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Application of the PDCA Cycle for Quality Improvement of Radial Artery Puncture in Critically Ill Emergency Patients

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Abstract

Objective: To investigate the effect of a combined quality improvement intervention based on the Plan-Do-Check-Act (PDCA) cycle on radial artery puncture outcomes in critically ill emergency patients, and to establish a standardized training and quality improvement model adapted for the emergency setting. **Methods:** A retrospective before-after study was conducted. Data were extracted from the electronic medical records and nursing records of the emergency department. A total of 202 critically ill patients who underwent radial artery puncture in January 2024 were consecutively enrolled as the pre-intervention group, in which the traditional palpation method was used. Another 650 patients treated between April and July 2024, following implementation of a PDCA-based combined intervention (including ultrasound-guided training, standardized procedures, senior-nurse support, and post-procedural follow-up), were consecutively assigned to the post-intervention group. Each patient contributed only one procedure to the analysis. The first-attempt success rate, overall success rate, mean number of puncture attempts, complication rate, and procedure duration were compared between groups. **Results:** After the combined intervention, the first-attempt success rate increased from 51.48% to 75.69% ($\chi^2 = 42.36$, $P < 0.001$), the overall success rate rose from 73.44% to 95.07% ($\chi^2 = 102.87$, $P < 0.001$), and the mean number of puncture attempts decreased from 1.86 ± 0.72 to 1.12 ± 0.41 ($t = 15.23$, $P < 0.001$). The complication rate fell from 14.85% to 5.53% ($\chi^2 = 19.64$, $P < 0.001$). The time to first successful puncture shortened from 4.8 ± 2.1 min to 3.2 ± 1.3 min, and total procedure duration decreased from 7.6 ± 3.5 min to 4.1 ± 1.8 min (both $P < 0.001$). Nurse competency scores improved significantly as assessed by paired analysis. All three key indicators met and exceeded the preset targets.

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Conclusions: Application of a PDCA-based combined intervention for quality improvement of radial artery puncture in the emergency department increases the puncture success rate, reduces complications, shortens procedure time, and enhances the overall technical proficiency of nurses. Owing to the before-after study design, the individual contributions of ultrasound guidance, training, and senior-nurse support cannot be isolated. This model is worthy of promotion in emergency departments and similar critical care settings.

Keywords

PDCA Cycle, Radial Artery Puncture, Ultrasound Guidance, Emergency Department, Critically Ill Patients, Quality Improvement

1. Introduction

Radial artery puncture is widely used in emergency resuscitation, both for arterial blood gas sampling and invasive arterial blood pressure monitoring. Puncture success and procedural speed directly determine whether critically ill patients can receive timely assessment and treatment [1]. Emergency patients present with complex clinical profiles—shock, hypotension, obesity, and edema are common, and the radial artery pulse is often difficult to palpate and localize. The first-attempt success rate of the traditional blind palpation method is low, and repeated attempts not only increase patient discomfort but also delay critical rescue time [1]-[3].

The widespread adoption of ultrasound guidance has effectively addressed this issue. Multiple studies have confirmed that ultrasound guidance improves the first-attempt success rate and reduces complications [1] [4]. However, standardized training for arterial catheterization in China still requires improvement. A survey by Yuan *et al.* [5] of intensive care units (ICUs) in 20 tertiary hospitals in Beijing found that 45.2% of peripheral arterial catheters were placed by nurses, but the standardization of procedures and training systems varied considerably across institutions. Wang *et al.* [6] noted a notable gap between current clinical practice and international standards regarding the indications, techniques, and maintenance of peripheral arterial catheterization.

The Plan-Do-Check-Act (PDCA) cycle, a widely used quality management tool, has been extensively applied in nursing. A systematic review and meta-analysis by Gao *et al.* [7] including 14 studies with 1,629 patients found that PDCA cycle nursing management improves nursing satisfaction (OR = 6.57, $P < 0.001$), enhances nursing quality, and improves patients' psychological well-being. Studies by Zhang *et al.* [8], Ma *et al.* [9], and Liu *et al.* [10] have also confirmed the effectiveness of the PDCA model in improving clinical nursing quality and safety outcomes across various nursing settings.

Existing research has primarily focused on ICUs and operating rooms, with relatively few reports of systematic improvement specifically in emergency depart-

ments. The emergency department differs substantially from the ICU: patients arrive in varying clinical states—shocked, agitated, unconscious, or requiring immediate resuscitation, and there is limited time for thorough preparation. Training and procedural approaches established in the ICU cannot be directly transferred to the emergency setting. Therefore, this study applied the PDCA cycle framework to a combined quality improvement intervention for radial artery puncture in critically ill emergency patients, with the aim of developing a quality improvement model adapted to the specific characteristics of the emergency department.

2. Materials and Methods

2.1. Study Population and Data Source

A retrospective before-after study design was employed. Data were extracted from the electronic medical records and nursing procedure records of the emergency department. All eligible patients who underwent radial artery puncture for arterial blood gas analysis or invasive arterial blood pressure monitoring during the study periods were consecutively enrolled. Each patient was included only once in the analysis to ensure independence of observations. A total of 202 patients treated in January 2024 were enrolled as the pre-intervention group, and 650 patients treated between April and July 2024, following implementation of PDCA-based improvement measures, were assigned to the post-intervention group.

Inclusion criteria: 1) age ≥ 18 years; 2) emergency patients requiring radial artery puncture for blood sampling or catheterization; 3) complete clinical and nursing records.

Exclusion criteria: 1) severe coagulation dysfunction; 2) infection or trauma at the puncture site; 3) abnormal Allen test indicating inadequate collateral hand circulation; 4) pregnancy or lactation. Radial artery patency was assessed by palpation of the radial pulse and confirmation of arterial waveform on ultrasound prior to the procedure.

There were no statistically significant between-group differences in baseline characteristics, including age, sex, body mass index (BMI), diagnostic category, or puncture site (all $P > 0.05$), indicating that the two groups were comparable (Table 1).

2.2. Intervention

The pre-intervention group underwent radial artery puncture using the traditional palpation method, performed by nurses based on individual experience without systematic standardized training. The post-intervention group received a combined quality improvement intervention based on the PDCA cycle framework, as described below.

2.2.1. Plan Phase

Current status investigation. All 202 radial artery puncture cases in the department

Table 1. Comparison of baseline characteristics between the two groups.

Characteristic	Pre-intervention (n = 202)	Post-intervention (n = 650)	Statistic	*P* value
Age (years, $\bar{x} \pm s$)	62.3 ± 15.8	61.8 ± 16.2	t = 0.38	>0.05
Sex (male/female, n)	118/84	376/274	$\chi^2 = 0.12$	>0.05
BMI (kg/m^2, $\bar{x} \pm s$)	24.6 ± 3.8	24.3 ± 3.5	t = 1.03	>0.05
APACHE II score ($\bar{x} \pm s$)	18.5 ± 5.2	18.2 ± 4.9	t = 0.76	>0.05
Diagnostic category (n)			$\chi^2 = 0.87$	>0.05
Respiratory failure	78 (38.61%)	248 (38.15%)		
Shock	62 (30.69%)	206 (31.69%)		
Post-cardiac arrest	34 (16.83%)	108 (16.62%)		
Other	28 (13.86%)	88 (13.54%)		
Puncture site (n)			$\chi^2 = 0.05$	>0.05
Left radial artery	92 (45.54%)	298 (45.85%)		
Right radial artery	110 (54.46%)	352 (54.15%)		

from January 2024 were reviewed. The first-attempt success rate was only 51.48% (104/202), the overall success rate was 73.44%, and the complication rate was 14.85%—considerably lower than levels reported in the literature for ultrasound-guided puncture [1].

Root cause analysis. Ninety-eight puncture failure cases from the pre-intervention period were consecutively documented and retrospectively analyzed across multiple dimensions, including nurse seniority, patient vascular condition, operating environment, and equipment preparation. The three leading causes of failure were technical issues (33.67%), poor vascular condition (32.65%), and inadequate arm fixation (12.24%). Using fishbone diagram analysis, contributing factors were categorized into four dimensions: personnel, equipment, environment, and patient.

Root cause verification. Identified causes were classified and statistically analyzed using a Pareto chart. According to the 80/20 rule, the top three root causes were identified: vessel displacement due to insufficient arm extension (28.57%), inaccurate localization (20.41%), and weak radial artery pulse in critically ill patients (20.41%). Together, these three factors accounted for 69.39% of failures and were designated as the primary targets of this quality improvement initiative.

Goal setting. Based on baseline values, evidence from the literature [1] [4], and the actual conditions of the department, the following improvement goals were established: increase the first-attempt success rate from 51.48% to 74.77%, increase the overall success rate from 73.44% to 86.19%, and reduce the complication rate from 14.85% to 5.94%.

2.2.2. Do Phase

Standardized training. Led by the head nurse, a training team consisting of two senior nurses and one ultrasound physician developed a standardized operating procedure based on the Clinical Practice Standards for Adult Arterial Blood Gas Analysis (Second Edition), as interpreted by Jin *et al.* [11], adapted to departmental conditions. The training covered radial artery anatomy, indications and contraindications for puncture, the Allen test, equipment preparation, aseptic technique, and post-procedural care. Training combined theoretical lectures, simulation exercises, and bedside teaching, with a total duration of two weeks.

Anatomical knowledge combined with ultrasound-guided positioning training. Specialized training was conducted using the department's existing ultrasound equipment. Training was not limited to procedural skills; it began with the anatomical course and surrounding structures of the radial artery, then progressed to ultrasound image recognition. In accordance with real-time B-mode ultrasound guidance techniques recommended by the Cochrane systematic review [1], training focused on the short-axis out-of-plane approach and dynamic needle tip positioning (DNTP) [12]-[14]. Nurses first practiced on simulation models, then advanced to bedside operations under supervision.

Senior nurse guidance system. The department established a rapid response mechanism for difficult punctures. When the first puncture attempt failed or high puncture difficulty was anticipated (e.g., in patients with shock and hypotension, agitation and poor cooperation, severe obesity with edema, or cardiopulmonary arrest), the on-duty nurse promptly called a senior nurse to the scene to avoid repeated unsuccessful attempts that would delay rescue. In emergency resuscitation, time is critical; repeated attempts not only increase vascular injury but also waste precious rescue time.

Patient psychological care. Before puncture, the performing nurse briefly explained the purpose, general process, and precautions to the patient to reduce anxiety. Clinically, we observed that greater patient anxiety was associated with a higher probability of radial artery spasm. A study by Deftereos *et al.* [15] also showed that moderate procedural sedation and analgesia can reduce the incidence of radial artery spasm from 8.3% to 2.6%.

Standardized operating procedure (SOP). A standardized operating procedure for radial artery puncture was developed, comprising five steps: 1) pre-procedural assessment—performing the Allen test to assess collateral hand circulation, palpating the radial artery pulse, and assessing the patient's consciousness and cooperation level; 2) equipment and position preparation—preparing all required supplies, positioning the patient's arm in abduction with the wrist dorsiflexed approximately 30˚ on a soft pillow, and performing standard skin disinfection; 3) localization—using ultrasound to identify the radial artery, observe its course and caliber, and mark the puncture point; 4) puncture procedure—using the short-axis out-of-plane approach with real-time ultrasound guidance and DNTP technique; and 5) post-procedural care—appropriate compression hemostasis and fixation.

Post-procedural follow-up. A post-puncture follow-up register was established. The responsible nurse inspected the puncture site at 2 hours and 24 hours after the procedure for hematoma, oozing, infection, upper limb numbness, and other abnormalities. Any abnormal findings were promptly addressed and documented for reporting.

2.2.3. Check Phase

Monthly quality monitoring. Each month, the quality control nurse compiled and analyzed indicators including the first-attempt success rate, overall success rate, and complication rate of radial artery puncture, and plotted trend charts to visually reflect the improvement effect.

Nurse competency assessment. Before and after the intervention, the same 18 participating nurses completed theoretical examinations (full score: 100 points) and practical assessments (full score: 100 points). Comprehensive scores were calculated as 40% theoretical score plus 60% practical score. Pre-post comparisons were performed using paired analysis.

Patient satisfaction survey. A self-designed questionnaire was used to evaluate patients' subjective experience and satisfaction with the puncture procedure.

2.2.4. Act Phase

A monthly quality analysis meeting was held, at which problems identified during the month were collectively discussed. Effective measures were integrated into the standardized operating procedure and formalized as departmental policies. Unresolved issues were carried forward to the next PDCA cycle for further improvement. For example, during the early implementation phase, we found that some junior nurses had insufficient proficiency in ultrasound image recognition; accordingly, additional ultrasound image recognition workshops were added.

2.3. Outcome Measures

Outcome measures included: 1) first-attempt success rate, defined as the percentage of cases with successful puncture on the first needle insertion; 2) overall success rate, defined as the percentage of ultimately successful puncture cases among all cases; 3) mean number of puncture attempts; 4) complication rate, including hematoma, vasospasm, pseudoaneurysm, local infection, and upper limb numbness, among others; 5) procedure duration, including time to first successful puncture and total procedure time; and 6) nurse theoretical examination and practical assessment scores.

2.4. Statistical Analysis

Data were analyzed using SPSS 26.0 statistical software (IBM Corp., Armonk, NY, USA). Normally distributed continuous variables are expressed as mean ± standard deviation ($\overline{x} \pm s$). Between-group comparisons of patient-level outcomes were performed using the independent-samples t-test. For nurse competency scores measured in the same 18 nurses before and after the intervention, paired-

samples t-tests were used to account for the repeated-measures design. Categorical variables are expressed as numbers and percentages, and between-group comparisons were conducted using the chi-square (χ^2) test. A two-tailed P-value < 0.05 was considered statistically significant.

3. Results

3.1. Baseline Characteristics

No statistically significant between-group differences were found in age, sex, BMI, diagnostic category, or puncture site (all $P > 0.05$), confirming that the groups were comparable (Table 1).

3.2. Monthly Trend of First-Attempt Success Rate

From April to July 2024, the monthly first-attempt success rate increased progressively: 66.9% in April (107/160), 73.5% in May (119/162), 77.7% in June (129/166), and 84.6% in July (137/162). Among the total of 650 cases, 492 were successful on the first attempt, yielding an overall first-attempt success rate of 75.69%.

3.3. Puncture Outcomes

Following the intervention, both the first-attempt success rate and the overall success rate were higher than at baseline, and the mean number of puncture attempts was reduced. All differences were statistically significant ($P < 0.001$) (Table 2).

Table 2. Comparison of puncture outcomes between the two groups.

Outcome measure	Pre-intervention (n = 202)	Post-intervention (n = 650)	Statistic	*P* value
First-attempt success [n (%)]	104 (51.48)	492 (75.69)	$\chi^2 = 42.36$	<0.001
Overall success [n (%)]	148 (73.44)	618 (95.07)	$\chi^2 = 102.87$	<0.001
Mean no. of attempts ($\bar{x} \pm s$)	1.86 ± 0.72	1.12 ± 0.41	t = 15.23	<0.001

3.4. Complications

Thirty patients in the pre-intervention group developed complications, yielding a complication rate of 14.85%; these included 12 cases of hematoma, 8 of vasospasm, 3 of pseudoaneurysm, 4 of local infection, and 3 of upper limb numbness. In the post-intervention group, 36 patients developed complications, for a rate of 5.53% (36/650). All types of complications decreased, with the most pronounced reductions observed for hematoma (from 5.94% to 0.77%) and vasospasm (from 3.96% to 1.23%). The between-group difference in overall complication rate was statistically significant ($\chi^2 = 19.64$, $P < 0.001$).

3.5. Procedure Duration

Following the intervention, the time to first successful puncture shortened from 4.8 ± 2.1 min to 3.2 ± 1.3 min, and total procedure duration decreased from 7.6 ±

3.5 min to 4.1 ± 1.8 min. Both differences were statistically significant ($P < 0.001$).

3.6. Nurse Competency Scores

The theoretical, practical, and comprehensive scores of the 18 participating nurses all improved after the intervention as assessed by paired-samples t-tests (all $P < 0.001$). Theoretical scores increased from 72.3 ± 9.1 to 89.5 ± 5.4 points, practical scores from 65.8 ± 10.2 to 92.1 ± 3.8 points, and comprehensive scores from 67.1 ± 8.6 to 90.7 ± 4.2 points.

3.7. Achievement of Key Indicators

All three key indicators met and exceeded the preset target values (Table 3).

Table 3. Achievement of key quality improvement indicators.

Indicator	Pre-intervention	Post-intervention	Target value	Target met
First-attempt success rate (%)	51.48	75.69	74.77	Yes
Overall success rate (%)	73.44	95.07	86.19	Yes
Complication rate (%)	14.85	5.53	5.94	Yes

4. Discussion

4.1. Effect of the PDCA-Based Combined Intervention on Puncture Success

Following implementation of the PDCA-based combined quality improvement intervention, the first-attempt success rate of radial artery puncture in critically ill emergency patients increased from 51.48% to 75.69%, and the overall success rate rose from 73.44% to 95.07%. All three core indicators met and exceeded the preset targets. The magnitude of improvement is consistent with findings of similar studies conducted in China and internationally [1] [16], but the more complex clinical profiles of emergency patients and the limited time available for procedures make this improvement particularly notable in the emergency setting.

Monthly data showed that the first-attempt success rate rose gradually from 66.9% in April to 84.6% in July, demonstrating a progressive upward trend consistent with the advancement of training and the gradual improvement of nurses' technical proficiency—reflecting the continuous improvement characteristic inherent in the PDCA cycle [7]-[10]. By July, the rate of increase had notably slowed and entered a plateau phase, suggesting that further improvement relying solely on the existing training model would be limited. The next quality improvement cycle may need to explore new technical approaches or targeted enhancement programs for high-difficulty cases.

4.2. Effect of Ultrasound-Guided Training on Puncture Accuracy

The training model combining anatomical knowledge with ultrasound-guided

positioning enabled nurses to correlate ultrasound images with the anatomical course and surrounding structures of the radial artery, establishing a three-dimensional understanding that improves image recognition and needle placement accuracy. Training focused on the short-axis out-of-plane approach and DNTP technique, consistent with recommendations from Cochrane evidence and clinical guidelines [1] [11] [16]. A recent randomized controlled trial by Mao *et al.* [14] also demonstrated that the DNTP technique may improve the first-attempt success rate in short-axis ultrasound-guided radial artery cannulation.

To address the root cause of "vessel displacement due to insufficient arm extension", we specified wrist dorsiflexion positioning and arm fixation methods in the SOP. During puncture, the vessel remains relatively fixed, reducing needle placement deviations caused by vessel movement. An ultrasound study by Xu *et al.* [17] demonstrated that radial artery spasm and vessel displacement are important anatomical factors in puncture failure, and proper positioning and accurate vessel localization can effectively mitigate their impact.

The advantage of ultrasound guidance is especially pronounced in patients with shock, hypotension, and a non-palpable radial pulse. A review by He *et al.* [3] noted that patients with shock and hypotension represent a particularly challenging population for radial artery puncture, and ultrasound guidance can significantly improve the puncture success rate in critically ill patients. A randomized controlled trial by Mesa *et al.* [16] showed that the ultrasound-guided DNTP technique achieved a first-attempt success rate of 97.9%, significantly higher than the conventional long-axis in-plane approach (83.3%).

4.3. Reduction in Complications

The complication rate decreased from 14.85% to 5.53%, with reductions observed across all complication types; the most pronounced decreases were for hematoma and vasospasm.

A reduced number of puncture attempts is the primary reason for the decrease in complications. Repeated punctures cause mechanical injury to the vascular wall, which is an important trigger for hematoma and vasospasm. The Cochrane systematic review showed that ultrasound guidance reduces the incidence of severe hematoma by 65% (relative risk = 0.35) [1]; Sandoval *et al.* [18] also noted in their review that the number of puncture attempts is an important risk factor for radial artery complications.

Implementation of the post-procedural follow-up system provided assurance for complication prevention and control. In their interpretation of the Clinical Practice Standards for Adult Arterial Blood Gas Analysis (Second Edition), Jin *et al.* [11] pointed out that after arterial blood sampling, the puncture site should be observed for complications such as bleeding and hematoma. The 2-hour and 24-hour follow-up mechanism established in this study is consistent with this standard and facilitates early detection and timely intervention for complications.

4.4. Training System Development and Study Limitations

After two weeks of systematic training, the theoretical, practical, and comprehensive scores of the 18 participating nurses all improved significantly, with the largest increase observed in practical scores (from 65.8 ± 10.2 to 92.1 ± 3.8 points), as confirmed by paired-samples analysis. This indicates that standardized training and ultrasound technology teaching are effective. A notable outcome of this project was the establishment of a departmental puncture training system—new staff receive basic training, key staff receive advanced ultrasound training, and the senior nurse guidance mechanism ensures technical backup for difficult cases.

The senior nurse guidance system provides technical support for junior nurses, ensuring patient safety while promoting the professional growth of younger staff. Liu *et al.* [19] reported that standardized nursing coordination helps improve the success rate of ultrasound-guided radial artery puncture and reduces complications, which is consistent with our practical experience.

This study has several limitations. First, it was a single-center study with a limited sample size; therefore, the results should be extrapolated with caution. Second, the before-after study design cannot isolate the individual contributions of each component of the combined intervention—including ultrasound guidance, standardized training, the senior-nurse support system, and the PDCA management framework—from other temporal changes. Third, subgroup comparisons of different puncture techniques (long-axis in-plane versus short-axis out-of-plane) were not performed. Future studies could employ multicenter randomized designs and compare the clinical effectiveness of different ultrasound-guided techniques.

5. Conclusion

In summary, a combined quality improvement intervention based on the PDCA cycle framework, adapted to the specific characteristics of the emergency department, can increase first-attempt and overall puncture success rates, reduce complication rates, shorten procedure time, and improve the technical proficiency of emergency nurses. The "layered training + rapid response + continuous improvement" management model established in this study can serve as a reference for emergency departments in similar hospitals. However, due to the before-after study design, the specific contribution of each intervention component cannot be determined, and further validation through multicenter randomized studies and exploration of long-term sustainability are needed.

Author Contributions

Bo Hu and Dan Shou contributed to the conceptualization and design of the study. Bo Hu, Yatong Liu, Jindan Huang, Qian Luo, Xiaotong Duan, Liping Yang, Hong Shu and Xiaofang Zhu contributed to the acquisition, analysis and interpretation of the data. Bo Hu drafted the manuscript. Dan Shou critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript and agree to be accountable for all aspects of the work.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Flumignan, R.L., Trevisani, V.F., Lopes, R.D., Baptista-Silva, J.C., Flumignan, C.D. and Nakano, L.C. (2021) Ultrasound Guidance for Arterial (Other than Femoral) Catheterisation in Adults. *Cochrane Database of Systematic Reviews*, **6**, CD013585. https://doi.org/10.1002/14651858.cd013585.pub2

[2] Shiloh, A.L., Savel, R.H., Paulin, L.M. and Eisen, L.A. (2011) Ultrasound-Guided Catheterization of the Radial Artery: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. *Chest*, **139**, 524-529. https://doi.org/10.1378/chest.10-0919

[3] He, J., Liu, X., Zhuang, S. and Xiao, Q. (2025) Techniques for Improvement of Success Rate in Ultrasound-Guided Radial Artery Catheterization: A Narrative Review. *Journal of Anesthesia, Analgesia and Critical Care*, **5**, Article No. 89. https://doi.org/10.1186/s44158-025-00289-0

[4] Levin, P.D., Sheinin, O. and Gozal, Y. (2003) Use of Ultrasound Guidance in the Insertion of Radial Artery Catheters. *Critical Care Medicine*, **31**, 481-484. https://doi.org/10.1097/01.ccm.0000050452.17304.2f

[5] Yuan, C., Xiao, Y.Y., Wang, Y., *et al.* (2021) Investigation on Peripheral Arterial Catheterization and Maintenance in ICU Patients in Tertiary Hospitals in Beijing. *Chinese Journal of Nursing*, **56**, 861-866. (In Chinese)

[6] Wang, Y., Han, L., Yuan, C., *et al.* (2020) Summary of Best Evidence for Peripheral Arterial Catheterization and Maintenance in Adult ICU Patients. *Chinese Journal of Nursing*, **55**, 600-606. (In Chinese)

[7] Gao, Y., Chen, X. and Kang, L. (2021) The Effect of Plan-Do-Check-Act Cycle Nursing Management of Gynecological Surgery: A Systematic Review and Meta-Analysis. *Annals of Palliative Medicine*, **10**, 8072-8081. https://doi.org/10.21037/apm-21-1590

[8] Zhang, N., Hu, L.H. and Wang, X.W. (2013) Application of PDCA Management Model in Nursing Management of PICC Catheterization of Peripheral Vessels in Oncology Department. *Chinese Journal of Practical Nursing*, **29**, 73-74. (In Chinese)

[9] Ma, Y. and Wang, B.Y. (2016) Effect of PDCA Nursing Management on PICC Catheterization in Elderly Patients with Malignant Tumors. *Chinese Journal of Modern Nursing*, **22**, 3961-3964. (In Chinese)

[10] Liu, H., Wang, X.L., Ma, Y.P., Liu, J., Wang, W., Li, Z., *et al.* (2025) Application of PDCA Cycle Management in Outpatient Nursing Management under the Background of New Quality Productive Forces. *Chinese Journal of Integrative Nursing*, **11**, 126-132. https://doi.org/10.55111/j.issn2709-1961.20241204002

[11] Jin, Y.H., Sun, H., Li, C.Y., *et al.* (2022) Interpretation of Clinical Practice Standards for Adult Arterial Blood Gas Analysis (Second Edition). *Chinese Nursing Management*, **22**, 1601-1606. (In Chinese)

[12] Purohit, A., Kumar, N., Bindra, A., Goyal, K. and Pathak, S. (2025) Comparison between Ultrasound-Guided Dynamic Needle Tip Positioning and Palpation Technique for Radial Artery Cannulation: Systematic Review and Meta-Analysis. *Indian Journal of Anaesthesia*, **69**, 1284-1293. https://doi.org/10.4103/ija.ija_715_25

[13] Takeshita, J., Yoshida, T., Nakajima, Y., Nakayama, Y., Nishiyama, K., Ito, Y., *et al.*

(2019) Dynamic Needle Tip Positioning for Ultrasound-Guided Arterial Catheterization in Infants and Small Children with Deep Arteries: A Randomized Controlled Trial. *Journal of Cardiothoracic and Vascular Anesthesia*, **33**, 1919-1925. https://doi.org/10.1053/j.jvca.2018.12.002

[14] Mao, K., Cai, M., Liang, J., Yang, G., Ye, Y., Lin, J., *et al.* (2026) Dynamic Needle Tip Positioning May Improve First-Attempt Success Rate in Short-Axis Radial Artery Cannulation: A Systematic Review and Meta-Analysis of Randomized Trials. *Journal of International Medical Research*, **54**, No. 6. https://doi.org/10.1177/03000605261452964

[15] Deftereos, S., Giannopoulos, G., Raisakis, K., Hahalis, G., Kaoukis, A., Kossyvakis, C., *et al.* (2013) Moderate Procedural Sedation and Opioid Analgesia during Transradial Coronary Interventions to Prevent Spasm. *JACC*: *Cardiovascular Interventions*, **6**, 267-273. https://doi.org/10.1016/j.jcin.2012.11.005

[16] Mesa, B.K., Sinha, M., Kumar, M., Ramchandani, S., Dey, C., Agrawal, N., *et al.* (2024) Radial Arterial Cannulation by Ultrasound-Guided Dynamic Needle-Tip Positioning Using the Short-Axis Out-of-Plane Approach versus the Long-Axis In-Plane Approach: A Randomized Controlled Study. *Cureus*, **16**, e54183. https://doi.org/10.7759/cureus.54183

[17] Xu, Y., Kong, L.Q., Liu, L., *et al.* (2013) Ultrasonographic Study on Imaging Characteristics of Radial Artery Spasm during Puncture and Catheterization. *Chinese Journal of Laboratory Diagnosis*, **17**, 1451-1454. (In Chinese)

[18] Sandoval, Y., Bell, M.R. and Gulati, R. (2019) Transradial Artery Access Complications. *Circulation*: *Cardiovascular Interventions*, **12**, e007386. https://doi.org/10.1161/circinterventions.119.007386

[19] Liu, X., Hu, M., Li, J., *et al.* (2023) Nursing Coordination in Palm-Held Wireless Ultra-Sound-Guided Radial Artery Puncture and Catheterization. *Journal of Nursing Sciences*, **38**, 44-46. (In Chinese)