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Ultrasound-guided short-axis out-of-plane *vs.* long-axis in-plane technique for radial artery catheterization: an updated meta-analysis of randomized controlled trials

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Abstract. – OBJECTIVE: Short-axis out-of-plane (SA-OOP) and long-axis in-plane (LA-IP) are the two major approaches used in ultrasound (US)-guided radial arterial catheterization. Nevertheless, their efficacy and safety remain controversial. Therefore, this meta-analysis aimed at comparing the two approaches for radial arterial catheterization.

MATERIALS AND METHODS: The PubMed, Embase, and Cochrane Library databases were searched for relevant articles published from database inception until December 2020. We selected randomized controlled trials comparing the short- and long-axis methods for US-guided radial artery catheterization. The results were analyzed using RevMan software to determine the adequacy and conclusiveness of the available evidence.

RESULTS: Six studies (725 patients) ultimately met the inclusion criteria. No significant difference was observed between the SA-OOP and LA-IP approaches for US-guided radial artery catheterization (relative risk [RR], 0.99; 95% confidence interval [CI], 0.96-1.03; p =0.61; I^2=0%). The first-attempt success rate was similar between the two groups (relative risk [RR], 1.02; 95% CI, 0.79-1.32; p =0.90; I^2=87%). The incidence of hematoma formation was similar between the two groups (RR, 1.91; 95% CI, 0.66-5.56; p =0.24; I^2=77%).

CONCLUSIONS: The SA-OOP approach does not increase the total or first-attempt success rate of radial artery catheterization using the LA-IP approach. More highly powered well-designed trials are needed to evaluate additional outcomes.

Key Words:
Ultrasound guidance, Long-axis in-plane, Short-axis out-of-plane, Radial artery catheterization.

Introduction

Arterial catheterization is the most commonly performed invasive procedure in the intensive care unit, operating room, and emergency department. Arterial cannulation, which enables continuous blood pressure measurement and blood sampling for blood gas analysis, can be applied to guide fluid therapy in critically ill or operative patients[1-3]. Due to its superficial location, the radial artery is a preferred site for arterial catheterization and has a low rate of procedural complications from arterial catheterization[4,5]. Radial artery catheterization is generally considered invasive but safe in critically ill patients. However, hematoma and thrombotic, mechanical, or infectious complications can occur during the procedure[6,7].

In an attempt to reduce cannulation failure rates and associated complications, ultrasound (US)-guided vascular cannulation has been generally advocated in recent years. Its use can improve the success rate of various vascular catheterization procedures and reduce complication rates[8]. Several meta-analyses have demonstrated the advantage of US-guided vascular catheteriza-

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tion over a digital palpation-guided approach[2,9,10]. However, controversy persists regarding the US-guided short-axis out-of-plane (SA-OOP) *vs.* long-axis in-plane (LA-IP) approach. Each method has distinct advantages and disadvantages, the results of which may increase or decrease complications[11]. A previous meta-analysis[12] of four studies demonstrated insufficient evidence of which approach was superior in patients undergoing US-guided radial arterial catheterization. Several randomized controlled trials (RCTs) have recently been published on this topic. Thus, this updated meta-analysis of RCTs aimed to compare the efficacy and safety of these two techniques to determine the adequacy and conclusiveness of the currently available evidence.

Materials and Methods

This meta-analysis was performed according to the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement[13]. The protocol for this meta-analysis was not registered.

Eligibility Criteria

Published RCTs comparing two-dimensional US-guided SA-OOP and LA-IP for radial artery cannulation in adult patients were included in this meta-analysis. The inclusion criteria were as follows: (1) population: patients requiring vascular catheterization; (2) comparison: study compared SA-OOP and LA-IP techniques for US-guided vascular catheterization; (3) outcome measure: the first-attempt success rate was reported; and (4) study design: RCTs. Two reviewers independently assessed and agreed to include each study in this systematic review.

Information Sources

Relevant articles published in all languages from database inception until December 27, 2020, were identified in PubMed, Embase, and the Cochrane Central Register of Controlled Trials. We also searched for references from previously published meta-analyses for eligible trials.

Search Strategy

We used exploded Medical Subject Headings and the appropriate corresponding keywords including "ultrasound," "ultrasonography," "ultrasonic," AND "catheterization"; "cannulation," "catheter," "catheters," "insertion," AND "long axis"; and "short axis," "in plane," "out of plane," "longitudinal," "transverse," AND "radial artery." Details of each search strategy are provided in the supplementary material. For completeness, the reference lists of the included RCTs and other accepted papers were manually reviewed to identify any additional studies.

Study Selection

Two authors independently searched the RCTs if they compared the real-time two-dimensional US-guided SA-OOP and LA-IP techniques for radial artery cannulation in patients. Full-text articles of the possible studies were retrieved and assessed for eligibility. Any divergence between the two authors' assessments was resolved by a third author *via* discussion.

Data Collection Process

The required data from the eligible RCTs and all data were extracted from a MAC number of data sheet by the two reviewers. Any divergence was resolved through discussion and consensus with the third author.

Data Items

The standard form used for the data collection from the full text of all studies included the following data: first author, year of publication, sample size, patient population, number of patients, patient ages, total success rate, cannulation time, number of attempts, operator experience, puncture site, and US equipment type. The primary outcome was the total success rate, while the secondary outcomes included the first-attempt success rate and access-site hematoma.

Risk of Bias of Individual Studies

Two authors independently assessed the internal validity of the included studies using the Cochrane Collaboration Risk of Bias tool[14]. The criteria included a method of randomization, allocation concealment, participant and personnel blinding, outcome assessment blinding, incomplete outcomes data, selective reporting, and any other bias. Criteria were individually scored as a low, unclear, or high risk of bias.

Summary Measures and Synthesis of Results

The primary outcome of this meta-analysis was "total success rate" among the included patients. Secondary outcomes were the first-attempt success rate and reported hematoma formation rate.

We calculated the weighted mean difference (WMD) with 95% confidence interval (CI) for continuous outcomes and the odds ratio (OR) for relative risk (RR) with a 95% CI for dichotomous outcomes. A random-effects model was used regardless of heterogeneity, which was reported using the I^2 statistic. Significant heterogeneity was indicated by a value of I^2>50%[15]. Potential sources of heterogeneity were determined if significant heterogeneity was observed. Potential publication bias was not assessed because of the small number of included RCTs. Possible sources of heterogeneity were assessed by sensitivity analyses performed by omitting one study in each turn and evaluating the influence of each on the overall estimate [14]. Unless indicated otherwise, two-tailed p-values < 0.05 were considered statistically significant. The statistical analysis was performed using RevMan software (version 5.3; Cochrane Collaboration, Copenhagen, Denmark) for outcome measurements.

Results

A total of 129 potentially relevant publications were identified. Of them, 52 duplicates were removed, while another 69 articles were removed after the title and abstract screening. 8 articles were subjected to full-text review; of them, two were excluded. Ultimately, six RCTs that fulfilled our inclusion criteria were included in the meta-analysis (Figure 1)[16-21].

Study Characteristics

The six included studies (725 patients) were published between 2013 and 2020. The sample of patients ranged from 84 to 163. The patients' baseline characteristics were similar between the two groups. All operators had experience performing US-guided radial artery catheterization. All studies reported the total success rate, first-attempt success rate, and various complications. The details of the study characteristics are presented in Table I.

Risk of Bias Assessment

None of the studies met the criteria for a low risk of bias. All RCTs were adequately randomized, minimizing the selection bias. For evident technical reasons, it was impossible to perform a blinded study. Publication bias was examined only for primary outcomes, and none was found. An overview of the risk of bias at the individual study level is shown in Figure 2.

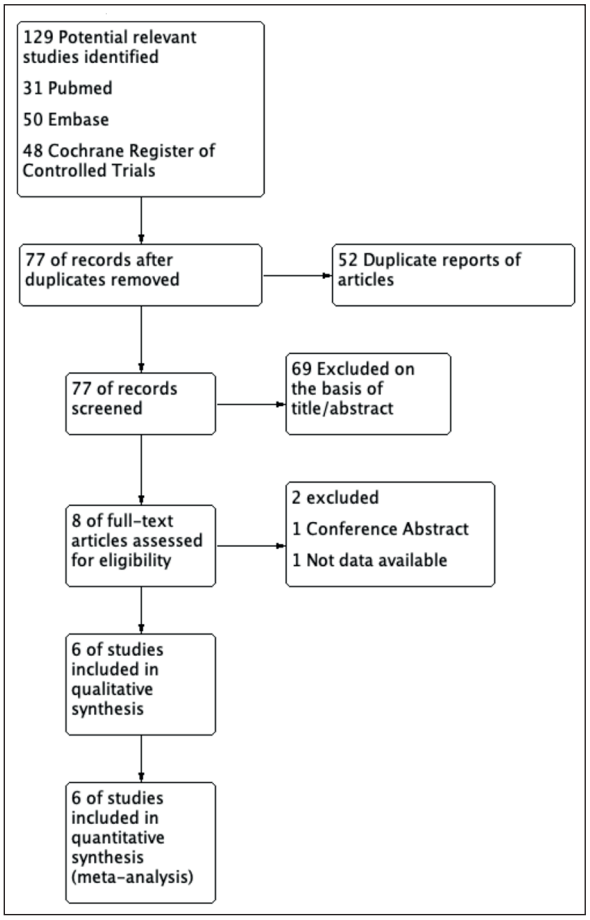

Figure 1. Flow chart of the study selection process.

Primary Outcome

Total Success Rate

All six RCTs investigated the overall success rates of SA-OOP and LA-IP for US-guided radial artery catheterization. However, no significant difference was observed between the two groups (RR, 0.99; 95% CI, 0.96-1.03; p =0.61; I^2=0%). A forest plot and pooled analysis of the risk ratio for total success rate are provided in Figure 3.

Second Outcome

First-attempt Success Rrate

The first-attempt success rate was similar between the SA-OOP and LA-IP approaches for

US-guided radial artery catheterization (RR, 1.02; 95% CI, 0.79-1.32; p =0.90; I^2=87%). A forest plot and pooled analysis of the risk ratio for first-attempt success rate are provided in Figure 4.

The reported incidence of hematoma formation was similar between the SA-OOP and LA-IP approaches for US-guided radial artery catheterization (RR, 1.91; 95% CI, 0.66-5.56; p =0.24; I^2=77%). A forest plot and pooled analysis of the risk ratio for hematoma formation rate are provided in Figure 5.

Discussion

The major findings of this meta-analysis were as follows: (1) The total success rates were similar between the SA-OOP and LA-IP approaches when used for radial artery catheterization; (2) The first-attempt success rate was also similar between the two approaches when used for US-guided radial artery catheterization; and (3) No significant intergroup differences in hematoma formation were observed.

The results of the previous meta-analysis showed a clear benefit from US guidance for radial artery catheterization compared with traditional palpation. US-guided radial artery catheterization increases the first-attempt success rate but not the total cannulation success *vs.* traditional palpation techniques. This substitution simultaneously reduces the number of attempts[9,22,23].

Table I. Characteristics of the individual studies.

Study	No. of patients (M/F)	Patient population	Mean age (years)	Weight	Total success rate (%)	First attempt success rate (%)
Berk et al[16] (2013; Turkey)	S: 54 (23/31) L: 54 (31/24)	ASA I-III, require an	S: 56 ± 1 L: 54 ± 2 arterial catheter	S: 78 ± 18 L: 76 ± 16	S: 100 L: 100	S: 51 L: 76
Quan et al[17] (2014; China)	S: 81 (59/22) L: 82 (64/18)	Undergo liver surgery or	S: 49.2 ± 8.1 L: 46.1 ± 7.9 splenic resection under general anesthesia	S: 76.4 ± 12.2 L: 72.1 ± 10.5	S: 100 L: 97.6	S: 88.9 L: 73.2
Abdalla et al[18] (2017; Egypt)	S: 42 (NR) L: 42 (NR)	Surgical and ICU patients	S: 55 ± 11 L: 59 ± 9 indicated for arterial catheterization	S: 84 ± 32 L: 84 ± 31	S: 60 L: 70	S: 50 L: 27
Sethi et al[19] (2017; India)	S: 75 (46/29) L: 75 (41/34)	Surgical patients indicated	S: 59.5 ± 8.2 L: 57.7 ± 7.6 for arterial catheterization	S: 62.8 ± 11.6 L: 64.6 ± 12.2	S: 92.0 L: 93.3	S: 80
Karam et al[20] (2020; Korea)	S: 70 (43/27) L: 66 (36/30)	Patients over 18 years of	S: 64.3 ± 13 L:63.6 ± 13.3 age who were scheduled for elective cardiac surgery requiring radial artery cannulation	S: 64.3 ± 14.9 L: 63.2 ± 12.2	S: 100 L: 100	S: 94.3 L: 68.2
Arora et al[21] (2020; Oman)	S: 42 (NR) L: 42 (NR)	Patients scheduled for elective cardiac surgery	S:54.10 ± 17.17 L:56.69 ± 14.82	NR	S: 100 L: 100	S: 57.1 L: 85.7

Continued

Table I *(Continued)*. Characteristics of the individual studies.

Cannulation time	No of attempts	No of needle redirections	Hematoma	Arterial puncture	Operator	Ultrasound equipment
S: 46.8 ± 34 L: 23.7 ± 17	S: 1.5 ± 0.5 L: 1.27 ± 0.4	S: 2 ± 1 L: 1.5 ± 0.6	S: 23 L: 2	NR	Anesthetists (had placed more than 50 ultrasound-guided arterial lines	Ultrasound system (Esaote My Lab 30, US Machine, Florence, Italy) and a linear probe with 18 MHz frequency
S: 29.7 ± 17.2 L: 26.2 ± 9.8	NR	NR	S: 12 L: 15	NR	Experienced anaesthetists, who had previously cannulated 450 radial arteries and used the ultrasound-guided technique for approximately 200 procedures	Terason 2000; Terason, Burlington, MA, USA
S: 28 ± 19 L: 66 ± 5	S: 1.6 ± 0.8 L: 1.8 ± 0.7	NR	S: 11 L: 11	NR	Expert operators	Toshiba Xario, Japan, PLT-805AT transducer
S: 28.4 ± 8.2 L: 27.6 ± 7.6	NR	NR	S: 8 L: 0	NR	Anesthetists had placed more than 100 arterial lines by using either in-plane or out-of-plane approaches	Probe (MicroMaxx SLA/13-6 MHz, SonoSite Inc., Bothell, WA, USA), ultrasound system (SonoSite MicroMaxx Ultrasound System, SonoSite Inc.)
S: 87.3 (71.9-107.5) L: 117.7 (92.6-181.8)	S: Number of attempts (1/2/3) 66/2/2 L: Number of attempts (1/2/3) 45/14/6	NR	S: 3 L: 7	S: 4 L: 9	Anesthetists had performed more than 100 cases of radial artery cannulation by using either DNTP or LAX-IP technique	Probe (L15-7io; Philips, seattle, Wa, Usa) , ultrasound system (iE33; Philips)
S: 108.21 ± 137.11 L: 75.90 ± 52.05	S: Number of attempts (1/2/3) 24/12/6 L: Number of attempts (1/2/3) 36/6/0	S: No redirections 24 1 redirection 10 ≥ 2 redirections 8 L: No redirections 36 1 redirection 6 ≥ 2 redirections 0	S: 3 L: 0	NR	Anesthetists had previously performed more than 50 radial artery cannulations in adult patients using either the in-plane or the out-of-plane ultrasound approach	Probe (L15-7io; Philips, seattle, Wa, Usa) , ultrasound system (iE33; Philips)

The US-guided technique enables visualization of the radial artery in the forearm and can guide the puncture needle in real time and visualize the arterial needle/catheter[24]. Both approaches have been used for US-guided radial arterial catheterization with variable success rates.

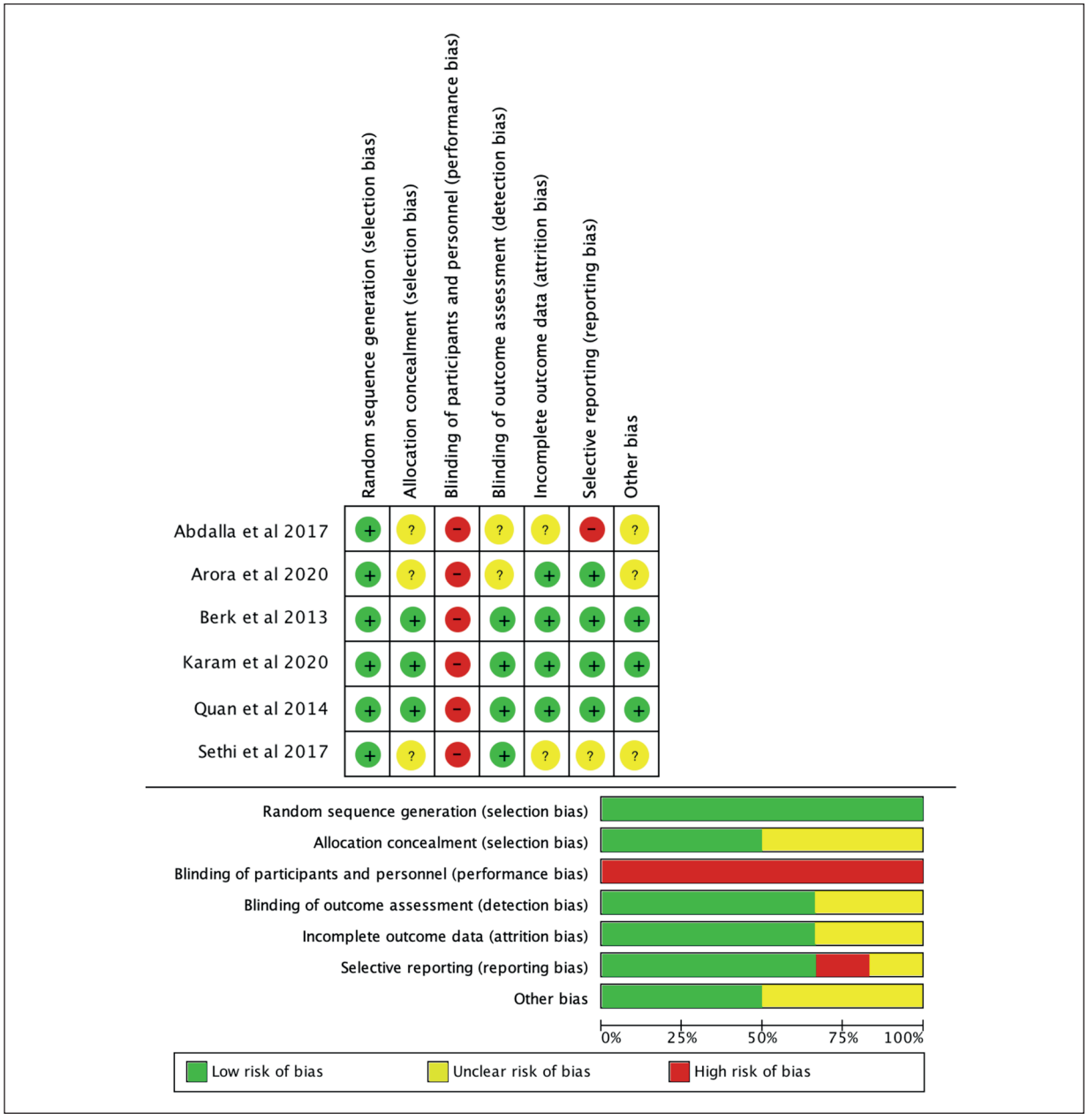

Figure 2. Assessment of the risk of bias.

The vessel and needle/catheter can be visualized along the long axis using the LA-IP approach, which therefore allows better visualization of the needle shaft and needle tip throughout the needle advancement, which allows it to be a theoretically more accurate method. The SA-OOP approach visualizes the vessel along its short axis. Relevant structures and their relationships can be visualized simultaneously and side by side during cannulation. The most recently described technique is termed dynamic needle tip positioning[25]. This was a modified version of the SA-OOP approach in which the cannula tip and transducer were alternately shifted so that the needle tip was successively visible or invisible on the screen[26,27]. Two of the included trials used US-guided dynamic needle tip visualization for radial artery puncture.

This meta-analysis found no advantage of US-guided cannulation in total success, first-attempt success, or hematoma formation rates in the two groups. The previous meta-analysis by Liu

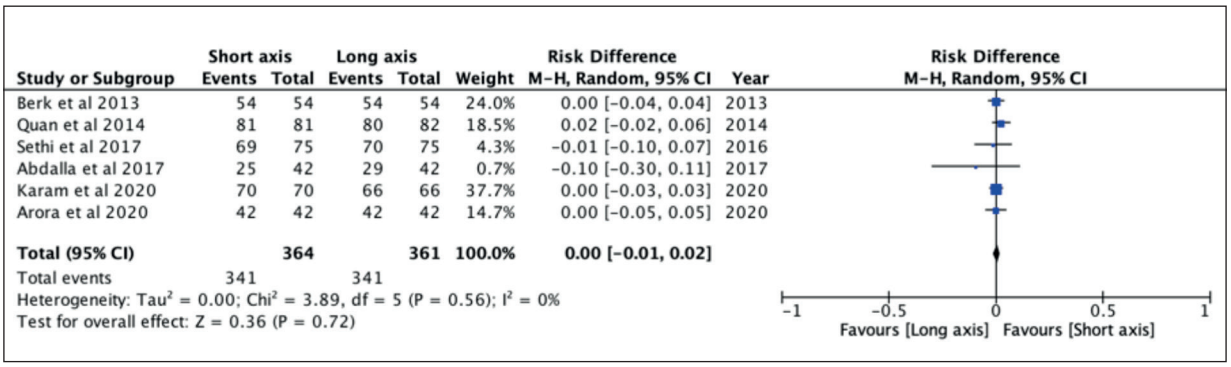

Figure 3. Forest plot of the total success rate.

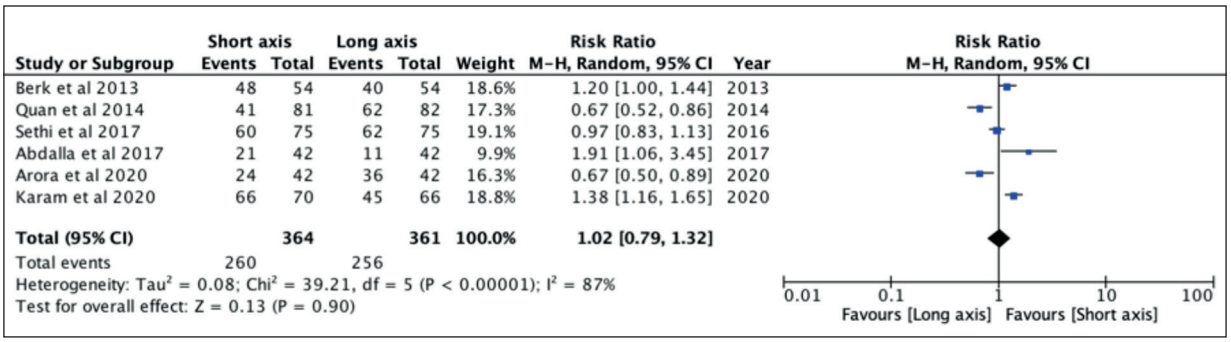

Figure 4. Forest plot of the first-attempt success rate.

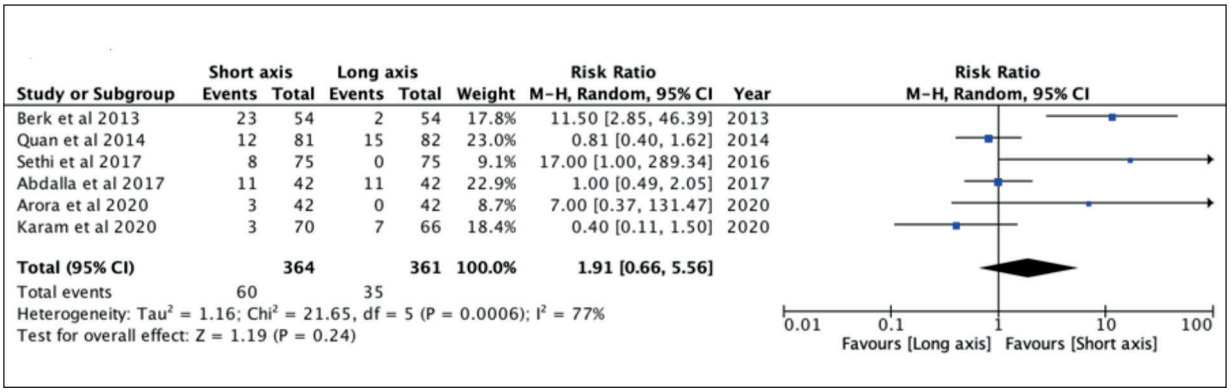

Figure 5. Forest plot of the hematoma formation rate.

et al[12] reported the same result of no significant differences in the total success rate, first-attempt success rate, cannulation times, or complications between the two approaches. Further high-quality trials are needed to confirm or refute this finding.

Limitations

This meta-analysis had several limitations. First, due to the features of the trials, double-blinding was not possible. This may have resulted in performance and detection bias. Second, we could not perform subgroup or sensitivity analyses because of the limited data. Third, there was considerable heterogeneity between the included studies related to differences in operator experience, patient populations, US equipment, and outcome definitions which might have biased our results.

Conclusions

The SA-OOP approach does not increase the total or first-attempt success rate over the LA-IP approach for radial artery catheterization. However, the findings of a meta-analysis should be interpreted with caution given the presence of heterogeneity.

Conflict of Interest

The Authors declare that they have no conflict of interests.

Acknowledgements

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