Liver - brain-dead recipient and living transplant recipient

In January 2024, a team from the University of Pennsylvania, using the "OrganOx" system, connected a liver manufactured by eGensisis to the bloodstream of a brain-dead patient. The organ, exposed to human blood, resumed its function and did not get rejected for 72 hours; however, it is worth remembering that the patient had a properly functioning liver [23]. On March 10, 2024, a team from Xijing Hospital in China attempted to transplant a kidney into a brain-dead patient. The kidney manufactured by Yunnan Agricultural University had six genetic modifications and was implanted in the lower abdomen (a non-physiological location). The experiment lasted 10 days and was terminated at the request of the deceased's family. Just 2 hours after surgery, bile production began, and albumin could be detected in the blood within the first 24 hours. Liver damage parameters were not elevated; unfortunately, early termination of this experiment did not allow for complete verification of the xenotransplant's performance [24]. Surgeons from the Hospital of Anhui Medical University in China attempted to transplant a pig liver into a patient who had had his right lobe of liver removed due to hepatitis B cirrhosis and hepatocellular carcinoma. A liver with 10 modified genes was implanted in place of removed part of liver, so graft was located in physiological region. After connecting the blood vessels, the organ began producing bile within hours, and albumin production was detected the day after surgery – same results as in previous experiment. A month after surgery, the patient developed microangiopathic haemolytic anaemia. Treatment was attempted, but unfortunately, the graft had to be removed on the 38th day after surgery. It is important to notice, the left liver lobe regenerated, and the patient lived for 171 more days, dying on November 5, 2024, from massive upper gastrointestinal bleeding – complication of hepatitis B cirrhosis [25].

3.8 Future of transplantation?

Current advances and successes in xenotranplantology, despite limitations in graft survival and complications, offer hope for shortening transplant waiting times and saving more lives. Future research should focus on improving genetic modification methods, enabling the use of increasingly effective immunosuppressive drugs, and engaging more centres worldwide in clinical trials.

4. Social aspect

Issues related to transplantology can be polarising in society. Xenotransplantology is still a novelty; when asked what it is, some people say they have never heard of it. Public opinion research to this date has been limited, but in 2024 a group of researchers conducted a survey with 5,238 respondents, of whom 5,008 completed the questionnaire (95.6% completion rate). The survey included questions about the respondents' demographic characteristics, knowledge of transplantation and xenotransplantation, attitudes toward the use of pig organs, concerns expressed about xenotransplantation, and whether they would accept transplants from animals. In addition to collecting responses, the survey included an educational section presenting the methods used to modify pigs and the purposes and clinical implications of the DNA modifications. A limitation of this study is that the respondents included people personally involved in transplantology (transplant recipients, people on the waiting list, families of patients, registered donors, and healthcare workers) as well as financial compensation for submitting the answers (private portal for questionnaires). However, nearly half of the participants (47.9%) had no experience with this issue. After analyzing the responses, the researchers identified the following key findings: ►women have a more negative attitude towards xenotransplantation – possibly due to more emotional nature; ►younger people, despite having greater knowledge, were less willing to accept animal transplantation; ►knowledge of xenotransplantation compared to transplantation is more than twice as low; ►discomfort when answering increased when question mention xeotransplantation for the respondent or a close relative, but decreased after familiarizing themselves with the educational materials; ►More than half would accept the use of pig organs to reduce waiting times, and one-third of respondents were willing to participate in clinical trials; ►The most significant concerns were raised by zoonotic diseases and the lack of sufficient clinical data [26]. A team of researchers from China conducted a survey at the end of 2023 and begging of 2024, including 539 patients awaiting transplant (different group than previously – everyone connected with issue of transplantation). After excluding respondents who did not meet the criteria, 477 questionnaires were analysed. They also compared their results to previously published studies from other regions. The research group indicated the following as their most important findings: ►as many as 88.5% of patients would accept xenotransplantation; ►factors that negatively influenced attitudes towards xenotransplantation were: 1. lack of health insurance (fear of the costs of the procedures), 2. faith (especially Islam), 3. lack of sufficient knowledge [27]. The most interesting and perhaps most significant study is the one published in October 2025. This is the first study analysing the real-life experiences of patients who received a porcine kidney. A limitation is the small number of participants – only three – but it is worth remembering that these are all living individuals (as of December 2024) who underwent pig-to-human kidney xenotransplantation. Each participant was interviewed and asked questions that allowed them to express their thoughts and subjective feelings about the quality of life after transplantation, related concerns, and communication with the medical team. Analysing their responses, the research team found that their quality of life improved, and patients regained hope and the possibility of returning to society. Significantly, they related their situation to the need to visit a dialysis centre (3-4 visits per week). One patient compared xenotransplantation as a way to "*escape the prison of dialysis*". They expressed concerns about complications from the transplant procedure, but, from a pragmatic perspective, it was an opportunity for them to return to daily life and contribute to science. In communication with medical staff, trust, professionalism, diverse help, and accessibility were paramount. Patients emphasised the importance of honest discussions about the risks of the procedure, psychological care, and constant access to team members [28]. The studies described demonstrate that social acceptance of xenotranplantology is complex. Still, it can be improved through education, publication of the results of thoroughly conducted research, and presentation of patient cases who have undergone this procedure. Implementing clear and open dialogue are crucial to reach future patients and the general public. Social acceptance will be a key factor in determining whether the promising field of xenotransplantation becomes a daily basis procedure and answer to the organ shortage.

5. Ethical aspect

An ethic aspect raised in discussions about xenotransplantation is the true voluntariness of patients undergoing experiments. Although they consent to the procedure, due to limited options, they are more likely to undergo the surgery. Those waiting for a transplant, despite being sceptical about receiving a pig kidney, were more willing to undergo the procedure, influenced by their decreasing health and the very slowly shortening waiting list for a transplantation. Voluntary choice becomes a kind of desperation, as the patient chooses between the experiment that might save his life and death. Such individuals are also under pressure from family, doctors, and themselves. In the patient's mind, being transported to dialysis sessions three to four times a week and spending several hours at the stations is a burden on their loved ones. Even though they do not object, the patient, wanting to "unburden" them, is more likely to consent – so surrender to internal and external pressure, which undermines their autonomy. A patient hearing from healthcare professionals that they could benefit from another treatment option, an experimental transplant, may figure these words as an attempt to persuade and pressure them, which can also distort their view of the real pros and cons of xenotransplantation. It's worth noting that the information provided by research groups is presented in a way that makes it seem better than it actually is. A 30% chance of success sounds better than a 70% chance of something going wrong. Zoonoses are also a topic of discussion. Researchers announcing that the risk of their occurrence is low, but because of limited human models studies, they don't know how low. The financial benefits accruing to patients participating in the experiment are also a subject of ethical debate; this may encourage poor and needy individuals to enrol not of their own free will, but rather because of their current life situation. A problem with studies examining the effectiveness of xenotransplantation is the lack of a full opt-out option. In drug testing, individuals can withdraw from the study at any time. In this case, even though the organ will be removed, the risk of a virus entering the human body remains, requiring patients to stay under medical care. This creates a bioethical problem: on the one hand, we have full patient autonomy, and on the other, the risk of a pandemic caused by a zoonotic virus that could have been present in the xenograft tissues [29]. Another dimension of bioethical problems is the need to classify individuals after animal transplants. Is a person with a pig's heart still fully human, or perhaps a hybrid, something inhuman? Studies have shown that people would be less willing to eat pig meat if the pig contained human neurons or if it were genetically modified to be more human-like [30].

6. Religious aspect

Humans are characterised by spirituality and a need for faith, which is why it is essential to examine the attitudes of representatives world's main religions toward xenotransplantation. A research team led by Daniel J. Hurst addressed this need by conducting a symposium on this topic at the 30th Transplant Congress in Istanbul in 2024. Religious scholars from Catholicism, The Church of Jesus Christ of Latter-day Saints, Hinduism, Shia Islam, Sunni Islam, Judaism, Protestant Christianity, African American religious traditions and the American Anglican Episcopal Church presented their respective views on xenotransplantation. Most important fact to notice is that none of these religions has expressed an absolute ban on xenotransplantation. However, they do have their own conditional acceptances. Catholics emphasise personal identity, which cannot be violated, thus prohibiting the transplantation of organs such as the brain or genitals. Due to medical advances in recent years, the leaders of the Catholic Church are currently developing a new report and position on this topic. The views of Shia and Sunni Islam are based on the Quran and on the interpretations of rulers. Sunnis are more rigorous, emphasising the conditional acceptance of using an unholy pig to save human life. This can lead to society distancing itself from xenotransplant recipients, who are considered spiritually impure. This assertion stems from the fact that the holy book contains stories of some societies transformed into animals for disobedience. Shiites, on the other hand, advance two key principles: Darura – if the procedure saves a life and there is no alternative, it is permissible; and Taharat – the principle of religious purity, which can be interpreted that time that organs spends outside of pig's body purified them and can be used for transplantation. Furthermore, they emphasise the importance of caring for animal wellbeing, minimalizing the risk of zoonotic diseases, and respecting human dignity. Judaism, on the other hand, has a very positive attitude towards xenotransplantation, despite Jewish law prohibiting the consumption of pork. According to the principle of Pikuach Nefesh, saving human life transcends all religious prohibitions and commandments. They emphasise the importance of Tza'ar Baalei Chayim, which teaches that animals should not be exposed to unnecessary suffering. Protestants emphasise the extent of modifications to pigs' bodies as their primary concern. Isn't implanting fragments of human DNA to pig genetic material consider "playing a God?". Bringing up love for neighbours and community, they note the risk of zoonotic diseases. Hinduism emphasises context and

individual consideration of each case. Saving a life can generate good karma, which contributes to the continued flow of positive energy. The principle of Ahiṃsā, which states that no living creature should suffer, seems prohibitive, but Mahatma Gandhi stated that it should not be absolute dealbreaker. The use of cows for "organ cultivation" also raises concerns, as cows are considered sacred in their belief. The Church of Jesus Christ of Latter-day Saints (LDS) prioritises human dignity and equal access to this procedure [31]. Although ethics may raise concerns about xenotransplantation, it is worth maintaining a rational, non-panic perspective. Religions around the world, from Islam to Protestantism, present frameworks and requirements, emphasising that these procedures are acceptable if being proceed with respect the dignity and autonomy of the individual. Creating a space that guarantees independent counselling, clear communication, and equal access to xenotransplants may be the answer to the organ shortage considering ethical and religious issues.

7. Discussion

Xenotransplantation is currently in a transitional phase, from isolated clinical experiments with conditional rules of execution, to a potential therapeutic method, thanks to FDA approvals granted to Revivicor and eGenetics wider clinical researches. While the results so far point to a bright future, we must not forget the ambiguous reports. Tim Andrew functioned for 271 days with a transplanted pig kidney, though this was an isolated case; most xenografts lasted only 2 to 4 months. The transplanted liver helped save the patient's life, but it's worth remembering that it was only a bridge until the rest of his original organ regenerated. It had to be removed due to inflammatory changes, demonstrating that, despite multifaceted immune protection through genetic modifications and new immunosuppressive drugs, science has yet to find a way to block transplant rejection entirely; the immune system always finds a way around it. Although two successful heart transplants have been performed in humans, both procedures resulted in death. Alarmingly, in one case, researchers identified PCMV infection as the cause of death, which should alert researchers to the need to minimise the risk of developing zoonotic diseases. In the coming years, the results of FDA-approved clinical trials will be crucial. Scientists must ensure accurate and reliable communication of all successes, limitations, and failures so that society has a complete understanding of the potential future of transplantology. Although procedures are not rejected, concerns remain, such as equal access and individual autonomy, as demonstrated in public opinion surveys. Regardless of their level of knowledge, young women showed most negative attitude to xenotransplantation, underscoring the need to build trust. It is worth emphasising that cultural differences influence the acceptance of xenografts, as demonstrated by surveys conducted in China and the United States, where Western populations presented a pragmatic, distrustful approach. Opinions of transplant recipients themselves are crucial, as analysing their cases can help improve procedures and the care of future patients. A critical element of xenotransplantation's acceptance is the lack of an absolute ban on this procedure by the world's major religions. However, they express concerns about respect for the individual, society, how to classify a person that underwent such a procedure, and the proper respect for animals. They emphasise, that human life is the highest value after all.

8. Conclusions

The coming years will be crucial for xenotransplantation to become a commonly used method for saving human lives. The lack of opposition from society and the world's major religions places organ genetic improvement, standardisation of procedures, prevention of rejection, and maintenance of organ function for as long as possible at the main concern of clinical research. Key structural measures should be taken to introduce regulations addressing equitable access to new technology. Proper communication, education, and increasing public awareness of the xenotransplant procedure are also crucial. With appropriate attention to each of these dimensions, transplanting organs from genetically modified pigs into humans could become routine within a dozen or so years.

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