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Original Research Article

AI IN XENOTRANSPLANTATION: RESHAPING THE FUTURE OF ORGAN TRANSPLANTATION

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Abstract:

This paper analyses the challenges Artificial Intelligence (AI) is helping solve in the field of xenotransplantation. Xenotransplantation is the field of transplanting animal organs into humans. Due to the global shortage of transplantable human organs, xenotransplantation has the potential to save lives. AI performs many of the complex tasks needed to make xenotransplantation a reality, including gene editing via CRISPR-Cas9, real-time monitoring of transplant rejection, remote biosafety screening, and more. Using a descriptive study and exploratory research strategy, this paper analyses secondary data and professional surveys collected from surgeons and pathologists. This paper also presents the findings from the survey study. From this data, the author developed AI risk management models to minimise hyper-acute rejection, which is a severe form of transplant rejection that occurs immediately after the transplant. AI can improve long-term Graft Re-integration (these are "Graft Survival" and "Graft Function" periods) via virtual cross-matching/new predictive modelling. This report establishes that even though many of the participants have expressed that there are many risks associated with AI, the reality is that xenotransplantation may soon (within 10 years) become a primary method of organ replacement surgery. As a result, the practice of organ transplants will have a vastly different focus.

Introduction:

Artificial intelligence (AI) is already part of our daily lives, from the use of voice recognition devices to accessing the internet. It always helps to improve our lives easily and simply, as well as higher analytical and data management processes across various industries. Due to the development of AI, various solutions are now available for addressing significant areas of opportunity in healthcare challenges. Including the achievement of Sustainable Development Goals. Day by day growth in artificial intelligence in healthcare has been revolutionary, and is completely reshaping the point of medication for the patients. Monitored, treated, and diagnosed. The impact of AI in healthcare is fluently chances every level of the medical ecosystem, from research and clinical documentation to treatment and patient engagement. AI is one of the most important tools that will helps physician and care teams to make better decisions easily, better decisions based on accurate and real-

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time monitoring, cost reduction, and time saving. Patient records that are now easily available to doctors and physicians improve the transparency between both doctor and patient. Whether identifying new therapies for diseases like cancer and other diseases, AI will be the game-changer in the healthcare field.

Similarly, just as AI "xenotransplantation" is also a game-changer in history that has revolutionised humankind. So many patient were died from organ failure, but a transplant is the only way to survive. However, there were not enough donors, which cause to dangerous wait. These delays can be life threatening for thousands of patients all over the world. Mechanical and dialysis only provide temporary respite. Other immune suppressions have various causes, like risk, malignancies, including infection and the considerably higher costs. Recent innovation helps to overcome the challenges faced by doctors or physicians.Meanwhile, xenotransplantation has progressed through editing of multiple genes of the donor pig and improved their immunosuppression protocols, which will lead to a reduction of hyper-acute rejection like kidney, heart and liver grafts. On the other side of the parallel, some are trying to reach regenerative medicine, including three-dimensional organoids, three- dimensional bio printing and also the stem cell therapies; these technologies are ready to create specific tissues of the patient that lead to rejection and improve graft longevity. Biomaterial and cell encapsulation (a protective bubble made with microscopic pores) will immunise the patient's body. During the transplant, the patient need take pills these keeps the organ safe but weaken the immune system, so these help to control post-transplant care. To adopt the clinical all widespread required strict, rigorous validation, an ethical framework and multidisciplinary integration. Critical areas are enhanced by AI, such as patient selection, immunosuppression, organ allocation, predictive modelling, and genetic editing and virus detection. By bringing everything together, we make sure research on transplantation grows and includes everyone. Its prove that AI can help us and fix all the biggest global issues.

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Review of Literature:

A) Loupy et al. (2025) defined AI as an "indispensable orchestrator" for gene editing, utilizing deep learning to predict off-target mutations in the porcine genome. This AI-guided engineering mitigates genetic defects, significantly reducing early graft failure.

B) Kawai et al. (2025) demonstrated the power of AI-driven Predictive Analytics during a landmark 69-gene-edited porcine kidney transplant. By monitoring multi-omic data in real-time, the system identified early molecular markers of rejection (TMA), enabling pre-emptive interventions that extended graft survival.

C) Kumar et al. (2025) introduced a "Smart Match" hybrid model for species-specific pairing. By integrating porcine genetic profiles with human antibody landscapes, the AI's virtual cross-matching improved long-term compatibility predictions by 30% over traditional methods.

D) Goutaudier et al. (2025) employed Computer Vision to map immune responses within biopsies. With 98% accuracy, the AI identified the critical "window of intervention" (Days 10–33), allowing for precisely timed immunosuppression.

E) **Olawade et al. (2025)** enhanced biosafety through machine learning algorithms that screen for zoonotic pathogens like PERVs. This AI- integrated protocol proved faster and more comprehensive than manual methods, ensuring the selection of "Specific Pathogen Free" organs for clinical use.

Objectives of Study:

1. ***Genetic Editing and Compatibility Enhancements:***
   Optimising compatibility of donor- recipient by editing genes of a pig kidney, heart, liver, etc., to increase the match rate by human recipient and mitigate the risk of organ rejection. With the help of AI, it is easy to analyse the extensive datasets and predict the effective genetic alteration to optimise future approaches.
2. ***Risk Assessment and Patient Selection:***
   Determining the suitability of the organ during the transplant through a large, comprehensive assessment of patient data, by analysing the medical history and genetic profile. AI-driven estimation can also maximise positive outcomes, improving the success rate and introducing potential complications for individual patients.
3. ***Immunosuppression Optimisation:***
   The drug dose given to the patient can be easily optimised and automated by specific factors. And allow for monitoring while enhancing the discovery of new types of rejection agents.
4. ***Virus Detection and Prevention:***
   Analysing zoonotic viral genomes to predict potential risks would allow for implementing early detection systems for viral infections.
5. ***Organ Allocation and Prioritisation:***
   AI models help to optimise the organ allocation, reducing the waiting time, medical urgency, and to get the fair distribution of organs compatibility factors is most important for transplant.

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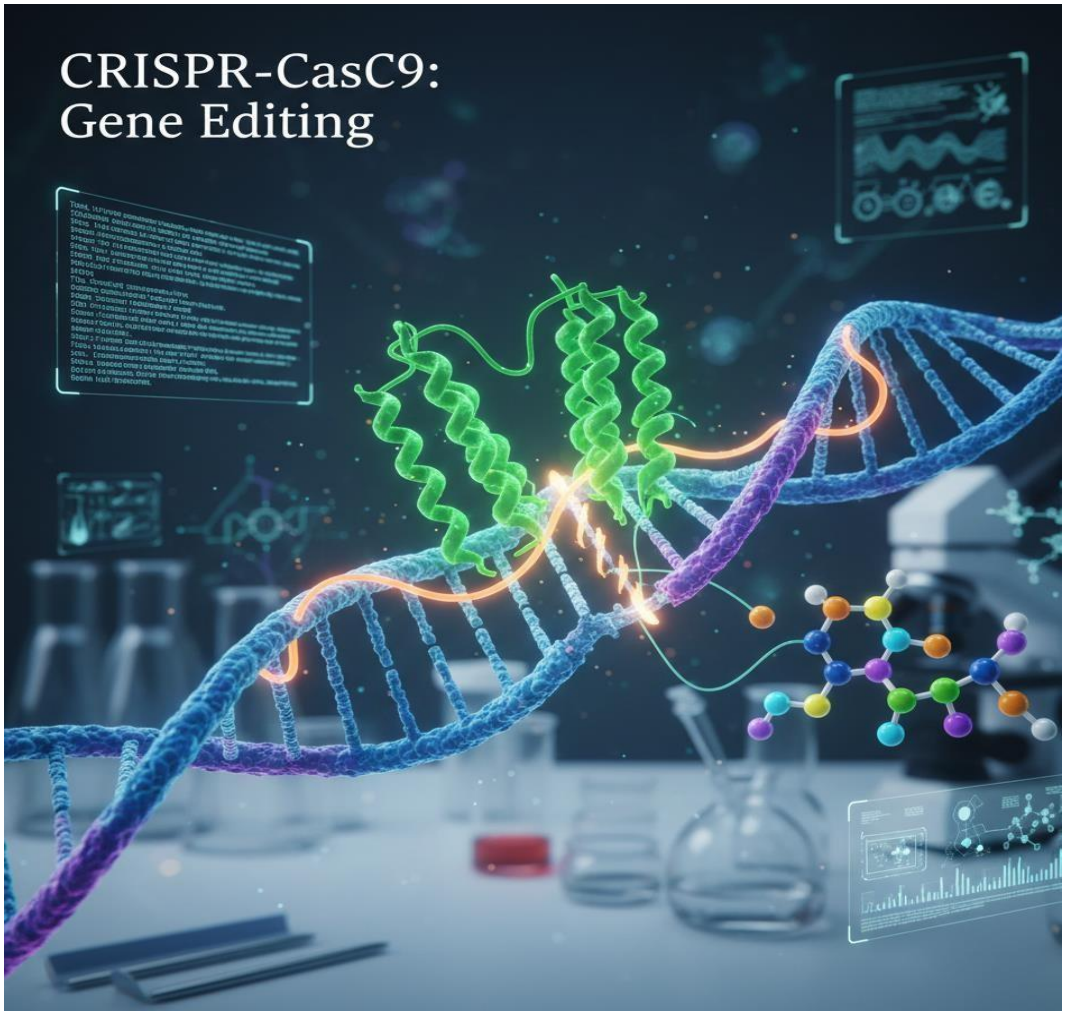

Hypothesis:

1) **H1:** The AI-driven model are the predictive model that significantly reduces the hyper-acute rejection in xenotransplantation as compared to the traditional cross-matching method.

   H0: The AI-driven model are the predictive model that does not significantly reduce the hyper-acute rejection in xenotransplantation as compared to the traditional cross-matching method.

2) **H1:** AI helps to optimise CRISPR-Cas9 gene editing, which produces porcine donor organs with fewer off-targets mutation than manual genetic engineering techniques.
   - **H0:** AI helps to optimise CRISPR-Cas9 gene editing, which does not produce porcine donor organs with fewer off-targets mutation than manual genetic engineering techniques.

3) **H1:** The collection of Mesenchymal Stem Cells (MSCs) at the transplant site, guided by AI secretome analysis, to improve the significant graft survival rates compared to standardised immunosuppressive drug therapy.

   H0: The collection of Mesenchymal Stem Cells (MSCs) at the transplant site, guided by AI secretome

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analysis, does not improve the significant graft survival rates compared to standardised immunosuppressive drug therapy.

4) **H1:** A computer vision system that is based on AI can detect microscopic signs of rejection organ earlier or more than traditional histopathological examination beyond human experts.
   H0: Computer vision systems that are based on AI do not detect microscopic signs of rejection organ earlier or more accurately than traditional histopathological examination beyond human experts.
5) **H1:** By using the AI, it is easy to manage the xenotransplantation protocol that reduces the overall cost and time of post-operative care of patient compare to traditional human-to-human transplant recovery protocols.
   H0: By using the AI, it is easy to manage the xenotransplantation protocol that does not significantly reduce the overall cost and time of post-operative care of the patient compared to traditional human- to-human transplant recovery protocols.

Research Methodology:

The research is exploratory. The nature is a descriptive study based on secondary data. The collected data is primarily from economic surveys of Various issues, and various articles have been published by both national and international journals, etc. Annual statistical data were used for analysis purposes. The data collected from various publications, which are reliable, Authentic and regularly used, is also taken into consideration. The study investigates these effects through surveys, interviews, and Secondary data analysis. The data collected from the surveys is qualitative and Quantitative in Nature.

❖ ***The Sample:***

Data were collected from **MS Surgeons (Master of Surgery)**, **Pathology Doctors (MD Pathologists)** in the neighbouring area of the city.

❖ ***Tool for Data Collection:***

A self-structured questionnaire was used for collecting the data.

❖ ***Research Design:***

This study is based on Qualitative and Quantitative research.

❖ ***Sampling Technique:***

A convenient sampling technique is used for this research study.

❖ ***Statistical Tool:***

The statistical tools used in analysing the data are in the pie chart form.

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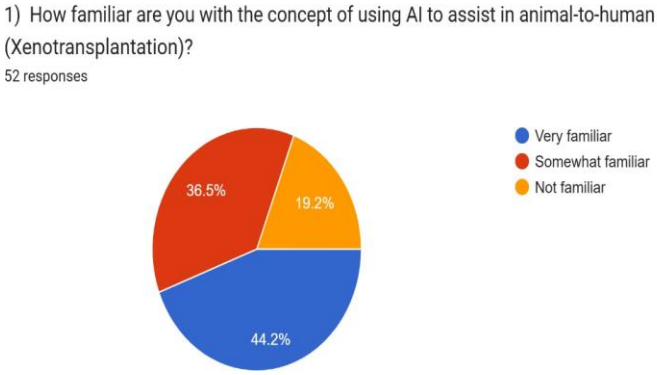
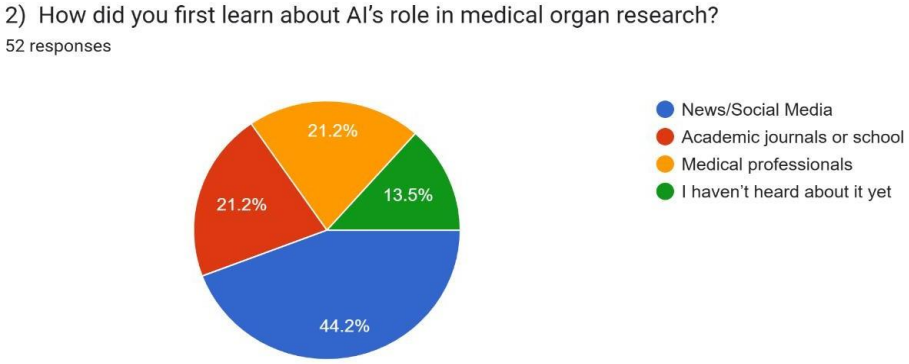
Finding, Analysis & Interpretation:



It was observed that among 52 respondents:

- 44.2% of Respondents are **very familiar with AI to assist in animal-to- human organ transplants (Xenotransplantation)**.
- 36.5% of Respondents are **somewhat familiar with AI to assist in animal-to-human organ transplants (Xenotransplantation)**.
- 19.2% of Respondents are **not familiar with AI to assist in animal-to- human organ transplants (Xenotransplantation.**



It was observed that among 52 respondents.

- 44.2% of Respondents have **first learn about AI's role in medical organ research from News/Social Media.**
- 21.2% of Respondents have **first learn about AI's role in medical organ research from Academic journals or school.**
- 21.2% of Respondents have **first learn about AI's role in medical organ research from Medical professionals.**
- 13.5% of Respondents **haven't heard about it yet, and learn about AI's role in medical organ research.**

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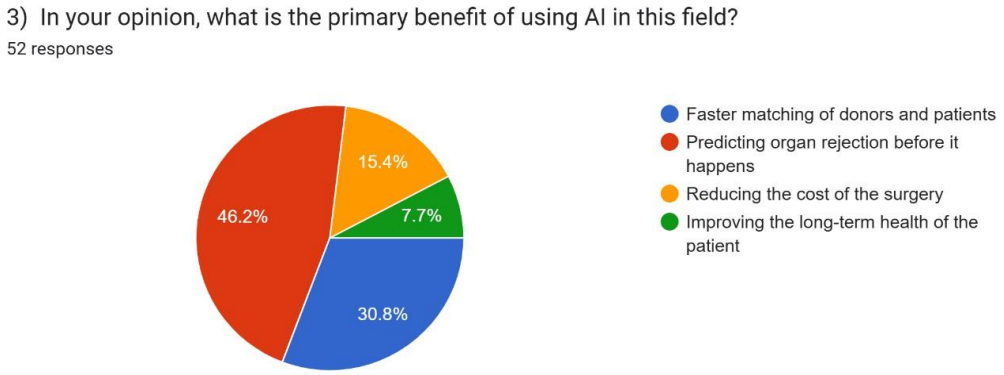
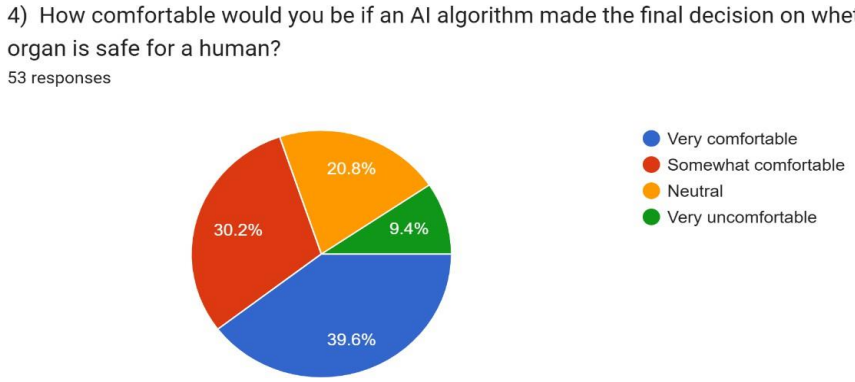


It was observed that among 52 respondents.

- 30.8% of Respondents have the **opinion that the primary benefit of using AI in this field is (Faster matching of donors and patients).**
- 46.2% of Respondents have the **opinion that the primary benefit of using AI in this field is (Predicting organ rejection before it happens).**
- 15.4% of Respondents have the **opinion that the primary benefit of using AI in this field is (Reducing the cost of the surgery).**
- 7.7% of Respondents have the **opinion that the primary benefit of using AI in this field is (Improving the long-term health of the patient).**



It was observed that among 53 respondents.

- 30.8% of Respondents are **very comfortable if an AI algorithm made the final decision on whether an animal organ is safe for a human.**
- 46.2% of Respondents are **somewhat comfortable if an AI algorithm made the final decision on whether an animal organ is safe for a human.**
- 15.4% of Respondents are **neutral if an AI algorithm made the final decision on whether an animal organ is safe for a human.**
- 7.7% of Respondents are **very uncomfortable if an AI algorithm made the final decision on whether an animal organ is safe for a human.**

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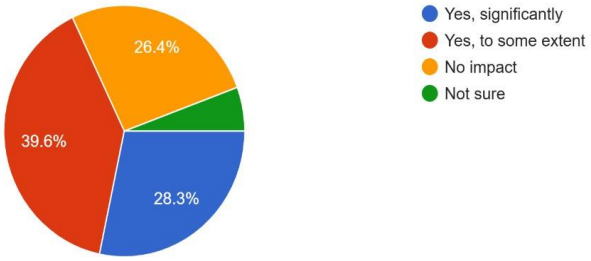
5) Do you believe AI can help make xenotransplantation more "ethical" by reducing the number of animals needed for testing ?

53 responses

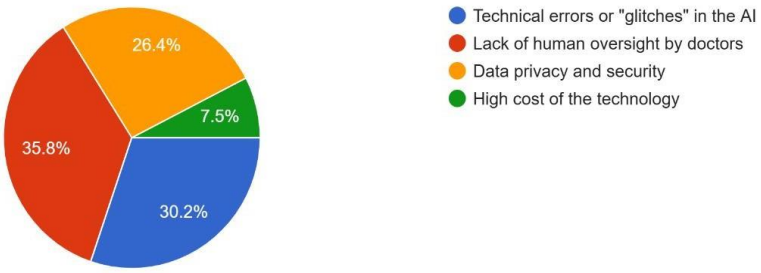


It was observed that among 53 respondents.

- 28.3% of Respondents are **say yes, significantly believe AI can help make xenotransplantation more "ethical" by reducing the number of animals needed for testing.**
- 39.6% of Respondents are **say yes, to some extent, believe AI can help make xenotransplantation more "ethical" by reducing the number of animals needed for testing.**
- 26.4% of Respondents are **believe that No impact if AI can help make xenotransplantation more "ethical" by reducing the number of animals needed for testing.**
- 7.5% of Respondents are **not sure that AI can help make xenotransplantation more "ethical" by reducing the number of animals needed for testing.**

6) What is your biggest concern regarding AI-driven organ transplants?

53 responses



It was observed that among 53 respondents.

- 30.2% of Respondents have the **biggest concern regarding AI- driven organ transplants is (Technical errors or "glitches" in the AI).**
- 35.8% of Respondents have the **biggest concern regarding AI- driven organ transplants, which is (Lack of human oversight by doctors).**
- 26.4% of Respondents have the **biggest concern regarding AI- driven organ transplants is (Data privacy and security).**
- 7.5% of Respondents have the **biggest concern regarding AI-driven organ transplants, the "high cost of the technology**

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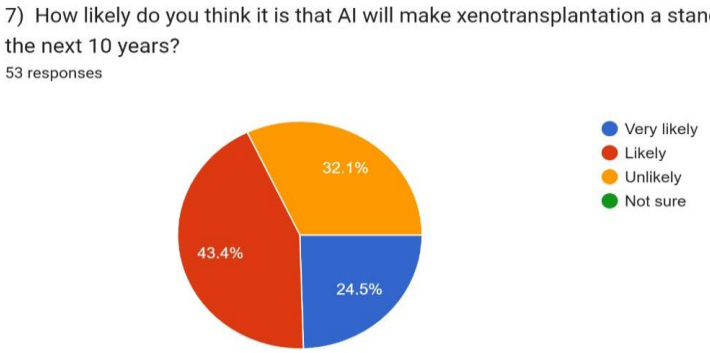
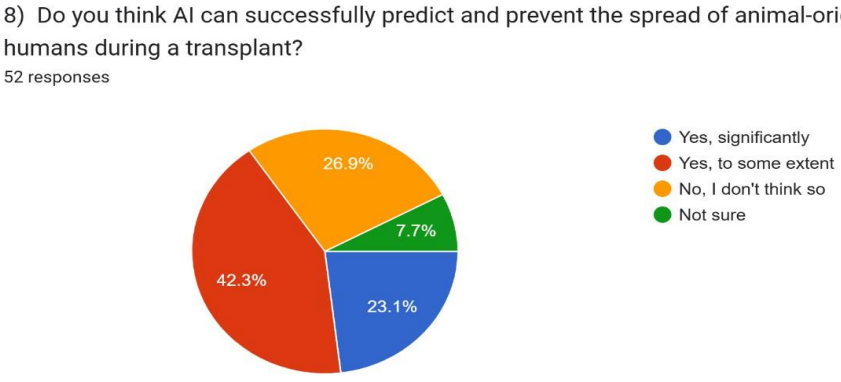


It was observed that among 53 respondents.

- 24.5% of Respondents are **very likely think it is that AI will make xenotransplantation a standard medical practice in the next 10 years.**
- 43.4% of Respondents are **likely think it is that AI will make xenotransplantation a standard medical practice in the next 10 years.**
- 32.2% of Respondents are **unlikely think it is that AI will make xenotransplantation a standard medical practice in the next 10 years.**
- 0% of Respondents are **not sure that AI will make xenotransplantation a standard medical practice in the next 10 years.**



It was observed that among 52 respondents.

- 23.1% of Respondents are **say yes, significantly, that AI can successfully predict and prevent the spread of animal-origin viruses to humans during a transplant.**
- 42.3% of Respondents are **say yes, to some extent that AI can successfully predict and prevent the spread of animal-origin viruses to humans during a transplant.**
- 26.9% of Respondents are **say No, I don't think so that AI can successfully predict and prevent the spread of animal-origin viruses to humans during a transplant.**
- 7.7% of Respondents are **not sure that AI can successfully predict and prevent the spread of animal-origin viruses to humans during a transplant.**

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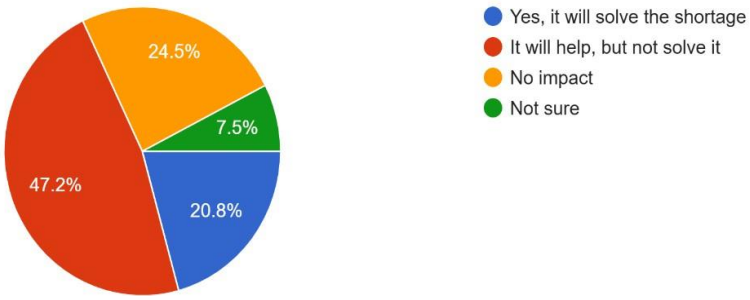
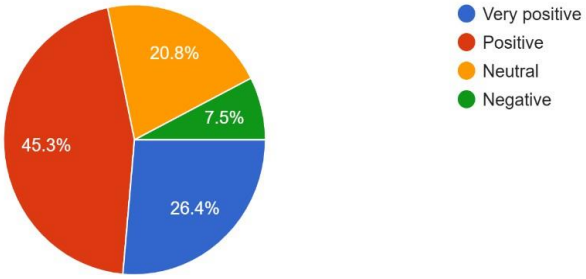
9) In your view, will AI help reduce the global shortage of human organs for transplant?
53 responses



It was observed that among 53 respondents.

- 20.8% of Respondents are **say yes, AI will solve the shortage of human organs for transplant.**
- 47.2% of Respondents are **say AI will help, but not solve the global shortage of human organs for transplant.**
- 24.5% of Respondents **say AI will have no impact on the global shortage of human organs for transplant.**
- 7.5% of Respondents are **not sure AI will solve the shortage of human organs for transplant.**

10) How do you feel about the use of AI to "genetically edit" animal organs to be more like human organs?
53 responses



It was observed that among 53 respondents.

- 26.4% of Respondents are **feel very positive about the use of AI to "genetically edit" animal organs to be more like human organs.**
- 45.3% of Respondents are **feel positive about the use of AI to "genetically edit" animal organs to be more like human organs.**
- 20.8% of Respondents are **feel neutral about the use of AI to "genetically edit" animal organs to be more like human organs.**
- 7.5% of Respondents are **feel negative about the use of AI to "genetically edit" animal organs to be more like human organs.**

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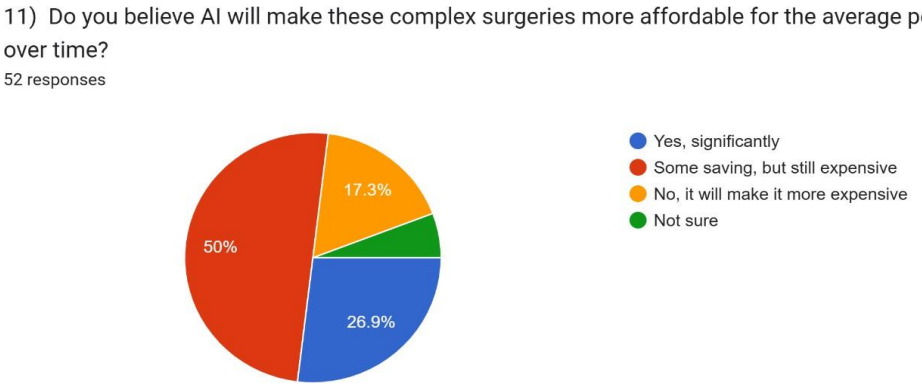
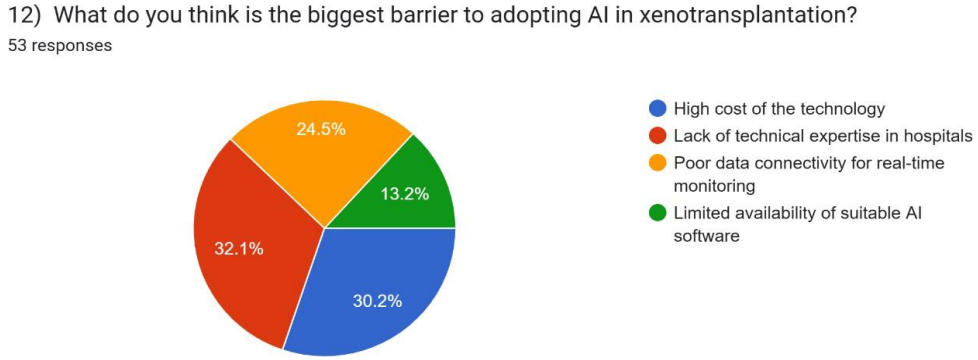


It was observed that among 52 respondents.

- 26.9% of Respondents are **say yes, significantly, AI will make these complex surgeries more affordable for the average person over time**
- 50% of Respondents are **say AI will help with some savings, but still expensive for complex surgeries, more affordable for the average person over time**
- 17.3% of Respondents are **say No; AI will make it more expensive for complex surgeries, more affordable for the average person over time.**
- 5.8% of Respondents are **not sure that AI will make these complex surgeries more affordable for the average person over time.**



It was observed that among 53 respondents.

- 30.2% of Respondents **think that the high cost of the technology is the biggest barrier to adopting AI in xenotransplantation.**
- 32.1% of Respondents **think that Lack of technical expertise in hospitals is the biggest barrier to adopting AI in xenotransplantation.**
- 24.5% of Respondents **think that Poor data connectivity for real-time monitoring is the biggest barrier to adopting AI in xenotransplantation.**
- 13.2% of Respondents **think that Limited availability of suitable AI software is the biggest barrier to adopting AI in xenotransplantation.**

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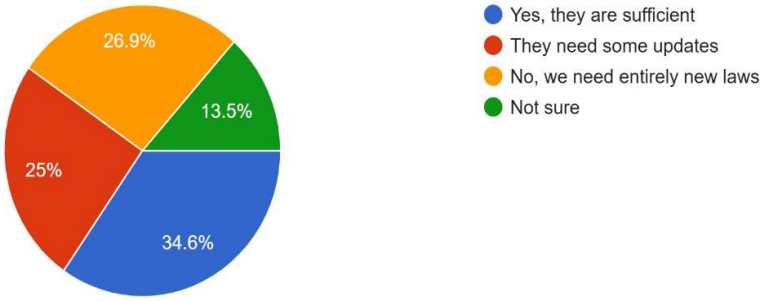
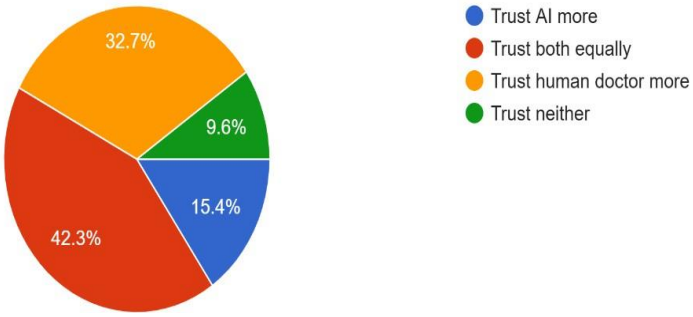
13) Do you feel that current medical laws are enough to regulate AI in this field?
52 responses



It was observed that among 52 respondents.

- 34.6% of Respondents are **say yes, that current medical laws are sufficient to regulate AI in this field.**
- 25% of Respondents are **think that current medical laws need some updates to regulate AI in this field.**
- 26.9% of Respondents are **say no, we need entirely new laws to regulate AI in this field.**
- 13.5% of Respondents are **not sure that current medical laws are enough to regulate AI in this field.**

14) How much do you trust AI compared to a human doctor when it comes to monitoring organ health?
52 responses



It was observed that among 52 respondents.

- 15.4% of Respondents **think that Trust AI more compared to a human doctor when it comes to monitoring organ health.**
- 42.3% of Respondents **think that they trust both equally when it comes to monitoring organ health.**
- 32.7% of Respondents **think that Trust human doctor more than** AI **when it comes to monitoring organ health.**
- 9.6% of Respondents **think that Trust neither when it comes to monitoring organ health.**

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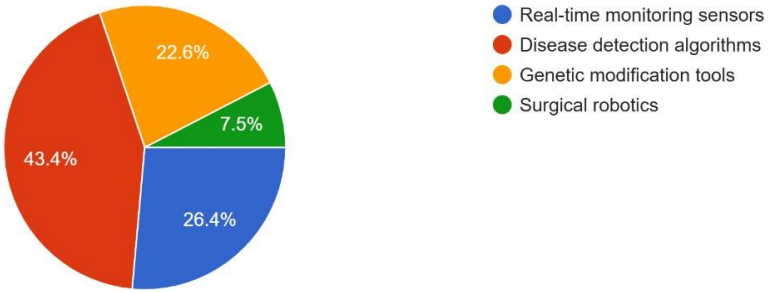
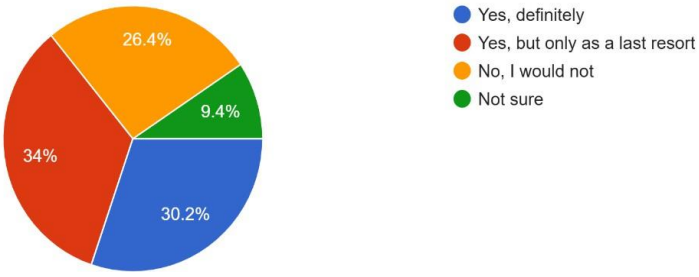
15) Which area of AI development do you think is most critical for transplant success?
53 responses



It was observed that among 53 respondents.

- 26.4% of Respondents **think that Real-time monitoring sensor development is most critical for transplant success.**
- 43.4% of Respondents **think that Disease detection algorithms development is most critical for transplant success.**
- 22.6% of Respondents **think that Genetic modification tools are most critical for transplant success.**
- 7.5% of Respondents **think that Surgical robotics is most critical for transplant success.**

16) If a family member needed a life-saving transplant, would you support an AI-monitored animal organ?
53 responses



It was observed that among 53 respondents.

- 26.9% of Respondents are **say yes, definitely, if a family member needed a life-saving transplant, support for an AI-monitored animal organ.**
- 50% of Respondents are **say yes, an AI-monitored animal organ, but only as a last resort, they will support a family member needed a life-saving transplant.**
- 17.3% of Respondents are **say No, I would not support an AI- monitored animal organ to a family member who needed a life- saving transplant.**
- 5.8% of Respondents are **not sure they support an AI-monitored animal organ when a family member needs a life-saving trans**

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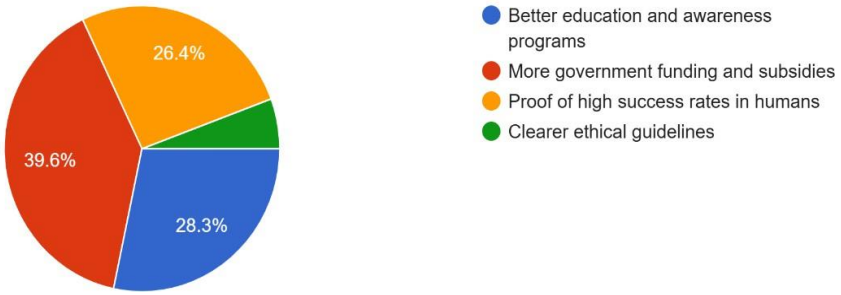
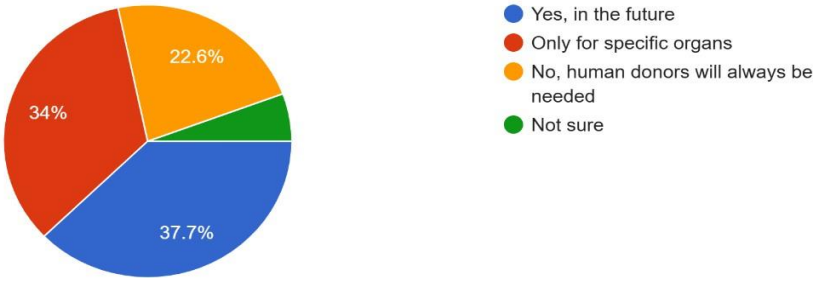
17) What kind of support is most needed for the public to accept this technology?
53 responses



It was observed that among 53 respondents.

- 28.3% of Respondents **think that Better education and awareness programs are most needed for the public to accept this technology.**
- 39.6% of Respondents **think that More government funding and subsidies are most needed for the public to accept this technology.**
- 26.4% of Respondents **think that Proof of high success rates in humans is most needed for the public to accept this technology.**
- 5.7% of Respondents **think that Clearer ethical guidelines are most needed for the public to accept this technology.**

18) Do you think AI will eventually replace the need for human organ donors entirely?
53 responses



It was observed that among 53 respondents.

- 37.7% of Respondents **say yes, in the future, AI will eventually replace the need for human organ donors entirely.**
- 34% of Respondents **say that, only for specific organs, AI will eventually replace the need for human organ donors entirely.**
- 22.6% of Respondents **say that no, human donors will always be needed.**
- 5.7% of Respondents **are not sure that AI will eventually replace the need for human organ donors entirely.**

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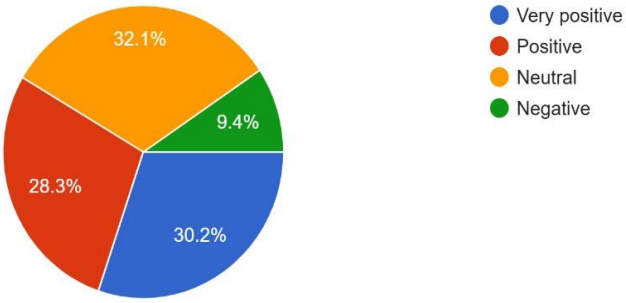
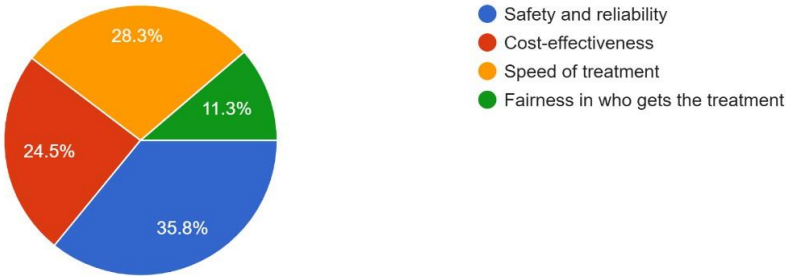
19) How would you rate your overall attitude toward AI in healthcare after considering these points?
53 responses



It was observed that among 53 respondents.

- 30.2% of Respondents are **feel a very positive attitude toward AI in healthcare after considering these points**
- 28.3% of Respondents are **feel a positive attitude toward AI in healthcare after considering these points.**
- 32.1% of Respondents are **feel a neutral attitude toward AI in healthcare after considering these points**.
- 9.4% of Respondents are **feel a negative attitude toward AI in healthcare after considering these points.**

20) What is the most important factor for you when evaluating new medical AI technology?
53 responses



It was observed that among 53 respondents.

- 35.8% of Respondents **think that Safety and reliability are the most important factors for you when evaluating new medical AI technology.**
- 24.5% of Respondents **think that cost-effectiveness is the most important factor for you when evaluating new medical AI technology.**
- 28.3% of Respondents **think that the speed of treatment is the most important factor for you when evaluating new medical AI technology.**
- 11.3% of Respondents **think that Fairness in who gets the treatment is the most important factor for you when evaluating new medical AI technology.**

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Suggestion:

AI-Enhanced Genetic Compatibility Screening: By using machine learning and control to analyse the donor-recipient genetic data, this data helps to predict the risk of Hyperacute Rejection (HAR) by identifying the specific porcine endogenous retroviruses (PERVs) that need silencing.

Predictive Secretome Profiling: AI-driven tools implement proteomic analysis to monitor the MSC secretome at the time of transplant (real- time), to ensure that the anti-inflammatory cytokines are stable and maintained at the transplant site.

Autonomous Immunomodulation Monitoring: A smart biosensor are deploy within the transplanted proteomic tissue, using AI to detect early molecular changes of graft-versus-host disease (GvHD) before showing any symptoms or changes in the physical body.

Deep Learning for Microvascular Integration: Analysing the imaging with the use of AI-powered tools(like OCT or intravital microscopy) to track the "humanisation" of the donor vascular system, conforming to the accurate, proper blood flow and nutrient exchange in the xeno-tissue.

In-Silico Clinical Trials: AI is the one that is used to create "digital twins" of the transplanted patient model, to identify how various MSC-derived secretome treatments will interact with different human phenotypes, and to identify the need reduce the extensive animal testing.

Conclusion*:*

The integration of Artificial Intelligence into xenotransplantation is challenging the concept of human limitation. It marks a historic shift that represents one of the most ambitious leaps in modern medicine. AI helps to move from experimental surgery to a high level of precision therapy. AI detects zoonotic viruses and locates the immune response with 98% accuracy, and also addresses the primary risk of infection and organ rejection that have previously thwarted animal-to-human transplants. Survey data suggest a high level of optimism among medical professionals, as they believe that AI will eventually reduce the shortage of organs globally and lower the cost of long-term complex surgeries. While a rigorous change in the ethical framework and new medical law is required, AI-guided engineering and real-time monitoring are the critical technologies that fulfil the potential in xenotransplantation to solve organ failure.

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