

Novel data visualization and risk analytic algorithm in a low-middle income country

Hina Inam¹, Fatima Amjad², Abdul Ahad Sohail³, Qalab Abbas⁴

Abstract

To discuss the use of T3™, a data aggregation, visualization, and risk analytic platform in a single centre and its framework for implementation of such a tool in clinical care. We share experience of a tool implemented in a tertiary care Intensive Care Unit (ICU) with limited resources. Superusers were identified and trained. Implementation involved monitoring, evaluation, and user engagement data for continuous emphasis on the use of this tool. Persistent display of T3 data enhanced nursing operational efficiency. Its use was expanded to use in nurses rounds and handover, mortality and morbidity meetings, clinical team teaching through selected teaching cases and analysis of stored data with different research questions. However, lack of infrastructure and technological comprehension, paucity of multidisciplinary teams makes it a challenge in its implementation. Clear framework of implantation and pre-designed studies to determine the clinical usage and effectiveness are important for wide-spread use of such tools.

Keywords: PICU, Artificial Intelligence, algorithm, risk analytics, data visualization

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Introduction

Patient management (monitoring and treatment) in the paediatric intensive care unit (PICU) generates an enormous amount of data.¹ This information is essential for critical, frequent decision-making related to patient care. The sources of this data are multiple, with continuous streams of continuous data coming from haemodynamic monitors, ventilators, infusions pumps, and laboratory results. Cumulatively, this puts immense cognitive load on the caring PICU team, at a time when timely decision-making is crucial.² Other challenges with handling such high-frequency and high-intensity data is its visualization, interpretation, storage, and ability to

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^{1,3,4}Department of Surgery, Aga Khan University Hospital, ²Department of Paediatrics and Child Health, Aga Khan University, Karachi, Pakistan

Correspondence: Hina Inam **Email:** hina.inam@aku.edu

ORCID ID. >>>

retrieve it later for education and research.

Pakistan, a low- and middle-income country (LMIC), has some of the worst under-five mortality rate in the world (69/1000 live births), which has not improved significantly over the past eight years.³ The major causes of such statistics are delayed recognition of deteriorating condition and treatment for the more common causes of mortality, including pneumonia and respiratory failure, shock from diarrhoea and sepsis, traumatic injuries, and congenital diseases, particularly congenital heart disease.³ Furthermore, healthcare providers are scarce and due to continuous brain drain are less well-trained in LMICs.^{4,5} Even in one of the better intensive care units like ours, the mortality rates remain very high; with the majority of reasons being preventable such as late presentation, delayed recognition of the deteriorating condition, and delayed intervention.⁵

PICUs are scarce resources in Pakistan. According to a survey done in 2023, there were only 53 PICUs all over Pakistan with a total 667 beds, equating to 0.7 bed for every 100,000 children.⁶ Within these units, there are only 20 trained paediatric intensivists. The situation is more critical for nursing staff. There is a severe shortage of critical care nurses. While the general nurse-to-patient ratio in Pakistan is 1:50, in ICUs this ratio is 1:1.3-to-1:1.7, well below the expectation in developed countries (ratio 1: 1-to-2).⁶

Task sharing and shifting is a concept being used by many healthcare systems and is also promoted by the WHO⁷ to help address the shortage of healthcare workers in LMICs. Technology and clinical decision support systems (CDDS) can be used to augment the awareness of an evolving clinical state and timely communication intervention by less skilled healthcare workers in LMICs. Use of technology and things like machine learning (ML) and artificial intelligence (AI) (incorporated in CDDS) specially in LMIC need to be user friendly (provide integrated data visualization on one screen) and have incorporated tested AI and ML capabilities which are contextual and have abilities to focus on solving ground problems. They have been used not only for clinical trials, but lead to the development of several other AI technologies deployed

in the clinical settings with variable success. They play an active role in neonatal and PICUs. For example, AI-based models have been used in the NICU to diagnose neonatal sepsis and respiratory distress syndrome.⁸⁻¹¹

We deployed a commercially available data integration, visualization, and risk analytic tool at our hospital, Aga Khan University Hospital, Karachi, Pakistan in PICU and paediatric cardiac intensive care unit in 2018. Here, we discuss about implementation, performance and challenges of this tool and propose the way forward for integration of such tools in clinical settings.

Role of different models for risk analysis in PICU

Utilizing continuous venous oximetry in the Cardiac Intensive Care Unit (CICU) has demonstrated enhanced outcomes and is recommended for monitoring patients' progress.^{11,12} It also provides information on oxygen transport dynamics, oxygen extraction ratio (OER), cardiac output, and oxygen delivery. Evidence from previous studies have shown that a SVO₂ of <40% or an OER of >50–60% have been associated with shock, lactic acidosis, and other worse outcomes.¹²⁻¹⁵

T3™ Platform

T3™, an FDA approved software [510(k) Number: K202306], is a data aggregation, visualization and risk analytic platform that displays data from multiple sources on a single screen and also estimates a patient's physiologic condition based on continuous patients' data coming from different sources. It has the unique

capability of zooming in to visualize data up to 3 seconds and out of time to visualize trends up to two weeks, and correlating different haemodynamic, laboratory, ventilatory, and infusion pump parameters. (Figure 1)

The IDO2 algorithm (an FDA approved algorithm) collects data of up to 10 physiologic values [heart rate, systolic blood pressure, diastolic blood pressure, mean blood pressure, oxygen saturation on pulse oximetry (SpO₂), right atrium pressure, central venous pressure, temperature, oxygen saturation in arterial blood gas (SaO₂), oxygen saturation in venous blood gas (SvO₂)] from the full data set available from the bedside monitor and laboratory values. It then transfers the data to the T3 platform to compute the IDO2 index in real-time. IDO2 calculation is based on a model-based risk assessment methodology described and validated previously.¹⁶ The index is computed every 5 seconds, offering a constant probability ranging from 0 to 100 for the mixed systemic venous saturation (SvO₂) being below 40% in the last 30 minutes.¹⁷ Utilizing continuous venous oximetry in the Cardiac Intensive Care Unit (CICU) has demonstrated enhanced outcomes and is recommended for monitoring patients' progress.^{12,13} Therefore, IDO2 provides continuous estimation of patients' risks of experiencing inadequate oxygen delivery with intermittent measurement of some of the data variables like blood gases and SVO₂ allowing healthcare team to escalate or de-escalate interventions aiming at improving patient morbidity and mortality.¹⁸ The IDO2 index can continue to

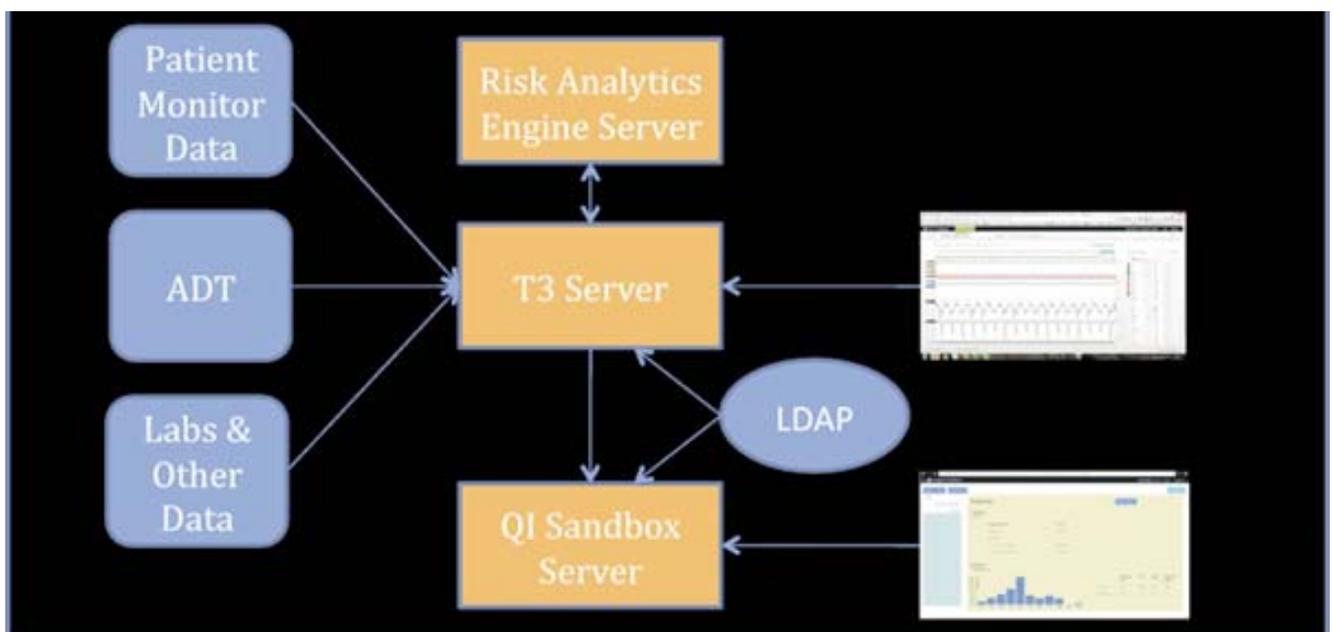


Figure-1: The Etiometry Platform consists of three separate, yet integrated, software modules: T3 Data Aggregation and Visualization (T3), the Risk Analytics Engine and the Quality Improvement Sandbox (QIS). The Platform features a web-based architecture that is hosted at the hospital's Data center and runs inside the hospital's firewall.

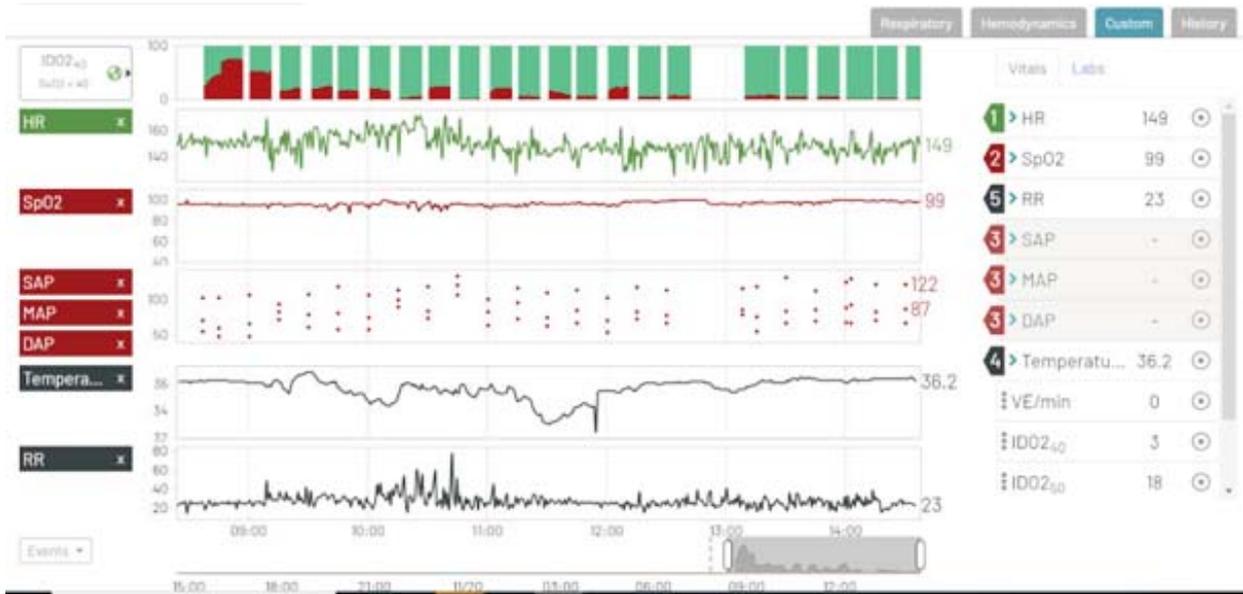


Figure-2: User interface of T3Platform screen showing trends of different parameters.

be computed based on previously acquired data even when data is missing at particular points in time.¹⁹ (Figure 2).

Framework of implementation and training process in our PICU

The goal was to make use of T3 platform an integral

component of nursing, residents, fellows, and attending workflow. So that it will lead to timely notification of patient problems, prompt intervention, a decrease in adverse events and better patient outcomes, such as reduced duration of mechanical ventilation and improved survival rates. (Figure 3 and 4)

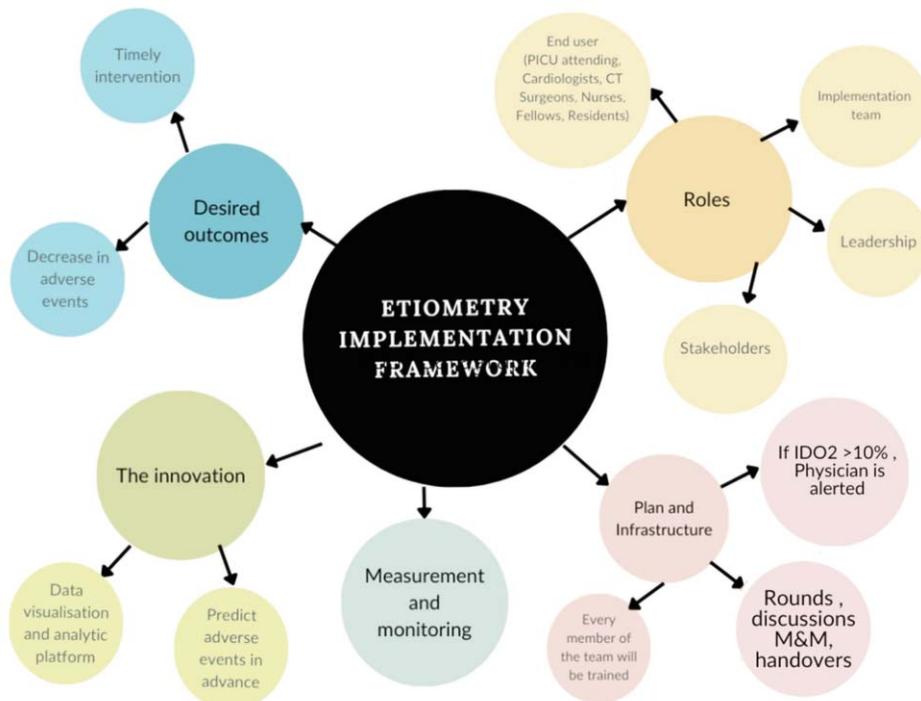


Figure-3: Process map of various components involved in implementation of risk estimation tool in PICU.

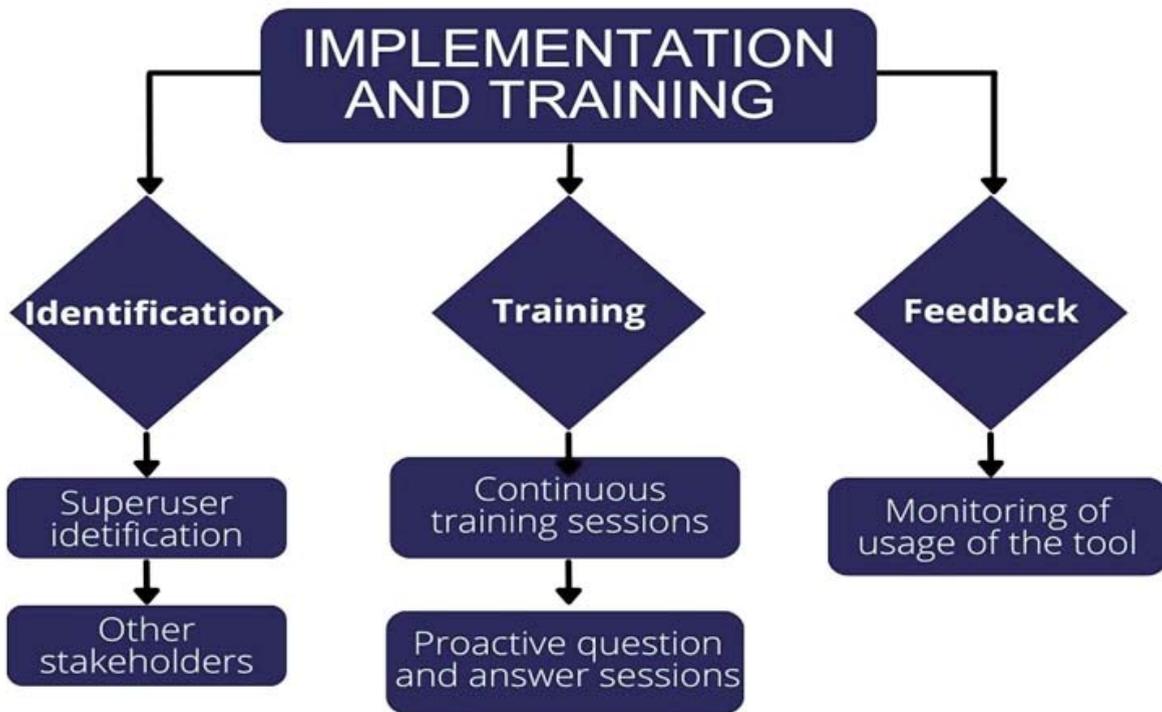


Figure-4: Flowchart for T3Platform implementation and training process.

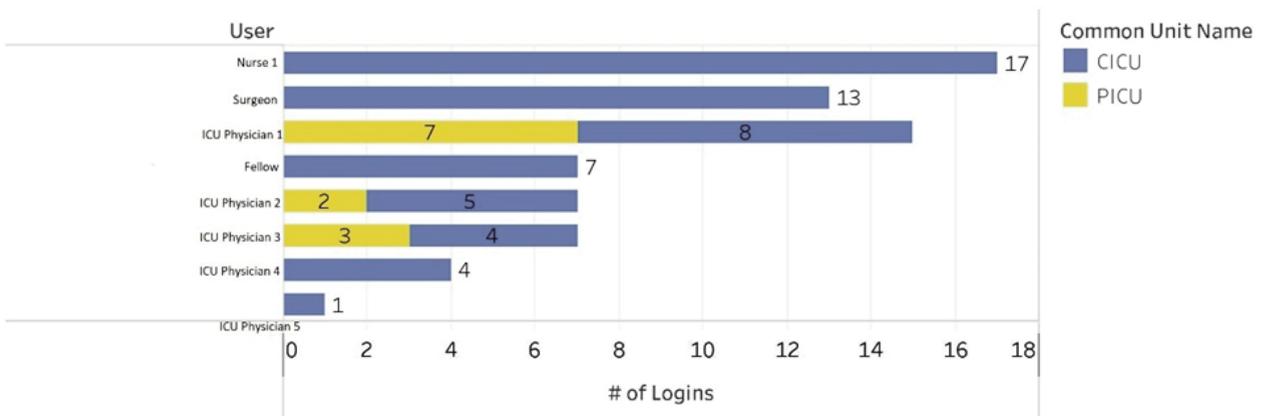
Implementation and Training Process

Before go-live, super users were identified and trained who then involved all stakeholders (nurses, physicians including intensivists, paediatric cardiac surgeons, paediatric cardiologists, paediatric critical care fellows), in the PICU and PCICU teams on the use of T3 and were provided access. IDO₂ values were documented in vital sign sheets, and if there was a significant increase or the value exceeded a certain threshold, the bedside team escalated the information to the physician team for earlier

intervention and better patient care.

The implementation journey included monitoring, evaluation, user engagement data for continuous emphasis on the use of this tool. Regular discussions with developer of this tool were done to provide the feedback and discuss challenges in the cases where it was used. This contributed to the maintenance and improvement of the system. (Figure 5 & 6)

Top Users - ICU



Here we filter out the duration that are greater than 360 mins (6h).

Figure-4: Flowchart for T3Platform implementation and training process.

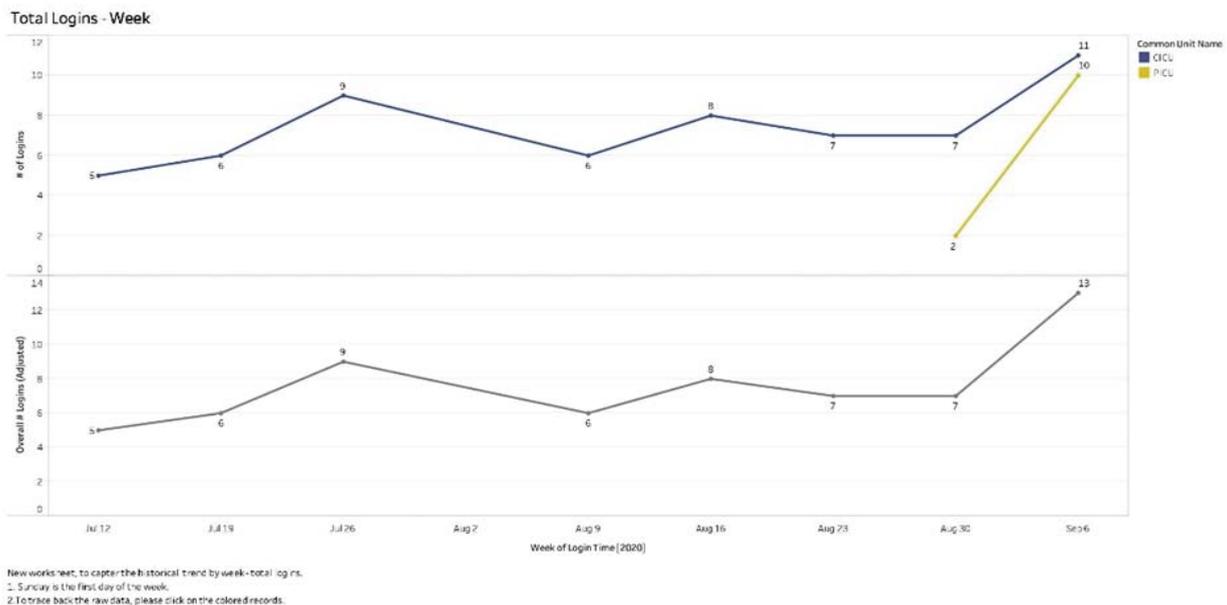


Figure-6: Trend of the usage of this tool in 2020. It has since then substantially increased.

Super user training for PICU attendants and fellows was started, and a nurse lead training was begun which involved Nurse Practitioners, Clinical Nurse Specialist, Clinical Nurse Intensivist and general nurse training. This was made mandatory. Training was also provided to nursing staff and unit receptionist for correct entry of patient data and correct labeling of blood sample collections.

Regular meetings with Biomedical department were held to ensure smooth operational workflow.

Communication and Timely Intervention

A dedicated WhatsApp group for PCICU issues was made to facilitate communication and collaboration among team members. Timely escalation and communication lead to interventions based on the information provided by T3, contributing to better patient outcomes.

Outcome and Maintenance

Regular discussions were held with Hospital support team (Biomedical IT department and Etiometry (the provider of T3) to determine accurate data entry, timings and interval of data update allowing use of most recent version of the software. All of which contributed to the maintenance and improvement of the system.

Current Use and Outcomes of this tool in a Tertiary Care Paediatric Intensive Care Unit in Pakistan

The study by Abbas et al focusing on the performance of IDO₂ analysis tool found that an average IDO₂ value of < 25 had the lowest risk of SvO₂ < 40%, with a relative risk of 0.33. No significant differences were observed between

IDO₂ ranges of 25-50 and 50-75. However, an average IDO₂ above 75 had the highest absolute risk (42.11) and relative risk (4.63) of SvO₂ < 40%, indicating a significant association. The tool also showcased modest results for a population that is geographically diverse.²⁰ Another study evaluating the outcome of implementation of IDO₂ among children who underwent cardiac surgery for congenital heart defects with subsequent admission to PICU, found that in comparison to the Cardiac Children's Hospital Early Warning Score (C-CHEWS) which has been previously validated to assess clinical deterioration and pick early warning signs in children with heart diseases, when compared to IDO₂ found that no significant statistical difference existed between the two methods in picking up an association between adverse events among patients. The median C-CHEWS scores were significantly higher in those who had an adverse event, 4.03 (IQR, 2.39–5.15) versus 2.77 (IQR, 2.06–3.39), $p = 0.003$. IDO₂ scores also showed similar trends (9.17 [IQR, 0.00–27.00]) versus (6.64 [0.00–24.87]).²¹ (Table 1)

Use in nursing staff efficiency

This persistent display of T3 data avoided multiple sign ins from the nursing staff. Placement of the monitor presenting data for the IDO₂ was a deliberate choice, with the device positioned in close proximity to the nursing station. This placement was aimed at enhancing operational efficiency and facilitating seamless handovers during shift changes.

Use in Mortality and Morbidity (M&M) meetings

Furthermore, it played a role in education sessions for our

Table-1: Outcomes of the use of Artificial Intelligence in PICU at a tertiary care in Pakistan.

Study	Institution(s)	Patients	Study Type	Model	Compared with	Conclusions
²⁰ Khalil, M., Abbas, Q., Azhar, M. K., Aamir, F. B., Hashmi, S., Ali, S., Faiz, T., & Malik, M. A. Cardiac Children Hospital Early Warning Score Versus the Inadequate Oxygen Delivery Index for the Detection of Early Warning Signs of Deterioration. <i>Critical care explorations</i> . 2023;5:e0833.	Aga Khan University Hospital	60	Single-center longitudinal pilot study	Inadequate Oxygen Delivery (IDO2) Index calculation every 2 hours.	Cardiac Children's Hospital Early Warning Score (C-CHEWS)	The area under the curve (AUC) for C-CHEWS scores fell in an acceptable range of 0.956 [95% confidence interval (CI)], 0.869–0.992), suggesting an optimal accuracy for identifying early warning signs of cardiopulmonary arrest. Whereas IDO2 showed no discriminatory power to detect the adverse events with an AUC of 0.522 (95% CI, 0.389–0.652).
¹⁹ Abbas, Q., Hussain, M. Z. H., Shahbaz, F. F., Siddiqui, N. U. R., Hasan, B. S. Performance of a Risk Analytic Tool (Index of Tissue Oxygen Delivery "IDO2") in Pediatric Cardiac Intensive Care Unit of a Developing Country. <i>Frontiers in pediatrics</i> . 2022;10, 846074.	Aga Khan University Hospital	65	Retrospective review of prospectively collected medical records	Inadequate Oxygen Delivery (IDO2) Index calculation.	None	The AUC of estimating SvO2 < 40% IDO2 was 0.87 [(CI): 0.79–0.94]. Average IDO2 above 75 had the highest absolute risk (42.11, CI: 20.25–66.50) and highest RR (4.63, CI: 2.31–9.28, p-value < 0.0001) of SvO2 < 40%.
Hyperlactetemia index in PCICU (<i>in progress</i>)	Multicentric study					
Early extubation after congenital heart disease surgery using risk analytics (<i>in progress</i>)	Multicentric study					

interns, resident, and physicians. It enhanced participant engagement by providing retrospective data-driven discussions of the association of T3™ with mortality and morbidity predictions, facilitating a deeper level of trust in the analytical process. This synergy between AI risk analysis models and M&M meetings signified a paradigm shift in how healthcare professionals engage with and derive insights from retrospective data, ultimately contributing to more informed and proactive decision-making in critical care settings paving way for evidence-based medicine.

Use in resident and fellow learning

Furthermore, by enabling real-time assessment of patient risks and its capability to archive cases for subsequent teaching sessions. The tool's capacity to identify deterioration, comprehending physiological dynamics, response to therapeutic measures, for educational sessions. By allowing healthcare professionals to revisit and study these archived cases, the AI tool becomes an effective platform for enhancing understanding and proficiency in critical care scenarios.

Ecological Validity—Can the IDO2 model be replicated in other ICUs in Pakistan?

To fully harness the benefits of the AI surge, it is imperative to cultivate a local capability for software and AI tool development. This approach not only helps in cost-effectiveness but also provides the flexibility to customize algorithms according to local requirements. Furthermore, as advancements unfold in this emerging domain, collaborative efforts with stakeholders spanning diverse socioeconomic backgrounds are essential. Consideration should be meticulously given to integrating the distinctive needs and limitations present in low-middle-income countries into AI governance frameworks, aiming to foster an inclusive and fair landscape. One major obstacle is the existing infrastructure limitations, where many healthcare facilities may lack the necessary technological framework to seamlessly incorporate AI systems. However, artificial intelligence plays a significant role in addressing the brain drain phenomenon by providing support to healthcare teams in optimizing patient care in resource and

physician scarce settings.

To make them useful in such settings, a clear framework of implementation, standard operating procedures, and above all, compliance to these management protocols centered around such risk analytic tools is critical and may be the missing piece in demonstrating the true benefit of such tools in improving patient outcomes.

Challenges

However, due to lack of infrastructure for encouraging the implementation and sustainability in LMIC, makes it an arduous journey for various reasons. Firstly, integration of an AI tool in a multidisciplinary care setting requires comprehensive understanding of the technological requirements for its implementation and compatibility of the AI tool with existing systems is essential. Biomedical department of a hospital plays a key role in facilitating the interfacing of the AI risk prediction tool with critical devices such as ventilators and monitors to harness a smooth synergistic relationship. Policies targeting the sustainability of AI resources are severely lacking. It is essential to remember “not one model is a fit for all” Pakistan’s healthcare landscape is mostly out of pocket payment based privatized sector or government care settings. With other critical areas requiring funding, stakeholders have to be cognizant of the return of investment in terms of patient mortality and morbidity outcomes. Therefore, focus of stakeholders often lies on increasing healthcare workforce and their training.

Even in our experience of T3™ despite engaging and training users, as well as providing continuous feedback, the tool’s utilization exhibited fluctuations over time due to variable user trust on the technology.

Recommendations and Future Steps

Therefore, to promote integration of AI risk analytic tools like T3™, It is important to deliberate and decide use cases, which should be an iterative process. The early adopters/super users of such technology need to be encouraged and acknowledged.

Stakeholders need to strongly advocate for the substantial benefits of utilizing AI in low resource settings, provided it is deployed safely and effectively. Significant advantages have been witnessed in Low- and Middle-Income Countries (LMICs) where AI has contributed to enhancing healthcare systems and mitigating the demand for specialists in resource-constrained environments.¹¹ Additionally, AI has proven valuable in implementing efficient triage strategies to streamline workflows. Notably, Pakistan has made noteworthy progress in the field of AI in recent years, fostering a

growing ecosystem of research, innovation, and success in the industry.

The objective of employing AI should be centered on enhancing patient care and facilitating healthcare professionals, such as doctors and nurses, in fulfilling their responsibilities without imposing additional burdens in resource-limited and high-workload settings. An essential feature of any AI technology is its user-friendliness across the entire healthcare team, accommodating varying levels of technological proficiency among physicians, nurses, and bedside caregivers. This inclusivity ensures that technological understanding does not create biases for or against the user interface of AI, a crucial consideration in the research context.

Limitations

Some of the studies analysed were from our own tertiary care setup, as T3 is still a new technology with limited access and usage acceptability in a low-middle income country PICU of other centres, therefore opinion based on its success, challenges and further recommendations are from a single centre experience and extrapolation from studies on its use from few other centres. There might be limited access to skilled personnel proficient in algorithm development and interpretation, posing an additional challenge to the successful implementation and continuous refinement of these risk assessment tools in other healthcare centres across the region and country.

Conclusion

In summary, the incorporation of T3 in the Paediatric Cardiac Intensive Care Unit (PCICU) demonstrates a holistic strategy for leveraging technology in real-time monitoring, predictive analytics, and enhanced communication. This integration culminates in improved patient care and outcomes within the critical care environment. At Aga Khan University Hospital (AKUH), we have successfully implemented the T3 system, setting a precedent for delivering exemplary healthcare to critically ill paediatric patients—an achievement unparalleled in a Low- to Middle-Income Country (LMIC) context.

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