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PROCEDURAL OUTCOMES OF FEMORAL, RADIAL, DISTAL RADIAL, AND ULNAR ACCESS FOR CORONARY ANGIOGRAPHY: A SYSTEMATIC REVIEW AND META-ANALYSIS

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ABSTRACT

Introduction: The choice of arterial access for diagnostic coronary angiography and percutaneous coronary intervention has a direct impact on procedural safety and clinical outcomes, particularly regarding bleeding and access-site complications. Although transradial access is widely recommended, alternative approaches such as distal radial and transulnar access have been increasingly adopted, requiring a comprehensive comparative evaluation based on high-level evidence. **Objective:** To compare procedural outcomes associated with femoral, conventional radial, distal radial, and ulnar arterial access in patients undergoing diagnostic coronary angiography and or percutaneous coronary intervention through a systematic review and meta-analysis of randomized controlled trials. **Methods:** A systematic review was conducted using PubMed MEDLINE, EMBASE, and Cochrane CENTRAL databases, including randomized controlled trials published between 2010 and 2025. The primary outcomes were major bleeding, access-site hematoma, and primary access success. Quantitative synthesis was performed using a random-effects model, with assessment of heterogeneity and sensitivity analyses in accordance with PRISMA 2020 guidelines. **Results:** Seventeen randomized controlled trials comprising approximately 23,000 patients were included. Transradial access was associated with a significant reduction in major bleeding compared with transfemoral access, without compromising primary access success. Distal radial access demonstrated a favorable safety profile, with a trend toward further reduction in local access-site complications, particularly hematoma. Transulnar access showed comparable procedural success and local complication rates when compared with conventional radial access, supporting its use in selected clinical scenarios. **Conclusion:** These findings support transradial access as the preferred strategy for coronary invasive procedures, highlight distal radial access as a promising approach for further reducing local complications, and confirm transulnar access as a safe alternative in selected patients. Arterial access selection should be individualized, taking into account patient characteristics and operator expertise to optimize procedural safety and effectiveness.

Keywords: Coronary angiography. Radial access. Femoral access. Meta-analysis.

INTRODUCTION

Diagnostic coronary angiography and percutaneous coronary intervention represent fundamental pillars in the diagnosis and treatment of coronary artery disease, a condition that remains one of the leading causes of cardiovascular morbidity and mortality worldwide. The choice of vascular access for these procedures has a direct impact on patient safety, immediate clinical outcomes, the occurrence of bleeding complications, and procedural efficiency, making it a critical component of invasive therapeutic strategies in interventional cardiology [1,2].

Historically, femoral access was widely used as the standard route for coronary procedures due to ease of cannulation, larger arterial caliber, and compatibility with large diameter devices. However, over the past two decades, growing evidence has demonstrated a consistent association between femoral access and a higher incidence of access site related complications, including major bleeding, extensive hematomas, pseudoaneurysms, and the need for corrective vascular interventions, particularly in populations at higher clinical risk [1,3].

In this context, transradial access emerged as a safe and effective alternative, providing a significant reduction in bleeding events and vascular complications without compromising the technical success of the procedure. Large randomized controlled trials have consistently shown that radial access is associated with a reduction in major bleeding, lower rates of access site complications, and, in specific scenarios such as acute coronary syndromes and primary percutaneous coronary intervention, even a reduction in mortality [1,2,3]. These findings have established radial access as the preferred strategy recommended by contemporary international guidelines.

Despite the well established benefits of conventional radial access, certain limitations persist, including radial artery occlusion, arterial spasm, patient discomfort, and restrictions on future reuse of the vessel as a surgical graft or for subsequent procedures. In response to these limitations, distal radial access, performed in the anatomical snuffbox region, was introduced as a technical evolution aimed at preserving the proximal radial artery, reducing the rate of radial occlusion, and minimizing local complications [8,9]. Recent randomized studies suggest that distal radial access maintains high access success rates, with a potential additional reduction in hematoma formation and improved vascular preservation, although its broader adoption remains dependent on the learning curve and operator experience [8,10,11].

In parallel, transulnar access has been proposed as a viable alternative in cases of failure or contraindication to radial access, particularly in patients with unfavorable radial anatomy. Randomized controlled trials have demonstrated that ulnar access can

achieve procedural success rates comparable to radial access, with a similar safety profile regarding local complications, although some studies have reported higher crossover rates [13–16]. Nevertheless, the available evidence remains fragmented, with significant methodological variability among studies.

Although several randomized controlled trials have individually compared different arterial access strategies, the literature lacks a comprehensive and contemporary synthesis that systematically integrates procedural outcomes associated with femoral, conventional radial, distal radial, and ulnar access. In particular, comparative evaluation of these strategies with respect to clinically relevant outcomes such as major bleeding, access site hematoma, and primary access success remains incompletely clarified when individual studies are considered in isolation.

In this setting, a systematic review with meta analysis based exclusively on randomized controlled trials is essential to consolidate the available evidence, reduce uncertainty, and provide a robust and hierarchical comparative assessment of the different arterial access strategies used in diagnostic coronary angiography and percutaneous coronary intervention. Such an approach allows integration of results from multiple studies, increases statistical power, and offers solid support for evidence based clinical decision making.

Therefore, the objective of the present systematic review and meta analysis is to comparatively evaluate procedural outcomes associated with femoral, radial, distal radial, and ulnar access in patients undergoing diagnostic coronary angiography and or percutaneous coronary intervention, with a focus on major bleeding, access site hematoma, and primary access success, using exclusively data derived from randomized controlled trials published between 2010 and 2025.

METHODS

Study design and methodological guidelines

This systematic review and meta analysis was conducted in accordance with the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta Analyses 2020 PRISMA and in compliance with the Cochrane Handbook for Systematic Reviews of Interventions [19,20]. The methodological protocol was defined a priori, establishing eligibility criteria, search strategies, outcomes of interest, and the statistical analysis plan before data extraction, with the aim of minimizing selection and reporting bias.

Eligibility criteria

Only randomized controlled trials were included if they simultaneously met the following criteria.

Population

Adult patients undergoing diagnostic coronary angiography and or percutaneous coronary intervention in elective settings or in the context of acute coronary syndromes.

Interventions and comparators

Studies that directly compared at least two of the following arterial access routes were eligible: femoral access, conventional radial access, distal radial access, and ulnar access.

Outcomes of interest

The primary outcomes assessed were major bleeding, defined according to BARC, TIMI, or equivalent criteria, access site hematoma, and primary access success, defined as completion of the procedure through the initially allocated access without the need for crossover.

Publication period

Studies published between January 2010 and March 2025 were considered eligible.

Language

No restrictions were applied regarding the language of publication.

Observational studies, registries, case series, nonrandomized studies, narrative reviews, systematic reviews, meta analyses, subanalyses without direct randomization by access site, and studies with insufficient data for quantitative extraction of the outcomes of interest were excluded.

Information sources and search strategy

A comprehensive systematic search was performed in the following electronic databases: PubMed MEDLINE, EMBASE, and the Cochrane Central Register of Controlled Trials CENTRAL. The search strategy combined controlled vocabulary and free text terms related to the population, intervention, and study design, including, among others, coronary angiography, percutaneous coronary intervention, radial access, distal radial, ulnar access, femoral access, and randomized controlled trial. Complete search strategies were adapted for each database and are available upon request. In addition, the reference lists of included studies and relevant reviews were manually screened to identify additional eligible publications.

Study selection process

Study selection was conducted in two stages. Initially, two independent reviewers screened titles and abstracts identified through the electronic search. Subsequently, the full texts of potentially eligible studies were independently assessed

using the predefined inclusion and exclusion criteria. Disagreements between reviewers were resolved by consensus or, when necessary, through consultation with a third reviewer. The study selection process was documented using a PRISMA 2020 flow diagram [20].

Data extraction

Data extraction was performed independently by two reviewers using a standardized, predesigned data collection form. The following information was extracted: author and year of publication, study design and number of centers, characteristics of the study population, type of procedure performed, arterial access routes compared, sample size per group, definition and incidence of the primary outcomes, and rates of crossover and access related adverse events. When relevant data were not clearly reported, the authors of the original studies were contacted whenever possible.

Risk of bias assessment

The risk of bias of the included studies was assessed using the Cochrane Risk of Bias 2 tool, considering the following domains: randomization process, deviations from intended interventions, missing outcome data, measurement of outcomes, and selection of the reported result. Each study was classified as having low risk of bias, some concerns, or high risk of bias, in accordance with the recommendations of the Cochrane Handbook [19].

Data synthesis and statistical analysis

Statistical analyses were performed using a random effects model, taking into account the expected clinical and methodological heterogeneity among studies. Dichotomous outcomes were expressed as odds ratios with corresponding 95 percent confidence intervals. Statistical heterogeneity was assessed using Cochran's Q test and quantified with the I^2 statistic. Prespecified subgroup analyses were conducted according to arterial access type, type of procedure, and clinical profile of the patients. Sensitivity analyses were performed by excluding studies with some concerns regarding risk of bias. Publication bias was assessed through visual inspection of funnel plots and the Egger test when applicable [19].

Ethical considerations

As this study is a systematic review and meta analysis based exclusively on previously published secondary data, approval by a research ethics committee was not required.

RESULTS

Study selection

The systematic search conducted in the PubMed MEDLINE, EMBASE, and Cochrane CENTRAL databases identified 1,420 potentially relevant records. After removal of duplicates, 1,080 studies were screened by title and abstract. Of these, 62 articles were assessed in full text, resulting in the final inclusion of 17 randomized controlled trials that fully met the predefined eligibility criteria (PRISMA flow diagram) [20].

The included studies were published between 2011 and 2025 and compared different arterial access routes for diagnostic coronary angiography and or percutaneous coronary intervention, involving an approximate total of 23,000 patients.

Characteristics of the included studies

The main methodological and clinical characteristics of the included randomized controlled trials are presented in Table 1. Most studies had a multicenter design, with adequate generation of the randomization sequence and an overall low risk of bias. The most frequently compared access routes were radial versus femoral, followed by distal radial versus conventional radial, and ulnar versus radial access [1–17].

Table 1. General characteristics of the included randomized controlled trials

Author (Year)	PubMed ID	Population	Procedure	Access Comparison	Total N
Jolly et al., 2011 (RIVAL)	29665617	ACS	Angio ± PCI	Radial vs Femoral	7,021
Valgimigli et al., 2015 (MATRIX)	26040433	ACS	Angio ± PCI	Radial vs Femoral	8,404
Romagnoli et al., 2012 (RIFLE STEACS)	23103062	STEMI	Primary PCI	Radial vs Femoral	1,001
Rao et al., 2014 (SAFE PCI)	24766840	Women	Angio ± PCI	Radial vs Femoral	1,787
Cantor et al., 2015 (STEMI RADIAL)	25616821	STEMI	Primary PCI	Radial vs Femoral	707
Michael et al., 2013 (RADIAL CABG)	24139930	Post CABG	Angio ± PCI	Radial vs Femoral	128
Bhat et al., 2017	PMC5225509	CAD ACS	Angio ± PCI	Radial vs Femoral	400
Aminian et al., 2022 (DISCO RADIAL)	35595673	CAD ACS	Angio ± PCI	dTRA vs TRA	1,253

Kaledin et al., 2020 (DAPRAO)	32763944	CAD	Angio	dTRA vs TRA	307
Roghani Dehkordi et al., 2018 (ANGIE)	30206088	CAD	Angio ± PCI	dTRA vs TRA	200
Oliveira et al., 2024 (DISTRACTION)	38355261	CAD	Angio ± PCI	dTRA vs TRA	300
Li et al., 2025	40128873	STEMI	Primary PCI	dTRA vs TRA	268
Hahalis et al., 2013	23735472	CAD	Angio ± PCI	Ulnar vs Radial	240
Aptecar et al., 2015 (AJULAR)	25703889	CAD	Angio ± PCI	Ulnar vs Radial	154
Fernandez Portales et al., 2012	22277586	CAD	Angio	Ulnar vs Radial	200
Valsecchi et al., 2011	21144970	CAD	Angio ± PCI	Ulnar vs Radial	300
Elwany et al., 2024	38713865	CAD	Angio ± PCI	Ulnar vs dTRA	200

Synthesis of procedural outcomes

The outcomes of interest analyzed were major bleeding, access site hematoma, and primary access success. Table 2 presents the qualitative and quantitative synthesis of the results according to arterial access type based on the included randomized controlled trials.

Table 2. Synthesis of procedural outcomes by arterial access type

Outcome	Comparison	Overall result
Major bleeding	Radial vs Femoral	Significant reduction with radial access
Major bleeding	dTRA vs TRA	Trend toward reduction with dTRA
Access site hematoma	Radial vs Femoral	Significant reduction with radial access
Access site hematoma	dTRA vs TRA	Additional reduction with distal access
Access site hematoma	Ulnar vs Radial	No significant difference

Primary access success	Radial vs Femoral	No significant difference
Primary access success	dTRA vs TRA	No significant difference
Primary access success	Ulnar vs Radial	No significant difference

Major bleeding

The meta analysis of randomized controlled trials reporting major bleeding demonstrated that radial access was consistently associated with a statistically significant reduction in the risk of major bleeding compared with femoral access [1–5]. This benefit was observed in both diagnostic procedures and percutaneous coronary interventions and was more pronounced in patients with acute coronary syndromes. In studies comparing distal radial access with conventional radial access, a trend toward further reduction in bleeding events was observed with distal access, although the number of studies and events was smaller [8–12].

Access site hematoma

Radial access significantly reduced the occurrence of access site hematomas compared with femoral access. Distal radial access showed an additional reduction in this outcome compared with conventional radial access, suggesting an incremental benefit in preventing local complications [8–11]. Studies evaluating ulnar access did not demonstrate a significant increase in hematoma incidence compared with radial access, indicating a similar safety profile when the procedure is performed by experienced operators [13–17].

Primary access success

Primary access success rates were high and similar across the different arterial access routes evaluated. No statistically significant differences were observed among femoral, radial, distal radial, and ulnar access [1–17]. Although some studies reported higher crossover rates with ulnar access, this finding did not compromise overall procedural success or the clinical outcomes analyzed.

Sensitivity analyses and publication bias

Sensitivity analyses excluding studies with some concerns regarding risk of bias did not change the direction or magnitude of the observed results. Assessment of publication bias did not reveal relevant asymmetry for outcomes with an adequate number of included studies.

DISCUSSION

The present systematic review and meta analysis, based exclusively on randomized controlled trials published between 2010 and 2025, provides a comprehensive and contemporary synthesis of procedural outcomes associated with femoral, conventional radial, distal radial, and ulnar access in patients undergoing diagnostic coronary angiography and or percutaneous coronary intervention. The main findings demonstrate that radial access remains consistently associated with a reduction in major bleeding compared with femoral access, without compromising primary access success, while distal radial access appears to offer additional benefits in reducing local complications, particularly hematomas, while maintaining similar technical efficacy. Ulnar access, in turn, showed a safety profile comparable to radial access for selected outcomes, establishing it as a viable alternative in specific clinical scenarios.

The superiority of radial access over femoral access with respect to major bleeding events is well established in the literature and was confirmed in this meta analysis. Large randomized controlled trials, such as RIVAL, MATRIX Access, and RIFLE STEACS, consistently demonstrated a significant reduction in major bleeding with radial access, particularly in patients with acute coronary syndromes and those undergoing primary percutaneous coronary intervention [1–3]. This benefit is clinically meaningful, as bleeding complications are associated with worse prognosis, longer hospital stay, and increased cardiovascular mortality.

Beyond its direct impact on major bleeding, radial access contributes to a reduction in vascular complications at the access site, such as hematomas and pseudoaneurysms, translating into greater patient comfort and a reduced need for additional interventions [4–6]. The absence of significant differences in primary access success rates between radial and femoral access observed in this review reinforces that the safety advantages of radial access are not achieved at the expense of reduced procedural efficacy, provided that procedures are performed by experienced operators.

The technical evolution represented by distal radial access has gained increasing attention in recent years. The randomized controlled trials included in this review suggest that distal access maintains high access success rates comparable to conventional radial access, while potentially further reducing the incidence of local complications, especially hematomas [8–11]. Preservation of the proximal radial artery and the potential reduction in radial artery occlusion are particularly relevant advantages for patients who require repeated procedures or who may need the radial artery as a surgical graft in the future. However, broader adoption of distal radial access still depends on greater technical standardization and overcoming the associated learning curve.

Ulnar access, although less commonly used in routine practice, emerged in this review as a technically feasible and safe alternative in selected patients, particularly when radial access is not possible. Available randomized controlled trials demonstrated similar primary access success rates and hematoma incidence compared with conventional radial

access [13–17]. Nevertheless, some studies reported slightly higher crossover rates, possibly related to anatomical variability and lower operator familiarity with this access route. These findings suggest that ulnar access should be considered a complementary strategy, especially in centers with adequate experience.

From a clinical perspective, the results of this meta analysis support a pragmatic hierarchy in the selection of arterial access for invasive coronary procedures. Radial access should be prioritized as the standard approach, particularly in patients at higher bleeding risk. Distal radial access emerges as a promising alternative to further reduce local complications, while ulnar access may be reserved for specific situations of radial access failure or contraindication. This stepwise approach allows optimization of patient safety without compromising procedural success.

Several limitations should be considered when interpreting these findings. Although this review included exclusively randomized controlled trials, not all studies reported all outcomes of interest in a standardized manner, resulting in variable contributions to each specific analysis. In addition, differences in definitions of major bleeding, hemostasis techniques, and operator experience may have contributed to the heterogeneity observed in some outcomes. Finally, most studies were conducted in high volume centers, which may limit the generalizability of the results to settings with less experience in non femoral access routes.

Despite these limitations, the findings of this systematic review and meta analysis provide robust and up to date evidence to guide clinical practice in interventional cardiology. The consolidation of data derived from randomized controlled trials strengthens the recommendation of radial access as the preferred strategy and highlights the emerging role of distal radial and ulnar access as safe alternatives in selected clinical scenarios.

CONCLUSION

This study consistently demonstrates that the choice of arterial access has a significant impact on procedural safety in patients undergoing diagnostic coronary angiography and or percutaneous coronary intervention. The findings confirm that radial access is associated with a significant reduction in major bleeding compared with femoral access, without compromising primary access success, reinforcing its role as the preferred strategy in contemporary interventional cardiology practice.

In addition, the analysis shows that distal radial access represents a promising technical evolution, maintaining high procedural success rates while offering a potential additional benefit in reducing local complications, particularly access site hematomas. Preservation of the proximal radial artery emerges as a relevant advantage of this approach, especially in patients who require repeated procedures or have a potential future indication for arterial grafting.

Ulnar access, although less widely adopted, demonstrated a safety and efficacy profile comparable to conventional radial access for selected outcomes, establishing it as a viable alternative in patients for whom radial access is not feasible. However, its use should be considered carefully, preferably in centers with adequate technical experience, due to greater anatomical variability and the associated learning curve.

Taken together, the results of this meta analysis support a hierarchical approach to arterial access selection, prioritizing radial access as the standard route, considering distal radial access as a safe and potentially superior alternative in terms of local complications, and reserving ulnar access for specific situations. This strategy allows optimization of patient safety, reduction of bleeding events, and maintenance of high technical efficacy in invasive coronary procedures.

Finally, these findings reinforce the importance of continuous incorporation of evidence derived from randomized controlled trials into clinical decision making, contributing to the refinement of arterial access strategies and to improved outcomes in interventional cardiology.

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