Systematic Review and Cost–Benefit Analysis of Radial Artery Access for Coronary Angiography and Intervention

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Background—Radial artery access for coronary angiography and interventions has been promoted for reducing hemostasis time and vascular complications compared with femoral access, yet it can take longer to perform and is not always successful, leading to concerns about its cost. We report a cost–benefit analysis of radial catheterization based on results from a systematic review of published randomized controlled trials.

Methods and Results—The systematic review added 5 additional randomized controlled trials to a prior review, for a total of 14 studies. Meta-analyses, following Cochrane procedures, suggested that radial catheterization significantly increased catheterization failure (OR, 4.92; 95% CI, 2.69–8.98), but reduced major complications (OR, 0.32; 95% CI, 0.24–0.42), major bleeding (OR, 0.39; 95% CI, 0.27–0.57), and hematoma (OR, 0.36; 95% CI, 0.27–0.48) compared with femoral catheterization. It added approximately 1.4 minutes to procedure time (95% CI, −0.22 to 2.97) and reduced hemostasis time by approximately 13 minutes (95% CI, −2.30 to −23.90). There were no differences in procedure success rates or major adverse cardiovascular events. A stochastic simulation model of per-case costs took into account procedure and hemostasis time, costs of repeating the catheterization at the alternate site if the first catheterization failed, and the inpatient hospital costs associated with complications from the procedure. Using base-case estimates based on our meta-analysis results, we found the radial approach cost $275 (95% CI, −$374 to −$183) less per patient from the hospital perspective. Radial catheterization was favored over femoral catheterization under all conditions tested.

Conclusion—Radial catheterization was favored over femoral catheterization in our cost–benefit analysis. (Circ Cardiovasc Qual Outcomes. 2012;5:454-462.)

Key Words: coronary angiography ■ cost–benefit analysis ■ femoral artery ■ heart catheterization ■ meta-analysis ■ radial artery

There is an increasing interest in the use of radial artery access for coronary angiography and interventions with proponents arguing that the technique is associated with lower rates of bleeding and major vascular complications, improved patient comfort, and shorter times to hemostasis and ambulation than femoral access.

Despite these possible benefits, detractors have pointed to the longer procedure times and access failures associated with radial artery access. As a result, the use of radial access varies widely by practitioner, institution, and region. Radial artery access is the primary mode of access in several European countries, Canada, and Japan at the same time as being used in the minority of catheterizations in the United States.1,2

Using a systematic review of randomized studies comparing radial and femoral artery vascular access, we performed a cost–benefit analysis from the hospital perspective to evaluate whether the reduction in procedure-related complications and reduction in hemostasis times attributable to radial artery catheterization would offset the increased procedure time and failure rate of radial catheterization. This information can then be used to support a local decision to switch to radial catheterization or continue using femoral catheterization.
WHAT IS KNOWN

- In the United States, radial artery catheterization is performed in the minority of diagnostic angiograms and percutaneous coronary interventions.
- Radial artery catheterization can reduce hemostasis time and vascular complications but can take longer to perform and may require conversion to the femoral site.

WHAT THE STUDY ADDS

- Cost savings from reducing complications appear to outweigh additional direct procedure costs of radial catheterization.
- On average, the radial approach saved $275 in direct hospital costs per patient as compared with the femoral approach.
- None of the changes to cost variables brought the net cost savings to a point that would favor femoral catheterization.

Methods

Overview

We updated a previously published systematic review\(^1\) to obtain the most up-to-date probability and cost estimates for our cost–benefit analysis. We then developed a stochastic simulation model to determine the incremental per-case cost of radial versus femoral catheterization. The component costs of radial and femoral catheterization were identified, and the incremental costs were calculated as the product of an estimated unit cost and an estimated frequency at which the cost would be incurred. So for example, the estimated cost per case of procedure time is the per-minute cost of procedure time (C\(_{\text{PT}}\)) multiplied by the procedure time difference between radial and femoral catheterization (T\(_{\text{PT}}\)); and the estimated per-case cost of major bleeding complications is the cost of a major bleed (C\(_{\text{MB}}\)) multiplied by the difference in the probability of a major bleed (P\(_{\text{MB}}\)) between radial and femoral catheterization. The model outcome, the incremental cost of radial versus femoral catheterization, is shown in Equation 1 and the component variables in Table 1.

Equation 1 Incremental cost per case

\[
(C_{\text{PT}} \cdot T_{\text{PT}}) + (C_{\text{MB}} \cdot P_{\text{MB}}) + (C_{\text{CH}} \cdot P_{\text{CH}}) + (C_{\text{Cas}} \cdot P_{\text{Cas}}) + (C_{\text{Ch}} \cdot P_{\text{Ch}})
\]

Systematic Review and Meta-Analysis

To estimate the cost of complications in catheterization procedures and the cost of unsuccessful catheterizations, we first must have evidence-based estimates of rates for these events. A systematic review providing these estimates was published by Jolly et al\(^3\) in 2009. We updated the systematic review and meta-analysis with data published from randomized controlled trials comparing radial and femoral catheterization.

Our review followed procedures set out in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement. Systematic searches of the Medline, EMBASE, and Cochrane Central Register of Controlled Trials (CENTRAL) databases were carried out in May 2011. Search strategies combined various indexing terms for coronary angiography and percutaneous coronary intervention (PCI) using an OR statement and then combined those results with a term for the radial artery. The Medline search was limited to articles published since 2008.

Studies were included in the review if they assigned patients to catheterization groups randomly and reported any of the outcomes of interest and included data from at least 25 patients per group. Studies were excluded if they selected for specific patient subgroups, because their results might not be representative of the whole. We did not exclude articles from consideration on the basis of language.

The literature searches yielded a total of 566 hits, which was reduced to 43 after screening of titles and abstracts and then reduced to 25 after elimination of duplicate records. All articles under consideration were successfully retrieved, and 5 met inclusion criteria. These were added to the 9 randomized controlled trials cited by Jolly to yield a total of 14 studies included in the meta-analyses (Figure 1). We assessed the quality of each included trial using a 9-point scale based on scales from Jadad\(^8\) and Chalmers\(^9\) (online-only Data Supplement Table I). The overall quality of the evidence base for each outcome of interest was assessed using the GRADE system\(^10-12\).

Meta-analyses were performed using Cochrane methods and RevMan Version 5.1 software. For dichotomous outcome variables such as complication rates, summary ORs and CIs were calculated. For continuous variables such as procedure time, we analyzed mean differences between radial and femoral groups. All analyses used fixed-effects models as the default; significant heterogeneity across studies was detected. Thresholds for use of random-effects methods were conservative: significant heterogeneity was defined as a Q statistic with a probability value <0.1 or an I\(^2\) statistic >50%.

Predefined variables for subgroup analysis included year of publication (before or since 2008), quality rating (≥5), use of closure devices in femoral catheterization (all or some patients versus no use), and trials involving only those undergoing PCI. We also tested the robustness of the conclusions by eliminating individual studies from the meta-analyses to determine if our conclusions were sensitive to an individual study.

Cost–Benefit Model

The stochastic simulation model was developed in TreeAge Pro 2009 (TreeAge Software Inc, Williamstown, MA) and Table 1 displays its inputs. Each patient entering the model had a risk of complications from their catheterization depending on location (radial or femoral). The analysis was from the hospital perspective and included the costs of catheterization laboratory and recovery room equipment and staffing (per minute), cost of a replacement catheter needed in the event access from the initial site failed, and the cost of added hospital stay, diagnosis, and treatment resulting from procedure complications. Input data for costs including those for C\(_{\text{CH}}\), hemostasis time in the recovery room (C\(_{\text{Recovery}}\)), and cost of supplies needed for catheterization at the alternate site (C\(_{\text{Al}}\)) were obtained from our local hospitals. These costs were in agreement with results of the Family-Mediated Exercise Intervention (FAME) trial,\(^4\) a large-scale multicenter clinical trial of coronary artery catheterization and stenting. We found estimates for complication costs (C\(_{\text{Cas}}\), C\(_{\text{Ch}}\), C\(_{\text{MB}}\), and C\(_{\text{Recovery}}\)) in studies identified in our meta-analysis of procedure times and risks and in a supplemental systematic Medline search limited to economic studies of coronary catheterization procedures published in English since 2007. These cost estimates include periprocedure costs as well as costs of extended hospital stays, tests, and treatments associated with complications.

The systematic review yielded meta-estimates for T\(_{\text{PT}}\) and T\(_{\text{CH}}\); the differences in minutes for procedure time and hemostasis time, respectively, for radial catheterization versus femoral catheterization. It also provided summary risk ratios and CIs comparing probability variables P\(_{\text{CH}}\): the access success rate at radial and femoral sites and P\(_{\text{CAS}}\), P\(_{\text{CH}}\), and P\(_{\text{MB}}\): the risk of minor complications, hemotoma, vascular complications, and major bleeding, respectively. These risk ratios were applied as multipliers on the baseline probabilities of each type of femoral access complication to determine the corresponding probabilities of complications from radial access (Table 1).

Each simulation sent 1000 patients through the model 1000 times for a total of one million trials with unique outcomes to calculate the incremental cost per case. Monte Carlo probabilistic sensitivity analyses simultaneously varied the time and complication probability

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variables throughout the ranges listed in Table 1 (CIs on the meta-analysis results were used as the range). In addition, one-way sensitivity analyses varied the cost of complications ($C_{mc}$, $C_h$, $C_{vc}$, and $C_{mb}$) and procedure costs ($C_{pt}$, $C_h$, and $C_{as}$) to determine the effect of each of these cost estimates on the incremental cost.

We used the mean cost across the studies as our baseline for each complication cost variable and the maximum and minimum costs as the range for sensitivity analysis (Table 1). Because only one trial reported specific costs of hematomas, $^6$ we multiplied and divided that cost by 2 to create a high and low range, respectively, for sensitivity analysis. For the procedure time cost and hemostasis time cost variables, we had to select arbitrary ranges for sensitivity analysis, ensuring we had at least a factor of 2 difference between baseline values and each extreme.

Results

Systematic Review and Meta-Analysis

Nine randomized controlled trials were included in Jolly’s previous meta-analysis. Our systematic searches for additional trials (see PRISMA flow diagram, Figure 1) yielded 5 additional trials meeting the inclusion criteria for a total of 14. The trials are described in Table 2. Not all of the trials reported every outcome under consideration, and definitions of bleeding and other complications varied from trial to trial.

Most trials, particularly the recent ones, combined patients undergoing purely diagnostic catheterization with those having PCI. Published results did not report outcomes separately in diagnostic and interventional procedures. Where femoral closure devices were included in study protocols, their use was usually at the discretion of the cardiologist performing the procedure, and outcomes were not separately reported for cases with and without the devices. The one exception was Reddy’s study $^{21}$ where patients were randomized in 3 groups: radial catheterization, femoral catheterization with closure device, and femoral catheterization without closure device. However, results of that study were confounded by differences in the catheters used for the closure device and control patients.

Catheterization, Procedure Success, and Cardiovascular Events

Detailed results of our meta-analyses are presented in the online-only Data Supplement, whereas the results are
summarized in Table 3. Meta-analysis of catheterization success rates (online-only Data Supplement Figure IA) found that patients randomized to radial catheterization were 5 times more likely to need conversion to the other access site than patients randomized to femoral catheterization (summary OR, 4.92; 95% CI, 2.69–8.98). However, the higher failure rate for initial catheterization did not affect overall success rates for the diagnostic or interventional procedure (OR, 1.03; 95% CI, 0.93–1.13; online-only Data Supplement Figure IB). Major adverse cardiovascular events also did not differ between radial and femoral catheterization groups (online-only Data Supplement Figure II).

Complications
Although definitions of “major complications” varied from study to study, and some included bleeding or hematoma in their figure for major complications, the meta-analyses showed remarkable consistency in the relative complication risks of radial and femoral catheterization (online-only Data Supplement Figure III). Complication rates were reduced 60% to 70% with radial catheterization compared with femoral catheterization, and the risk reduction had high statistical significance. We could not meta-analyze results for minor complication rates because one of the included studies reported only the percentage reduction and not the absolute number of minor complications in each group (it did report absolute numbers for the other types of complications). Therefore, to be conservative in our estimate of the safety benefits of radial catheterization, we chose the smallest summary effect size result from the other meta-analyses to use in the cost–benefit analysis for minor complications.

Although significant heterogeneity was found in some of the variables meta-analyzed, the meta-analysis results were robust. None of our subgroup analyses, selecting more recent trials, higher-quality trials, trials involving only patients undergoing PCI, or trials where femoral closure devices were used made any substantive changes in conclusions. In addition, none of the conclusions were dependent on a single trial.

Time-Related Variables
Many of the clinical trials reported mean times for completing the catheterization procedure as well as fluoroscopy time. Our meta-analysis (online-only Data Supplement Figure IV) found a trend toward longer procedure times with the radial approach, but the statistical significance ($P=0.09$) did not reach the standard threshold. However, the time difference was significant for fluoroscopy, supporting a hypothesis that the observed effect for procedure time is real and not a chance finding. Because the time results favor femoral catheterization, we presumed for the sake of our cost model that there was a real time cost for the radial approach.

Meta-analysis of hemostasis time data found a significant reduction in time with radial catheterization, although we are less certain of the magnitude of the effect due to heterogeneity of the study results.

Cost–Benefit Analysis
Using baseline figures for the costs of catheterization (Table 1), we estimated net hospital cost savings of $275
(95% CI, −$374 to −$183; negative values imply cost savings) per patient using radial catheterization instead of femoral catheterization. The large cost savings was driven primarily by complication costs because the procedure costs of radial catheterization were on average $1.52 (95% CI, $0.52–$2.56) more than procedure costs of femoral catheterization.

Figure 2 shows the results of our sensitivity analysis. None of the changes to the input variables tipped the balance of costs in favor of femoral catheterization (ie, all 95% CIs were negative, implying cost savings for radial catheterization).

Figure 3 shows the sensitivity of the net cost difference to changes in the time it takes to perform a radial catheterization. Our meta-analysis of clinical trials found that on average, the radial procedure takes 1.4 minutes longer than the femoral procedure (see dotted line in Figure 3). That difference would have to increase to approximately 20 minutes for the added cost of catheterization laboratory time to fully offset the other cost differences and make the overall cost of femoral catheterization less than the cost of radial catheterization.

Similarly, Figure 4 shows the effect of reducing complication rates in femoral catheterization on the net cost results. The left end of the graph represents our baseline rates for each of the 4 complication types modeled. Moving to the right on the x axis simultaneously reduces all 4 rates by the same proportion with no change to the complication rates of radial catheterization. To overturn the finding that radial catheterization is less costly, the rates of all those complications of femoral catheterization would have to be reduced by approximately 60%.

Table 2. Table of Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Quality (0–9)</th>
<th>Patients</th>
<th>Closure Devices for Femoral Group</th>
<th>Major Complication Definition</th>
<th>Major Bleeding Definition</th>
<th>Other Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>†RIVAL, 201113</td>
<td>7</td>
<td>2361</td>
<td>*Some (26%)</td>
<td>Pseudoaneurysm requiring closure, arteriovenous fistula, “large” hematoma, or ischemia requiring surgery (major bleeding reported separately)</td>
<td>Death, transfusion of 2+ units, hypotension requiring inotropes, disability, hemoglobin decreased 5 g/dL, intracranial or intraocular bleed</td>
<td></td>
</tr>
<tr>
<td>Hou, 201014</td>
<td>4</td>
<td>100</td>
<td>None</td>
<td>Reported individually</td>
<td>Hemoglobin decrease ≥2 g/dL or transfusion</td>
<td></td>
</tr>
<tr>
<td>Brueck, 200915</td>
<td>5</td>
<td>654</td>
<td>*Most (93%)</td>
<td>Transfusion, hemoglobin decreased ≥3 g/dL, pseudoaneurysm, hematoma, etc</td>
<td>Hemoglobin decrease &gt;3 g/dL or transfusion</td>
<td></td>
</tr>
<tr>
<td>Santas, 200916</td>
<td>5</td>
<td>533</td>
<td>None</td>
<td>Retropertitoneal bleed, transfusion, hemoglobin decrease ≥5 g/dL, vascular complication requiring surgery</td>
<td>Minor complications: pseudoaneurysm, ischemia hematoma &gt;5 cm</td>
<td></td>
</tr>
<tr>
<td>Achenbach, 200817</td>
<td>4</td>
<td>228</td>
<td>None</td>
<td>Reported individually</td>
<td>Minor complications reported individually</td>
<td></td>
</tr>
<tr>
<td>Lange, 200618</td>
<td>2</td>
<td>195</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td></td>
</tr>
<tr>
<td>†OUTCLAS, 200519</td>
<td>5</td>
<td>644</td>
<td>None</td>
<td>Reported individually</td>
<td>Hemoglobin decrease ≥3 g/dL or transfusion</td>
<td></td>
</tr>
<tr>
<td>OCTOPLUS, 200420</td>
<td>5</td>
<td>193</td>
<td>*Some (7%)</td>
<td>Reported individually</td>
<td>Hemoglobin decrease ≥3 g/dL or transfusion</td>
<td></td>
</tr>
<tr>
<td>Reddy, 200421</td>
<td>4</td>
<td>75</td>
<td>Study variable</td>
<td>Reported individually</td>
<td>Transfusion</td>
<td></td>
</tr>
<tr>
<td>CARAFE, 200122</td>
<td>5</td>
<td>108</td>
<td>Interventional patients only</td>
<td>Reported individually</td>
<td>Transfusion</td>
<td></td>
</tr>
<tr>
<td>†Cooper, 199923</td>
<td>5</td>
<td>200</td>
<td>None</td>
<td>Transfusion, pseudoaneurysm, ischemia</td>
<td>Transfusion</td>
<td>Hematoma defined as any measurable discoloration</td>
</tr>
<tr>
<td>Mann, 199824</td>
<td>3</td>
<td>142</td>
<td>All</td>
<td>Reported individually</td>
<td>Transfusion</td>
<td></td>
</tr>
<tr>
<td>BRAFE, 199725</td>
<td>5</td>
<td>150</td>
<td>All</td>
<td>Reported individually</td>
<td>Not reported</td>
<td></td>
</tr>
<tr>
<td>†ACCESS, 199726</td>
<td>4</td>
<td>900</td>
<td>None</td>
<td>Reported individually</td>
<td>Hemoglobin decrease ≥3 g/dL or transfusion</td>
<td></td>
</tr>
</tbody>
</table>

†RIVAL indicates Radial Versus Femoral Access for Coronary Intervention; OUTCLAS, Outpatient Coronary Low-Profile Angioplasty Study; OCTOPLUS, Comparison of Transradial and Transfemoral Approaches for Coronary Angiography and Angioplasty in Octogenarians; CARAFE, Coronary Angiography Through the Radial or the Femoral Approach; BRAFE, Brachial, Radial, or Femoral Approach for Elective Palmaz-Schatz Stent Implantation; ACCESS, A Randomized Comparison of Percutaneous Transluminal Coronary Angioplasty by the Radial, Brachial and Femoral Approaches.

Quality of articles assessed using modified Jadad scale (see online-only Data Supplement Table I) where scores can range from 0 (lowest quality) to 9 (highest quality).

*Closure devices used at physician’s discretion.
†Authors report funding or sponsorship by device or drug manufacturer.
‡Female patients excluded.
Discussion

Our cost–benefit analysis suggests that radial catheterization lowers hospital costs at the same time that it reduces adverse effects to patients. In addition, none of the changes to cost variables brought the net cost savings to a point that would favor femoral catheterization. Widespread adoption of radial catheterization could result in substantial savings for the US healthcare system given that over one million coronary catheterizations are performed in the United States annually.27,28 Since the first cases were reported in the late 1980s,29 radial artery access for diagnostic coronary angiography and PCI has gained momentum in many hospitals in Europe and Asia.2 Advocates of the radial approach argue that it reduces vascular complications and rates of major bleeding, which has been demonstrated clearly in a recently published large randomized clinical trial: Radial Versus Femoral Access for Coronary Intervention Study (RIVAL).13 In addition, without the need for lengthy postprocedural bedrest, earlier ambulation and therefore discharge are possible, potentially reducing hospital costs and improving patient satisfaction.30 They also report greater patient satisfaction with radial catheterization than with femoral.13,26

In the United States, however, radial artery cases account for <10% of the diagnostic cases and approximately 1% of PCI cases.1 In addition, the radial approach is used less commonly in elderly patients, women, and patients with acute coronary syndromes.1 This discrepancy appears to stem from concerns about increases in procedure time, radiation exposure, and access failure in patients undergoing radial artery catheterization offsetting the benefits of decreased vascular complications. We estimate that the procedure time would need to increase by 20 minutes per case to make a femoral artery access strategy less costly than radial access, whereas our meta-analysis found a difference of only 1 minute 23 seconds between them. There was a small but statistically significant increase in fluoroscopy time associated with radial access, but the increase was <1 minute.

Due to the steeper learning curve for gaining proficiency with the radial approach, we recognize that the benefits we

Table 3. Summary of meta-Analysis Results

<table>
<thead>
<tr>
<th>Outcome</th>
<th>No. of Trials</th>
<th>No. of Patients</th>
<th>Summary OR (95% CI)</th>
<th>Favors</th>
<th>Significance</th>
<th>Effect of Recent Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catheterization failure</td>
<td>12</td>
<td>11273</td>
<td>4.92 (2.69 to 8.98)</td>
<td>Femoral</td>
<td>P&lt;0.001</td>
<td>No change</td>
</tr>
<tr>
<td>Procedure success</td>
<td>11</td>
<td>10579</td>
<td>0.97 (0.89 to 1.07)</td>
<td>No difference</td>
<td>NS</td>
<td>No change</td>
</tr>
<tr>
<td>MACE</td>
<td>11</td>
<td>10531</td>
<td>0.96 (0.77 to 1.21)</td>
<td>Radial</td>
<td>P&lt;0.001</td>
<td>No change</td>
</tr>
<tr>
<td>Major complications</td>
<td>13</td>
<td>11913</td>
<td>0.32 (0.24 to 0.42)</td>
<td>Radial</td>
<td>P&lt;0.001</td>
<td>No change</td>
</tr>
<tr>
<td>Major bleeding</td>
<td>12</td>
<td>10908</td>
<td>0.39 (0.27 to 0.57)</td>
<td>Radial</td>
<td>P&lt;0.001</td>
<td>No change</td>
</tr>
<tr>
<td>Hematoma</td>
<td>10</td>
<td>9661</td>
<td>0.36 (0.27 to 0.48)</td>
<td>Radial</td>
<td>P&lt;0.001</td>
<td>No change</td>
</tr>
<tr>
<td>Minor complications</td>
<td></td>
<td></td>
<td>Insufficient data for meta-analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean Difference, min (95% CI)

| Procedure time         | 9             | 3086            | 1.38 (−0.22 to 2.97) | Femoral    | P=0.09       | More uncertainty          |
| Hemostasis time        | 3             | 1255            | 13.1 (2.3 to 23.9)  | Radial     | P=0.02       | Smaller difference         |

NS indicates nonsignificant; MACE, major adverse cardiovascular events.

Figure 2. Tornado diagram showing the effect of changes in each cost component variable on the net cost savings of radial catheterization as compared with femoral catheterization. Baseline values from our meta-analyses are indicated by the vertical line. None of the changes to the component variables tip the balance of costs in favor of femoral catheterization.
demonstrate may not be observed early as practitioners develop facility with radial arterial access. One trial has shown that procedural time for the radial approach was longer than for the femoral approach at an interim analysis but that at the end of the learning curve, there were no significant differences in procedure time. Performing enough procedures to attain proficiency may pose a practical challenge for many cardiologists in the United States who have been trained to use the femoral artery approach but do not have the opportunity to learn radial arterial access. Nevertheless, our systematic review and meta-analysis indicate that it would be to the benefit of patients for cardiologists to obtain training so they can use the radial approach over the long term.

Our study demonstrated that the savings from reduced vascular complications outweighed the increased costs of longer procedure times and access failure associated with radial artery access by a large margin. Although procedure outcomes as measured by major adverse cardiovascular events were equivalent between the 2 groups, radial artery access was associated with significantly reduced vascular access site complications and bleeding. Despite using procedure times and cost estimates unfavorable to radial artery access, a radial artery strategy was still superior due to the high cost of vascular complications associated with femoral access. Even if the difference in hemostasis time were equivalent between the techniques (such as if a femoral artery closure device were used on every case), the reduction in vascular complications would still make radial access less costly.

The pooled vascular event rate in the patients undergoing femoral access was 3.3% versus 1.0% for radial access. This

![Figure 3](http://circoutcomes.ahajournals.org/)

**Figure 3.** Relationship of procedure time difference between radial and femoral catheterization and cost savings with radial catheterization. The vertical line represents the actual difference in procedure time as determined by the meta-analysis. If radial and femoral procedures take the same time, the model concludes that radial catheterization will be $297 less costly. The cost advantage of radial catheterization disappears only if it takes approximately 20 minutes longer than femoral catheterization.

![Figure 4](http://circoutcomes.ahajournals.org/)

**Figure 4.** Using baseline risks of femoral and radial catheterization from the meta-analyses, radial catheterization saves $275 per patient. Risks of femoral catheterization must be reduced by approximately 60% with no corresponding change to radial risk for the net costs to be equal.
estimation is somewhat higher than the major femoral vascular event rate of 2.1% to 2.8% published in a large clinical registry. In our study, a >60% reduction in all complications of femoral catheterization, with no corresponding reduction in complications of radial catheterization, would be needed to bring the net cost of femoral catheterization to that of radial catheterization. Recent retrospective studies have demonstrated a very low femoral vascular complication rate with the use of an arterial closure device; however, no randomized studies have shown that femoral artery catheterization, with or without a vascular closure device, lower rates of vascular complications compared with radial access. If there were no differences at all between the vascular access site complications of radial versus femoral access, the increased cost for the radial artery strategy would only be $1.18 per patient, primarily due to the cost of access site failure. On the other hand, even if the absolute reduction in the rate of hematomas, major bleeding, and major vascular complications from radial access was only 0.1% for total events, there would still be a $18.07 per-case cost savings from the radial artery access strategy. Therefore, even a slight reduction of vascular complications would result in a cost savings from using a radial artery access strategy.

**Perspective**

It needs to be emphasized that our cost study is analyzed from the hospital perspective, because costs were calculated based on reports of actual hospital expenditures to cover catheterization laboratory time, hospitalization, blood transfusions, and treatment of vascular complications. In particular, we considered major bleeding and vascular complications separately, therefore treating the costs as additive. Although the extra cost to the hospital of a blood transfusion is independent of the cost for prolonged hospitalization, imaging studies, and vascular repair, from the payer’s perspective, a blood transfusion would likely be subsumed under a diagnosis-related group for a patient who undergoes a vascular repair. Because the cost of complications was the primary driver of increased costs of the femoral artery approach, the cost savings of a radial artery strategy to the payer and to society may not be as evident. Importantly, we did not consider the comfort or preference of patients and physicians, which could arguably be the primary reason a particular vascular access site is chosen.

**Limitations**

An important objection to the published literature comparing these access strategies is that many studies evaluate outcomes among operators who are already highly proficient with the procedure. The radial technique has a steeper learning curve than femoral artery access. Failed access and radial artery complications are high early on and decrease as operators became more skilled at the procedure. Furthermore, the patients enrolled in clinical trials comparing these strategies must be suitable candidates for either procedure, which might exclude high-risk patients with complicated access issues. Therefore, our estimates of complication rates, procedure, and recovery times may be vulnerable to a publication bias that favors the radial access strategy. Although one early trial excluded female patients because of their smaller arteries, subsequent trials have included a broad range of patients.

Another limitation is the estimation of costs assigned to clinically significant hematomas, which may necessitate vascular imaging, surgical consultation, possible intervention, and longer hospitalizations. It is unclear whether small- or moderate-sized hematomas that would not necessarily lead to these costly measures were counted in the clinical trials. However, our conclusions are not solely dependent on the cost impact of hematomas. They contribute just $40 to $56 to the $275 per-case savings of radial versus femoral catheterization.

There are complications of radial access that did not factor into our analysis. Radial artery occlusions occur in approximately 5% of radial cases, but it is difficult to attribute a cost to this complication because there may be no immediate consequences. A radial occlusion, however, can limit vascular access and conduits for surgical bypasses, which could significantly affect the kinds of therapies available to patients in the future.

Finally there was significant heterogeneity of study results in some of the meta-analyses used to estimate procedure times and success rates for our cost–benefit analysis (see online-only Data Supplement Figures I and IV). To test whether or not heterogeneity could be driving our conclusions, we excluded the studies most favorable to radial catheterization in analyses with significant heterogeneity (P<0.1 or F ≥50%) and repeated those analyses. The resulting changes to the meta-analytic results were small and did not change our conclusions. For example, excluding the Reddy and Santas trials from the meta-analysis of procedure time (online-only Data Supplement Figure IVA) reduced F from 80% to 6% but raised the summary time difference only from 1.38 minutes to 2.30. That change would reduce the net savings of radial catheterization from $275 to $251. Heterogeneity was not significant in the complication rate differences, which make the largest contribution to cost savings.

**Conclusion**

A strategy of routine radial artery access for coronary angiography is associated with an overall reduction in hospital costs and vascular complications if operators have the proficiency with radial artery access to approximate the outcomes of clinical trials.

**Acknowledgments**

The authors thank Meriem Aberra of UPHS Cardiovascular Services for supplying catheterization lab cost data.

**Source of Funding**

This study was funded under National Institutes of Health/National Center for Research Resources grant RR025015 and the National Institute of General Medical Sciences Models of Infectious Disease Agent Study (MIDAS) grant 1U54GM088491-0109.

**Disclosures**

Dr Don is supported by grant RR025015 from the National Center for Research Resources.


Systematic Review and Cost–Benefit Analysis of Radial Artery Access for Coronary Angiography and Intervention
Matthew D. Mitchell, Jaekyoung A. Hong, Bruce Y. Lee, Craig A. Umscheid, Sarah M. Bartsch and Creighton W. Don

_Circ Cardiovasc Qual Outcomes_. 2012;5:454-462; originally published online June 26, 2012; doi: 10.1161/CIRCOUTCOMES.112.965269
_Circulation: Cardiovascular Quality and Outcomes_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 1941-7705. Online ISSN: 1941-7713

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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http://circoutcomes.ahajournals.org/content/suppl/2012/07/12/CIRCOUTCOMES.112.965269.DC1

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Supplemental Table 1. Modified Jadad Scale For RCT Quality

Randomization:
1. J Described as randomized?
2. J Randomization appropriately performed?

Blinding:
3. J Study described as double-blinded?
4. C Outcome assessor blinded?
5. J Study participant blinded (e.g. intervention described as indistinguishable, active placebo, identical placebo or dummy)?
6. C Investigator blinded?

Patient attrition:
7. J Attrition described?
8. C Attrition smaller than 10-15% of assigned patients?
9. C Attrition appropriately analyzed (i.e. intention-to-treat analysis for superiority studies)?

J–components from original Jadad scale (4); C–components from Chalmers list (5)
Supplemental Figures

Forest plots of systematic review and meta-analysis results for each outcome included in the cost-benefit model.

Supplemental figure 1. Meta-analysis results: access and procedure success

A–Successful catheterization via radial or femoral artery

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Radial Events</th>
<th>Femoral Events</th>
<th>Odds Ratio (Non-event)</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCESS 1997</td>
<td>54</td>
<td>56</td>
<td>5.19 [0.24, 110.45]</td>
<td>1997</td>
</tr>
<tr>
<td>BRAFE 1997</td>
<td>37</td>
<td>30</td>
<td>2.61 [0.01, 18.69]</td>
<td>1997</td>
</tr>
<tr>
<td>Cooper 1999</td>
<td>74</td>
<td>101</td>
<td>1.45 [0.08, 27.70]</td>
<td>2001</td>
</tr>
<tr>
<td>CARAFE 2001</td>
<td>139</td>
<td>140</td>
<td>1.10 [0.53, 2.27]</td>
<td>2004</td>
</tr>
<tr>
<td>OCTOPLUS 2004</td>
<td>175</td>
<td>192</td>
<td>1.62 [2.40, 140.00]</td>
<td>2009</td>
</tr>
<tr>
<td>Hou 2010</td>
<td>96</td>
<td>100</td>
<td>9.37 [0.50, 176.43]</td>
<td>2010</td>
</tr>
<tr>
<td>RIVAL 2011</td>
<td>3242</td>
<td>3507</td>
<td>4.02 [3.95, 5.26]</td>
<td>2011</td>
</tr>
<tr>
<td><strong>Total (95% CI)</strong></td>
<td><strong>5304</strong></td>
<td><strong>5275</strong></td>
<td><strong>4.92 [2.69, 9.00]</strong></td>
<td></td>
</tr>
</tbody>
</table>

Total events: 5387

Heterogeneity: Tau² = 0.39; Chi² = 25.05; df = 10; P = 0.005; I² = 80%
Test for overall effect: Z = 5.17 (P < 0.00001)

B–Procedure success including crossover to alternate access site

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Radial Events</th>
<th>Femoral Events</th>
<th>Odds Ratio (Non-event)</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCESS 1997</td>
<td>275</td>
<td>300</td>
<td>1.04 [0.59, 1.85]</td>
<td>1997</td>
</tr>
<tr>
<td>BRAFE 1997</td>
<td>51</td>
<td>56</td>
<td>0.19 [0.02, 1.64]</td>
<td>1997</td>
</tr>
<tr>
<td>Cooper 1999</td>
<td>101</td>
<td>99</td>
<td>Not estimable</td>
<td>1999</td>
</tr>
<tr>
<td>CARAFE 2001</td>
<td>139</td>
<td>140</td>
<td>13.03 [1.54, 110.49]</td>
<td>2001</td>
</tr>
<tr>
<td>OCTOPLUS 2004</td>
<td>86</td>
<td>93</td>
<td>1.23 [0.27, 5.67]</td>
<td>2004</td>
</tr>
<tr>
<td>Reddy 2004</td>
<td>25</td>
<td>25</td>
<td>1.55 [0.06, 39.31]</td>
<td>2004</td>
</tr>
<tr>
<td>OUTCLAS 2005</td>
<td>309</td>
<td>322</td>
<td>0.76 [0.33, 1.76]</td>
<td>2005</td>
</tr>
<tr>
<td>Achenbach 2008</td>
<td>152</td>
<td>155</td>
<td>Not estimable</td>
<td>2008</td>
</tr>
<tr>
<td>Brueck 2009</td>
<td>512</td>
<td>512</td>
<td>Not estimable</td>
<td>2009</td>
</tr>
<tr>
<td>Hou 2010</td>
<td>96</td>
<td>100</td>
<td>1.26 [0.33, 4.85]</td>
<td>2010</td>
</tr>
<tr>
<td>RIVAL 2011</td>
<td>2204</td>
<td>2235</td>
<td>0.97 [0.88, 1.07]</td>
<td>2011</td>
</tr>
<tr>
<td><strong>Total (95% CI)</strong></td>
<td><strong>5304</strong></td>
<td><strong>5275</strong></td>
<td><strong>0.97 [0.89, 1.07]</strong></td>
<td></td>
</tr>
</tbody>
</table>

Total events: 3950

Heterogeneity: Chi² = 6.59; df = 7 (P = 0.28); I² = 19%
Test for overall effect: Z = 0.56 (P = 0.58)
## Supplemental figure 2. Meta-analysis results: cardiovascular events

### Major adverse cardiovascular events

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Radial Events</th>
<th>Femoral Events</th>
<th>Total Events</th>
<th>Weight</th>
<th>Odds Ratio M-H, Fixed, 95% CI</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCESS 1997</td>
<td>20</td>
<td>16</td>
<td>300</td>
<td>9.6%</td>
<td>1.27 [0.64, 2.50]</td>
<td>1997</td>
</tr>
<tr>
<td>BRAFE 1997</td>
<td>3</td>
<td>0</td>
<td>55</td>
<td>0.3%</td>
<td>8.18 [0.41, 162.38]</td>
<td>1997</td>
</tr>
<tr>
<td>Mann 1998</td>
<td>0</td>
<td>0</td>
<td>77</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooper 1999</td>
<td>0</td>
<td>1</td>
<td>99</td>
<td>1.0%</td>
<td>0.32 [0.01, 8.04]</td>
<td>1999</td>
</tr>
<tr>
<td>CARAFE 2001</td>
<td>0</td>
<td>0</td>
<td>140</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reddy 2004</td>
<td>0</td>
<td>2</td>
<td>50</td>
<td>1.1%</td>
<td>0.38 [0.02, 8.23]</td>
<td>2004</td>
</tr>
<tr>
<td>OUTCLASS 2005</td>
<td>11</td>
<td>15</td>
<td>322</td>
<td>9.3%</td>
<td>0.72 [0.33, 1.60]</td>
<td>2005</td>
</tr>
<tr>
<td>Achenbach 2008</td>
<td>0</td>
<td>1</td>
<td>155</td>
<td>1.0%</td>
<td>0.34 [0.01, 8.35]</td>
<td>2008</td>
</tr>
<tr>
<td>Brueck 2009</td>
<td>3</td>
<td>6</td>
<td>512</td>
<td>3.8%</td>
<td>0.50 [0.12, 2.00]</td>
<td>2009</td>
</tr>
<tr>
<td>Hou 2010</td>
<td>4</td>
<td>5</td>
<td>100</td>
<td>3.1%</td>
<td>0.79 [0.21, 3.04]</td>
<td>2010</td>
</tr>
<tr>
<td>RIVAL 2011</td>
<td>112</td>
<td>114</td>
<td>3514</td>
<td>70.9%</td>
<td>0.98 [0.75, 1.28]</td>
<td>2011</td>
</tr>
</tbody>
</table>

**Total (95% CI)** 5207 | 5324 | 100.0% | 0.96 [0.77, 1.21] |

Total events: 153 | 160

Heterogeneity: Chi² = 5.28, df = 8 (P = 0.73); I² = 0%

Test for overall effect: Z = 0.32 (P = 0.75)
Supplemental figure 3. Meta-analysis results: complications

A–Major vascular complications

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Radial Events</th>
<th>Femoral Events</th>
<th>Total Weight</th>
<th>Odds Ratio M-H, Fixed, 95% CI Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRAFE 1997</td>
<td>2</td>
<td>50</td>
<td>53</td>
<td>1.4%</td>
</tr>
<tr>
<td>ACCESS 1997</td>
<td>0</td>
<td>300</td>
<td>6</td>
<td>300</td>
</tr>
<tr>
<td>Mann 1998</td>
<td>0</td>
<td>68</td>
<td>3</td>
<td>77</td>
</tr>
<tr>
<td>Cooper 1999</td>
<td>0</td>
<td>101</td>
<td>0</td>
<td>99</td>
</tr>
<tr>
<td>CARAFE 2001</td>
<td>3</td>
<td>140</td>
<td>4</td>
<td>70</td>
</tr>
<tr>
<td>OCTOPLUS 2004</td>
<td>3</td>
<td>192</td>
<td>12</td>
<td>185</td>
</tr>
<tr>
<td>Reddy 2004</td>
<td>0</td>
<td>25</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>OUTCLAS 2005</td>
<td>1</td>
<td>322</td>
<td>2</td>
<td>322</td>
</tr>
<tr>
<td>Achenbach 2008</td>
<td>0</td>
<td>152</td>
<td>5</td>
<td>155</td>
</tr>
<tr>
<td>Brueck 2009</td>
<td>3</td>
<td>512</td>
<td>19</td>
<td>512</td>
</tr>
<tr>
<td>Santas 2009</td>
<td>0</td>
<td>670</td>
<td>4</td>
<td>335</td>
</tr>
<tr>
<td>Hou 2010</td>
<td>1</td>
<td>100</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>RIVAL 2011</td>
<td>49</td>
<td>3507</td>
<td>131</td>
<td>3514</td>
</tr>
</tbody>
</table>

Total (95% CI) 6139 5774 100.0% 0.32 [0.24, 0.42]

Heterogeneity: Chi² = 6.89, df = 11 (P = 0.81); I² = 0%
Test for overall effect: Z = 7.95 (P < 0.00001)

B–Major bleeding

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Radial Events</th>
<th>Femoral Events</th>
<th>Total Weight</th>
<th>Odds Ratio M-H, Fixed, 95% CI Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCESS 1997</td>
<td>0</td>
<td>300</td>
<td>4</td>
<td>300</td>
</tr>
<tr>
<td>BRAFE 1997</td>
<td>1</td>
<td>50</td>
<td>3</td>
<td>55</td>
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<tr>
<td>Mann 1998</td>
<td>0</td>
<td>68</td>
<td>3</td>
<td>77</td>
</tr>
<tr>
<td>Cooper 1999</td>
<td>0</td>
<td>101</td>
<td>0</td>
<td>99</td>
</tr>
<tr>
<td>CARAFE 2001</td>
<td>1</td>
<td>140</td>
<td>2</td>
<td>70</td>
</tr>
<tr>
<td>OCTOPLUS 2004</td>
<td>1</td>
<td>192</td>
<td>7</td>
<td>185</td>
</tr>
<tr>
<td>Reddy 2004</td>
<td>0</td>
<td>25</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>OUTCLAS 2005</td>
<td>9</td>
<td>322</td>
<td>21</td>
<td>322</td>
</tr>
<tr>
<td>Achenbach 2008</td>
<td>0</td>
<td>152</td>
<td>3</td>
<td>155</td>
</tr>
<tr>
<td>Brueck 2009</td>
<td>0</td>
<td>512</td>
<td>14</td>
<td>512</td>
</tr>
<tr>
<td>Hou 2010</td>
<td>0</td>
<td>100</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>RIVAL 2011</td>
<td>24</td>
<td>3507</td>
<td>33</td>
<td>3514</td>
</tr>
</tbody>
</table>

Total (95% CI) 5469 5439 100.0% 0.39 [0.27, 0.57]

Heterogeneity: Chi² = 11.35, df = 9 (P = 0.25); I² = 21%
Test for overall effect: Z = 4.86 (P < 0.00001)
### C–Hematoma

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Radial Events</th>
<th>Femoral Events</th>
<th>Total Events</th>
<th>Weight</th>
<th>Odds Ratio M-H, Fixed, 95% CI</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRAFE 1997</td>
<td>0</td>
<td>2</td>
<td>55</td>
<td>1.4%</td>
<td>0.21 [0.01, 4.52]</td>
<td>1997</td>
</tr>
<tr>
<td>Mann 1998</td>
<td>0</td>
<td>3</td>
<td>77</td>
<td>1.9%</td>
<td>0.16 [0.01, 3.06]</td>
<td>1998</td>
</tr>
<tr>
<td>Cooper 1999</td>
<td>12</td>
<td>17</td>
<td>99</td>
<td>8.7%</td>
<td>0.65 [0.29, 1.44]</td>
<td>1999</td>
</tr>
<tr>
<td>CARAFE 2001</td>
<td>2</td>
<td>4</td>
<td>70</td>
<td>3.0%</td>
<td>0.24 [0.04, 1.34]</td>
<td>2001</td>
</tr>
<tr>
<td>OCTOPLUS 2004</td>
<td>7</td>
<td>21</td>
<td>185</td>
<td>11.8%</td>
<td>0.30 [0.12, 0.71]</td>
<td>2004</td>
</tr>
<tr>
<td>Reddy 2004</td>
<td>0</td>
<td>18</td>
<td>50</td>
<td>7.0%</td>
<td>0.03 [0.00, 0.60]</td>
<td>2004</td>
</tr>
<tr>
<td>Achenbach 2008</td>
<td>0</td>
<td>1</td>
<td>155</td>
<td>0.8%</td>
<td>0.34 [0.01, 8.35]</td>
<td>2008</td>
</tr>
<tr>
<td>Brueck 2009</td>
<td>0</td>
<td>3</td>
<td>512</td>
<td>2.0%</td>
<td>0.14 [0.01, 2.76]</td>
<td>2009</td>
</tr>
<tr>
<td>Hou 2010</td>
<td>2</td>
<td>6</td>
<td>100</td>
<td>3.4%</td>
<td>0.32 [0.06, 1.62]</td>
<td>2010</td>
</tr>
<tr>
<td>RIVAL 2011</td>
<td>42</td>
<td>106</td>
<td>3514</td>
<td>60.0%</td>
<td>0.39 [0.27, 0.56]</td>
<td>2011</td>
</tr>
</tbody>
</table>

Total (95% CI) 4847 4817 100.0% 0.36 [0.27, 0.48]

Total events 65 181

Heterogeneity: $\chi^2 = 6.16$, df = 9 ($P = 0.72$); $I^2 = 0$

Test for overall effect: $Z = 7.05$ ($P < 0.00001$)
**Supplemental figure 4. Meta-analysis results: time-related variables**

**A–Procedure time**

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Radial Mean [min]</th>
<th>SD [min]</th>
<th>Total Mean [min]</th>
<th>SD [min]</th>
<th>Total</th>
<th>Weight IV, Random, 95% CI [min]</th>
<th>Year</th>
<th>Mean Difference IV, Random, 95% CI [min]</th>
<th>Favors radial</th>
<th>Favors femoral</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRAFE 1997</td>
<td>55.8</td>
<td>31.3</td>
<td>56</td>
<td>42.2</td>
<td>21.8</td>
<td>56</td>
<td>2.2%</td>
<td>13.60 [-16.1, 23.59]</td>
<td>1997</td>
<td></td>
</tr>
<tr>
<td>ACCESS 1997</td>
<td>40</td>
<td>24</td>
<td>300</td>
<td>38</td>
<td>24</td>
<td>300</td>
<td>8.2%</td>
<td>2.00 [-0.84, 3.84]</td>
<td>1997</td>
<td></td>
</tr>
<tr>
<td>Cooper 1999</td>
<td>18.6</td>
<td>9</td>
<td>101</td>
<td>16.4</td>
<td>10</td>
<td>99</td>
<td>11.0%</td>
<td>2.20 [-0.44, 4.84]</td>
<td>1999</td>
<td></td>
</tr>
<tr>
<td>CARAFE 2001</td>
<td>13.3</td>
<td>5.8</td>
<td>140</td>
<td>11.3</td>
<td>3.3</td>
<td>70</td>
<td>14.4%</td>
<td>2.00 [0.77, 3.23]</td>
<td>2001</td>
<td></td>
</tr>
<tr>
<td>Reddy 2004</td>
<td>22.5</td>
<td>3.5</td>
<td>25</td>
<td>25.5</td>
<td>5.4</td>
<td>50</td>
<td>12.5%</td>
<td>-3.00 [-5.03, -0.97]</td>
<td>2004</td>
<td></td>
</tr>
<tr>
<td>OCTOPLUS 2004</td>
<td>18.5</td>
<td>10.5</td>
<td>192</td>
<td>15.9</td>
<td>9.5</td>
<td>185</td>
<td>12.6%</td>
<td>2.60 [0.58, 4.62]</td>
<td>2004</td>
<td></td>
</tr>
<tr>
<td>Achenbach 2008</td>
<td>18.1</td>
<td>10</td>
<td>152</td>
<td>15</td>
<td>8</td>
<td>155</td>
<td>12.5%</td>
<td>3.10 [1.07, 5.13]</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Santas 2009</td>
<td>28</td>
<td>12</td>
<td>670</td>
<td>29</td>
<td>9</td>
<td>335</td>
<td>14.2%</td>
<td>-1.00 [-2.32, 0.32]</td>
<td>2009</td>
<td></td>
</tr>
<tr>
<td>Hou 2010</td>
<td>37.2</td>
<td>7.1</td>
<td>100</td>
<td>35.7</td>
<td>8.1</td>
<td>100</td>
<td>12.3%</td>
<td>1.50 [-0.61, 3.61]</td>
<td>2010</td>
<td></td>
</tr>
</tbody>
</table>

Total (95% CI) 1736 1350 100.0% 1.38 [-0.22, 2.97] 

Heterogeneity: Tau² = 4.21; Chi² = 40.09, df = 8 (P < 0.00001); I² = 80%

Test for overall effect: Z = 1.69 (P = 0.09)

**B–Fluoroscopy time**

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Radial Mean [min]</th>
<th>SD [min]</th>
<th>Total Mean [min]</th>
<th>SD [min]</th>
<th>Total</th>
<th>Weight IV, Random, 95% CI [min]</th>
<th>Year</th>
<th>Mean Difference IV, Random, 95% CI [min]</th>
<th>Favors radial</th>
<th>Favors femoral</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCESS 1997</td>
<td>13</td>
<td>11</td>
<td>300</td>
<td>11</td>
<td>10</td>
<td>300</td>
<td>6.0%</td>
<td>2.00 [0.32, 3.68]</td>
<td>1997</td>
<td></td>
</tr>
<tr>
<td>CARAFE 2001</td>
<td>4</td>
<td>2.2</td>
<td>140</td>
<td>3.1</td>
<td>1.7</td>
<td>70</td>
<td>13.3%</td>
<td>0.90 [0.36, 1.44]</td>
<td>2001</td>
<td></td>
</tr>
<tr>
<td>OCTOPLUS 2004</td>
<td>6</td>
<td>4.4</td>
<td>192</td>
<td>4.5</td>
<td>3.7</td>
<td>185</td>
<td>11.2%</td>
<td>1.50 [0.68, 2.32]</td>
<td>2004</td>
<td></td>
</tr>
<tr>
<td>Reddy 2004</td>
<td>5.9</td>
<td>1.1</td>
<td>25</td>
<td>6.8</td>
<td>1.5</td>
<td>50</td>
<td>12.9%</td>
<td>-0.90 [-1.50, -0.30]</td>
<td>2004</td>
<td></td>
</tr>
<tr>
<td>Lange 2005</td>
<td>2.8</td>
<td>2.1</td>
<td>92</td>
<td>1.7</td>
<td>1.4</td>
<td>103</td>
<td>13.5%</td>
<td>1.10 [0.59, 1.61]</td>
<td>2005</td>
<td></td>
</tr>
<tr>
<td>Achenbach 2008</td>
<td>5.6</td>
<td>5.9</td>
<td>152</td>
<td>4.7</td>
<td>3.9</td>
<td>155</td>
<td>9.1%</td>
<td>0.90 [-0.22, 2.02]</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Santas 2009</td>
<td>5</td>
<td>5</td>
<td>670</td>
<td>4</td>
<td>3</td>
<td>335</td>
<td>13.6%</td>
<td>1.00 [0.50, 1.50]</td>
<td>2009</td>
<td></td>
</tr>
<tr>
<td>Hou 2010</td>
<td>11.8</td>
<td>2</td>
<td>100</td>
<td>11.4</td>
<td>1.8</td>
<td>100</td>
<td>13.4%</td>
<td>0.40 [-0.13, 0.93]</td>
<td>2010</td>
<td></td>
</tr>
</tbody>
</table>

Total (95% CI) 1772 1397 100.0% 0.76 [0.24, 1.28] 

Heterogeneity: Tau² = 0.46; Chi² = 39.03, df = 8 (P < 0.00001); I² = 80%

Test for overall effect: Z = 2.85 (P = 0.004)

**C–Hemostasis time**

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Radial Mean [min]</th>
<th>SD [min]</th>
<th>Total Mean [min]</th>
<th>SD [min]</th>
<th>Total</th>
<th>Weight IV, Random, 95% CI [min]</th>
<th>Year</th>
<th>Mean Difference IV, Random, 95% CI [min]</th>
<th>Favors radial</th>
<th>Favors femoral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooper 1999</td>
<td>4.7</td>
<td>0.6</td>
<td>101</td>
<td>26.5</td>
<td>2.3</td>
<td>99</td>
<td>33.4%</td>
<td>-21.80 [-22.27, -21.33]</td>
<td>1999</td>
<td></td>
</tr>
<tr>
<td>Reddy 2004</td>
<td>4.7</td>
<td>0.8</td>
<td>25</td>
<td>16.1</td>
<td>2.3</td>
<td>25</td>
<td>33.3%</td>
<td>-11.40 [-12.35, -10.45]</td>
<td>2004</td>
<td></td>
</tr>
<tr>
<td>Santas 2009</td>
<td>4.7</td>
<td>6</td>
<td>670</td>
<td>13</td>
<td>4</td>
<td>335</td>
<td>33.3%</td>
<td>-6.00 [-6.62, -5.38]</td>
<td>2009</td>
<td></td>
</tr>
</tbody>
</table>

Total (95% CI) 796 459 100.0% -13.07 [-23.85, -2.29] 

Heterogeneity: Tau² = 90.69; Chi² = 1656.42, df = 2 (P < 0.00001); I² = 100%

Test for overall effect: Z = 2.38 (P = 0.02)