



From Virtual Model to Clinical Reality: Review on AI Enabled In Silico Twins in Organ Transplantation

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Abstract:

The major difficulties seen in organ transplantation are organ rejection and infection during the surgery, shortage of organs and mainly the donor-recipient matching. By finding solutions to these problems the AI enabled In Silico twins plays a key role in development seen in organ transplantation.[3] The combination of AI In Silico twins, a virtual replica of individual patients created by using physiological, biological and clinical data. These virtual models can predict the organ rejection by [6] immunosuppressive therapy, organ function and disease progression and also help in medical treatment based on the type of organ. The AI enabled In Silico twins provide a real time data and gives the information about the organ function and donor selection. By combining the AI in organ transplantation medical procedure, the positive outcomes will be enhanced. The In-Silico twins technology will reduce ethical risks and minimize the clinical trials and clinical errors in patients. This technology gives a safer procedure by creating the virtual replica by using the physiology of organs and predict better donor-recipient matching and modify the clinical practice and improve the transplant success rapidly developing through AI and it is continuously evolving in all sectors; the virtual twins could soon become an essential tool making the transplant safer and more successful for patients throughout the world.

Keywords:

AI enabled In Silico twins, virtual Replica, AI-artificial intelligence, Immunosuppressive therapy, clinicians.

INTRODUCTION:

Organ transplantation is one of the most complex and delicate medical procedure. It requires careful planning and clarity. The success depends upon immune responses of population based on guidelines donor- recipient match .AI have introduced the theory of In Silico twins. Patient health care scenarios with high accuracy these digital twins can predict the results. Evaluate risk and personalize medicines technique before treatment occurs. In Silico twins are responsive digital models designed from patient specific data such as physiological parameters, medical images,[11] gene expression, protein analysis and patient history data.

THEORY OF IN SILICO TWINS: An In-Silico twin is a [7] digital twin, computerized replica of an individual patient. Which is created using patient personal data based upon on their physiological, biological and clinical data. These digital models represent how patient body and their organs stimulate to their diseases, treatment and medical trails.[2] The first man Dr. Michael Grieves used the word digital twin as a virtual model. These virtual models support clinicians to predict the patient's future outcomes and also improves patient care.



IMPORTANCE IN ORGAN TRANSPLANTATION:

AI enabled In-Silico twins are digital models of patients that simulate organ behavior, playing a crucial role in organ transplantation by [4] continuous monitoring to detect early diagnosis and tailored treatments, enabling personalized predictions of transplant outcomes, identifying potential complications, optimizing donor-recipient matching, and aiding complex surgeries. They have been applied in kidney and liver transplantation to predict acute kidney injury,[12] graft rejection, and post-transplant outcomes, with future potential in AI integration and expanded use in other organs. Organ transplantation is the crucial element of advanced medical care. It is a medical procedure that enhances the treatment of end-stage organ failure and saves lives by replacing a failure organ with the healthy one. It brings hope for patients with terminal organ diseases, offers extended survival rate. Transplantation reduces the long-term burden of chronic illness caused by the diseases like diabetes, heart failure, and chronic kidney and liver, lung diseases. it also contributes to better clinical results compared to prolonged surgical and medical management. Transplantation permits many patients to minimizes the repeated hospitalizations and offering hope to many. Despite its significant impact transplantation remains to face major challenges such as limited donor availability and immune induced resistance. These highlights are the essential role of further investigation and advancement to further enhance transplant consequences. Overall, organ transplantation is a phenomenal achievement in medicine.

WORK FLOW OF DIGITAL TWIN SIMULATION:

An In-Silico twin is a virtual computer-generated copy of a real patient; the doctors can treat on this copy before trying them in real life. It is built by using patient medical data such as scans, lab result, genetics and clinical history. Digital twinning aims to create a highly accurate virtual model of a physical system or process to stimulate

system behavior condition monitoring, detection of abnormal pattern errors. There are several steps involved like data collection, digital twin creation, [9] disease simulation and designing, optimization and decision support, physical intervention, continuous monitoring and updates. This idea is to create a digital model that behaves like a patient's real body or organ. It helps to make organ transplants safer, more personalized and more successful.



APPLICATIONS OF IN SILICO TWINS IN ORGAN TRANS PLANTATION:

1. Predicting organ rejection:
 - In silico twin simulates patient immune response before the surgery.
 - Helps to identify the risk of acute or chronic rejection.
 - Allows proactive adjustment of immunosuppressive drugs.
2. Individualized immune suppression:
 - In silico twins analyze different drug combinations and doses.
 - Helps to find the optimal dose for each patient.
 - Reduces long-term sides effects and disorders.
3. Enhancing tissue matching:
 - Improves transplant outcome.
 - Increases organ distribution decision
 - In silico models compare donor

BENEFITS AND ADVANTAGES:

AI can analyze thousands of data sets, genetics and clinical parameters at once and prevents complications that require premium medical care. In Silico twin's replicate compatibility before the surgery, and identifies early sign of immunological reactions, avoid patient risks and saves time and reduce side effects. The use of virtual patient data to enhance [5] pediatric clinical trials could have numerous advantages, including decreased exposure of children to potentially ineffective or risky interventions, shorter trial durations leading to more rapid improvement of safety and effectiveness of interventions, and faster drug approvals. AI with in silico twin

predict the success rate before human trails. There are several benefits of AI enabled In Silico twins such as improves accuracy and also enhances personalized medicines and improve efficiency.

CHALLENGES AND LIMITATIONS:

AI-assisted organ transplantation using In Silico twins faces various challenges. To create an accurate digital twin, it requires a high-quality profile including genomics, imaging, physiology, and clinical background. In many cases, incomplete data may lead to wrong predictions. Another major limitation is prominent computers are needed to duplicate immune responses, organ function, and drug interactions. Advanced digital twins not fully replicate the complexity of human science, which can affect the sureness of predictions. In addition to, the technology demands high expensive, tailored infrastructure, and trained professionals, making it difficult for widespread adoption. Ethical issues, uncertain legal responsibilities, and the risk of data privacy contravention a stimulate challenges. Moreover, the lack of standard guidelines and limited large-scale clinical validation reduce trust among surgeons or clinicians, slowing its combination into real transplant workflows.

FUTURE PROSPECTS:

Future prospects for AI driven In Silico twins in organ transplantation look promising, it will revolutionize organ transplantation by enabling personalized predictions, improving outcomes, expanding applications. They facilitate precise treatment plans, reduce complications, and improve the graft survival. With virtual patient replicas, medicine is stepping into the future where complications can be anticipates long before they occur. As AI and [10] computerized modeling advance In Silico twins stand at the leading edge of a new era in transplant medicine.



Conclusion:

Therefore, the above information of article concludes that the virtual recreation of human systems through AI enabled in silico twins mark major development in organ transplantation. Basically, the organ transplantation performed by replacing damaged organs. [1] The organs may damage due to the occurrence of several diseases or any other injuries in a human body. The virtual recreation of human systems has rapidly developed in medical research for example the virtual recreation in organ transplantation like development of digital twins (DTs) for patients to enhance the effective treatments in a cheaper, quicker and more effective manner. Basically, the organ transplantation is a very critical procedure for which the AI enabled In Silico twins were introduced to reduce these complications and improve the long-term outcomes. The use of AI enabled Insilco twins has various applications in various fields such as genomics, physiology, scans and real time health matrices. It can predict the medication strategies, organ recovery and their functions and also improves the [8] personalized treatment planning. AI enabled In Silico twins will mark a significant evolution in organ transplantation in the near future

making this article more relevant.

References (APA style)

1. Asad Razzaq., (2018). Organ Transplantation: An Overview from History to Challenges. International Journal of Cell Science and Molecular Biology, IntJ cellSci & mol biol.2018;5(2): 555659.Doi:
[10.19080/IJCSMB.2018.05.555659](https://doi.org/10.19080/IJCSMB.2018.05.555659)
2. MarianLukaniszyn1.,Lukasz Majka2., BarbaraGrochowicz1., Dariusz Mikołajewski3,4., and Aleksandra Kawala-Sterniuk5., (2024). Digital Twins Generated by Artificial Intelligence in Personalized Healthcare. International Journal of Applied sciences by MDPI Appl.Sci.2024 14(20),9404;
<https://doi.org/10.3390/app14209404>
3. Tim Kreuzer., Panagiotis Papapetrou., Jelena Zdravkovic., (2024). Artificial intelligence in digital twins- A systematic literature review. The Journal of data & Knowledge Engineering, Volume 151.
<https://doi.org/10.1016/j.datak.2024.102304>
4. Adam Bohr¹., and Kaveh Memarzadeh²., (2020). The rise of artificial intelligence in healthcare applications. Book of Artificial Intelligence in Health Care, Chapter-2, pages 25 to 60.
<https://doi.org/10.1016/B978-0-12-818438-7.00002-2>
5. ProfMohanPammi, MD^a., PrakashShah,MD^b., LiuKyang,phd^c., JosephHagan,ScD^a.,NimaAghaeepour,PhD^c., ProfjosefNeu,MD^d.,(2025). Digital twins, synthetic patient data, and in-silico trials: can they empower pediatric clinical trials. The Journal of Lancet Digital Health, Volume 7.
[https://www.thelancet.com/journals/landig/article/PIIS2589-7500\(25\)00007-X/fulltext](https://www.thelancet.com/journals/landig/article/PIIS2589-7500(25)00007-X/fulltext)
6. Thierry Burney., (2025). Transplant International, Volume 38.
<https://share.google/O9ny7AZEMlq8KYE5>
7. Vinay Kulkarni., Tony Clark., Balbir S., Barn., (2025). Digital Twins for Simulation- Based Decision-Making.
<https://link.springer.com/book/10.1007/978-3-031-89654-5 - author-1-0>
8. Tianhua Chen., Jenny Carter., Mufti Mahmud., Arjab Singh Khuman.,(2022).Book of Artificial Intelligence in Healthcare Recent Applications and Developments.
<https://share.google/PWHZsTGbJleOh6QMl>
9. Ehsan Samei., (2025). The future of in silico trials and digital twins in medicine. The Journal of National Institutes of Health.
<https://share.google/Ir1NOF8oH6GdIxLnx>
10. Philippe Moingeon 1., Marylore Chenel 2., Cécile Rousseau 3., Emmanuelle Voisin 3., Mickael Guedj 1.,(2023).Virtual patients, digital twins and causal disease models: Paving the ground for in silico clinical trials. Book of Drug Discovery Today, Volume-28
<https://share.google/1n5xnJGoiWZbGNLqo>
11. Josep M Grinyo¹.,(2013). why the organ transplantation is important Journal of Cold Spring Harbor Perspective in Medicine.

<https://share.google/26d7Re2flkw3d7t6k>

12. Idrisyakubu¹, AbdolrezaHarira², Stephen Bartlett², Tracy Sparkes¹, (2018). Successful Renal Transplantation between Identical Twins with Very Brief immune suppression. Journal of Case Report in Transplantation.

<https://share.google/YL6ilZ5BEjtHyxrzL>