International Conference on Artificial Intelligence; City, Industry, Health, and Sustainable Development (AICIHSD 2025)
Islamic University of Najaf, Iraq | 26-28 April 2025

Smart Access: Artificial Intelligence-Enhanced Vein Assessment for Improved Peripheral Intravenous Catheter Placement in Pediatric Oncology: A Conceptual Design

Faridokht Yazdani[1]

[1]*Department of Nursing and Midwifery, Nursing and Midwifery Sciences Development Research Center, Na.C., Islamic Azad University, Najafabad, Iran*

Abstract: Peripheral intravenous catheter (PIVC) placement in pediatric oncology patients is a challenging procedure due to anatomical and physiological complexities, leading to high failure rates, patient distress, and procedural delays. This conceptual study introduces "Smart Access," an Artificial Intelligence (AI)-enhanced vein assessment system designed to improve PIVC placement success rates through predictive analytics and multimodal imaging integration. The system leverages machine learning algorithms trained on pediatric venous anatomy datasets to identify optimal vein sites with high precision, combining ultrasound and infrared imaging for comprehensive visualization. Additionally, its adaptive learning capabilities refine recommendations based on clinical feedback, ensuring personalized care for diverse patient profiles. By reducing procedural variability, enhancing clinician confidence, and minimizing patient discomfort, "Smart Access" aligns with the principles of patient-centered care and procedural efficiency. While the proposed framework demonstrates significant potential, future research must focus on prototype development, clinical validation, and addressing challenges related to data availability, cost optimization, and workflow integration. This study highlights the transformative potential of AI-driven solutions in procedural medicine and sets a foundation for advancing PIVC placement standards in pediatric oncology.

Keywords: Artificial intelligence, multimodal imaging, pediatric oncology, personalized medicine, peripheral intravenous catheter placement.

1. Introduction

Peripheral intravenous catheter (PIVC) placement is a routine yet challenging procedure in pediatric oncology due to factors such as small vein size, fragile vasculature, and patient distress [1, 2]. Despite advancements in medical technology, failure rates for first-attempt PIVC insertion remain high, leading to increased patient discomfort, procedural delays, and healthcare costs. Efficient vein assessment is essential to improving outcomes; however, traditional methods rely heavily on clinician expertise and are prone to variability [3].

Artificial intelligence (AI) has emerged as a transformative tool in healthcare, offering solutions for complex diagnostic and procedural challenges [4]. Recent studies highlight AI's potential in enhancing medical imaging and decision-making processes, particularly in pediatric oncology. For instance, AI algorithms have demonstrated efficacy in tumor classification, treatment planning, and imaging segmentation [5]. However, its application to procedural interventions like PIVC placement remains underexplored.

The integration of AI into vein assessment tools could revolutionize PIVC placement by providing real-time insights into vein location, depth, and suitability [4]. AI-enhanced systems can analyze patient-specific anatomical data to optimize catheter selection and insertion techniques. In pediatric oncology patients—where accurate and minimally invasive procedures are critical—such innovations could significantly improve procedural success rates while reducing patient distress [6].

This conceptual design proposes "Smart Access," an AI-powered vein assessment system tailored for pediatric oncology. By leveraging machine learning algorithms trained on diverse datasets of pediatric venous anatomy, the system aims to predict optimal insertion sites with high precision. Furthermore, it incorporates adaptive learning capabilities to refine its recommendations based on user feedback and clinical outcomes.

The novelty of this research lies in its focus on addressing the unique challenges of PIVC placement in pediatric oncology through AI-driven solutions. Unlike existing vein visualization technologies that rely solely on ultrasound or infrared imaging, Smart Access combines multimodal imaging with predictive analytics to offer a comprehensive assessment tool. This approach not only enhances procedural accuracy but also aligns with the broader goals of personalized medicine by adapting interventions to individual patient profiles.

In summary, this study seeks to bridge the gap between technological innovation and clinical practice by introducing an AI-enhanced framework for vein assessment. By improving the efficiency and success rates of PIVC placement in pediatric oncology patients, Smart Access has the potential to set a new standard for procedural care in this vulnerable population.

2. Methods

Study Design

This study adopts a conceptual design approach to develop and evaluate "Smart Access," an AI-powered vein assessment system tailored for pediatric oncology patients. The methodology encompasses three key phases: data acquisition, algorithm development, and prototype testing. Each phase is designed to ensure the system's clinical applicability, accuracy, and usability in a real-world healthcare setting. This approach allows us to systematically explore the potential benefits and challenges of integrating advanced technology into routine nursing practices.

Data Acquisition

A comprehensive dataset of pediatric venous anatomy is essential for training and validating the AI algorithms. This dataset will be sourced from anonymized medical imaging databases, including ultrasound and infrared vein visualization images, obtained from pediatric oncology patients aged 2–18 years. The inclusion criteria focus on patients undergoing routine PIVC placement, ensuring diverse anatomical variations are represented. Ethical approval will be obtained from relevant institutional to ensure patient privacy and data security.

The process involves:

- **Data Collection**: Gathering existing medical images and related clinical data from hospital databases. This includes ultrasound and infrared images, which capture different aspects of the veins.
- **Anonymization**: Removing any identifying information to protect patient privacy while retaining relevant medical details.
- **Quality Control**: Ensuring the images are of high quality and suitable for analysis.

The dataset will include:

- **Ultrasound images**: These images capture vein depth, diameter, and surrounding tissue characteristics, providing detailed information about the subsurface structure of the veins.
- **Infrared images**: These images highlight superficial veins using near-infrared technology, making them easier to visualize.
- **Clinical metadata**: This includes patient age, weight, hydration status, and previous PIVC placement history, which helps in understanding factors that influence vein assessment and PIVC success.

Algorithm Development

The AI model will be developed using a supervised machine learning approach. A convolutional neural network (CNN) architecture is chosen due to its proven efficacy in image analysis tasks. CNNs are particularly effective at identifying patterns and features in images, making them suitable for vein assessment [7]. The algorithm will be trained to identify optimal vein locations based on parameters such as vein size, depth, accessibility, and proximity to sensitive structures.

The development process involves:

- **Feature Extraction**: Identifying key features in the images that are relevant to vein assessment.
- **Model Training**: Using a portion of the dataset to train the CNN model to recognize patterns and make predictions.
- **Optimization**: Fine-tuning the model to improve its accuracy and efficiency.

Training and Validation

To ensure the AI model is robust and reliable, a rigorous training and validation process will be implemented:

- **Training phase**: 70% of the dataset will be used for training the model. Data augmentation techniques (e.g., rotation, scaling) will be applied to enhance robustness. This involves artificially increasing the size of the dataset by applying transformations to the existing images.
- **Validation phase**: 20% of the dataset will validate the model's performance in predicting vein suitability. Metrics such as sensitivity (the ability to correctly identify suitable veins), specificity (the ability to correctly identify unsuitable veins), and accuracy (overall correctness) will be calculated.
- **Testing phase**: The remaining 10% of the dataset will test the algorithm's generalizability across unseen cases. This assesses how well the model performs on new, previously unanalyzed data.

Adaptive Learning

To ensure continuous improvement, the system incorporates adaptive learning capabilities. Feedback from clinicians during prototype testing will be used to refine the algorithm's predictions. This allows the system to learn from real-world experiences and improve its performance over time.

Prototype Development

The Smart Access system integrates AI-driven analytics with multimodal imaging hardware. The prototype includes:

1. **Imaging module**: Combines ultrasound and infrared imaging for real-time vein visualization. This module captures and processes images of the patient's veins.
2. **AI software**: Processes imaging data to provide predictive analytics on optimal insertion sites. This software runs the trained AI model to analyze the images and provide recommendations.
3. **User interface**: Displays vein assessment results in an intuitive format for clinicians. This interface will present the AI's recommendations in a clear and easy-to-understand manner, allowing nurses to make informed decisions.

Prototype Testing

The prototype will undergo initial testing in a simulated clinical environment using manikins designed to replicate pediatric venous anatomy. Following successful simulation testing, a pilot study involving 30 pediatric oncology patients will evaluate its clinical performance.

The testing process includes:

- **Simulation Testing**: Using manikins to assess the system's usability and accuracy in a controlled environment.
- **Pilot Study**: Evaluating the system's performance with real patients under the supervision of experienced clinicians.

Evaluation Metrics

The system's efficacy will be assessed based on:

- **First-attempt success rate** of PIVC placement compared to traditional methods. This measures the percentage of successful PIVC insertions on the first attempt, comparing "Smart Access" to standard nursing practices.
- **Procedure time**, measured from vein assessment to catheter insertion. This evaluates the efficiency of the system by comparing the time taken with and without "Smart Access".
- **Clinician satisfaction**, evaluated through surveys and interviews. This captures the nurses' perceptions of the system's ease of use and usefulness in their clinical practice.

Statistical Analysis

Quantitative data (e.g., success rates, procedure times) will be analyzed using descriptive and inferential statistics (e.g., t-tests or chi-square tests). Descriptive statistics will summarize the data, while inferential statistics will determine if the differences observed are statistically significant. Qualitative feedback from clinicians will undergo thematic analysis to identify usability strengths and areas for improvement. Thematic analysis involves identifying common themes and patterns in the nurses' responses, providing insights into their experiences with the system.

By combining advanced AI algorithms with multimodal imaging technology, this methodology aims to create a clinically viable solution that addresses the unique challenges of PIVC placement in pediatric oncology patients while prioritizing patient comfort and procedural efficiency.

3. Results

As this study represents a conceptual design for the development of "Smart Access," no empirical data or experimental outcomes are available at this stage. However, based on the proposed methodology and existing literature, several anticipated findings and theoretical insights can be outlined to demonstrate the potential impact and feasibility of this innovation.

Anticipated Findings

1. **Improved PIVC Placement Success Rates**

   By leveraging AI-driven vein assessment, the Smart Access system is expected to enhance first-attempt success rates for PIVC placement in pediatric oncology patients. This improvement will likely stem from the system's ability to identify optimal vein sites with high precision, reducing procedural variability and reliance on clinician expertise.

2. **Reduction in Procedural Time**

   The integration of real-time imaging and predictive analytics is anticipated to streamline vein assessment and catheter insertion processes. This reduction in procedural time could minimize patient distress and optimize clinical workflow, particularly in busy oncology units.

3. **Enhanced Clinician Confidence**

The user-friendly interface and actionable insights provided by Smart Access are expected to improve clinician confidence in performing PIVC placement, especially among less experienced healthcare providers. This benefit aligns with the broader goal of democratizing access to advanced procedural tools.

4. **Adaptability Across Diverse Patient Profiles**

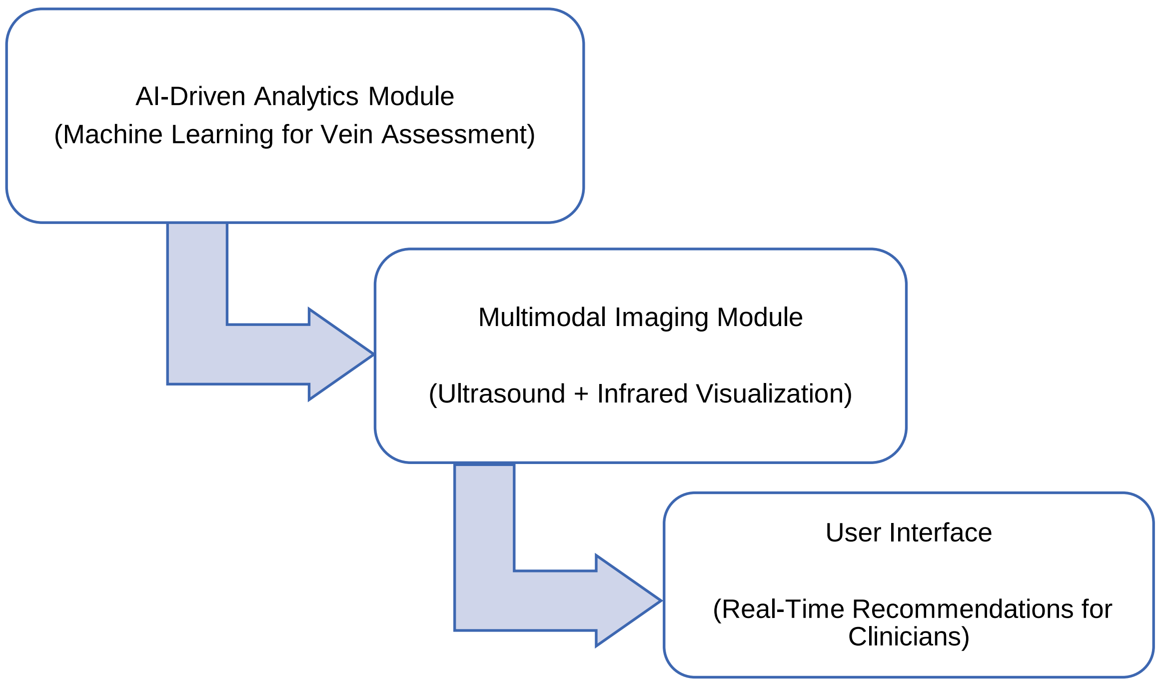
   The adaptive learning capabilities of the AI model may enable Smart Access to refine its recommendations based on individual patient characteristics (e.g., age, weight, hydration status). This adaptability could make the system suitable for a wide range of pediatric oncology cases, including those with challenging venous anatomy.

5. **Potential for Multimodal Imaging Synergy**

   Combining ultrasound and infrared imaging modalities is anticipated to provide a more comprehensive view of venous anatomy compared to single-modality systems. This synergy could enhance vein visualization and improve decision-making during PIVC placement.

To further illustrate the conceptual design of the "Smart Access" system, Fig. 1 provides a schematic representation of its core components and their interactions. This diagram highlights how multimodal imaging, AI-driven analytics, and a user-friendly interface are integrated to enhance vein assessment and PIVC placement.

Fig. 1: Conceptual Diagram of the Smart Access System



To better illustrate the anticipated benefits and improvements of the proposed "Smart Access" system compared to traditional methods, a summary table 1 is provided below. This table highlights key procedural metrics, technological advancements, and expected impacts on clinical practice and patient outcomes.

Category	Traditional Methods	Smart Access (Proposed System)	Expected Impact
First-attempt PIVC success rate	Highly variable (50–70%)	Predicted to exceed 85%	Reduced patient discomfort and procedural delays
Procedural time	Longer due to manual vein assessment	Shortened by real-time AI-driven recommendations	Optimized clinical workflow
Clinician reliance	Dependent on experience	AI-assisted, reducing variability	Improved accessibility for less experienced staff
Imaging modalities used	Single modality (ultrasound or infrared)	Multimodal imaging (ultrasound + infrared)	Enhanced vein visualization
Adaptability to patient profiles	Limited adaptability	Adaptive learning based on patient-specific data	Personalized care
Patient distress	Higher due to multiple insertion attempts	Lower due to improved accuracy	Enhanced patient satisfaction

Table 1: Comparison of traditional PIVC placement methods versus the proposed "Smart Access" system, highlighting expected impacts and advantages based on the conceptual design.

4. Discussion

The conceptual design of the "Smart Access" system offers a fresh perspective on tackling the persistent challenges of peripheral intravenous catheter (PIVC) placement in pediatric oncology patients. By thoughtfully integrating artificial intelligence (AI) and multimodal imaging, this system aspires to boost procedural accuracy, ease patient discomfort, and streamline clinical workflows. While this framework holds considerable promise, it's essential to explore its potential impact, practical implementation, and future development pathways.

The infusion of AI into vein assessment marks a notable shift in procedural care. Traditional vein visualization relies heavily on the skills of clinicians and single-imaging techniques, often leading to inconsistent results. In contrast, "Smart Access" employs predictive analytics to pinpoint ideal vein sites, presenting a more standardized approach that aims to cut down on procedural errors. This shift aligns with broader healthcare efforts to reduce variability and improve precision in patient care, mirroring trends seen in other AI-enhanced diagnostic tools [8, 9].

This conceptual design underscores the real-world potential of integrating AI into procedural interventions like PIVC placement, addressing a significant void in current healthcare tech. It highlights how AI-driven solutions can propel personalized medicine and procedural accuracy forward. Moreover, the system's adaptive learning capabilities ensure ongoing improvements by integrating feedback from clinical use. This feature is key in pediatric oncology, where the complex nature of cases and anatomical differences can complicate interventions. By customizing recommendations to each patient, "Smart Access" embodies the core principles of personalized medicine [10].

Consistent with the goals of patient-centered care, the proposed system aims to enhance first-attempt success rates. In pediatric oncology, where children require minimally invasive and efficient procedures to lessen physical and emotional distress, "Smart Access" could make a real difference by reducing the number of insertion attempts and improving patient comfort. Additionally, the system's ability to shorten procedural times aligns with the need to optimize workflows in high-pressure clinical settings [11].

The accessible interface of "Smart Access" also equips clinicians with valuable insights, eliminating the need for extensive training in advanced imaging. This democratization of innovative tools has the potential to narrow gaps in procedural care across various healthcare settings [12].

By emphasizing minimally invasive techniques and lessening patient discomfort, "Smart Access" reflects the core values of patient-centered care in pediatric oncology. The conceptual framework underscores the significance of adapting interventions to meet individual needs while upholding high standards of clinical efficacy.

Limitations

Despite its innovative design, we must acknowledge several limitations:

1. **Lack of Empirical Validation:** This study, as a conceptual framework, lacks empirical data to confirm the effectiveness of "Smart Access." Future research should prioritize prototype development and clinical trials to gauge its real-world performance. This mirrors the path taken by other AI-based medical tools, where initial concepts are rigorously tested before widespread adoption.

2. **Data Availability:** The success of AI-driven systems hinges on having access to high-quality datasets for training and validation. The limited availability of pediatric venous anatomy datasets, due to ethical and logistical challenges, could hinder algorithm development. Addressing this will require collaborative efforts among healthcare institutions to pool resources and data, as seen in other successful AI implementations in medicine [13].

3. **Integration Challenges:** Incorporating "Smart Access" into existing clinical workflows might require significant adjustments in infrastructure and staff training. Resistance to adopting new technologies is a common hurdle, as noted in studies on implementing electronic health records and other digital tools [14, 15].

4. **Cost Considerations:** The development and deployment of advanced imaging hardware and AI software could entail substantial costs, potentially limiting accessibility for resource-constrained healthcare facilities. Finding cost-effective solutions will be vital to ensure equitable access, similar to strategies employed in making telehealth and other healthcare technologies more affordable.

5. **Potential Over-Reliance on Technology:** While AI can enhance decision-making, there's a risk of over-relying on automated systems, potentially reducing clinician engagement and critical thinking [16]. Striking a balance between AI assistance and human oversight will be crucial, echoing concerns raised in discussions about AI in other healthcare domains [17].

Future Directions

To address these limitations and further refine the "Smart Access" system, the following steps should be considered:

- **Prototype Development:** Building a functional prototype for testing in simulated environments to gain insights into its usability and technical viability. This step aligns with established practices in engineering and medical device development.
- **Clinical Trials:** Conducting pilot studies with pediatric oncology patients to assess the system's effectiveness and pinpoint areas for refinement. These trials should adhere to rigorous ethical standards and involve diverse patient populations.
- **Dataset Expansion:** Collaborating with healthcare institutions to create extensive datasets of pediatric venous anatomy, which will bolster algorithm robustness. This effort could benefit from data-sharing agreements and standardized data collection protocols.
- **Development of Training Programs:** Creating training programs to ensure healthcare providers are proficient in using the "Smart Access" system and are well-informed about its limitations. This training should emphasize the importance of critical thinking and human oversight in AI-assisted decision-making.

5. Conclusion

The "Smart Access" system has the potential to revolutionize PIVC placement in pediatric oncology through the integration of AI-driven analytics and multimodal imaging. While its conceptual design highlights numerous benefits, it is essential to address the identified limitations through empirical validation and strategic implementation to fully realize its impact on clinical practice. By prioritizing patient-centered care and responsibly leveraging technological innovation, this system represents a promising advancement in procedural medicine for vulnerable populations.

6. References

[1] A. Crocoli *et al.*, "Vascular access in pediatric oncology and hematology: state of the art," *Children,* vol. 9, no. 1, p. 70, 2022.

[2] M. B. H. Davis, D. Doellman, S. Pitts, and T. Kleidon, "Minimum Education and Training for Pediatric and Neonatal Peripheral Intravenous Catheter Care for All Clinicians: Position Paper," *Journal of the Association for Vascular Access,* vol. 29, no. 2, pp. 23-33, 2024.

[3] T. M. Kleidon, M. Takashima, C. M. Rickard, J. A. Schults, A. C. Bulmer, and A. J. Ullman, "A Prospective Cohort Study of Technique and Technology Used to Improve First Time PIVC Insertion Success in Hospitalised Paediatric Patients," *Journal of Advanced Nursing,* 2025.

[4] A. Bahl, S. Johnson, N. Mielke, M. Blaivas, and L. Blaivas, "Anticipating impending peripheral intravenous catheter failure: A diagnostic accuracy observational study combining ultrasound and artificial intelligence to improve clinical care," *The Journal of Vascular Access,* p. 11297298241307055, 2025.

[5] R. Obuchowicz, M. Strzelecki, and A. Piórkowski, "Clinical applications of artificial intelligence in medical imaging and image processing—A review," vol. 16, ed: MDPI, 2024, p. 1870.
[6] S. Ramesh *et al.*, "Applications of artificial intelligence in pediatric oncology: a systematic review," *JCO Clinical Cancer Informatics,* vol. 5, pp. 1208-1219, 2021.
[7] M. A. Abdou, "Literature review: Efficient deep neural networks techniques for medical image analysis," *Neural Computing and Applications,* vol. 34, no. 8, pp. 5791-5812, 2022.
[8] N. Nimmagadda, E. Aboian, S. Kiang, and U. Fischer, "The Role of Artificial Intelligence in Vascular Care," *JVS-Vascular Insights,* p. 100179, 2024.
[9] T. Takahashi, G. Nakagami, R. Murayama, M. Abe-Doi, M. Matsumoto, and H. Sanada, "Automatic vein measurement by ultrasonography to prevent peripheral intravenous catheter failure for clinical practice using artificial intelligence: development and evaluation study of an automatic detection method based on deep learning," *BMJ open,* vol. 12, no. 5, p. e051466, 2022.
[10] A. M. Mao, "Using smart and secret sharing for enhanced authorized access to medical data in blockchain," Carleton University, 2020.
[11] G. Clark-SIngh, "Ultrasound-Guided Intravenous Insertion for Patients in the Hospital With Difficult Access," Grand Canyon University, 2025.
[12] R. Najjar, "Digital frontiers in healthcare: integrating mHealth, AI, and radiology for future medical diagnostics," 2024.
[13] P. Esmaeilzadeh, "Challenges and strategies for wide-scale artificial intelligence (AI) deployment in healthcare practices: A perspective for healthcare organizations," *Artificial Intelligence in Medicine,* vol. 151, p. 102861, 2024.
[14] C. S. Kruse, C. Kristof, B. Jones, E. Mitchell, and A. Martinez, "Barriers to electronic health record adoption: a systematic literature review," *Journal of medical systems,* vol. 40, pp. 1-7, 2016.
[15] Z. Niazkhani, E. Toni, M. Cheshmekaboodi, A. Georgiou, and H. Pirnejad, "Barriers to patient, provider, and caregiver adoption and use of electronic personal health records in chronic care: a systematic review," *BMC medical informatics and decision making,* vol. 20, pp. 1-36, 2020.
[16] M. Abdelwanis, H. K. Alarafati, M. M. S. Tammam, and M. C. E. Simsekler, "Exploring the risks of automation bias in healthcare artificial intelligence applications: A Bowtie analysis," *Journal of Safety Science and Resilience,* 2024.
[17] P. Calleja and M. Fenech, "Artificial intelligence in healthcare: balancing automation and human oversight," 2024.