# Peripherally Inserted Central Catheters: A Survey on Complications and Prediction Models

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## Abstract

This survey paper provides a comprehensive analysis of peripherally inserted central catheters (PICCs), emphasizing their critical role in modern healthcare for providing reliable venous access, particularly in oncology and neonatal care. Despite their benefits, PICCs are associated with complications such as catheter-related infections and venous thrombosis, necessitating effective prediction models and risk assessment strategies to mitigate these risks. The integration of advanced technologies, including deep learning models for catheter detection and segmentation, shows promise in enhancing the accuracy of PICC placement and reducing device misidentification and malposition. Logistic regression and other statistical methodologies offer a robust framework for understanding risk factors, enabling evidence-based practices. The development of automated systems and synthetic data generation further enhances the predictive capabilities of risk assessment models, offering scalable solutions to traditional data challenges. This paper underscores the importance of continuous research and innovation to optimize PICC management, reduce complication rates, and improve patient outcomes. By leveraging advanced technologies and methodologies, healthcare providers can ensure the safe and effective use of PICCs, ultimately enhancing the quality of care for patients requiring these essential medical devices.

## 1 Introduction

### 1.1 Significance of PICC in Medical Practice

Peripherally inserted central catheters (PICCs) are integral to modern healthcare, offering versatile and effective intravenous therapy solutions. Since their introduction in the late 1970s, PICCs have been widely adopted for intermediate-term venous access, particularly in oncology, where they are crucial for cancer patients undergoing chemotherapy who are at heightened risk for infections [1, 2]. Their role extends to neonatal care, where PICCs are vital for premature infants needing parenteral nutrition and concentrated solutions essential for survival and growth. In intensive care units (ICUs), PICCs serve as a safer alternative to traditional central venous catheters, albeit with an ongoing risk of bloodstream infections [3].

Advancements in PICC technology, such as the introduction of PICC-ports, have mitigated risks associated with traditional catheter ports, notably reducing catheter-related thrombosis and device failure, thus enhancing clinical efficacy [4]. Despite limited research on their use in cancer patients receiving radiotherapy, PICCs are favored in both outpatient and inpatient settings for their potential to improve patient outcomes [5]. The applicability of totally implantable venous access ports (TIVAP) and PICCs in non-hematological malignancies remains debated due to differing placement requirements and clinical implications [6]. However, their use in gynecological cancer patients undergoing systemic adjuvant therapy is well-documented, demonstrating their widespread benefits [7].

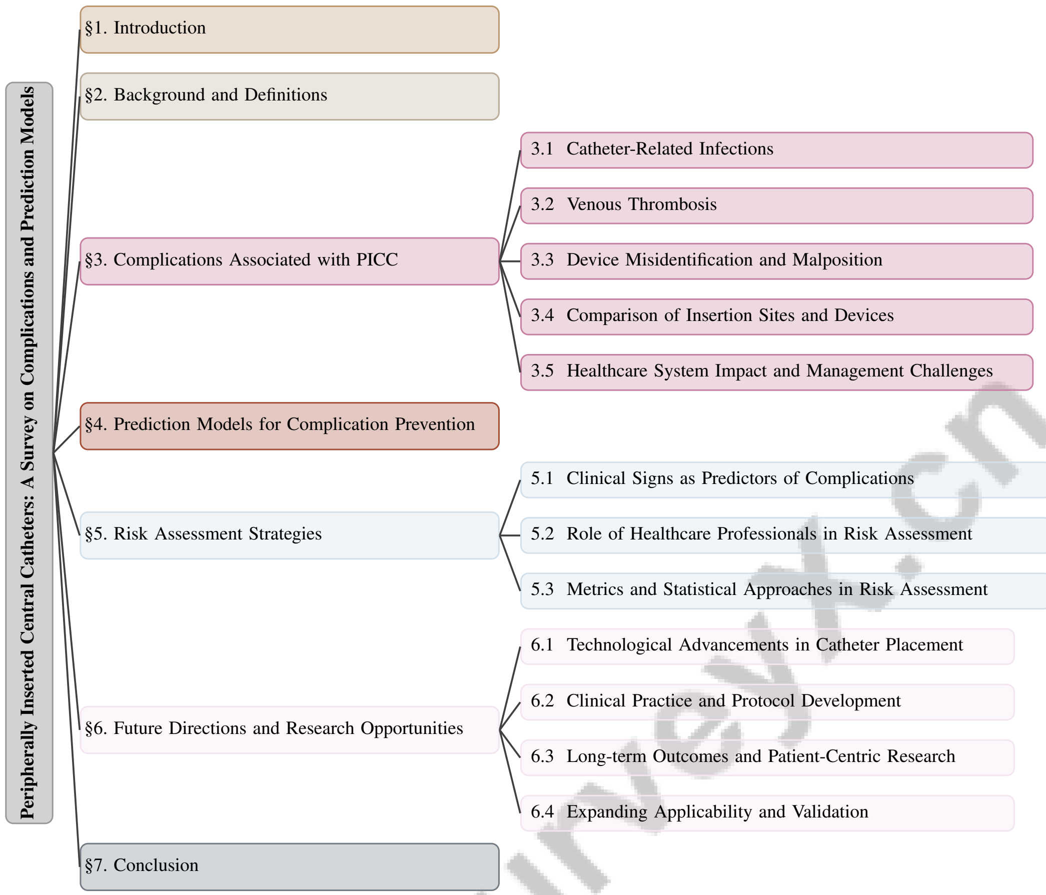


Figure 1: chapter structure

The extensive use of PICCs across various medical contexts underscores their critical role in enhancing patient care by facilitating complex treatment regimens while minimizing venous access-related complications, such as local infections and thrombosis. Their ease of insertion by trained nurses in outpatient settings further solidifies their status as a preferred choice for long-term venous access across diverse patient populations [8, 9, 7, 10, 6].

### 1.2 Importance of Prediction Models and Risk Assessment

The implementation of prediction models and risk assessment strategies is crucial for managing complications associated with PICCs, particularly in identifying and mitigating risks such as catheter-related bloodstream infections (CRBSIs) and thrombosis. In cancer patients undergoing chemotherapy, the incidence of PICC-related bloodstream infections has been benchmarked against noncancer patients to address the specific risks faced by this population [2]. In neonatal care, where PICCs are essential, recognizing and addressing risk factors for CRBSIs is vital for improving outcomes [11].

Prediction models are pivotal in early identification of these risk factors, enabling timely interventions. Moreover, evaluating the clinical effectiveness and safety of PICC-ports compared to traditional vascular access devices highlights the role of prediction models in enhancing the safety profile of PICCs [4]. These models facilitate comparisons of various catheter types and configurations, such as double-lumen catheters, which may lower infection rates by providing a dedicated pathway for parenteral nutrition infusion [12].

Understanding the impact of arm selection on PICC complications further emphasizes the necessity of risk assessment. By analyzing the relationship between insertion site and complication rates, healthcare providers can make informed decisions that improve patient outcomes and reduce costs [8]. The safety profile and feasibility of using PICCs in cancer patients undergoing radiotherapy have also been studied, focusing on complications and patient-related factors during treatment [5].

Additionally, the patient experience with PICCs, encompassing both positive and negative aspects, necessitates comprehensive risk assessment to enhance satisfaction and adherence to treatment protocols [10]. In non-hematological malignancies, the effectiveness and safety of TIVAP compared to PICCs have been evaluated, focusing on placement success rates, complication rates, and cost-effectiveness [6]. Prediction models are instrumental in these analyses, guiding the selection of the most suitable vascular access device for individual patient needs.

### 1.3 Structure of the Survey

This survey is meticulously structured to provide an in-depth analysis of peripherally inserted central catheters (PICCs), focusing on their complications and the role of prediction models in managing these issues. The introduction emphasizes the significance of PICCs in medical practice, detailing their widespread use and common complications, such as catheter-related infections and venous thrombosis. The subsequent section discusses the importance of prediction models and risk assessment, highlighting their critical role in mitigating PICC-related complications.

The survey comprises several key sections. The first major section, Background and Definitions, offers a detailed explanation of PICCs, including their uses and benefits in clinical settings, along with definitions of key terms relevant to PICC usage, such as catheter-related infections and prediction models. The following section, Complications Associated with PICC, explores various complications arising from PICC use, focusing on catheter-related infections, venous thrombosis, and device misidentification and malposition.

Subsequently, the survey examines Prediction Models for Complication Prevention, analyzing methodologies and the effectiveness of existing models used to assess complication risks in patients with PICCs. This is followed by a section on Risk Assessment Strategies, evaluating strategies for risk assessment in the context of PICCs and discussing how these approaches facilitate early identification and management of potential complications.

Finally, the survey concludes with Future Directions and Research Opportunities, identifying gaps in current research and proposing future directions for enhancing prediction models and risk assessment strategies. This section also discusses potential advancements in technology and methodology that could improve the management of PICC-related complications, offering a forward-looking perspective on the topic.The following sections are organized as shown in Figure 1.

## 2 Background and Definitions

### 2.1 Definition and Characteristics of PICC

Peripherally inserted central catheters (PICCs) are long intravenous devices inserted through a peripheral vein and advanced to a central vein, typically the superior vena cava, facilitating intravenous solution administration [12]. They are crucial in both inpatient and outpatient settings, offering long-term intravascular access with a relatively low infection risk, advantageous over other venous access devices. Their usage is prevalent among neonates and patients with non-hematological malignancies undergoing chemotherapy, where effective venous access is vital.

PICCs have variable insertion sites, notably the right and left arm, with differing complication rates based on the chosen site [8]. Designed for intermediate to long-term use, they cater to patients requiring extended intravenous therapy [11]. However, complications such as device failure and thrombosis can arise, potentially leading to severe health issues, including pulmonary embolism.

Advancements have led to PICC-ports, addressing challenges associated with traditional venous access devices and enhancing safety and efficacy [4]. These innovations reflect ongoing efforts to optimize PICC design and functionality to meet diverse patient needs. Microbiological considerations and the incidence of PICC-related bloodstream infections (PR-BSIs) are critical in evaluating PICC safety, necessitating thorough clinical assessments to manage associated risks [1].

### 2.2 Uses and Benefits of PICC in Clinical Settings

PICCs provide reliable long-term intravenous access for therapies like chemotherapy and nutritional support, essential in both inpatient and outpatient settings. Their utility is pronounced in critical care,



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oncology, and hematology, where prolonged treatment is often necessary. PICCs are associated with improved patient comfort, reduced complication rates, and lower healthcare costs, making them a preferred choice for sustained venous access [9, 5, 7, 13, 6]. In neonatology, PICCs are crucial for administering medications and nutritional support to neonates during their critical early stages.

PICCs are favored for patient comfort and lower complication rates compared to other venous access devices, particularly in parenteral nutrition [9]. Studies involving numerous PICC insertions demonstrate their extensive use and effectiveness in managing complex treatment protocols.

In adult patients, PICC-ports have enhanced clinical outcomes by reducing catheter-related complications, as evidenced by a multicenter study involving 4,480 PICC-port insertions with a median follow-up of 15.5 months [4]. This advancement highlights continuous efforts to optimize PICC technology for evolving patient care needs.

The role of PICCs in oncology is well-established, especially for chemotherapy administration, providing a stable and efficient means of delivering treatment while minimizing complications. Comparative studies between totally implantable venous access ports (TIVAP) and PICCs reinforce their safety and effectiveness in managing non-hematological malignancies [6].

The catheter to vein ratio (CVR) significantly impacts thrombosis rates, with established benchmarks identifying optimal CVR cut-offs to enhance the safety profile of PICCs [14]. This focus on thrombosis prevention is essential for the long-term success of PICC-based therapies.

The diverse clinical applications and benefits of PICCs, coupled with ongoing advancements in catheter technology, underscore their integral role in modern healthcare. Emphasizing patient education and professional training is crucial for maximizing PICC advantages, as highlighted by methodologies aimed at improving patient outcomes and satisfaction [10].

### 2.3 Key Terms and Definitions

Understanding key terms related to peripherally inserted central catheters (PICCs) is essential for grasping the complexities of their use and management. This section defines critical terms such as catheter-related infections, venous thrombosis, prediction models, and risk assessment, pivotal in discussing PICC-related complications.

Catheter-related infections, particularly catheter-related bloodstream infections (CRBSIs), occur when bacteria or fungi enter the bloodstream through a catheter. PICC-associated infections are a major concern in clinical settings, especially in intensive care units, as they can lead to severe complications like sepsis. Significant risk factors for these infections include low birth weight, prolonged catheter duration, and specific insertion sites [11, 3]. The incidence of CRBSIs is influenced by various factors, including catheter insertion site, duration of catheterization, and patient-specific characteristics.

Venous thrombosis involves blood clot formation within a vein, which can occur as a complication of PICC placement. This condition can lead to serious health issues, such as pulmonary embolism, if not promptly diagnosed and managed. The catheter to vein ratio (CVR) is a critical parameter in evaluating thrombosis risk associated with PICCs, with a specific cut-off of 45% identified as predictive of increased risk; adhering to this cut-off is essential for clinical decision-making, particularly in patients with malignancies, where exceeding this ratio more than doubles the risk of thrombotic events [15, 13, 14].

Prediction models are analytical tools used to forecast the likelihood of complications associated with PICC use. These models incorporate various patient and procedural factors to estimate the risk of adverse events, facilitating proactive management strategies. In the context of PICCs, prediction models play a crucial role in identifying patients at elevated risk for complications, such as mispositioned catheter tips, which can lead to serious adverse events like embolism or cardiac arrhythmias. Utilizing these models enables healthcare providers to implement personalized interventions tailored to individual risk profiles, enhancing patient safety and improving overall outcomes [8, 16, 13].

Risk assessment involves systematically evaluating factors that could lead to complications in patients with PICCs. This process is vital for early detection and proactive management of potential complications, significantly improving patient safety and clinical outcomes by reducing risks of mispositioning and associated adverse events [8, 13, 12]. Effective risk assessment strategies in-



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corporate clinical signs and predictive analytics to provide a comprehensive overview of potential complications, enabling healthcare providers to implement preventive measures.

These definitions establish a crucial foundation for understanding key terms related to PICC complications, prediction models, and risk assessment, highlighting their significance in enhancing patient care and safety. This understanding is essential for addressing complications such as catheter-related infections and optimizing insertion site selection, as evidenced by studies demonstrating variations in complication rates based on arm selection and patient characteristics. Integrating these definitions into clinical practice can improve decision-making processes regarding PICC usage, ultimately leading to better patient outcomes [8, 9, 12, 3].

## 3 Complications Associated with PICC

The complexities of peripherally inserted central catheters (PICCs) are significant, influencing patient outcomes and healthcare expenditures. Among these, catheter-related infections are notably prevalent and impactful. This section examines catheter-related infections, emphasizing their frequency, risk factors, and the importance of effective management.

To provide a comprehensive understanding of the complications associated with PICCs, Figure 2 illustrates the hierarchical structure of these complications. This figure highlights key categories, including catheter-related infections, venous thrombosis, device misidentification and malposition, as well as the comparison of insertion sites and devices. Furthermore, it addresses the broader implications for healthcare systems, including management challenges and specific risk factors, management strategies, and technological advancements related to each category. Such a visual representation underscores the multifaceted nature of PICC complications and reinforces the necessity for meticulous management and innovative solutions in clinical practice.

### 3.1 Catheter-Related Infections

Catheter-related bloodstream infections (CRBSIs) are a significant complication of PICC usage, resulting in increased morbidity and healthcare costs. Oncology patients are particularly vulnerable, exhibiting higher PICCR-BSI rates of 2.6 per 1000 catheter days compared to 1.0 in non-cancer patients [2]. This highlights the need for vigilant monitoring and tailored preventative measures for this demographic.

In neonatal care, CRBSIs significantly extend hospital stays and increase mortality rates, necessitating rigorous infection control and prompt interventions [11, 12]. Research has extensively analyzed the microbiological traits and risk factors of PICCR-BSIs to improve clinical management and reduce infection rates [3]. These infections mirror those of conventional central venous catheters (CVCs), suggesting similar preventive strategies could be effective [1]. Identifying pathogens and their resistance profiles is crucial for optimizing antimicrobial treatments.

The insertion site is a critical factor in CRBSI incidence, with right-sided insertions showing a statistically significant reduction in complications compared to left-sided [8]. This emphasizes the need for careful anatomical and procedural considerations in PICC placement.

The high incidence of catheter-related infections across age groups underscores the necessity for comprehensive risk assessments and evidence-based practices. Factors such as low birth weight, extended PICC duration, and specific sites elevate CRBSI rates, particularly in vulnerable populations like neonates. Targeted interventions based on these insights can mitigate infection risks and improve patient outcomes [8, 1, 11, 3]. Continuous surveillance and advancements in catheter technology are essential for reducing CRBSI burdens and enhancing PICC safety and efficacy in clinical practice.

### 3.2 Venous Thrombosis

Venous thrombosis is a major complication of PICCs, particularly in cancer patients. The incidence of catheter-related thrombosis (CRT) varies with factors such as catheter type, insertion site, and patient-specific risks [15]. Cancer patients face an elevated risk, especially with power PICCs, which have higher morbidity rates than standard ones [3].

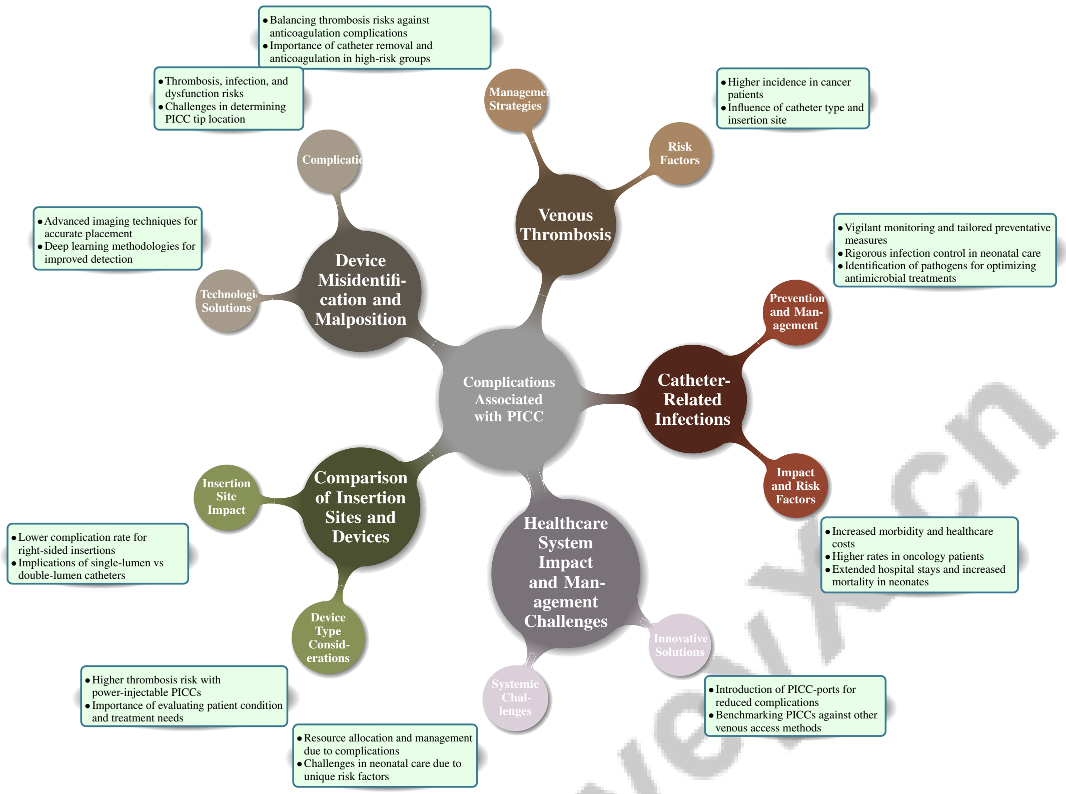


Figure 2: This figure illustrates the hierarchical structure of complications associated with peripherally inserted central catheters (PICCs), highlighting key categories such as catheter-related infections, venous thrombosis, device misidentification and malposition, comparison of insertion sites and devices, and healthcare system impact and management challenges. Each category is further broken down into specific risk factors, management strategies, and technological advancements.



Managing CRT effectively is crucial, as thrombi can lead to severe complications like pulmonary embolism and catheter dysfunction. The decision to remove the catheter or use anticoagulation therapy is vital. While catheter removal may suffice in some cases, adding anticoagulation can improve outcomes, particularly in high-risk groups [15].

The type of PICC and patient's condition affect thrombosis incidence. Power PICCs are associated with higher morbidity than standard PICCs [3]. Additionally, insertion sites impact complications; right-sided insertions have lower rates than left-sided [8].

Despite PICC benefits, the risk of venous thrombosis remains a concern, especially in cancer patients. Managing CRT requires balancing thrombosis risks against anticoagulation complications. Healthcare providers must weigh catheter removal benefits against anticoagulation needs, particularly in high-risk cancer patients [15]. Understanding venous thrombosis occurrence is crucial for enhancing patient safety and optimizing PICC use.

### 3.3 Device Misidentification and Malposition

Accurate identification and placement of PICCs are essential to minimize complications and ensure effective outcomes. Device misidentification and malposition pose significant risks, potentially leading to thrombosis, infection, and dysfunction. The challenge of determining PICC tip location is compounded by the multiple fragments phenomenon (MFP), complicating accurate placement [13].

Mispositioned catheters are linked to increased thrombotic complications and malfunction rates. Comparative analyses show PORT devices have fewer thrombotic complications and lower malfunction rates than PICCs, underscoring the importance of accurate placement and device selection [7].



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Chest radiographs (CXRs) are commonly used to verify PICC placement, but tip position detection remains challenging. Advanced methodologies, including deep learning, have improved PICC tip detection accuracy in CXRs, preventing malposition-related complications [16]. Innovative approaches, such as bottom-up instance segmentation, enhance catheter identification and placement precision in complex scenarios [17].

Addressing device misidentification and malposition is critical for optimizing PICC outcomes. Incorporating advanced imaging techniques can significantly improve placement precision, minimizing risks associated with mispositioned catheters and enhancing patient safety [16, 13].

### 3.4 Comparison of Insertion Sites and Devices

| Benchmark | Size | Domain | Task Format | Metric |
|---|---|---|---|---|
| PICC-Comp[8] | 7,657 | Vascular Access | Complication Rate Analysis | Odds Ratio, p-value |
| CVR[14] | 2,438 | Vascular Access | Risk Assessment | Relative Risk, Confidence Interval |
| PICC-PORT[4] | 4,480 | Surgical Oncology | Clinical Outcome Evaluation | Device Failure Rate, Adverse Event Incidence |
| CRT-BM[15] | 83 | Hematology | Comparative Analysis | Major bleeding, Secondary VTE events |
| PICC-BSI[2] | 721 | Infectious Diseases | Comparative Analysis | PICCR-BSI rate, Double-lumen PICC association |
| CRBSI-PICC[11] | 386 | Neonatology | Risk Factor Analysis | Odds Ratio, p-value |
| PR-BSI[1] | 901 | Infectious Diseases | Observational Study | NPV, PPV |
| PICC-Benchmark[3] | 402 | Infectious Disease | Risk Factor Analysis | Morbidity Rate, Antibiotic Sensitivity |

Table 1: Table ef presents a comprehensive overview of various benchmarks used in the evaluation of peripherally inserted central catheters (PICCs) across different medical domains. It includes details such as the benchmark name, size, domain, task format, and the specific metrics utilized for analysis, providing insight into the diverse methodologies and metrics applied in clinical and observational studies.

Appropriate insertion site and device type selection for PICCs is vital for minimizing complications like infections and thrombosis. Research shows right-sided insertions have a lower complication rate than left-sided [8].

The type of PICC also affects adverse event likelihood. Power-injectable PICCs, while beneficial for certain procedures, carry a higher thrombosis risk than standard PICCs [14]. Evaluating patient condition and treatment needs is essential when selecting the appropriate catheter type.

Catheter configuration, such as single-lumen versus double-lumen, impacts infection and thrombosis risk. Double-lumen catheters may carry higher infection risks due to increased handling [4]. Selecting the appropriate configuration is crucial for optimizing outcomes and minimizing complications.

Advanced imaging techniques, including deep learning models for automated catheter detection and segmentation, improve PICC placement accuracy and reduce misidentification and malposition risks. Recent studies show deep learning systems achieve a mean absolute distance of only 3.10 mm from the ground truth in tip detection, expediting confirmation processes and potentially decreasing complications [16, 13]. Table 1 provides a detailed overview of the representative benchmarks utilized in the study of peripherally inserted central catheters (PICCs) across various medical domains, highlighting the diversity in study size, domain focus, task format, and evaluative metrics.

### 3.5 Healthcare System Impact and Management Challenges

The integration of PICCs into healthcare systems influences patient care and resource allocation, presenting management challenges due to complications. The widespread use of PICCs, especially in oncology and neonatal care, highlights their importance for reliable venous access. However, complications like CRT and CRBSIs pose substantial challenges [11].

In neonatal populations, managing PICC-related complications is challenging due to unique CRBSI risk factors. This group's vulnerability necessitates stringent infection control and careful monitoring [11]. Challenges are compounded by limited double-lumen catheter availability and difficulties maintaining dedicated parenteral nutrition access, leading to undesirable interactions with other solutions [12].



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From a healthcare perspective, PICC-related complications can extend hospitalization and increase costs. Interventions like catheter removal or replacement strain resources. However, studies suggest catheter removal alone may suffice for some CRT patients, particularly those at high bleeding risk, potentially reducing invasive interventions [15].

PICC-ports have been introduced to mitigate challenges, offering a safe and effective alternative to traditional devices. With low complication incidence and high patient satisfaction, PICC-ports represent a promising advancement [4]. Benchmarks indicate PICCs are a viable alternative to other central venous access methods, offering flexibility and reduced complication rates in cancer patients [5].

In non-hematological cancer patients, comparing totally implantable venous access ports (TIVAP) and PICCs provides valuable insights. These benchmarks assist clinicians in making informed decisions regarding the most suitable device, balancing benefits and risks to optimize outcomes [6].

While PICCs offer considerable benefits, such as enhanced comfort and reduced complication rates, they present management challenges. These include careful monitoring and resource allocation to address complications like CRT and infection, as highlighted by studies emphasizing arm selection and individualized care to minimize risks [8, 15, 9, 7]. Developing advanced catheter technologies and implementing evidence-based strategies are essential to addressing challenges and enhancing PICC efficacy in healthcare systems.

# 4 Prediction Models for Complication Prevention

| Category | Feature | Method |
|---|---|---|
| **Deep Learning Models for Catheter Detection and Segmentation** | Feature Representation<br>Sequential Processing | AEC[17]<br>CSAI[16] |
| **Logistic Regression and Statistical Approaches** | Predictive Analysis | PICC[12] |
| **Automated Systems for Complication Prevention** | Structured Process Frameworks | SRN-CD[18], MFCN[13] |

Table 2: This table provides a comprehensive overview of various methodologies employed in the management of peripherally inserted central catheters (PICCs) to prevent complications. It categorizes approaches into deep learning models for catheter detection and segmentation, logistic regression and statistical methods for predictive analysis, and automated systems designed for complication prevention. The table highlights the specific features and methods associated with each category, referencing key studies that contribute to advancements in this field.

The development of advanced prediction models is pivotal in reducing complications associated with peripherally inserted central catheters (PICCs). Table 2 presents a detailed classification of methodologies utilized in enhancing catheter management, focusing on deep learning models, statistical approaches, and automated systems aimed at reducing complications associated with PICCs. Additionally, Table 4 offers a comprehensive comparison of different methods used for catheter management, emphasizing their significance in reducing complications associated with PICCs. This section delves into various methodologies aimed at enhancing catheter management through sophisticated algorithms and statistical techniques. The following subsections highlight deep learning models that have shown potential in improving catheter detection and segmentation, addressing significant clinical challenges.

## 4.1 Deep Learning Models for Catheter Detection and Segmentation

| **Method Name** | **Model Architecture** | **Clinical Application** | **Data Processing Techniques** |
|---|---|---|---|
| MFCN[13] | Multi-stage Framework | Improve Clinical Outcomes | Patch-based Refinement |
| SRN-CD[18] | Recurrent Architecture | Enhance Detection Accuracy | Synthetic Data Generation |
| AEC[17] | Branched Hrnet | Catheter Instance Segmentation | Data Augmentation Techniques |
| CSAI[16] | Two Fcns | Improve Patient Safety | Synthetic Data Generation |

Table 3: Overview of deep learning models and their respective architectures, clinical applications, and data processing techniques for catheter detection and segmentation. The table highlights the methods employed to improve clinical outcomes and patient safety through advanced data processing strategies.

Deep learning models have become integral in the detection and segmentation of PICCs, effectively preventing complications from misplacement and misidentification. Table 3 presents a comprehensive summary of various deep learning models utilized for catheter detection and segmentation, detailing their architectures, clinical applications, and data processing techniques. The Multi-fragment Complementary Network (MFCN) exemplifies this advancement, using a multi-stage deep learning approach to enhance PICC line extraction and tip localization, tackling the multiple fragments phenomenon (MFP) [13]. In pediatric cases, the Scale-Recurrent Network for Catheter Detection (SRN-CD) combines synthetic data generation with a recurrent architecture, significantly improving detection accuracy and clinical outcomes [18]. Additionally, associative embeddings for catheter instance segmentation enhance the identification and differentiation of individual catheters in complex imaging scenarios [17]. A fully automated deep-learning system with cascading segmentation AI, utilizing two fully convolutional networks (FCNs), has been proposed to accurately detect PICC lines and tip locations, thereby minimizing risks associated with catheter malposition [16]. Integrating these deep learning models into clinical practice represents a significant advancement in catheter management, offering potential reductions in complications related to PICC use by leveraging advanced algorithms and innovative data processing techniques, thus improving clinical outcomes and patient safety [16, 13].

### 4.2 Logistic Regression and Statistical Approaches

Logistic regression and other statistical methodologies are crucial for predicting complications associated with PICCs, assessing risk factors and outcomes to inform clinical decision-making and enhance patient safety. Logistic regression has effectively analyzed risk factors for catheter-related bloodstream infections (CRBSIs), demonstrating its predictive capability [11]. Statistical analyses using propensity-score matching have provided insights into infection rates among cancer and noncancer patients, allowing accurate comparisons by adjusting for confounding variables [2]. Furthermore, logistic regression has been applied to compare complication rates, employing one-tailed hypothesis testing to assess the significance of observed differences [8]. The relationship between catheter to vein ratio (CVR) and thrombosis rates has been evaluated through a log binomial generalized linear model, offering a nuanced understanding of how catheter dimensions influence complication rates [14]. The integration of statistical methods such as Cox proportional hazards regression and multivariate analysis has been pivotal in evaluating risk factors and infection outcomes, enabling a comprehensive assessment of clinical variables and their impact on patient safety [12].

### 4.3 Automated Systems for Complication Prevention

Automated systems play a vital role in mitigating complications associated with PICCs by utilizing advanced deep learning techniques for precise localization of catheter tips, significantly reducing the risk of misplacement and its potentially life-threatening complications. These systems enhance tip detection accuracy through a multi-stage framework that processes imaging data, addresses challenges such as multiple fragments in catheter line prediction, and expedites confirmation of catheter placements, ultimately improving patient safety and care efficiency [16, 13]. The MFCN offers a robust framework for improving tip detection accuracy, ensuring more reliable clinical outcomes [13]. In pediatric care, automated systems have shown remarkable efficacy in accurately detecting catheters in X-ray images, even when trained on adult data, thus enhancing clinical decision-making by prioritizing images for review and ensuring timely interventions [18]. The integration of these systems into clinical practice underscores their transformative potential in catheter management, enabling accurate monitoring and predictive capabilities that significantly reduce risks associated with catheter misplacement [16, 18, 17, 12, 13].

### 4.4 Synthetic Data Generation for Risk Assessment

Synthetic data generation has emerged as a transformative approach in enhancing risk assessment models for PICCs by simulating diverse clinical scenarios. This advanced deep learning technique facilitates the creation of extensive and high-quality datasets essential for training predictive models, significantly improving their accuracy and reliability in detecting potential complications associated with PICC use. By employing a multi-stage framework that refines the extraction of PICC lines and accurately localizes tip positions, this method addresses common issues such as tip misplacement, which can lead to serious complications like embolism and cardiac arrhythmias [16, 13]. Synthetic data generation addresses the limitations of real-world data, which often suffers from incompleteness, bias, and limited sample sizes. By simulating various clinical conditions and patient profiles, synthetic datasets enable the development of more generalized and adaptable risk assessment models. These predictive models can accurately forecast complications associated with PICCs, such as catheter-related infections and venous thrombosis, by effectively localizing catheter tip positions and analyzing the catheter-to-vein ratio, thereby enhancing patient safety and clinical outcomes [8, 15, 13, 14]. Moreover, synthetic data facilitates exploration of new catheter materials and development of clinical practice guidelines tailored to different medical contexts, aiding in reducing complications and supporting the implementation of innovative solutions in catheter technology [9]. The integration of synthetic data into risk assessment strategies underscores the potential for continuous improvement in managing PICC-related complications, paving the way for more effective and personalized patient care.

| Feature | Deep Learning Models for Catheter Detection and Segmentation | Logistic Regression and Statistical Approaches | Automated Systems for Complication Prevention |
|---|---|---|---|
| **Technique Type** | Deep Learning | Statistical Methods | Automated Systems |
| **Clinical Application** | Detection And Segmentation | Risk Prediction | Tip Localization |
| **Data Handling** | Advanced Algorithms | Propensity-score Matching | Multi-stage Framework |

Table 4: This table provides a comparative analysis of various methodologies employed for catheter management, focusing on deep learning models, statistical techniques, and automated systems. It highlights the technique type, clinical application, and data handling approach for each method, illustrating their roles in enhancing catheter detection, segmentation, and complication prevention.

# 5 Risk Assessment Strategies

## 5.1 Clinical Signs as Predictors of Complications

Identifying clinical signs as early predictors of complications associated with peripherally inserted central catheters (PICCs) is crucial for improving patient safety and treatment outcomes. In neonatal care, indicators such as low birth weight and low Apgar scores are significant predictors of PICC-related complications, necessitating vigilant monitoring in this vulnerable group [11]. These early indicators enable timely interventions that can mitigate adverse outcomes.

In intensive care unit (ICU) settings, understanding risk factors and microbiological characteristics related to PICC-associated bloodstream infections (PR-BSI) is essential, given their profound impact on patient outcomes. Key risk factors include the duration of PICC maintenance, insertion site, and patient demographics, notably low birth weight, alongside clinical symptoms like fever and chills. Pathogens such as Enterobacterales and coagulase-negative Staphylococci are commonly implicated, underscoring the need for targeted prevention and management strategies to reduce PR-BSI risks [1, 11, 3]. Although fever and chills are associated with PR-BSI occurrence, their high negative predictive values (NPVs) and low positive predictive values (PPVs) suggest that while their presence may not definitively predict infections, their absence can guide clinical decision-making.

Accurate catheter placement detection is vital for predicting complications from misidentification and malposition. Advanced deep-learning systems have shown promise in predicting PICC tip locations with high precision, achieving a mean predicted location within 3.10 mm of the true position [16]. This technological advancement highlights the potential of integrating machine learning tools in clinical practice to enhance early identification of malpositioned catheters, thereby preventing associated complications.

Catheter-related thrombosis (CRT) often presents asymptomatically, complicating the identification of clinical signs. Benchmarks indicate that catheter removal alone may suffice as treatment without the added risk of anticoagulation in asymptomatic cases [15]. This underscores the importance of clinical guidelines in effectively managing PICC-related complications.

The catheter-to-vein ratio (CVR) significantly impacts thrombosis rates, offering clinicians guidelines for PICC insertions that may reduce these rates and enhance patient safety [14]. Additionally, a comprehensive dataset encompassing patient demographics, PICC characteristics, insertion details, and complication occurrences can further inform clinical practices and improve predictive accuracy [8].

Integrating clinical signs as predictors of PICC-related complications is vital for proactive risk management. By combining traditional clinical indicators with innovative technological solutions, healthcare providers can improve patient outcomes and significantly lower complication risks, as evidenced by studies highlighting factors such as arm selection on complication rates, the comparative effectiveness of totally implantable venous access ports (TIVAPs) versus PICCs, and the efficacy of catheter removal strategies in managing CRT [8, 6, 15].

### 5.2 Role of Healthcare Professionals in Risk Assessment

Healthcare professionals are pivotal in assessing and managing risks associated with peripherally inserted central catheters (PICCs). Their expertise is crucial for early identification of potential complications, implementation of targeted preventive measures, and facilitation of optimal patient outcomes, especially in complex cases involving various comorbidities and treatment requirements. Factors such as arm selection and catheter placement significantly contribute to minimizing risks, including mispositioning and infections, thereby enhancing the effectiveness of intravenous therapies like parenteral nutrition [8, 9, 17, 13, 12].

In neonatal care, healthcare providers must vigilantly monitor for signs of catheter-related bloodstream infections (CRBSIs) and other complications, as these can severely impact this vulnerable population [11]. Proactive identification of risk factors, including low birth weight and specific clinical indicators, enables timely interventions that enhance patient safety.

Moreover, healthcare professionals are instrumental in integrating advanced technologies and prediction models into clinical practice. The application of deep learning systems for catheter detection and segmentation necessitates clinicians' expertise to interpret and act upon the generated data [16]. Leveraging these technological advancements can improve PICC placement accuracy and reduce complications associated with device misidentification and malposition.

The management of CRT further underscores healthcare professionals' critical role in decision-making. Clinicians must evaluate the benefits and risks of catheter removal versus anticoagulation therapy, particularly in high-risk patients such as those with cancer [15]. Their clinical judgment is vital in determining the most appropriate course of action to minimize thrombotic risks while ensuring patient safety.

Active participation of healthcare professionals in assessing and managing risks associated with PICCs is essential for enhancing patient safety and optimizing clinical applications. Recent studies have highlighted the impact of factors such as arm selection on complication rates and the benefits of PICCs in providing long-term intravenous therapy, particularly for critical and oncology patients [8, 9, 12]. Through their expertise and collaboration with interdisciplinary teams, healthcare providers can enhance patient care, reduce complications, and improve the overall efficacy of PICC-related treatments.

### 5.3 Metrics and Statistical Approaches in Risk Assessment

Enhancing risk assessment strategies for peripherally inserted central catheters (PICCs) relies on robust metrics and advanced statistical methodologies, particularly in addressing challenges like high tip mispositioning rates leading to serious complications such as thrombosis and embolism. Recent studies employing deep learning technologies have shown potential for improved PICC tip localization, while adherence to specific catheter-to-vein ratio (CVR) thresholds can further mitigate thrombosis risk, especially in malignancy patients [16, 13, 14]. These methodologies are crucial for understanding factors contributing to complications and for developing interventions that enhance patient safety and treatment efficacy.

A primary challenge in risk assessment is the variability in complication rates reported across studies, complicating decision-making for healthcare providers [7]. This variability necessitates standardized metrics and statistical models to provide a consistent framework for evaluating risk factors and outcomes.

Statistical approaches, such as logistic regression, are commonly used to analyze relationships between patient characteristics, catheter features, and complication likelihood. This method helps identify key predictors for adverse events, enabling clinicians to focus on high-risk patients and implement tailored interventions that enhance safety and treatment outcomes [13, 12]. Additionally, propensity-score matching in statistical analyses aids in controlling confounding variables, allowing clearer comparisons of complication rates across patient populations.

Metrics like CVR are vital for assessing thrombosis risk associated with PICCs. Research indicates that a CVR cut-off of 45

Advanced statistical techniques, including Cox proportional hazards regression and multivariate analysis, assess the interplay between clinical variables and their impact on patient outcomes. These approaches yield insights into factors contributing to complications associated with PICCs, such as arm selection, birth weight, duration of catheter stay, and insertion site, aiding in formulating robust risk assessment models that enhance clinical decision-making and patient care [8, 11, 12, 13].

Integrating metrics and statistical approaches is vital for enhancing the accuracy and reliability of risk assessments in PICC use. By implementing evidence-based methodologies, such as optimal arm selection and tailored management strategies, healthcare providers can improve patient care, minimize complications, and effectively utilize PICCs for long-term intravenous therapies, particularly in vulnerable populations like oncology and hematology patients [8, 15, 9].

## 6 Future Directions and Research Opportunities

### 6.1 Technological Advancements in Catheter Placement

Recent technological advancements have significantly enhanced the safety and precision of peripherally inserted central catheter (PICC) placements, reducing complications and improving patient outcomes. Future research should focus on optimizing PICC applications in parenteral nutrition by addressing tip misplacement and infection risks, while leveraging advanced methodologies like deep learning for improved tip localization and catheter segmentation [17, 16, 13, 12]. The Multi-fragment Complementary Network (MFCN) shows promise in enhancing catheter placement precision through improved tip detection, suggesting further exploration across various catheter types and imaging scenarios [13]. Developing robust algorithms to manage occlusions and enhance spatial consistency could significantly reduce catheter misplacements.

Incorporating advanced imaging techniques and automated systems into clinical workflows is crucial. Enhancing existing systems to identify additional vascular access devices and improving algorithm robustness against false positives could further refine catheter placement accuracy [16]. Exploring new insertion and maintenance protocols, alongside employing diverse catheter types in larger populations, could provide valuable insights into optimizing PICC utilization [12]. Strategies such as limiting PICC lumens and reducing catheter indwelling duration are vital for minimizing infection risks, as highlighted by recent studies [2]. These approaches, coupled with categorizing PICCs as a primary option for intravenous treatments due to their safety and efficacy, underscore the need for ongoing research to enhance catheter technology and clinical practices [9].

Developing comprehensive training programs for healthcare professionals is essential to effectively implement these technological advancements. Emphasizing both technical skills and the psychosocial aspects of patient experiences with PICCs can foster a more holistic approach to catheter management [10].

### 6.2 Clinical Practice and Protocol Development

Establishing clinical practices and protocols is vital for managing PICC-related risks, standardizing care, reducing complications, and optimizing patient outcomes. Implementing evidence-based guidelines that address catheter type selection, insertion techniques, and maintenance procedures is a primary focus [12]. Standardized protocols should prioritize accurate catheter placement and incorporate advanced imaging techniques, such as deep learning-based systems, for precise verification of catheter tip positioning, thereby minimizing complications from misplacement [18, 16, 17, 12, 13]. Integrating deep learning models into clinical workflows can significantly improve catheter placement accuracy and reduce incidents of malposition and misidentification.

Protocols should also emphasize minimizing catheter lumens and reducing indwelling duration to lower catheter-related infection risks [2]. Standardized procedures for catheter maintenance, including regular flushing and dressing changes, are essential for preventing infections and ensuring catheter patency [9]. Adopting multidisciplinary approaches in clinical practice can further enhance PICC risk management. Collaboration among healthcare professionals, including nurses, physicians, and radiologists, is crucial for ensuring comprehensive care and adherence to established protocols.

Training programs addressing both technical skills and the psychosocial aspects of patient experiences with PICCs can contribute to a holistic catheter management approach [10].

Clinical protocol development should be informed by ongoing research and continuous outcome evaluations. By integrating findings from recent randomized controlled trials and adapting to technological advancements, healthcare providers can enhance their practices for PICCs, ultimately leading to improved patient outcomes and a more effective response to the diverse needs of patients, particularly those requiring long-term intravenous therapy [8, 6, 9, 12].

### 6.3 Long-term Outcomes and Patient-Centric Research

Investigating long-term outcomes and integrating patient perspectives are essential for advancing PICC research and application. Understanding the long-term safety and efficacy of PICCs is vital for optimizing patient care, especially across diverse populations. Future prospective studies are necessary to validate existing findings and examine the implications of PICC use over extended periods [5]. This research should address the long-term risks and benefits of PICCs, ensuring the provision of effective and safe vascular access solutions.

Prioritizing patient satisfaction and experiences with PICCs is crucial. Surveys indicate varied patient perspectives, with some appreciating the relief and convenience of PICCs, while others report dissatisfaction due to complications and insufficient professional support [10]. Understanding these perspectives is critical for tailoring interventions to enhance the overall patient experience with PICCs.

Comparative research on totally implantable venous access ports (TIVAP) and PICCs regarding long-term outcomes and patient satisfaction is promising. Future studies should evaluate the costs associated with these devices across different regions and their impact on patient satisfaction and clinical outcomes [6]. Incorporating economic considerations and patient feedback can help healthcare providers make informed decisions aligning clinical efficacy with patient preferences.

Future research should also explore the implementation of infection prevention bundles and ongoing education for healthcare workers to further reduce PICC-related bloodstream infection (PR-BSI) rates [1]. Prospective randomized trials comparing PICC-ports with other vascular access devices are necessary to validate their safety and effectiveness, providing a comprehensive understanding of device performance in various clinical settings [4]. Moreover, interventions to mitigate identified risk factors should be validated across diverse patient populations, ensuring effectiveness and applicability in various clinical scenarios [3]. By focusing on long-term outcomes and integrating patient-centric research, future studies can develop more effective, patient-friendly vascular access solutions, ultimately enhancing care quality for individuals requiring PICCs.

### 6.4 Expanding Applicability and Validation

Expanding the applicability and validation of prediction models and risk assessment tools for PICCs is crucial for optimizing clinical practices and improving patient outcomes. Future research should prioritize prospective studies to validate existing findings and explore the long-term implications of various interventions. In the context of catheter-related thrombosis (CRT) management, studies should focus on validating the efficacy of catheter removal alone, particularly in high-risk populations, to establish its long-term outcomes and potential as a standard treatment approach [15].

Exploring optimal catheter-to-vein ratio (CVR) cut-offs for different patient populations is another critical area for future research. Establishing specific benchmarks for CVR can guide clinical decision-making and mitigate thrombotic complications across diverse clinical settings [14]. Tailoring CVR guidelines to specific demographics can enhance the safety and efficacy of PICC use.

Understanding the long-term implications of complication rates is vital for improving PICC success. Future studies should investigate how variables such as insertion techniques, catheter types, and patient characteristics impact PICC outcomes over extended periods [8]. This research will yield valuable insights into optimizing PICC management strategies and ensuring consistent success across diverse patient populations.

Additionally, expanding the validation of prediction models involves integrating advanced technologies, such as deep learning and synthetic data generation, into risk assessment frameworks.



AI-generated, for reference only.

These tools significantly enhance the predictive accuracy of medical models, enabling healthcare professionals to identify patients at risk of complications associated with PICCs and implement targeted interventions tailored to their needs [12, 13]. By continuously refining prediction models and risk assessment tools, healthcare providers can improve patient care and reduce the incidence of PICC-related complications.

## 7 Conclusion

Peripherally inserted central catheters (PICCs) are indispensable in contemporary healthcare, serving as a cornerstone for secure venous access across various patient demographics, notably in oncology and neonatal settings. While their utility is undeniable, the associated risks, such as catheter-related infections and venous thrombosis, underscore the necessity for robust prediction and risk management frameworks. The integration of sophisticated prediction models and risk assessment strategies is crucial for the early identification of high-risk patients, allowing for the implementation of precise interventions that bolster patient safety and optimize therapeutic outcomes.

Emerging technologies, including deep learning algorithms for catheter detection and segmentation, show promise in enhancing the precision of PICC placement, thereby minimizing complications related to device misidentification and malposition. Statistical techniques such as logistic regression provide a rigorous foundation for evaluating risk factors and clinical outcomes, facilitating the adoption of evidence-based medical practices.

The development of automated systems and the use of synthetic data enhance the predictive accuracy of risk assessment models, offering a flexible and scalable solution to the constraints of conventional data sources. These advancements herald a new era of continuous improvement in the management of PICC-related complications, paving the way for more effective and individualized patient care.

## References


[1] Koko Barrigah-Benissan, Jerome Ory, Claire Simon, Paul Loubet, Aurelie Martin, Jean-Paul Beregi, Jean-Philippe Lavigne, Albert Sotto, and Romaric Larcher. Clinical factors associated with peripherally inserted central catheters (picc) related bloodstream infections: a single centre retrospective cohort. *Antimicrobial Resistance & Infection Control*, 12(1):5, 2023.

[2] Romaric Larcher, Koko Barrigah-Benissan, Jerome Ory, Claire Simon, Jean-Paul Beregi, Jean-Philippe Lavigne, and Albert Sotto. Peripherally inserted central venous catheter (picc) related bloodstream infection in cancer patients treated with chemotherapy compared with noncancer patients: a propensity-score-matched analysis. *Cancers*, 15(12):3253, 2023.

[3] Shumin Zhang, Xiaofeng Sun, and Yan Lei. The microbiological characteristics and risk factors for picc-related bloodstream infections in intensive care unit. *Scientific reports*, 7(1):15074, 2017.

[4] Sergio Bertoglio, Maria Giuseppina Annetta, Fabrizio Brescia, Alessandro Emoli, Fabio Fabiani, Maria Fino, Domenico Merlicco, Andrea Musaro, Marina Orlandi, Laura Parisella, et al. A multicenter retrospective study on 4480 implanted picc-ports: a gavecelt project. *The Journal of Vascular Access*, 24(5):1114–1120, 2023.

[5] Dorothea Mielke, Andrea Wittig, and Ulf Teichgräber. Peripherally inserted central venous catheter (picc) in outpatient and inpatient oncological treatment. *Supportive Care in Cancer*, 28:4753–4760, 2020.

[6] Baiying Liu, Zhiwei Wu, Changwei Lin, Liang Li, and Xuechun Kuang. Applicability of tivap versus picc in non-hematological malignancies patients: a meta-analysis and systematic review. *PLoS One*, 16(8):e0255473, 2021.

[7] Vito Andrea Capozzi, Luciano Monfardini, Giulio Sozzi, Giulia Armano, Diana Butera, Elisa Scarpelli, Giuseppe Barresi, Alessandro Benegiamo, and Roberto Berretta. Peripherally inserted central venous catheters (picc) versus totally implantable venous access device (port) for chemotherapy administration: a meta-analysis on gynecological cancer patients. *Acta Bio Medica: Atenei Parmensis*, 92(5):e2021257, 2021.

[8] France Paquet, Louis-Martin Boucher, David Valenti, and Richard Lindsay. Impact of arm selection on the incidence of picc complications: results of a randomized controlled trial. *The Journal of Vascular Access*, 18(5):408–414, 2017.

[9] Elena Pallejà Gutiérrez, Magdalena López Carranza, and Pedro Luis Jiménez Vilches. Catéteres venosos de inserción periférica (picc): un avance en las terapias intravenosas de larga permanencia. *Nutr Clin Med*, 11(2):114–127, 2017.

[10] Juliana Pereira Machado, Carolina Barbosa Costa Rodrigues, Cássia Carolina da Costa Silva, and Rouver Henrique Gouvêa dos Santos. Experiência do cliente com cateter venoso central de inserção periférica (picc). *Revista Interdisciplinar de Saúde e Educação*, 2(2), 2021.

[11] Yan Hu, Yun Ling, Yingying Ye, Lu Zhang, Xiaojing Xia, Qianwen Jiang, and Fang Sun. Analysis of risk factors of picc-related bloodstream infection in newborns: implications for nursing care. *European Journal of Medical Research*, 26:1–6, 2021.

[12] Cristine Ruviaro de Oliveira et al. Avaliação da utilização de cateter central de inserção periférica (picc) para nutrição parenteral: estudo randomizado. 2017.

[13] Automated precision localization of peripherally inserted central catheter tip through model-agnostic multi-stage networks.

[14] Catheter to vein ratio and risk.

[15] Joseph J Shatzel, Dylan Mart, Jeffrey Y Bien, Ashray Maniar, Sven Olson, Timothy K Liem, and Thomas G DeLoughery. The efficacy and safety of a catheter removal only strategy for the treatment of picc line thrombosis versus standard of care anticoagulation: a retrospective review. *Journal of Thrombosis and Thrombolysis*, 47:585–589, 2019.

[16] Hyunkwang Lee, Mohammad Mansouri, Shahein Tajmir, Michael H Lev, and Synho Do. A deep-learning system for fully-automated peripherally inserted central catheter (picc) tip detection. *Journal of digital imaging*, 31:393–402, 2018.

[17] Francesca Boccardi, Axel Saalbach, Heinrich Schulz, Samuele Salti, and Ilyas Sirazitdinov. Bottom-up instance segmentation of catheters for chest x-rays, 2023.

[18] Xin Yi, Scott Adams, Paul Babyn, and Abdul Elnajmi. Automatic catheter detection in pediatric x-ray images using a scale-recurrent network and synthetic data, 2018.