Meta-analysis Comparing Transradial Versus Transfemoral Secondary Access in Transcatheter Aortic Valve Implantation

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Up to a quarter of vascular complications during transcatheter aortic valve implantation (TAVI) result from secondary access via the femoral artery (FA). The radial artery (RA) is increasingly used as an alternative to the FA for secondary access in TAVI. Limited data exist on the outcomes of RA secondary access versus FA secondary access. We therefore conducted a systematic review and meta-analysis comparing secondary access sites. PubMed, EMBASE, Scopus, Cochrane library and CINAHL were searched systematically for studies comparing RA and FA as secondary access sites for TAVI. Primary outcomes of interest were vascular complications and major bleeding. Secondary outcomes included all-cause mortality, stroke and myocardial infarction (MI). Risk ratio (RR), standardized mean difference and corresponding 95% confidence intervals (CI) were calculated using a random effects model. Six observational studies comprising 6,373 patients (RA: 1,514, FA: 4,859) met inclusion criteria. Secondary access was utilized for aortography during valve deployment and to manage primary access site complications. Procedural characteristics were similar in both groups. RA was associated with a lower risk of major bleeding (RR: 0.51, 95% CI: 0.40 to 0.64, p <0.00001). No statistically significant difference was observed in the incidence of overall vascular complications, however, the risk of major vascular complications was lower with RA (RR: 0.45, 95% CI: 0.32 to 0.63, p <0.00001). The incidence of stroke and all-cause mortality was lower in RA, whereas no difference was observed in the risk of MI. In conclusion, our meta-analysis suggests that RA secondary access is associated with better outcomes for TAVI than FA. **(Am J Cardiol 2020;131:74−81)**

Global utilization of transcatheter aortic valve implantation (TAVI) for severe aortic stenosis has steadily increased over the last decade.[1,2] Based on the results of 2 landmark clinical trials, the US Food and Drug Administration (FDA) recently expanded indications for TAVI to include patients with severe aortic stenosis and low surgical risk.[3,4] With improved patient selection, technological advancements and increasing operator experience, mortality associated with TAVI has decreased.[5] However, procedural complications remain common and are associated with increased 1-year mortality and poor quality of life among survivors.[6] The incidence of major vascular complications associated with TAVI is reported between 4.2% to 14.3%.[7,8] A quarter of these vascular complications may be related to the secondary arterial access site.[9] Traditionally, the contralateral femoral artery (FA) has been used for secondary access in transfemoral TAVI to facilitate angiographic guidance for primary access, aortography during valve deployment and management of complications at the primary access site. The radial artery (RA) has emerged as a safe alternative to the FA for access for percutaneous coronary intervention (PCI) in acute coronary syndromes with lower incidence of major bleeding and major vascular complications.[10] However, data are limited regarding utilization of the RA as a secondary access site for TAVI. We therefore performed a systematic review and meta-analysis to compare RA versus FA secondary access in patients undergoing TAVI.

Methods

Systematic review and meta-analysis were performed according to the PRISMA (preferred reporting items for systematic reviews and meta-analysis) guidelines.[11] A systematic search without any language restriction was performed in Medline, Cumulative Index to Nursing and Allied Health Literature (CINAHL), the Excerpta Medica database (EMBASE), the Cochrane Library database and Scopus from inception to March 15, 2020 for studies comparing RA and FA as secondary access in patients undergoing TAVI. The reference lists of original studies and relevant review articles were further reviewed to obtain additional studies. A varied combination of the following

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keywords was used in the search strategy: *radial*, *transradial*, *secondary access*, *alternate access*, *TAVI*, *TAVR*, *transcatheter aortic valve implantation* and *transcatheter aortic valve replacement*. We did not use the terms *femoral* or *transfemoral* because FA has been the standard access site, so all studies comparing FA and RA would include radial keywords.

Studies were selected for analysis if they met the following prespecified inclusion criteria: (1) patients underwent TAVI utilizing any primary access approach (i.e., transfemoral, transapical, transcarotid, direct aortic access and so on), (2) studies compared RA and FA for secondary vascular access, and (3) procedural outcomes were compared between the 2 secondary access sites including vascular complications and major bleeding. Studies were excluded if: (1) only abstracts were available without full text publication and (2) data comparing outcomes between RA and FA for secondary access were unavailable.

Two investigators (AJ and DRA) independently performed literature searches, screened studies for eligibility and extracted data using a standardized data collection form. Any differences in the included studies and collected data were resolved through consensus among the authors. Data on study characteristics, baseline characteristics of the included patients, procedural characteristics and clinical outcomes were collected.

Our primary outcomes of interest were vascular complications and major bleeding. Secondary outcomes included all-cause mortality, stroke, myocardial infarction, procedural duration, fluoroscopy time, radiation dose, and contrast volume used.

The meta-analysis was performed using Review Manager (RevMan), Version 5.3. (Copenhagen: The Nordic Cochrane Center, The Cochrane Collaboration). Due to heterogeneity in the methodologies of the included studies, the risk ratios (RR) and 95% confidence intervals (CIs) were calculated using the random effects Mantel-Haenszel method for dichotomous variables. Standardized mean differences (SMD) and corresponding 95% CIs were reported for continuous variables. Heterogeneity was assessed using Higgins' and Thompson's I^2 statistics, with I^2 values of <25%, 25%-75%, and >75% corresponding to low, moderate and high levels of heterogeneity, respectively. Publication bias was estimated by visual inspection of the funnel plots. A 2-sided p value of <0.05 was considered statistically significant for all analyses.

Results

A total of 705 records were initially identified. After removing duplicates and studies that did not meet inclusion criteria, 6 observational studies were included in the quantitative analysis (Figure 1). The meta-analysis included 6,373

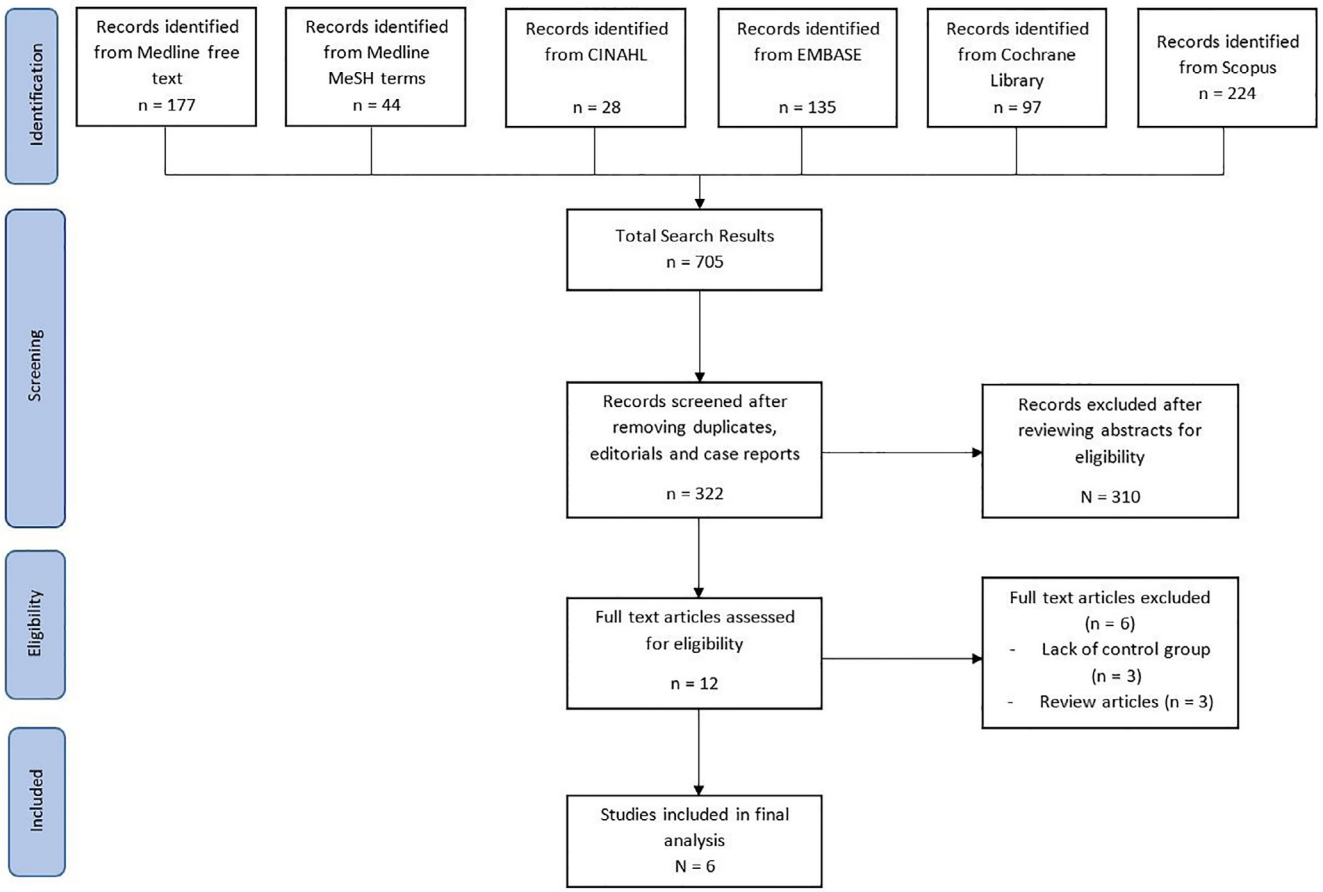

Figure 1. Flow diagram of the search strategy. (CINAHL = cumulative index to nursing and allied health literature, EMBASE = Excerpta Medica database, MeSH = medical subject headings).

patients: 1,514 patients underwent TAVI using the RA and 4,859 using the FA as the secondary access site.[9,12–16] Five studies were single-center retrospective studies, 4 were conducted in Europe and 1 in Canada. One was a multicenter study conducted across Canada and Europe.[16] Study quality assessment was performed using the Newcastle-Ottawa scale for observational studies (Supplementary Table 1).

FA was the only primary access site in 4 of the 6 studies while other alternate primary access approaches were commonly employed in 2 studies (Table 1). The secondary access site was used to guide primary femoral access under angiography, manage primary access site complications and for aortography during valve deployment. Primary access site hemostasis was obtained using a vascular closure device in 4 studies and with surgical cutdown in 1 study. One study reported the use of both methods for primary access site hemostasis. The mean age of the study populations ranged from 80 to 84.9 years, and 49% were males (Supplementary Table 2). The prevalence of hypertension (HTN) and diabetes mellitus (DM) were 71% and 31% respectively. Mean Society of Thoracic Surgeons Predicted Risk of Mortality (STS-PROM) score was comparable between the 2 groups (6.0 ± 1.3 for RA vs 6.5 ± 1.9 for FA, $p = 0.68$). Procedural success rate was 95.6% with RA and 95.8% with FA secondary access ($p = 0.95$). A trend towards improvement in procedural success rate was seen with more recent studies. All included studies reported clinical outcomes as defined by the Valve Academic Research Consortium (VARC) and VARC-2 criteria at 30 days.[17]

The incidence of overall vascular complications (including both primary and secondary access) was lower with RA as compared with FA secondary access, however this difference was not statistically significant (15.6% vs 18.4%, RR 0.89, 95% CI 0.64 to 1.23, $p = 0.47$, Figure 2), and heterogeneity was moderate ($I^2 = 60\%$). The incidence of major bleeding was significantly lower with RA compared with FA secondary access (5.3% vs 10.7%, RR 0.51, 95% CI 0.40 to 0.64, $p < 0.00001$), and heterogeneity was low ($I^2 = 0\%$).

RA was associated with a significantly lower all-cause mortality compared with FA (2.6% vs 4.9%, RR 0.56, 95% CI 0.40 to 0.79, $p = 0.0009$, Figure 3), and heterogeneity was low ($I^2 = 0\%$). Moreover, the incidence of stroke was lower in the RA as compared with FA group (1.3% vs 3.3%, RR 0.43, 95% CI 0.27 to 0.67, $p = 0.0003$), and heterogeneity was low ($I^2 = 0\%$). Data on MI were reported in 3 studies, and no statistically significant difference was observed (0.8% vs 1.9%, RR 0.60, 95% CI 0.16 to 2.23, $p = 0.44$).

Data on procedural outcomes were available in 4 studies. No difference was observed in the volume of contrast used (SMD 0.33, 95% CI −0.27 to 0.94, $p = 0.28$), fluoroscopy time (SMD 0.18, 95% CI −0.19 to 0.54, $p = 0.34$) and radiation dose (SMD 0.08, 95% CI −0.45 to 0.60, $p = 0.78$), Figure 4. Five out of the 6 studies stratified the access-site related vascular complications based on severity (major and minor). Subgroup analysis showed that incidence of major vascular complications was lower in RA than FA (2.7% vs 6.4%, RR 0.45, 95% CI 0.32 to 0.63, $p < 0.00001$). No

Table 1
Characteristics of included studies

Variable	Curran 2013	Allende 2014	Fernandez-Lopez 2019	Jackson 2019	Lefèvre 2019	Junquera 2020
Total Number of Patients	87	462	411	179	285	4949
Study Period	June 2011 to March 2012	2007 to 2014	September 2015 to May 2017	May 2015 to June 2017	January 2015 to December 2017	2007 to 2018
Single vs Multi Center	Single Center	Single Center	Single Center	Single Center	Single Center	Multi-center
Type of Valve Implanted	Edwards Sapien, Medtronic CoreValve	N/A	Edwards Sapien XT, Medtronic CoreValve Evolut R	Edwards Sapien 3, St. Jude Portico	Edwards Sapien 3, Medtronic CoreValve Evolut R	N/A
Primary access site	100% transfemoral	48% transfemoral 44% transapical	100% transfemoral	100% transfemoral	100% transfemoral	83% transfemoral 9% transapical
Closure/Hemostasis of Primary Femoral Access	Prostar Preclosure device	Surgical cutdown	Two Proglide closure devices	Two Proglide closure devices	Two Proglide closure devices	Surgical cutdown and percutaneous closure
Utilization of Secondary Access	Primary vascular access management	Primary vascular access management	Primary vascular access management, aortography for valve deployment	Vascular access management, aortography for valve deployment	Primary vascular access management, aortography for valve deployment	Primary vascular access management
Closure/Hemostasis of Secondary Femoral Access	N/A	Manual compression, vascular closure device	Vascular closure device	N/A	Manual compression, vascular closure device	Manual compression, vascular closure device
Closure/Hemostasis of Secondary Radial Access	N/A	Mechanical compression	N/A	N/A	TR band or mechanical compression	Manual compression
Endpoints	30-day VARC outcomes and vascular bleeding	Periprocedural and 30-day VARC outcomes	30-day VARC-2 outcomes	VARC-2 outcomes, 30-day mortality	30-day VARC-2 outcomes	30-day VARC-2 outcomes

VARC = Valve Academic Research Consortium.

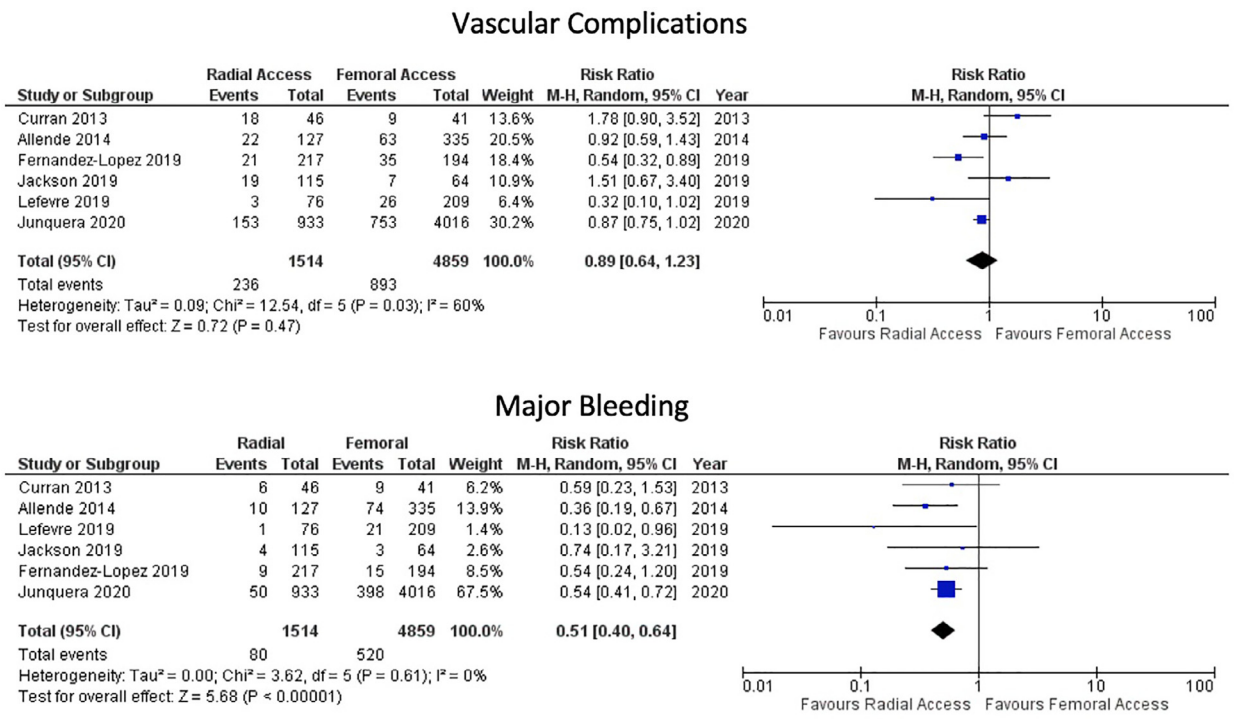

Figure 2. Co-primary outcomes of vascular complications and major bleeding in TAVI patients using RA versus FA for secondary access.

significant difference was seen in the incidence of minor vascular complications (11.2% vs 11.3%, respectively, RR 0.99, 95% CI 0.65 to 1.50, p = 0.97, Figure 5).

A sensitivity analysis was performed by removing one study at a time and studying the impact on primary outcomes (vascular complications and major bleeding). No significant difference was noted on the effect measure (Supplementary Figures 1 and 2). The meta-analysis included a small number of studies, and visual inspection of the funnel plots did not suggest publication bias for the primary outcomes (Supplementary Figure 3).

Discussion

In this meta-analysis of 6 studies including 6,373 patients, we found that RA secondary access was associated with a 49% reduction in major bleeding events as compared with FA secondary access for TAVI at 30 days. No significant difference was observed in the incidence of overall vascular complications, however RA was associated with a 55% reduction in major vascular complications in a subgroup analysis. RA secondary access was also associated with a 44% lower risk of all-cause mortality and a 71% lower risk of stroke. No significant difference was observed in procedural characteristics including contrast volume, fluoroscopy time and radiation dose.

Vascular complications and bleeding represent major sources of morbidity and mortality associated with TAVI. In a meta-analysis of 16 studies including 3,519 patients, the pooled incidence of major bleeding and overall vascular complications was 22.3% and 18.8% respectively using standardized VARC definitions.[18] A more recent study from the transcatheter valve therapy registry involving 26,414 TAVI procedures across 348 centers in United States showed an improvement in incidence of major bleeding from 5.5% in 2012-2013 to 4.2% in 2014. Rates of vascular complications improved from 5.6% to 4.2% during the same time period.[5] Such complications are associated with a lower rate of long-term survival. An analysis of patients enrolled in the PARTNER 2 study found that major bleeding within 30 days following TAVI was associated with a 46% higher odds of mortality at 1 year.[6] Another study including 45,884 TAVI patients in the transcatheter valve therapy registry found that 30-day bleeding was independently associated with increased risk of death within 3 months.[19] The majority of bleeding events associated with TAVI result from vascular complications.[20] Female gender, use of large diameter arterial sheaths, pelvic vessel tortuosity, coronary artery disease and a higher sheath-to-femoral artery diameter ratio have been identified as some of the predictors of vascular complications following transfemoral TAVI.[21–23]

Radial access has gained popularity as a safe and effective route for PCI. A meta-analysis of 24 randomized clinical trials showed that RA access for PCI was associated with a significantly lower risk of all-cause mortality, major adverse cardiac events, major bleeding and major vascular complications as compared with FA access.[10] Thus, RA may be reasonable for secondary access in TAVI to reduce complication rates. The incidence of major vascular complications was significantly lower in the RA group in our analysis, which may in part be due to lower incidence of vascular complications involving the radial secondary access site since 5 out of the 6 studies (Allende et al, Fernandez Lopez et al, Jackson et al, Lefèvre et al and Junquera et al) reported no major vascular complications at all

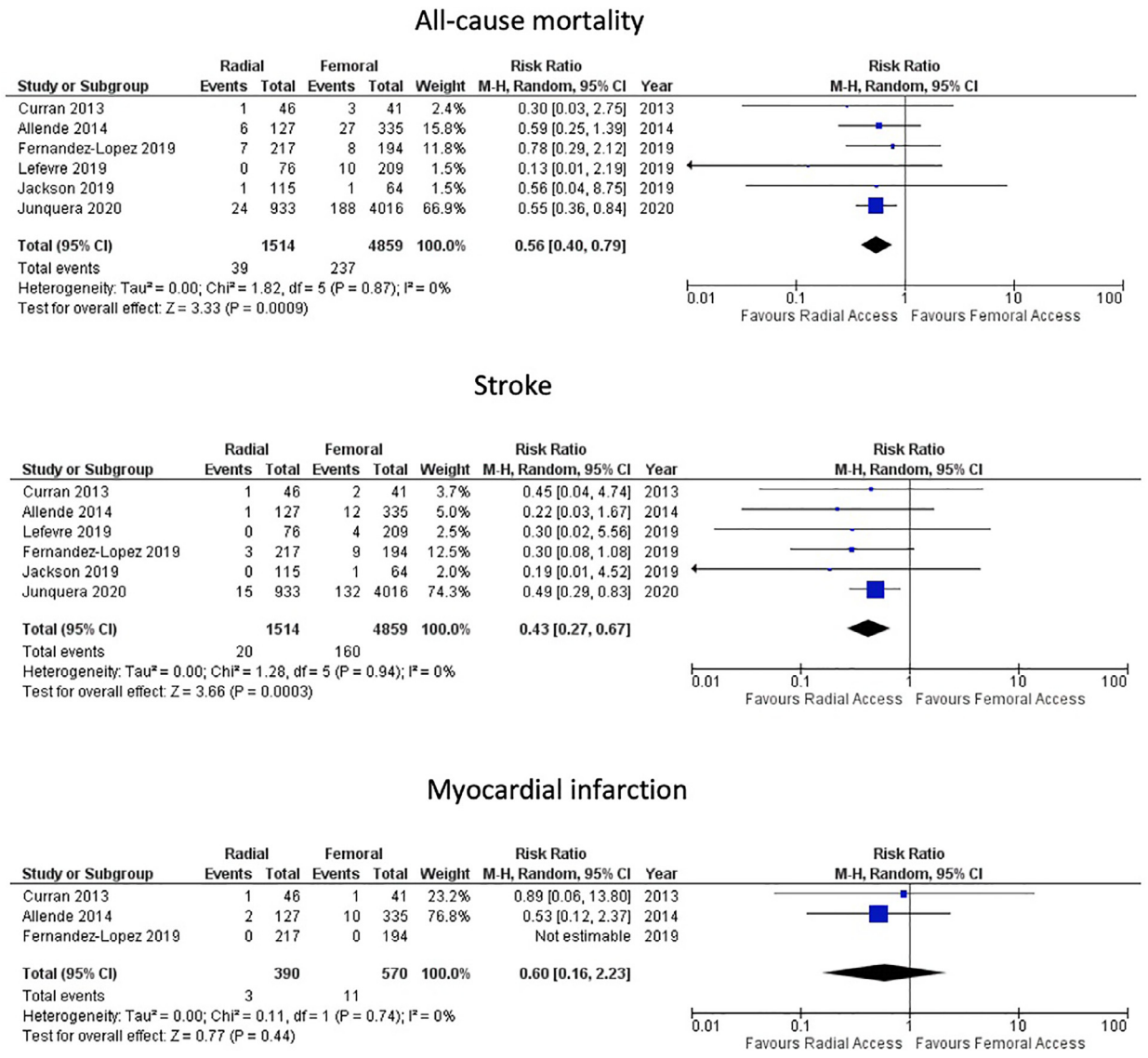

Figure 3. Secondary outcomes of all-cause mortality, stroke and myocardial infarction in TAVI patients using RA versus FA for secondary access.

occurring at RA that was used for secondary access.[9,13–16] Major bleeding events were stratified based on the access site (primary vs secondary access) in 2 of the 6 studies (Allende et al and Junqueara et al). Interestingly, no major bleeding event was reported in relation to the RA secondary access site in both of the studies.

Secondary arterial access is not only useful for aortography to identify the annular plane during valve deployment but can also be used to guide primary access and to manage access site complications. Both angiography from the RA or contralateral FA can identify the appropriate primary access site relative to the FA bifurcation. Moreover, to minimize the risk of bleeding, the cross-over technique with balloon occlusion from the contralateral FA access site proximal to the primary access site prior to vascular sheath removal has been replicated via the RA with similar results.[12,24] In case of complications such as ongoing bleeding or occlusive femoral dissection, angioplasty may readily be performed from the RA as an alternative to the FA.[25] However, femoral intervention from the RA requires specialized instruments including longer wires and stents and balloons with longer shafts, which may not be readily available in all TAVI centers.[26]

Our analysis also identified a significantly lower incidence of stroke in the RA group. Historically, no such difference has been documented in the PCI literature.[27] In TAVI, the RA is frequently used for deployment of embolic protection devices (EPDs); however the efficacy of EPDs in prevention of clinical stroke has not been demonstrated in multiple clinical trials.[28,29] Data on use of EPDs in the included studies was not available, and the mechanism of benefit of RA in stroke reduction remains unclear.

Although the findings of our analysis are significant, they must be interpreted with caution, and several limitations require consideration. First, all 6 studies included in the analysis were retrospective observational studies and not randomized, thus introducing the risk of selection bias.

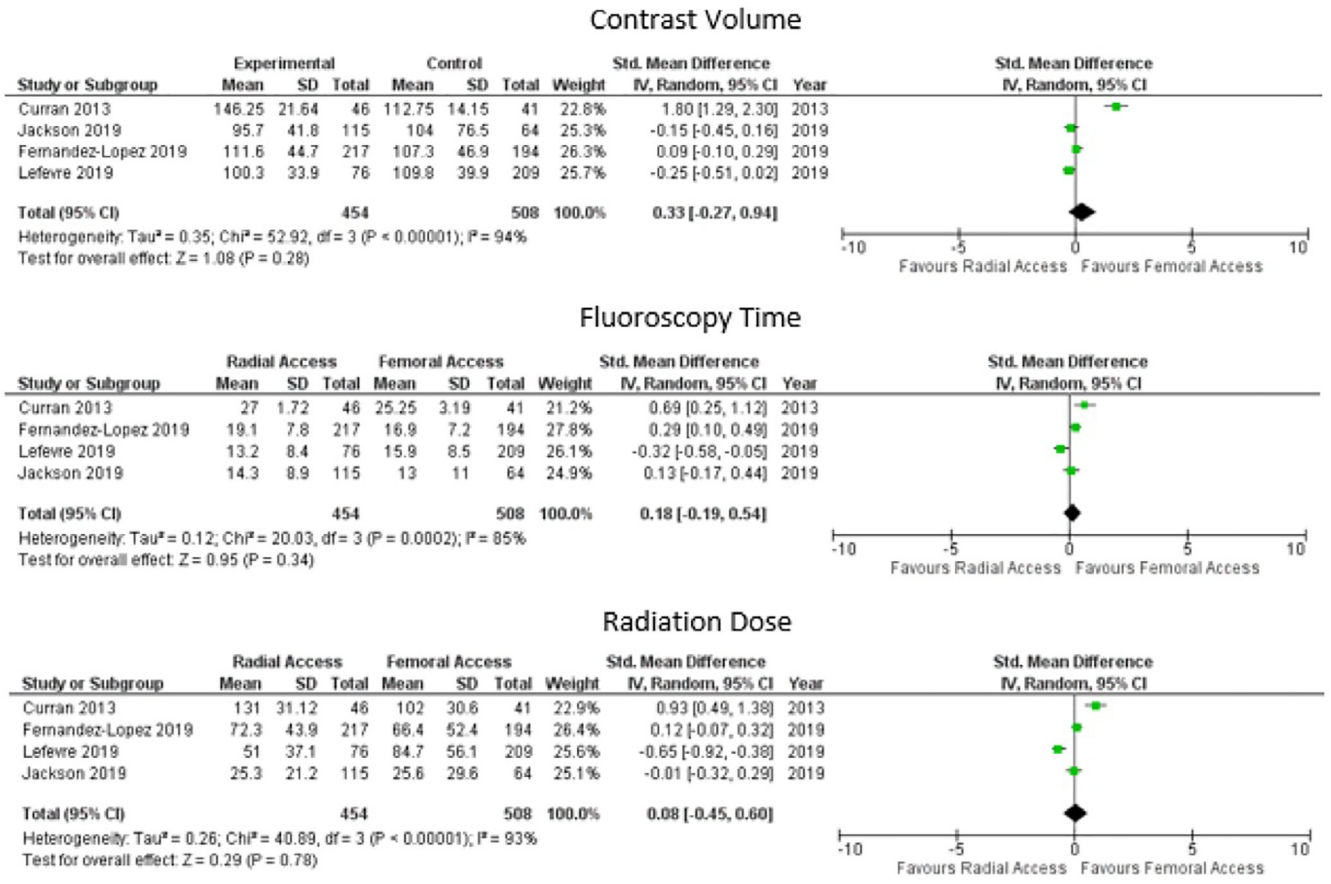

Figure 4. Procedural characteristics including contrast volume, fluoroscopy time and radiation dose in TAVI patients using RA versus FA for secondary access.

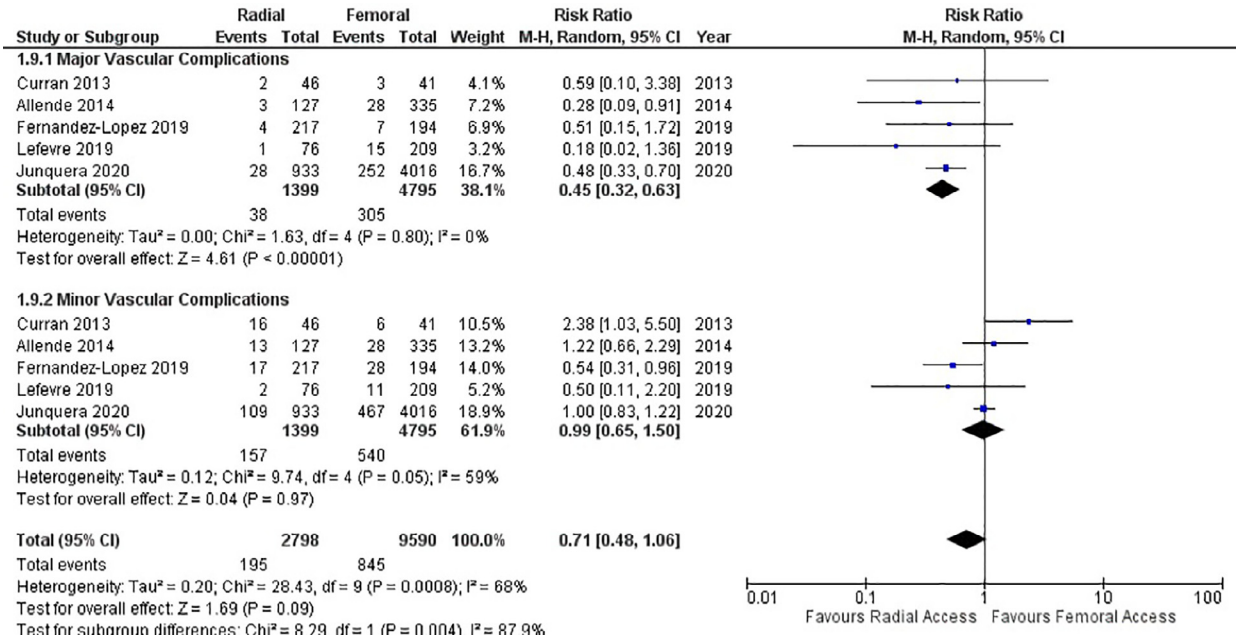

Figure 5. Subgroup analysis of vascular complications based on severity (major and minor) in TAVI patients using RA versus FA for secondary access.

Second, though the definition of end points was standardized between studies, information regarding access and nonaccess related major bleeding was not readily available, so it is unclear as to what percentage of major bleeding was attributable to vascular complications. Third, data regarding crossover balloon protection from secondary access sites was unavailable in the studies. Fourth, 2 of the 6 studies included nontransfemoral TAVI procedures, and these patients may have had higher rates of ileofemoral peripheral artery disease. Finally, an inherent limitation of any meta-analysis is publication bias.

In conclusion, among patients undergoing TAVI, the use of secondary radial access is associated with favorable outcomes as compared with femoral access, resulting in significantly lower rates of major bleeding, major vascular complications, all-cause mortality, and stroke.

CRediT Author Statement

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Disclosures

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this study.

Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.amjcard.2020.06.032.

1. Goldsweig AM, Tak HJ, Chen LW, Aronow HD, Shah B, Kolte DS, Velagapudi P, Desai N, Szerlip M, Abbott JD. The evolving management of aortic valve disease: 5-year trends in surgical aortic valve replacement, transcatheter aortic valve replacement, and medical therapy. *Am J Cardiol* 2019;124:763–771. Available at: https://doi.org/10.1016/j.amjcard.2019.05.044.
2. Gupta T, Kolte D, Khera S, Goel K, Villablanca PA, Kalra A, Abbott JD, Elmariah S, Fonarow GC, Rihal CS, Einstein A, Hospital MG. The changing landscape of aortic valve replacement in the USA. *EuroIntervention* 2019;15:968–974.
3. Popma JJ, Michael Deeb G, Yakubov SJ, Mumtaz M, Gada H, O'Hair D, Bajwa T, Heiser JC, Merhi W, Kleiman NS, Askew J, Sorajja P, Rovin J, Chetcuti SJ, Adams DH, Teirstein PS, Zorn GL, Forrest JK, Tchétché D, Resar J, Walton A, Piazza N, Ramlawi B, Robinson N, Petrossian G, Gleason TG, Oh JK, Boulware MJ, Qiao H, Mugglin AS, Reardon MJ. Transcatheter aortic-valve replacement with a self-expanding valve in low-risk patients. *N Engl J Med* 2019;380:1706–1715.
4. Mack MJ, Leon MB, Thourani VH, Makkar R, Kodali SK, Russo M, Kapadia SR, Chris Malaisrie S, Cohen DJ, Pibarot P, Leipsic J, Hahn RT, Blanke P, Williams MR, McCabe JM, Brown DL, Babaliaros V, Goldman S, Szeto WY, Genereux P, Pershad A, Pocock SJ, Alu MC, Webb JG, Smith CR. Transcatheter aortic-valve replacement with a balloon-expandable valve in low-risk patients. *N Engl J Med* 2019;380:1695–1705.
5. Holmes DR, Nishimura RA, Grover FL, Brindis RG, Carroll JD, Edwards FH, Peterson ED, Rumsfeld JS, Shahian DM, Thourani VH, Tuzcu EM, Vemulapalli S, Hewitt K, Michaels J, Fitzgerald S, Mack MJ. Annual outcomes with transcatheter valve therapy. From the STS/ACC TVT Registry. *Ann Thorac Surg* 2015;101:789–800. Available at: http://dx.doi.org/10.1016/j.athoracsur.2015.10.049.
6. Arnold SV, Zhang Y, Baron SJ, McAndrew TC, Alu MC, Kodali SK, Kapadia S, Thourani VH, Miller DC, Mack MJ, Leon MB, Cohen DJ. Impact of short-term complications on mortality and quality of life after transcatheter aortic valve replacement. *JACC Cardiovasc Interv* 2019;12:362–369.
7. Beohar N, Kirtane AJ, Blackstone E, Waksman R, Holmes D, Minha S, Alli O, Suri RM, Svensson LG, Leon M, Kodali S. Trends in complications and outcomes of patients undergoing transfemoral transcatheter aortic valve replacement: experience from the PARTNER continued access registry. *JACC Cardiovasc Interv* 2016;9:355–363.
8. Wendler O, Schymik G, Treede H, Baumgartner H, Dumonteil N, Ihlberg L, Neumann FJ, Tarantini G, Zamarano JL, Vahanian A. SOURCE 3 registry: design and 30-day results of the european postapproval registry of the latest generation of the sapien 3 transcatheter heart valve. *Circulation* 2017;135:1123–1132.
9. Allende R, Urena M, Cordoba JG, Ribeiro HB, Amat-Santos I, Delarochellière R, Paradis JM, Doyle D, Mohammadi S, Côté M, Abdul-Jawad O, Trigo M Del, Ortas MR, Laflamme L, Laflamme J, Delarochellière H, Dumont E, Rodés-Cabau J. Impact of the Use of transradial versus transfemoral approach as secondary access in transcatheter aortic valve implantation procedures. *Am J Cardiol* 2014;114:1729–1734.
10. Ferrante G, Rao SV, Jüni P, Costa BR Da, Reimers B, Condorelli G, Anzuini A, Jolly SS, Bertrand OF, Krucoff MW, Windecker S, Valgimigli M. Radial versus femoral access for coronary interventions across the entire spectrum of patients with coronary artery disease: a meta-analysis of randomized trials. *JACC Cardiovasc Interv* 2016;9:1419–1434.
11. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JPA, Clarke M, Devereaux PJ, Kleijnen J, Moher D. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *PLOS Med* 2009;6:e1000100. Available at: https://doi.org/10.1371/journal.pmed.1000100.
12. Curran H, Chieffo A, Buchanan GL, Bernelli C, Montorfano M, Maisano F, Latib A, Maccagni D, Carlino M, Figini F, Cioni M, Canna G La, Covello RD, Franco A, Gerli C, Alfieri O, Colombo A. A comparison of the femoral and radial crossover techniques for vascular access management in transcatheter aortic valve implantation: the milan experience. *Catheter Cardiovasc Interv* 2014;83:156–161.
13. Fernandez-Lopez L, Chevalier B, Lefèvre T, Spaziano M, Unterseeh T, Champagne S, Benamer H, Sanguineti F, Garot P, Hovasse T. Implementation of the transradial approach as an alternative vascular access for transcatheter aortic valve replacement guidance: experience from a high-volume center. *Catheter Cardiovasc Interv* 2019;93:1367–1373.
14. Jackson MWP, Muir DF, Belder MA de, Palmer S, Owens WA, Goodwin A, Hayat U, Williams PD. Transradial secondary access to guide valve implantation and manage peripheral vascular complications during transcatheter aortic valve implantation. *Hear Lung Circ* 2019;28:637–646. Available at: https://doi.org/10.1016/j.hlc.2018.02.025.
15. Lefèvre G, Jégou A, Dambrin G, Picard F, Anconina J, Pouzet B, Guesnier L, Cheikh Khelifa R, Hilpert L, Doan HL, Favereau X. Comparison of TransFemoral transcatheter aortic valve replacement performed with a minimally invasive simplified technique: "FAST" versus a standard approach. *J Invasive Cardiol* 2019;31:300–306.
16. Junquera L, Urena M, Latib A, Munõz-Garcia A, Nombela-Franco L, Faurie B, Veiga-Fernandez G, Alperi A, Serra V, Regueiro A, Fischer

Q, Himbert D, Mangieri A, Colombo A, Munõz-Garciá E, Vera-Urquiza R, Jiménez-Quevedo P, La Torre JM De, Pascual I, Garcia Del Blanco B, Sabaté M, Mohammadi S, Freitas-Ferraz AB, Guimarães L, Couture T, Côté M, Rodés-Cabau J. Comparison of transfemoral versus transradial secondary access in transcatheter aortic valve replacement. *Circ Cardiovasc Interv* 2020.

17. Kappetein AP, Head SJ, Généreux P, Piazza N, Mieghem NM Van, Blackstone EH, Brott TG, Cohen DJ, Cutlip DE, Es GA Van, Hahn RT, Kirtane AJ, Krucoff MW, Kodali S, MacK MJ, Mehran R, Rodés-Cabau J, Vranckx P, Webb JG, Windecker S, Serruys PW, Leon MB. Updated standardized endpoint definitions for transcatheter aortic valve implantation: the valve academic research consortium-2 consensus document. *Eur Heart J* 2012;33:2403–2418.
18. Généreux P, Head SJ, Mieghem NM Van, Kodali S, Kirtane AJ, Xu K, Smith C, Serruys PW, Kappetein AP, Leon MB. Clinical outcomes after transcatheter aortic valve replacement using valve Academic Research Consortium definitions: a weighted meta-analysis of 3,519 patients from 16 studies. *J Am Coll Cardiol* 2012;59:2317–2326.
19. Arnold SV, Manandhar P, Vemulapalli S, Kosinski A, Desai ND, Bavaria JE, Carroll JD, Mack MJ, Thourani VH, Cohen DJ. Impact of short-term complications of transcatheter aortic valve replacement on longer-term outcomes: results from the STS/ACC Transcatheter Valve Therapy Registry. *Eur Hear J - Qual Care Clin Outcomes* 2020. Available at: https://doi.org/10.1093/ehjqcco/qcaa001.
20. Généreux P, Cohen DJ, Williams MR, Mack M, Kodali SK, Svensson LG, Kirtane AJ, Xu K, McAndrew TC, Makkar R, Smith CR, Leon MB. Bleeding complications after surgical aortic valve replacement compared with transcatheter aortic valve replacement: insights from the PARTNER i trial (Placement of Aortic Transcatheter Valve). *J Am Coll Cardiol* 2014;63:1100–1109.
21. Batchelor W, Patel K, Hurt J, Totten J, Burroughs P, Smith G, Cuervo M, Davis L, Damluji AA, Epps K, Sherwood M, Barnett S, Geloo N, Yazdani S, Sarin E, Ryan L, Noel T. Incidence, prognosis and predictors of major vascular complications and percutaneous closure device failure following contemporary percutaneous transfemoral transcatheter aortic valve replacement. *Cardiovasc Revascularization Med* 2020:1–9. Available at: https://doi.org/10.1016/j.carrev.2020.01.007.
22. Généreux P, Webb JG, Svensson LG, Kodali SK, Satler LF, Fearon WF, Davidson CJ, Eisenhauer AC, Makkar RR, Bergman GW, Babaliaros V, Bavaria JE, Velazquez OC, Williams MR, Hueter I, Xu K, Leon MB. Vascular complications after transcatheter aortic valve replacement: insights from the PARTNER (placement of AoRTic TraNscathetER valve) trial. *J Am Coll Cardiol* 2012;60:1043–1052.
23. Krishnaswamy A, Parashar A, Agarwal S, Modi DK, Poddar KL, Svensson LG, Roselli EE, Schoenhagen P, Tuzcu EM, Kapadia SR. Predicting vascular complications during transfemoral transcatheter aortic valve replacement using computed tomography: a novel area-based index. *Catheter Cardiovasc Interv* 2014;84:844–851.
24. Sharp ASP, Michev I, Maisano F, Taramasso M, Godino C, Latib A, Denti P, Dorigo E, Giacomini A, Iaci G, Manca M, Ielasi A, Montorfano M, Alfieri O, Colombo A. A new technique for vascular access management in transcatheter aortic valve implantation. *Catheter Cardiovasc Interv* 2010;75:784–793.
25. Cortese B, Trani C, Lorenzoni R, Sbarzaglia P, Latib A, Tommasino A, Bovenzi F, Cremonesi A, Burzotta F, Pitì A, Tarantino F, Colombo A. Safety and feasibility of iliac endovascular interventions with a radial approach. Results from a multicenter study coordinated by the Italian Radial Force. *Int J Cardiol* 2014;175:280–284. Available at: http://dx.doi.org/10.1016/j.ijcard.2014.05.012.
26. Lorenzoni R, Lisi C, Lazzari M, Bovenzi F. Tools & techniques: above the knee angioplasty by transradial access. *EuroIntervention* 2012;7:1118–1119.
27. Sirker A, Kwok CS, Kotronias R, Bagur R, Bertrand O, Butler R, Berry C, Nolan J, Oldroyd K, Mamas MA. Influence of access site choice for cardiac catheterization on risk of adverse neurological events: a systematic review and meta-analysis. *Am Heart J* 2016;181:107–119. Available at: http://www.sciencedirect.com/science/article/pii/S0002870316301752.
28. Kapadia SR, Kodali S, Makkar R, Mehran R, Lazar RM, Zivadinov R, Dwyer MG, Jilaihawi H, Virmani R, Anwaruddin S, Thourani VH, Nazif T, Mangner N, Woitek F, Krishnaswamy A, Mick S, Chakravarty T, Nakamura M, McCabe JM, Satler L, Zajarias A, Szeto WY, Svensson L, Alu MC, White RM, Kraemer C, Parhizgar A, Leon MB, Linke A, Makkar R, Al-Jilaihawi H, Kapadia S, Krishnaswamy A, Tuzcu EM, Mick S, Kodali S, Nazif T, Thourani V, Babaliaros V, Devireddy C, Mavromatis K, Waksman R, Satler L, Pichard A, Szeto W, Anwaruddin S, Vallabhajosyula P, Giri J, Herrmann H, Zajarias A, et al. Protection against cerebral embolism during transcatheter aortic valve replacement. *J Am Coll Cardiol* 2017;69:367–377.
29. Lansky AJ, Schofer J, Tchetche D, Stella P, Pietras CG, Parise H, Abrams K, Forrest JK, Cleman M, Reinöhl J, Cuisset T, Blackman D, Bolotin G, Spitzer S, Kappert U, Gilard M, Modine T, Hildick-Smith D, Haude M, Margolis P, Brickman AM, Voros S, Baumbach A. A prospective randomized evaluation of the TriGuard™ HDH embolic DEFLECTion device during transcatheter aortic valve implantation: results from the DEFLECT III trial. *Eur Heart J* 2015;36:2070–2078. Available at: https://doi.org/10.1093/eurheartj/ehv191.