# Smart Critical Care

# Taichung Veterans General Hospital

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## *Executive Summary*

- Critical care medicine is one of the crucial disciplines in the modern healthcare system. It is even more apparent when we face the global challenges of the COVID-19 pandemic. To improve the quality of care and alleviate the heavy workload of healthcare professionals in intensive care units, we tried to apply intelligence technology in our daily clinical practices. By adopting 4C strategies (Connection, Collection, Clearing, and Computation), we have developed a series of prediction models of common and essential critical illnesses by artificial intelligence, including acute respiratory distress syndrome (ARDS), acute kidney injury (AKI), bacteremia, and discharge outcomes. We integrated these prediction models into several dashboards to facilitate clinical decisions and disease management.
- We also have established a critical care capacity center dashboard for better management of essential resources of care. We aimed to provide high-quality and efficient medical care for critically ill patients by integrating human and artificial intelligence.

## *Define the Clinical Problem and Pre-Implementation Performance*

- The COVID-19 global pandemic on healthcare systems, particularly the strain on intensive care units (ICUs). With over 3 million confirmed cases and 200,000 deaths globally, the strain on healthcare systems, including ICU collapses in many countries, has been witnessed. Taiwan faces challenges in critical care medicine, such as a decline in the number of subspecialty-certified physicians, uneven distribution of ICU beds, high equipment installation costs, threats from multidrug-resistant pathogens, complex integration of patient monitoring data, and ethical conflicts.
- **The incidence rate of AKI (Acute Kidney Injury)：**
  AKI is highly prevalent(~40%) with essential impact in critically ill patients。
  The percentage of ICU patients who develop AKI (Acute Kidney Injury). Define the numerator：The number of ICU patients discharged during the month who experienced AKI (Acute Kidney Injury)；Define the denominator：The number of patients admitted to the intensive care unit (ICU) during the month.
- **The incidence rate of AI-ARDS (Acute Respiratory Distress Syndrome)：**
  Patients who are placed on advanced ventilatory support within 48 hours of ICU admission should be assessed hourly, with at least one assessment conducted per hour. Define the numerator：Patients diagnosed with ARDS within 48 hours of admission to the hospital.；Define the denominator：All cases diagnosed within 48 hours of hospital admission.
- **Tidal Volume (cc/kg)：**
  tidal-volume -Vt ≤ 8 mL/kg.
  The average tidal volume per hour, calculated by dividing the tidal volume per hour within the first 48 hours of ARDS inference by the patient's body weight, for positive ARDS inference cases.
- **Plateau Pressure:**
  The first measurement value recorded within 48 hours after positive inference of AI-ARDS.
- **The use of muscle relaxants：**
  The average duration of use within 48 hours after positive inference of AI-ARDS.
- **Ventilator days：**
  a. The mean +/- standard deviation of the duration of advanced ventilator use during ICU stay for all positive cases inferred by the AI-ARDS model.
  b. The mean +/- standard deviation of the duration of advanced ventilator use during ICU stay for all negative cases inferred by the AI-ARDS model.
- **The mortality rate of ARDS：**
  The number of positive cases inferred by the AI-ARDS model that resulted in mortality.：Define the numerator：The number of positive cases inferred by the AI-ARDS model that resulted in discharge status as deceased.；Define the denominator：Positive inference by the AI-ARDS model.

## *Design and Implementation Model Practices and Governance*

- The first phase of research (2020-2023) involved a cross-disciplinary team from Taichung Veterans General Hospital, Tunghai University, and Advantech Corporation. Their project, "Zoe: AI+HI Smart Intensive Care System and Cross-Hospital Practice New Model," aimed to address critical care challenges by integrating artificial intelligence (AI) and medical expertise. Key achievements included establishing a comprehensive national ICU database, developing an AI-assisted clinical decision-making system, and conducting cross-hospital federated learning for AI risk prediction models. Additionally, the team collaborated with other medical centers and published 17 papers, obtaining patents in both Taiwan and the United States.

- In the second phase (2022-present), a new cross-disciplinary team from Taichung Veterans General Hospital, Tunghai University, and Huede Technology Corporation focuses on commercializing software and medical devices. They aim to develop "AI+HI Interactive Smart Intensive Care Treatment Decision Support," focusing on AI-assisted risk prediction for acute kidney injury and acute respiratory distress syndrome, among other areas. The team has obtained certification for their AI acute kidney injury prediction software and is working on certification for other models. They have also applied for government grants and incentives to support their research on AI classification models for acute respiratory distress syndrome.

- The TCVGH team led by Director Shih-Ann Chen includes 12doctors, 15 nurses, 11 IT engineers, and 30 medical technicians and research assistants. The Tunghai AI center team led by Professor Ruey-Kai Sheu includes four other professors and two engineers. There were 18 members in Advantech Co. team. The Huede Healthtech team led by General Manager of Huede Healthtech Jennifer Lee includes one technical chief, four RD/QA/QC experts, two research assistants, and three project managers.

## *Clinical Transformation enabled through Information and Technology*

- The Zoe team has developed Taiwan's most extensive critical care database. From 2015 to 2022, the team has used international coding systems, such as ICD, LOINC, ATC, and FHIR, to build the critical care database with 86.2 million records across 25 categories and 339 features. The data will continue to expand yearly. According to the MIMIC IV de-identification technology, the dataset will become open to the public. (Figure 1)

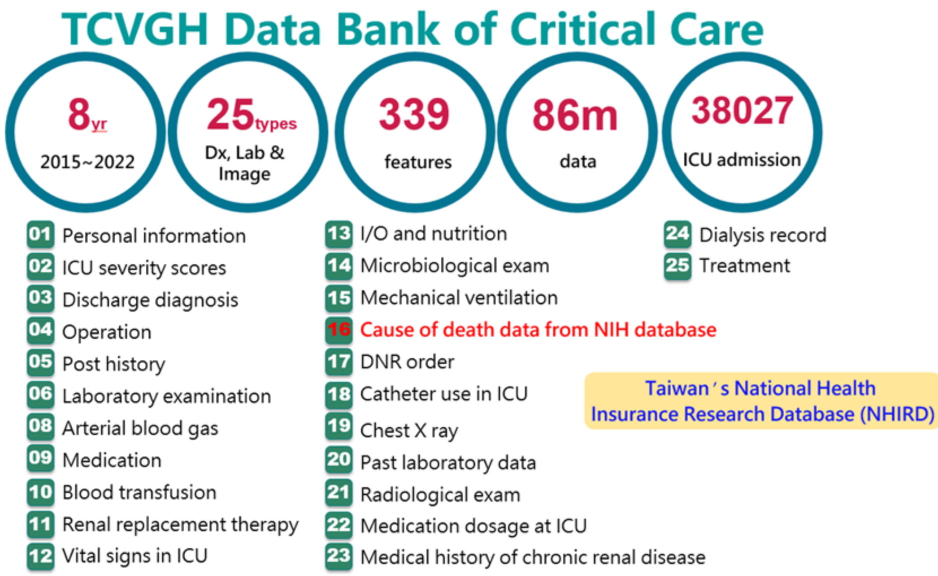



Figure1. TCVGH Critical Care Databank

- **(1) Renal Critical Condition: Acute Kidney Injury (AKI) Prediction Model**
  The model was trained using data from the Taichung Veterans General Hospital intensive care database from 2015 to 2019, with the 2020 dataset used for testing. It predicts the likelihood of developing AKI within 24 hours (as shown in Figure 2). The model employs a total of 21 features, including clinical physiological parameters, medication usage, and laboratory test data. Through data preprocessing, clinical physiological parameter data are captured every 6 hours, and the mean and variance of the data within each interval are calculated. Additionally, features such as medication usage within 168 hours and the latest laboratory test data within 168 hours are included.
  The features include: Clinical parameters (body temperature, respiratory rate, pulse rate, pulse pressure, systolic blood pressure, diastolic blood pressure, blood oxygen level, urine output), 17 medication and laboratory data (WBC, Neutrophil, Hemoglobin, Platelet count, BUN, Total bilirubin, Serum Creatinine). Using SHAP (Shapley Additive Explanations) values and clinical expertise, the model's interpretation reveals the direction and strength of each feature's influence on the prediction outcome (as depicted in Figure 3).

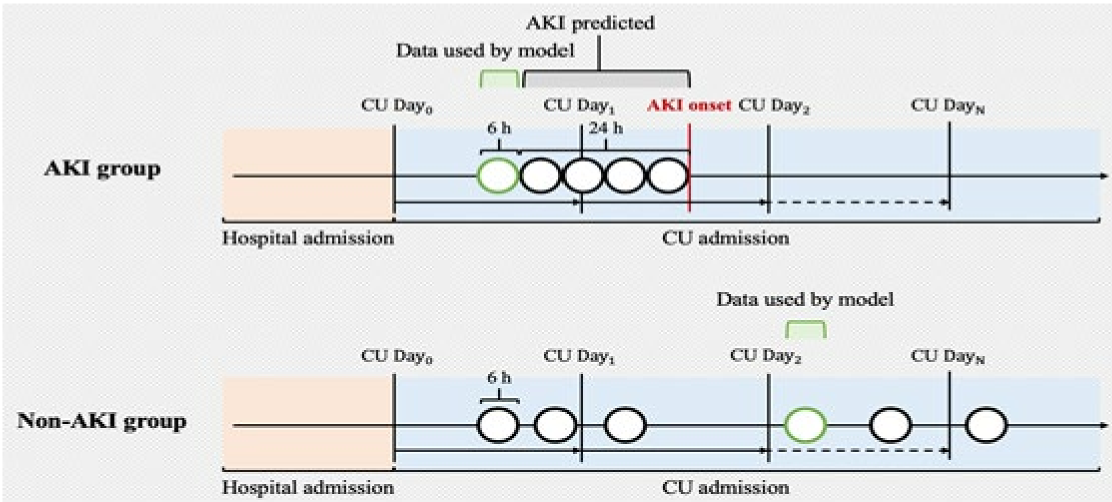
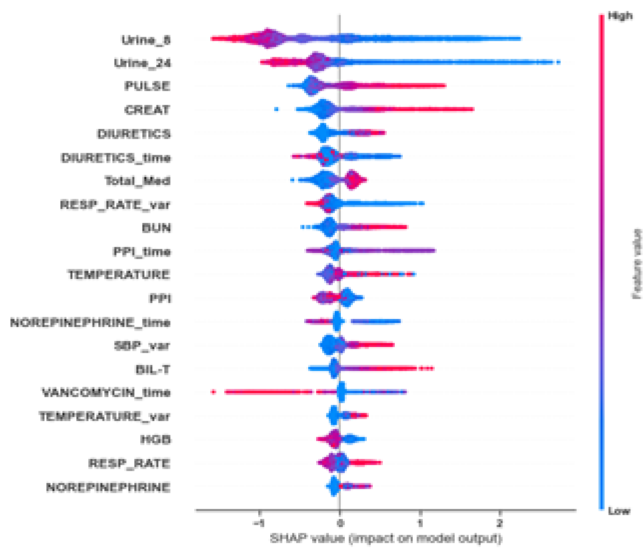
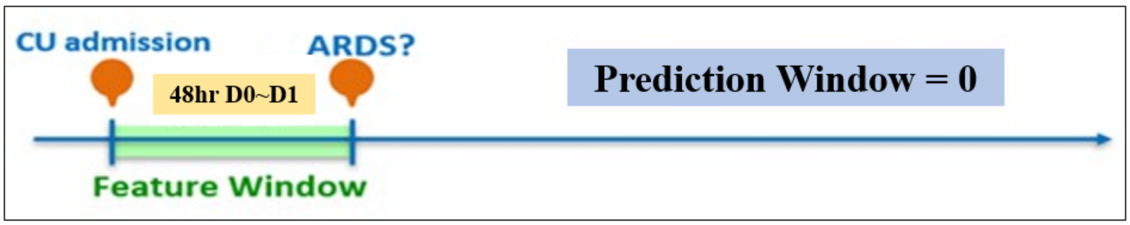



Figure2. illustrates the scope of data inclusion for the Acute Kidney Injury (AKI) prediction model.

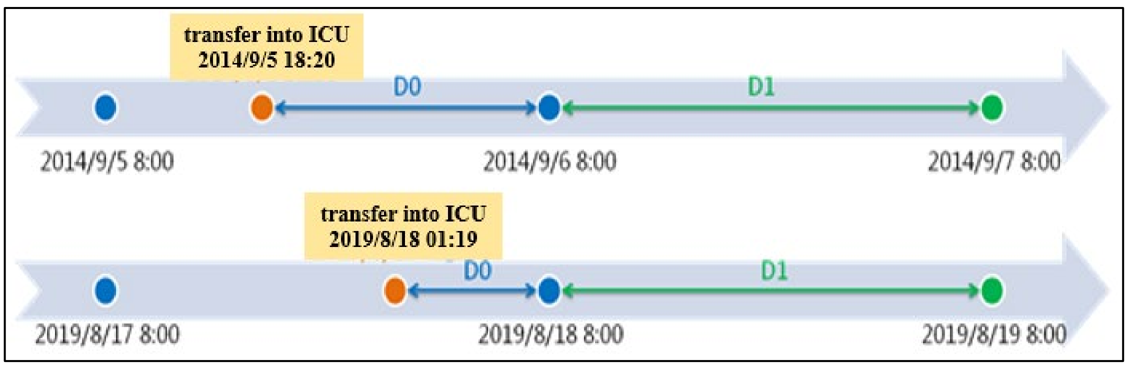



- Figure3. SHAP Values for the Acute Kidney Injury (AKI) Prediction Model.

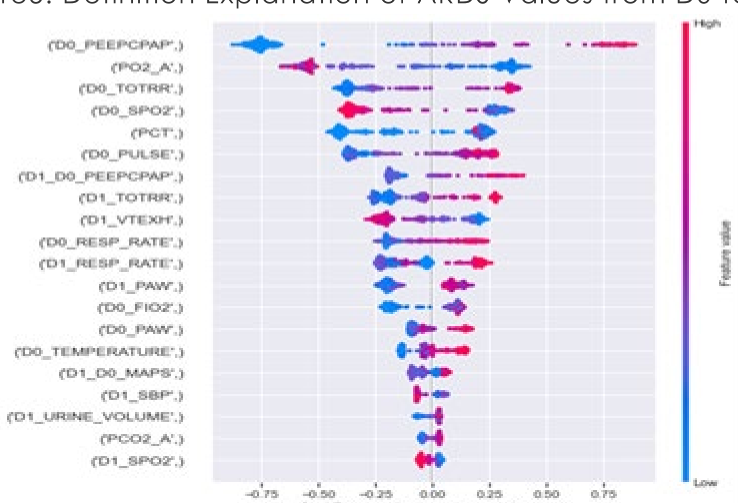
- **(2) Severe Respiratory Illness:**
Acute Respiratory Distress Syndrome (ARDS) Model A machine learning model for predicting the occurrence of Acute Respiratory Distress Syndrome (ARDS) in patients within 48 hours of admission to the intensive care unit (ICU) was developed using data from the Taichung Veterans General Hospital ICU database from 2018 to 2019. The inclusion criteria were patients aged 20 years or older who were admitted to the ICU and received invasive mechanical ventilation. Day 0 (D0) was defined as the first day of ICU admission until 8 a.m. the next day, and Day 1 (D1) was defined as the first complete day after ICU admission. Individual case explanations are provided (as shown in Figures 4 and 5).




- Figure4. Illustration of the Scope of Included Predictive Data




- Figure5. Definition Explanation of ARDS Values from D0 to D1




- Figure6. Feature Importance in ARDS Model Training

**(3) Application scenarios:**

(A) During 24-hour care in ICUs, the AICU will transmit AI inferences every hour to proactively remind the healthcare professionals to implement suitable measures in timely fashion (as shown in Fig. 7).

(B) The AI inferences are sent to medical teams to analyze the patients' conditions and make appropriate treatment decisions during their daily rounds. (as shown in Fig. 8)

(C) Through periodic feedback from physicians and nurses, information technology staff will adjust the model (as shown in Fig. 9)

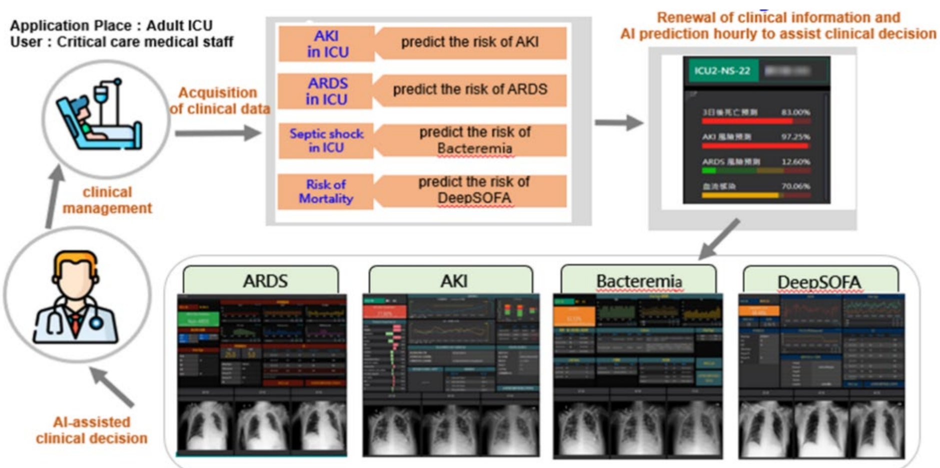



Figure 7. Application scenarios

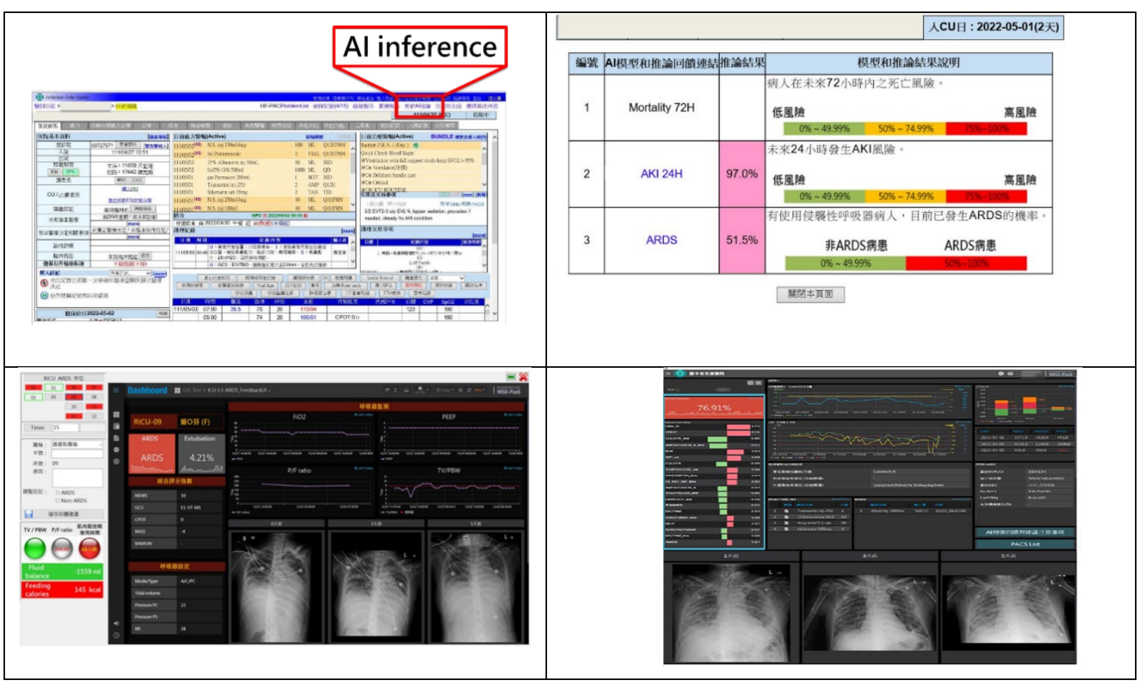



Figure 8. application scenario flow

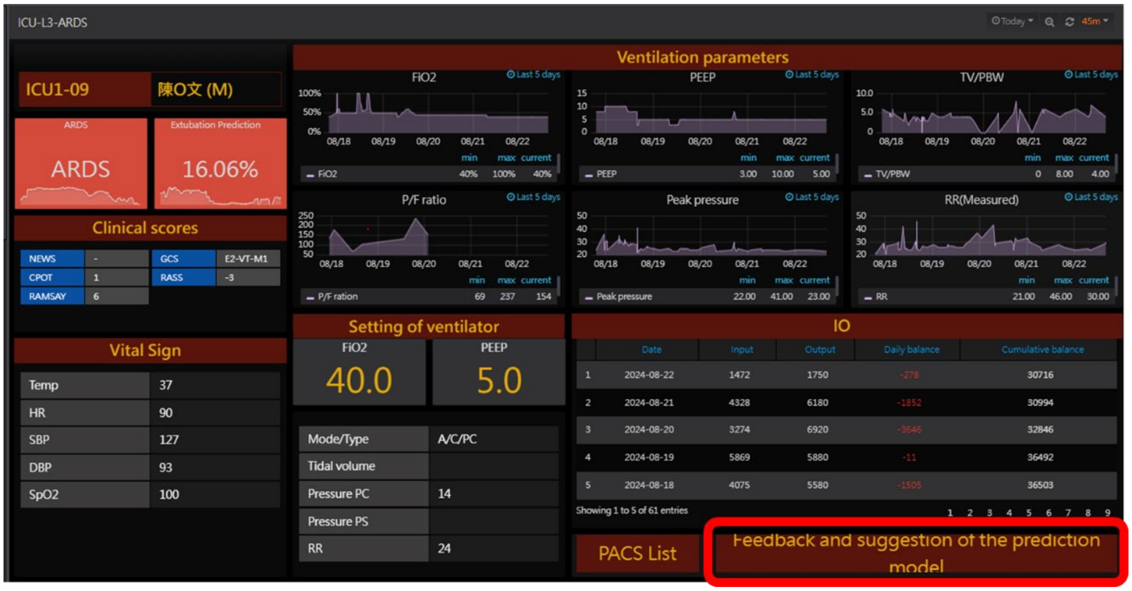



Figure 9.Through periodic feedback from physicians and nurses, information technology staff will adjust the model

### *Improving Adherence to the Standard of Care*

- To ensure smooth integration into clinical practice in the future, various thematic models are currently being developed. Through the implementation of the "Smart Intensive Care System: Multi-organ Risk Alert Clinical Decision Support System," activities are being conducted to enhance the quality of care in the intensive care unit (ICU). Clinical staff (physicians, specialized nurses, and respiratory therapists) are encouraged to provide feedback on the models online. This feedback includes alerts for risks of mortality after 72 hours, occurrence of acute kidney injury (AKI) after 24 hours, risk of bacteremia after 24 hours, and inference of acute respiratory distress syndrome (ARDS) at the current time point, among other inference results provided to medical personnel for clinical reference.
- This activity took place from February to June 2022. In the initial stage of the activity (February 2022), due to system instability, adjustments were made after testing and feedback from physicians and specialized nurses regarding program abnormalities.
  By March 2022, the platform had become more stable, and active participation from clinical staff was encouraged in various departments, resulting in a significant increase in the proportion of staff completing feedback forms. Respiratory therapists had the highest number of submissions, totaling 6,214, followed by nurses with a total of 4,129 submissions (as shown in Table 1).

Table1. Number of Feedback Submissions by Job Category from February to June 2022

| DATE | VS | PGY | NP | NS | RT | TOTAL |
|---|---|---|---|---|---|---|
| 2022/02 | 17 | 11 | 11 | 0 | 0 | 39 |
| 2022/03 | 270 | 259 | 542 | 812 | 2,024 | 3,907 |
| 2022/04 | 279 | 909 | 654 | 1,463 | 1,575 | 4,880 |
| 2022/05 | 326 | 1,821 | 1,618 | 1,504 | 1,538 | 6,807 |
| 2022/06 | 65 | 427 | 494 | 350 | 1,077 | 2,413 |
| TOTAL | 957 | 3,427 | 3,319 | 4,129 | 6,214 | 18,046 |

## *Improving Patient Outcomes*

AKI incidence rate:

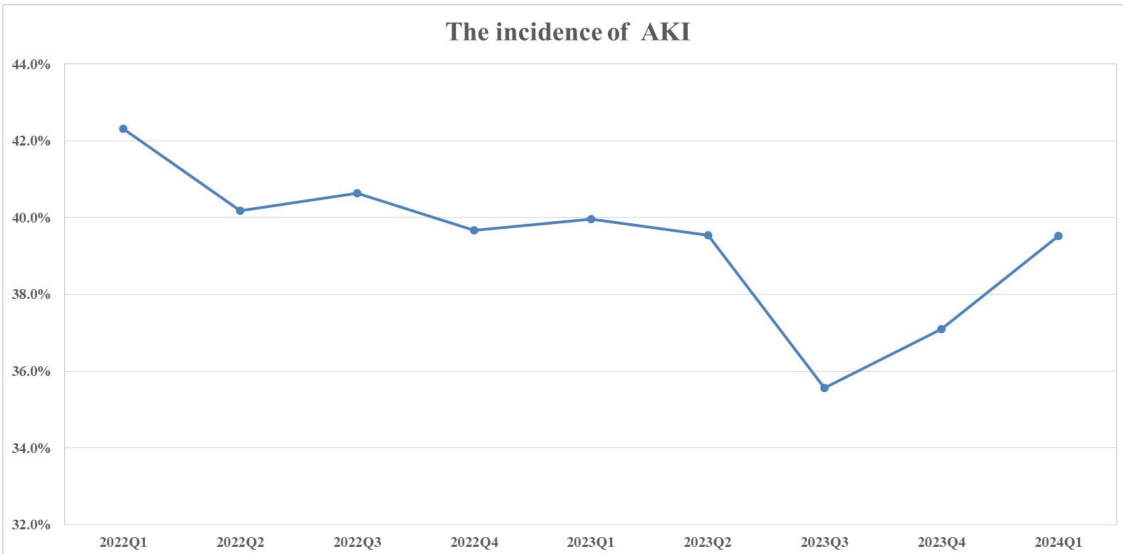



Figure7. Incidence rate of acute kidney injury (AKI) from Q1 2022 to Q1 2024

The incidence rate of Acute Kidney Injury (AKI) in the Taichung Veterans General Hospital's ICU is approximately 40%. We are currently developing an AI-powered real-time inference dashboard and working to enhance clinical staff's usage habits with the dashboard. Our goal is to maximize the clinical benefits of the AKI prediction model.

ARDS incidence rate:

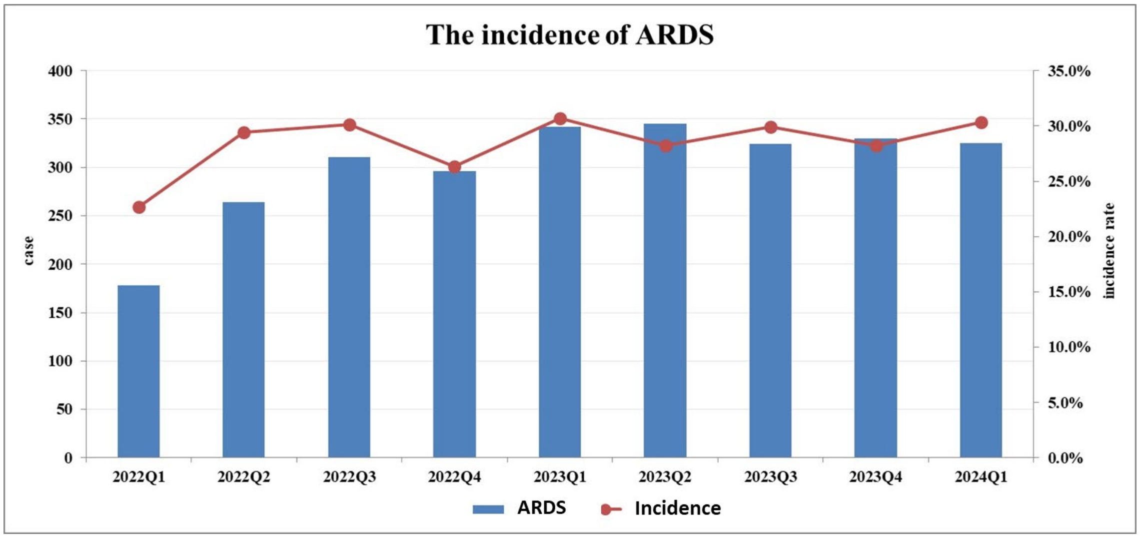



Figure8. Incidence rate of Acute Respiratory Distress Syndrome(ARDS) from Q1 2022 to Q1 2024

We have implemented a smart critical care decision support system that provides real-time inference feedback, automatically determining whether patients using ventilators have developed Acute Respiratory Distress Syndrome (ARDS) within 48 hours. Based on statistical data from Q1 2022 to Q1 2024, the overall AI-inferred ARDS incidence rate is approximately 30%. Through early warning alerts to the clinical team, appropriate interventions and adjustments can be made promptly.

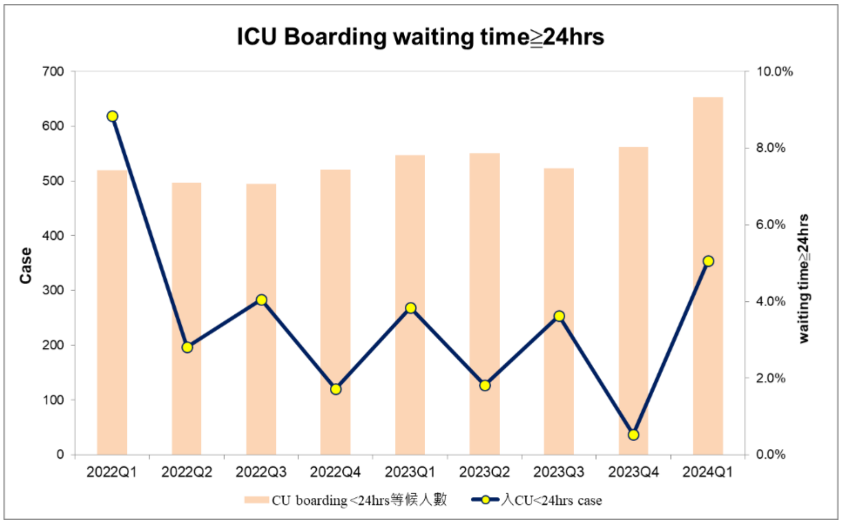



Figure9. Shortening of ICU boarding time from Q1 2022 to Q1 2024

The impact of patient comorbidities and severity of illness upon admission is related to various aspects of the entire care process.

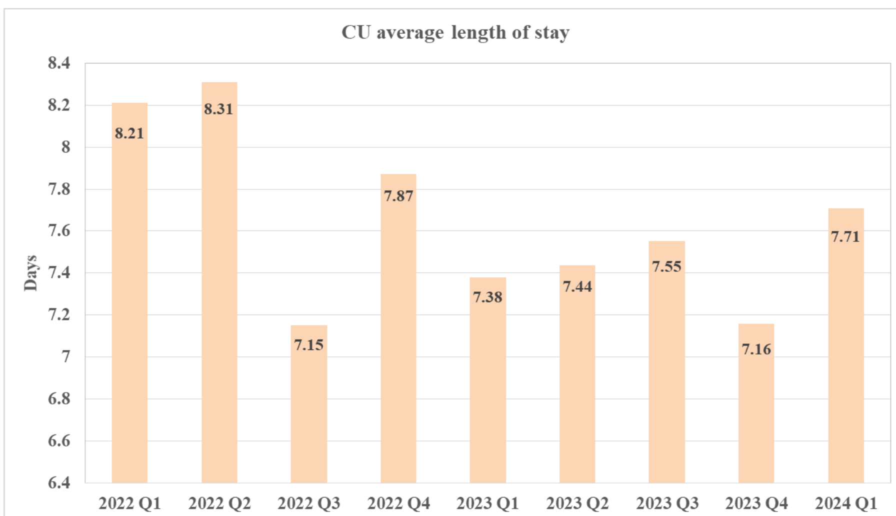



Figure10. Shortening of ICU length of stay from Q1 2022 to Q1 2024

The average length of stay in the intensive care unit is related to the severity of the patient's condition and the medical care provided. According to statistics from the Critical Care Department of Taichung Veterans General Hospital from 2022 to the first quarter of 2024, the overall average length of stay in the ICU was 7.64 days. We will continue to monitor the impact of the Smart Intensive Care System on the average length of stay in the ICU.

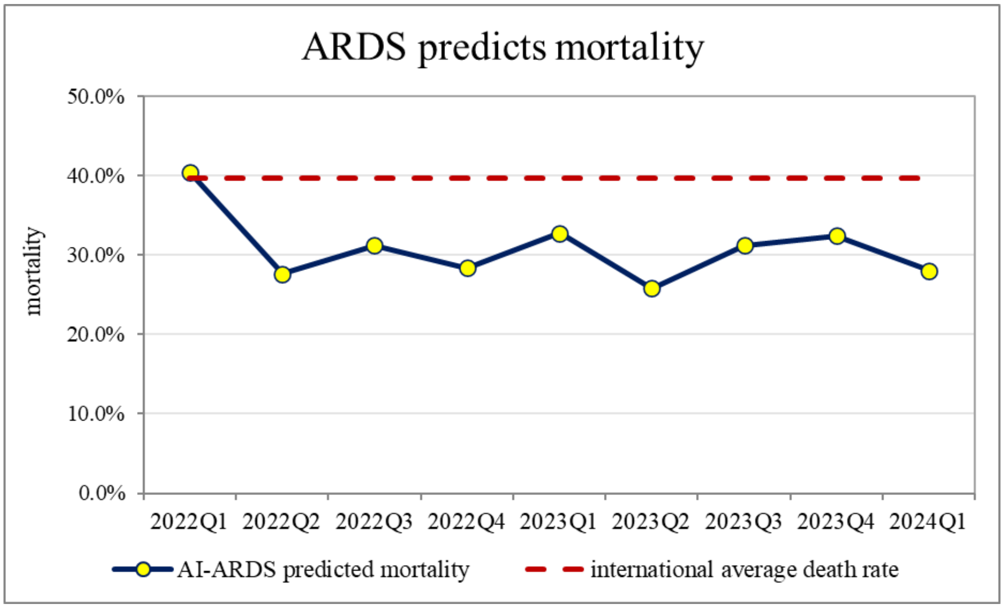



Figure11. Decrease of ARDS mortality

From the first quarter of 2022 to the first quarter of 2024, the overall mortality rate for AI-ARDS model-inferred positive cases was 31.22%. The complex nature of acute respiratory distress syndrome (ARDS) mortality involves factors such as the severity of the underlying disease, comorbidities, respiratory settings, and related interventions, all of which impact patient outcomes. Surveillance of ARDS is crucial, highlighting the urgent need for integrated care to improve overall treatment prognosis.

Cross-institutional validation & federated learning

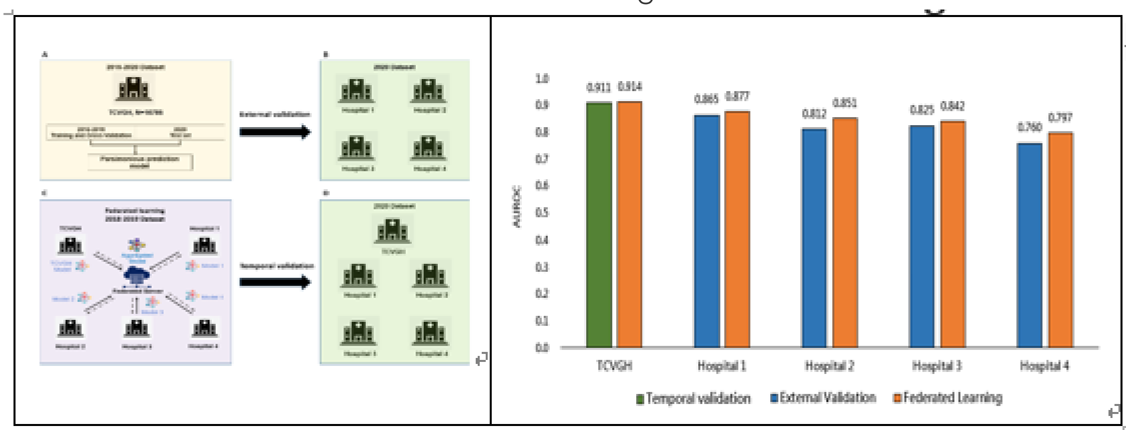



Figure12. Cross-institutional validation of AKI model and improved performance other federated learning

### *Accountability and Driving Resilient Care Redesign*

Health is the goal pursued by humanity, but achieving comprehensive medical care faces many challenges. These include an aging population, complex comorbidities, and a shortage of healthcare professionals. With a forward-looking vision under the planning of the Ministry of Science and Technology, medical institutions, academic research capacities, and technology industries are effectively integrated and allocated. This project focuses on smart healthcare and critical care, realizing the application of artificial intelligence in medical settings. Modules and platforms for clinical decision support are developed for physicians, nurses, respiratory therapists, pharmacists, and dietitians to utilize in care scenarios. These will be integrated into medical information systems, providing personalized applications for intensive care professionals. The trend towards smart hospital management and the integration of AI into healthcare will greatly enhance clinical care efficiency. Through the synergy of medicine and technology, infinite possibilities are created for human health.

## *AI patent portfolio, publications, and medical device approvals*

1. AI patent portfolio
   (1). Granted patents: Two patents have been granted by the United States Patent and Trademark Office. Five inventions, four utility model patents, and one design patent has been granted by the Taiwan Intellectual Property Office.

Table 2. Details of the granted patents

| No. | Title | Country | Type | Patent number |
|---|---|---|---|---|
| 1 | RESPIRATORY STATUS CLASSIFYING METHOD AND SYSTEM THEREOF | U.S. | Invention | US 11908136 |
| 2 | ACUTE KIDNEY INJURY PREDICNG SYSTEM AND METHOD THEREOF | U.S. | Invention | US 11937932 |
| 3 | AI-ASSISTED MEDICAL CARE SYSTEM FOR DECISION SUPPORT IN MULTIPLE DISEASES WITH REAL-TIME FEEDBACK | Taiwan | Invention | I776638 |
| 4 | RESPIRATORY STATUS CLASSIFYING METHOD AND SYSTEM THEREOF | Taiwan | Invention | I787130 |
| 5 | ACUTE KIDNEY INJURY PREDICTING SYSTEM AND METHOD THEREOF | Taiwan | Invention | I796228 |
| 6 | BLOODSTREAM INFECTION PREDICTING SYSTEM AND METHOD THEREOF | Taiwan | Invention | I835176 |
| 7 | IMAGE RECOGNITION METHOD AND ELECTRONIC APPARATUS THEREOF | Taiwan | Invention | I805485 |
| 8 | RESPIRATORY STATUS CLASSIFYING SYSTEM | Taiwan | Utility model | M631912 |
| 9 | ACUTE KIDNEY INJURY PREDICTING SYSTEM | Taiwan | Utility model | M631259 |
| 10 | BLOODSTREAM INFECTION PREDICTING SYSTEM | Taiwan | Utility model | M632034 |
| 11 | SYSTEM FOR PREDICTING EXTUBATION USING MACHINE LEARNING MODELS | Taiwan | Utility model | M648156 |
| 12 | GRAPHICAL USER INTERFACE FOR SOFTWARE PRODUCTS | Taiwan | Design | D221959 |

(2). Under review: two inventions are being reviewed by the Taiwan Intellectual Property Office, and three inventions have been submitted to the United States Patent and Trademark Office for review (as shown in Table 3).

Table 3. Details of the patent applications under review

| No. | Title | Country | Type | Application number | Date of submission |
|---|---|---|---|---|---|
| 1 | BLOODSTREAM INFECTION PREDICTING SYSTEM AND METHOD THEREOF | U.S. | Invention | 17/847,475 | 2022/6/23 |
| 2 | IMAGE RECOGNITION METHOD AND ELECTRONIC APPARATUS THEREOF | U.S. | Invention | 63/291,904 | 2021/12/20 |
| 3 | SYSTEM AND METHOD THEREOF FOR ESTABLISHING EXTUBATION PREDICTION USING MACHINE LEARNING MODEL | U.S. | Invention | 18/339220 | 2023/6/21 |
| 4 | SYSTEM AND METHOD THEREOF FOR ESTABLISHING EXTUBATION PREDICTION USING MACHINE LEARNING MODEL | Taiwan | Invention | 112119171 | 2023/5/23 |
| 5 | SYSTEM AND METHOD THEREOF FOR USING MACHINE LEARNING TO MAKE EARLY PREDICTIONS OF LIBERATION FROM DIALYSIS IN ICU PATIENTS | Taiwan | Invention | 113111398 | 2024/3/27 |

2. Publications

17 articles have been published over the course of the whole project (as shown in Table 4).

Table 4. Publications

| No. | Title | Year of publication |
|---|---|---|
| 1 | AEP-DLA: Adverse Event Prediction in Hospitalized Adult Patients Using Deep Learning Algorithms. IEEE Access. 2021, 9: 55673 - 55689 DOI: 10.1109/ACCESS.2021.3070618. | 2020 |
| 2 | Explainable Machine Learning to Predict Successful Weaning Among Patients Requiring Prolonged Mechanical Ventilation: A Retrospective Cohort Study in Central Taiwan. Front Med (Lausanne). 2021 Apr 23;8:663739. doi: 10.3389/fmed.2021.663739. | |
| 3 | The association between culture positivity and long-term mortality in critically ill surgical patients. J Intensive Care. 2021;9(1):66. | 2021 |
| 4 | Culture positivity may correlate with long-term mortality in critically ill patients. BMC infectious diseases. 2021;21(1):1-10 | |
| 5 | Deep Learning-Based Pain Classifier Based on the Facial Expression in Critically Ill Patients. Front Med (Lausanne). 2022; 9: 851690. | |
| 6 | Explainable machine learning to predict long-term mortality in critically ill ventilated patients: a retrospective study in central Taiwan. BMC Med Inform Decis Mak. 2022 25;22(1):75. doi: 10.1186/s12911-022-01817-6 | |
| 7 | Artificial intelligence–aided diagnosis model for acute respiratory distress syndrome combining clinical data and chest radiographs. DIGITAL HEALTH.2022;8, 20552076221120317. https://doi.org/10.1177/20552076221120317 | 2022 |
| 8 | Week-One Anaemia was Associated with Increased One-Year Mortality in Critically Ill Surgical Patients. International Journal of Clinical Practice, 2022, 8121611. https://doi.org/10.1155/2022/8121611 | |
| 9 | Explainable machine learning approach to predict extubation in critically ill ventilated patients: a retrospective study in central Taiwan. BMC Anesthesiol 22, 351 (2022). https://doi.org/10.1186/s12871-022-01888-y | |
| 10 | Interpretable Classification of Pneumonia Infection Using eXplainable AI (XAI-ICP), in IEEE Access, vol. 11, pp. 28896-28919, 2023, doi: 10.1109/ACCESS.2023.3255403. | |
| 11 | Anaemia in the first week may be associated with long-term mortality among critically ill patients: propensity score-based analyses. BMC Emergency Medicine, 23(1), 32(2023). https://doi.org/10.1186/s12873-023-00806-w | |
| 12 | Association between early blood urea nitrogen-to-albumin ratio and one-year post-hospital mortality in critically ill surgical patients: a propensity score-matched study. BMC Anesthesiol. 2023;23(1):247. doi: 10.1186/s12871-023-02212-y. | 2023 |
| 13 | The Association Between Absolute Lymphocyte Count and Long-Term Mortality in Critically Ill Medical Patients: Propensity Score-Based Analyses. Int J Gen Med. 2023 22:16:3665-3675. doi: 10.2147/IJGM.S424724. | |

| No. | Title | Year of publication |
|---|---|---|
| 14 | Federated machine learning for predicting acute kidney injury in critically ill patients: a multicenter study in Taiwan. Health Inf Sci Syst. 2023;11(1): 48.doi: 10.1007/s13755-023-00248-5 | |
| 15 | Prolonged use of neuromuscular blocking agents is associated with increased long-term mortality in mechanically ventilated medical ICU patients: a retrospective cohort study. J Intensive Care. 2023 11(1):55. doi: 10.1186/s40560-023-00696-x. | |

3. Medical device approvals

   Medical device approval was obtained from the Ministry of Health and Welfare of the R.O.C. on November 29, 2023.

   Name of approved medical device: "Huede" AI-aided AKI Risk Prediction Software

   Medical device license number: Ministry of Health and Welfare Medical Device License No. 008112

   Medical device quality management system number: QMS1837

## *Awards*

1. **Won the 5th Government Service Award from the National Development Council**

   On December 19, 2022, the National Development Council held the 5th Government Service Award ceremony. The TCVGH won a prize under the "Master of AI computation, zero-lag smart care" theme, which was presented by Mr. Su Tseng-chang, Premier of the Executive Yuan.

2. **Received a silver prize at the National Biotechnology and Medical Care Quality Award of the Institute for Biotechnology and Medicine Industry (IBMI)**

   On February 14, 2023, the IBMI held the 25th National Biotechnology and Medical Care Quality Award and Symbol of National Quality (SNQ) awards ceremony.

   The Department of Critical Care Medicine of the TCVGH won the silver prize under the smart medicine category for the "Zoe: AI+HI Smart Critical Care System," which was presented by Vice President Lai Ching-te.

3. **Received a press release at the American Society of Nephrology (ASN) Kidney Week**

   We participated in the 2022 ASN Kidney Week on 11/03/2022–11/06/2022 and received a press release in the conference's designated media partner.

4. **Selected to make an oral presentation at the 28th International Conference on Advances in Critical Care Nephrology (2023)**

   On 3/29/2023–04/01/2023, we participated in the 28th International Conference on Advances in Critical Care Nephrology (AKI & CRRT 2023).

5. **Received the 2023 Future Tech award from the NSTC**

**On October 14, 2023, the NSTC held the 2023 Future Tech Awards ceremony.**
The Department of Critical Care Medicine of the TCVGH won a prize for its "AI-aided AKI prediction: interactive critical care system with real-time inferencing," which was presented by Wu Zhengzhong, chairman of the National Science Council.

6. **Won prizes in the Academic Research and Clinical Research categories of the 20th National Innovation Award of the IBMI**

On December 27, 2023, the IBMI held the 20th National Innovation Awards ceremony.

The Department of Critical Care Medicine of the TCVGH won prizes in the Academic Research and Clinical Research categories for its "AKI prediction system" and "AI-aided ARDS diagnostic system."

## *HIMSS Global Conference Audience Guidance*

Topic Guidance: Check three which apply to this case study

ɋ Clinical Informatics and Clinician Engagement

Clinically Integrated Supply Chain

Consumer/Patient Engagement and Digital/Connected Health

Consumerization of Health

Culture of Care and Care Coordination

ɋ Data Science/Analytics/Clinical and Business Intelligence

Disruptive Care Models

Grand Societal Challenges

Health Informatics Education

Health Information Exchange

Interoperability

Data Integration, and Standards

ɋ Data Integration, and Standards

ɋ Healthcare Applications and Technologies Enabling Care Delivery

Healthy Aging and Technology

Iɋ mproving Quality Outcomes

Innovation, Entrepreneurship, and Venture Investment

Leadership, Governance, and Strategic Planning

Population Health Management and Public Health

Precision Medicine and Genomics

ɋ Process Improvement, Workflow, and Change Management

Social, and Behavioral Determinants of Health

Telehealth

User Experience (UX)