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Review Article

Technological advancements, digital transformation, and future trends in blood transfusion services

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ABSTRACT

Misidentification, mistransfusion, and pre-analytical errors are all regarded as major challenges and risks in safe blood transfusion procedures. To provide a high level of accuracy, traceability, automation, and reliability in blood transfusion services, traditional methods should be upgraded with modern technologies such as block chain technology, machine learning, artificial intelligence (AI), artificial neural networks, algorithm-based learning, and the implementation of radio frequency identification (RFID) and the internet of things (IoT). This technology helps reduce errors, retrieve data, forecast blood demand, reduce blood waste, manage blood storage, and manage workload, ensuring transfusion safety. The technology is still in the initial stages of development and by addressing issues such as data loss, patient data privacy, and cost-effectiveness, the technology will become a revolution in transfusion services.

Keywords: RFID, Internet of small things, Block chain technology, AI, Blood transfusion

INTRODUCTION

Transfusion Medicine is a multidisciplinary field that deals with the collection, testing, processing, storing, and transfusing of blood and blood components in the treatment of human diseases. Pre-analytical errors, misidentification, and mistransfusion are all regarded as major impediments and risks in safe blood transfusion practices.[1] Several incidents have been documented worldwide during the collection, transport, storage, and transfusion of blood. Human errors during the process of blood collection to blood transfusion are a life-threatening issue. In order to reduce errors and ensure safety, blood transfusion. Following proper guidelines and protocols, along with use of technology which helps to reduce human generated errors in blood transfusion process. Traditional blood transfusion practise in many institutions includes a lot of manual stages with a significant potential of error. Hospitals and blood banks now require modern and innovative systems that provide high levels of accuracy, traceability, automation, and reliability to assure ultimate quality of services. In order to ensure quality blood transfusion implementation of technologies, including block chain technology, machine learning, AI, artificial neural networks, algorithm-based learning and introduction of RFID and IoT. Transfusion medicine is still in its early stages of technological adoption; data loss, patient data privacy, cost effectiveness, remain issues.

In this paper, we discuss current updates on introducing technology in transfusion services, future advances in transfusion medicine, and how these technologies can reduce errors, retrieve data, predict demand for blood, reduce blood wastage and manage blood storage, manage workload, and ensure transfusion safety.

Aim

Aim of the study is to check the current status, future advances and limitations of modern technology in transfusion services including blockchain technology, machine learning, AI, artificial neural networks, algorithm-based learning and introducing RFID and IoT.

CURRENT TECHNOLOGIES, FUTURE TRENDS OF MODERN TECHNOLOGY IN TRANSFUSION SERVICES

Current and future updates on RFID and IoT

Radio-frequency identification (RFID) use electromagnetic waves to recognise and track digitally encoded tags attached to items whereas the IoT is a network of physical objects-"things"-embedded with sensors, software, and other technology that allow them to connect to and share data with other devices and systems over the internet. The key challenges to establishing IoT technology are seamless data transmission rate with low or no data loss, cost-effectiveness, no time data retrieval, and machine-to-machine or device-to-device connectivity.[2] The volume of data handled by IoT devices is growing at an exponential rate, and the security and privacy of data collected from IoT devices, whether during transmission to or storage in the cloud, are major unresolved concerns.[3]

Current and future updates on block chain technology in blood transfusion

Blockchain is a revolutionary framework that provides a new design for data storage and exchange among members of a certain network.[15] The following is a current and future update and application of block chain technology in transfusion services (Table 2).

Current and future updates on AI, algorithm-based machine learning, and deep neural networks in transfusion medicine

AI, algorithm-based machine learning and deep neural networks are modern advances in blood transfusion services which can be used as supportive tool to improve the quality, efficacy and to reduce errors in transfusion services. The following are the recent updates in AI and algorithm-based machine learning and deep neural networks (Table 3).

Table 1: Current and future updates on RFID and IoT.

Research area	Outcomes and findings
Future of IoT in blood transfusion safety	Blood bags integrated with smart devices integrated with environment sensors with active RFID, DASH7 alliance protocol-an open-source wireless sensor assisting in continuous monitoring of blood transfusion bags, ensuring good condition and quality of shipped products, and assisting in safe blood transfusion.[4]
Block chain technology-IoT incorporation	Using block chain technology in conjunction with IoT allows for continuous data collection, real-time monitoring, and traceability.[5,6]
IoT in blood supply management and monitoring	Incorporating IoT aids in tracking cold chain management of shipped products, identifying and authenticating patients who will receive blood products, tracking real-time information of patients' health information, improving inventory management, and improving overall care and procedure traceability.[7]
RFID ISBT approved barcode tags	The international society for blood transfusion (ISBT) and the United States food and drug administration (FDA) have accepted 13.56 MHz ISO/IEC 18000-3 mode 1 RFID tags as data carriers to combine with and augment ISBT 128 barcode data contained on blood supplies.[8]
RFID system in transfusion services	A pilot study in one Lowa hospital system found that misidentification of patients and/or blood products during transfusion was decreased by 3-10%, indicating that RFID-enabled transfusion practises increase productivity and product quality by reducing work and errors.[9]
RFID to provide better patients service by reducing errors	RFID integration in healthcare contexts has sparked a lot of interest in recent years. RFID characteristics and capabilities are regarded to have the potential to provide better service to patients by reducing errors.[10]
RFID in cold chain transportation	RFID equipped with external sensors recently broadened its application range. RFID with sensors can be used to notify when the proper temperature is not maintained during cold chain transportation.[11]
Evaluating the efficacy of RFID in cold chain logistics	A study done in assessing the quality of cold chain logistics of RBCs discovered that potentials of RFID in detecting potential impediments in healthcare organisations' processes by using objective data, which are to be addressed in process redesign initiatives, can be utilised to measure RBC management compliance.[12]
Evaluating efficacy of RFID in transfusion service -a pilot study	A pilot study conducted at the university of Iowa hospitals and clinics (UIHC) in the United States revealed that the RFID system could offer high standards of safety for error reduction and detection, as well as productivity increases.[13]
Future of blood transfusion using technology	A blood bank ecosystem powered by augmented reality, AI, and IoT technology is proposed to improve the efficiency of blood supply chain with the use of smart labels, IoT sensors, and AI, an automated management system will be able to monitor inventories in real-time.[14]

Table 2: Current and future updates on block chain technology in blood transfusion.

Research area	Outcomes and findings
Block chain technology	The Hyperledger fabric platform. built a system based on block chain technology to support trust-based blood transfusion and the development of an end-to-end blood process.[16,17]
Block chain-based framework	KanCoin is an Ethereum blockchain-based architecture that manages optimal distribution planning in the blood delivery system from donors to distribution centres and patients in a more efficient manner than traditional techniques.[18]
Platform based on block chain and other techniques for efficient blood management system	A proposed management platform that employs techniques such as long short-term memory (LSTM), k-means clustering, geographic information systems (GIS), and blockchain. enabling the blood bank to forecast blood demand and secure the blood supply chain.[19]
Block chain technology a promising technology in health care	Blockchain minimises the likelihood of disastrous breaches while simultaneously providing data integrity, anonymity, and robust storage and because this strategy maintains data in a distributed manner, the possibility of a single point of failure is decreased.[20]
Blood bank chain data encryption in block chain technology	The 'advanced encryption standard (AES)' is a symmetric key crypto-system based on block chain technology that is used on a part of blood-chain data before transmitting transactions to the ordering service and adding blocks to the ledger and only authorized person will have access decrypt the encrypted data increasing the security.[21]
Block chain technology based-smart blood and organ donation system	Web-based secure-smart blood and organ donation system built with blockchain technology developed by Ethereum smart contract (ESC) estimates blood demand for the next ten years using a linear regression model, reducing blood shortages and waste.[22]
Combination of block chain and IoT technology	The combination of blockchain and IoT technology allows for the sharing of real-time information in the blood cold chain supply.[23]
Block chain technology for smart blood banking system	A blockchain-based blood bank system helps to access, trace, manage, and share health and blood-related information, and provides a secure environment that serves as a communication hub between donors, recipients, doctor and testing laboratories.[24,25]
Blockchain based blood management system	It is important to construct blood and its products management system, which is now done using traditional methods/manually. Hyperledger fabric platform is novel proposal to developing countries for blockchain-based blood and blood product management operations.[26]
Block chain-based technology in blood utilization	A blood bank management system proposal based on private blockchain technology for securing information visibility and reducing blood supply time, which aids in the effective utilisation of blood and blood products by allowing them to keep their blood stock intact while maintaining excess blood inventory.[27]

Table 3: Current and future updates on AI, algorithm-based machine learning, and deep neural networks in transfusion medicine.

Research area	Outcomes and findings
Machine learning algorithm for blood utilization management	The Ligh tgbm algorithm-based mode for constructing AI is more accurate than clinician experience-based in predicting preoperative RBC transfusion, which reduces the risk of insufficient preoperative blood preparation and the unnecessary cost of blood compatibility testing caused by excessive preoperative blood preparation.[28]
Algorithm for blood and blood products management	Patient blood management (PBM) has played an important role in perioperative management, and an HPI-based treatment algorithm is a useful tool for patient blood management.[29]
Computational strategies based on machine learning in transfusion medicine	Machine learning approaches have the potential to revolutionise the field of transfusion medicine, as they can be used to perform high-content evaluations of red blood cell morphology in microfluidic devices, generate in silico models of red blood cells membrane to predict deformability and bending rigidity, or develop systems biology maps of the red blood cell metabolome to drive the research and development of novel storage additives.[30]
Application of large language models in transfusion medicine	LLMs (Large language models) such as Bard, GPT-3.5, and GPT-4 LLMs displayed a range of performance when confronted with various transfusion medicine tasks, but GPT-4 consistently scored very well in all tests, indicating that more research is needed to assess the utility of LLMs in transfusion medicine practise.[31]

Continued.

Research area	Outcomes and findings
Digitally enabled hemovigilance	Digitally enabled hemovigilance enables real-time response to transfusion responses, resulting in faster response and enhanced transfusion reaction identification.[32]
Deep learning platform for fast and accurate decision making in transfusion medicine	Inhouse developed deep learning platform developed by CiRA CORE can speed up the blood group identification process and automatically record traceable results, implying that deep learning can be integrated with low-cost paper-based analytical device (PAD) for blood group typing with fast and accurate decision making.[33]
Artifical intelligence for reducing blood wastage and preventing shortage	A proposed system optimises the blood donation process by preventing blood shortages and minimising blood unit wastage due to expiration, and demonstrates promising results using a set of optimisation equations built for optimising the blood donation process to reduce blood wastage and prevent blood shortage.[34]
Neural network model	Using the YOLO neural network model, blood banks can reduce time and effort while enhancing accuracy accuracy of evaluation of blood transfusion resulting in faster and better medical diagnosis.[35]
Forecasting blood supply using machine learning	Smart data-driven blood bank management platform that can reduce blood demand uncertainty by anticipating blood collection and demand, as well as blood wastage and shortages by balancing blood donation and distribution based on optimal blood inventory management in conjunction with bio-inspired algorithms such as genetic algorithms and evolutionary strategies, to optimise the scheduling of blood donation sessions that are convenient for both the blood bank and the donor.[36]
AI to balance blood supply vs demand	In critical scenarios for blood supply chains, a novel omnichannel blood supply chain (OBSC) model based on AI can address the supply and demand imbalance.[37]

DISCUSSION

Transfusion medicine is still in the early stages of using RFID technology, and important challenges to RFID utilisation include startup costs, patient privacy, and patient information security. RFID tags are not widely used because of the lack of security on RFID tags and the limited storage space for data. Traditional blood transfusion practise in many institutions includes a lot of manual stages with a significant potential of error. Hospitals and blood banks now require modern and innovative systems like RFID or IoT that provide high levels of accuracy, traceability, automation, and reliability to assure ultimate quality of services.

The use of machine learning in transfusion medicine contributed to uniformity and standardisation, which was followed by the development of deep learning algorithms to forecast transfusion needs and compatibility, which contributed to enhanced patient care safety.[38] Future research in machine algorithm-based learning would need to evaluate the impact of feature significance on model accuracy, as well as incorporating these models into clinical routine via the real-time prospective study designs.[39]

AI enables blood banks to more effectively recruit and retain donors, to more efficiently and accurately match donor blood with recipient blood, to predict demand for blood and ensure that the appropriate blood products are available for transfusion, and to forecast if a patient will require transfusion during a surgery, enabling active blood product management.[40] Conventional statistical prediction methods in blood transfusion should be replaced with artificial neural networks (ANNs) and auto-regressive integrated moving average (ARIMA) models to reduce supply chain uncertainty because they are more accurate in predicting demand uncertainties.[41]

CONCLUSION

The introduction of modern technologies such as block chain technology, machine learning, AI, artificial neural networks, algorithm-based learning, and the emergence of RFID and the IoT, will help to reduce human-generated errors in the blood transfusion process and ensure the safety of the process. However, transfusion medicine is still in its early phases of technological adoption, with difficulties such as data loss, patient data privacy, and cost-effectiveness remaining. Implementing these technologies into transfusion medicine will aid in the reduction of errors and blood management, forecasting blood demand, and reducing blood waste.

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