

Safety and Effectiveness of Carbon Dioxide Angiography for Endovascular Aneurysm Repair: Systematic Review and Meta-analysis

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Safety and Effectiveness of Carbon Dioxide Angiography for Endovascular Aneurysm Repair: Systematic Review and Meta-analysis

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Dedicatória

Ao Professor Doutor João Rocha Neves, pela disponibilidade, paciência e incentivo constantes perante o desafio proposto, e pelos valiosos ensinamentos que me proporcionou.

Aos meus pais, que sempre preencheram a minha vida com amor, alegria e apoio incondicional. Obrigada por acreditarem nos meus sonhos.

À minha Paulinha, a minha pessoa, por ser a minha maior fã e companheira das memórias mais bonitas.

Ao Jorge, por acalmar as tempestades desta jornada com um carinho e amor incansáveis, em todos os momentos.

E aos meus amigos – os que convocam casa, e os que fizeram do Porto a segunda.

Obrigada, de coração.

Safety and Effectiveness of Carbon Dioxide Angiography for Endovascular Aneurysm Repair: Systematic Review and Meta-analysis

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AUTHOR CONTRIBUTIONS

Each author contributed significantly to this study:

- Concept and design: AFF, JRN
- Data collection and analysis: AFF, JRN
- Manuscript drafting: AFF, JRN, LD, MD
- Critical revision for intellectual content: AFF, JRN, LD, MD, HR, SL
- Statistical analysis: JRN

All authors reviewed and approved the final manuscript.

CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

ACKNOWLEDGMENTS

The authors have no acknowledgments to declare.

FUNDING

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This article was supported by National

Funds through FCT - Fundação para a Ciência e a Tecnologia, I.P., within CINTESIS, R&D Unit (reference UIDB/4255/2020).

6-item study sponsor checklist:

- 1) The author(s) received no financial support for the preparation.
- 2) The author(s) received no financial support for the preparation.
- 3) The author(s) received no financial support for the preparation.
- 4) The author(s) received no financial support for the preparation.
- 5) The author(s) received no financial support for the preparation.
- 6) The author(s) received no financial support for the preparation.

Total word count: 4413

References: 40

KEYWORDS: Abdominal aortic aneurysm, digital subtraction angiography, carbon dioxide (CO₂), Endovascular procedures, Acute kidney Injury (AKI)

ABSTRACT

BACKGROUND

Endovascular aortic aneurysm repair (EVAR) traditionally relies on iodinated contrast media (ICM), which poses risks for patients with renal insufficiency or iodine allergy. Carbon dioxide (CO₂) emerged as an alternative, however further investigation is required.

This systematic review and meta-analysis assess the safety and efficacy of CO₂ angiography in EVAR.

MATERIALS AND METHODS

A comprehensive literature search in PubMed, Cochrane Library, Scopus and ISI databases identified studies published up to February 2025. The primary safety endpoint was acute kidney injury (AKI) occurrence, while for efficacy it was technical success.

Random-effects meta-analysis pooled AKI incidence, with heterogeneity explored via meta-regression. The assessment of studies' quality used National Heart, Lung, and Blood Institute (NHLBI) Study Quality Assessment Tool and Risk of Bias 2 tools.

RESULTS

Eight observational studies involving 1699 patients were included, with 581 undergoing EVAR with CO₂ angiography and 1118 receiving ICM.

No significant difference in AKI risk was found (RR 0.65, 95% CI: 0.27–1.56, $I^2=0\%$). CO2 angiography reported longer procedural times and higher radiation exposure in some studies. Intraoperative endoleak detection was similar, or slightly higher, in the CO2 group. CO2-related adverse events reported were mostly mild and resolved spontaneously. Mortality rates were comparable between groups.

CONCLUSION

CO2 angiography reduces postoperative renal function deterioration and shows comparable safety and efficacy to ICM in EVAR procedures. Nevertheless, further large-scale randomized trials are pivotal for optimizing CO2 angiography as a viable alternative to ICM.

INTRODUCTION

Endovascular aneurysm repair (EVAR) is recommended as the first-line treatment for most patients with an abdominal aortic aneurysm (AAA) and suitable anatomy, according to most recent clinical practice guidelines (1). Its success relies on imaging to achieve minimally invasive procedures (2). Subsequently, iodinated contrast medium (ICM) has been used as the gold standard contrast agent for diagnostic and therapeutic purposes. However, its nephrotoxic potential has been well described and could increase the likelihood of contrast-induced nephropathy, especially in patients with already impaired renal function (3-9). Moreover, there is a risk of hypersensitivity reactions to ICM and, although there are pretreatment protocols that reduce their incidence and severity, patients with a history of anaphylaxis would significantly benefit from completely avoiding ICM. (10). Indeed, renal impairment is a recurrent comorbidity in AAA patients and stands alone as an independent predictor of mortality after EVAR itself (11, 12). Li et al (13) reported that 39.33% of patients undergoing EVAR for complex AAA presented with CKD and Zarkowsky et al (14) reported that 3.3% of patients developed AKI or hemodialysis requirement after EVAR, leading to a 14% lower estimated 5-year survival rate compared to patients without renal dysfunction.

Aiming at protecting the patient's renal function and bypassing a possible hypersensitivity reaction, carbon dioxide (CO₂) angiography has become a viable alternative option. CO₂ angiography has been employed in numerous vascular interventions for more than 30 years (7, 8). Nonetheless, its usefulness in EVAR remains less well-established (8). From a practical standpoint, CO₂ can be used as a single contrast agent (i.e. zero-ICM procedures) or an adjunct, significantly diminishing the amount of ICM employed. Its physical-chemical characteristics present a series of

advantages, such as being non-nephrotoxic and non-allergenic (9, 15, 16). However, new challenges emerge such as poorer visualization of visceral vessels originating in the posterior aortic wall, possibly higher radiation exposure and increased operative times (7-10, 12, 17, 18).

Several studies have recently analyzed the application of CO₂ angiography in EVAR with promising results regarding renal impairment and endoleak detection (2, 8, 12, 17). Nevertheless, outcomes related to procedural success rate, image quality and complications often vary and a comprehensive interpretation of the existing evidence is clinically relevant. Therefore, this systematic review was directed at evaluating the safety and effectiveness of CO₂ angiography compared to standard ICM-based protocols in EVAR procedures.

MATERIALS AND METHODS

Literature Search

This systematic review was conducted in accordance with The Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) Statement and the Assessing the Methodological Quality of Systematic Reviews (AMSTAR)-2 critical appraisal tool (19, 20). Given the nature of this study design, ethical approval from an institutional review board was not required. The review protocol was registered at PROSPERO with the reference CRD42024530932.

The following PICO (Population, Intervention, Comparison, Outcomes) frame was implemented: in patients with AAA (P) undergoing elective or non-elective EVAR (I) how does CO₂ angiography perform as compared with ICM use (C) regarding safety and efficacy (O).

A systematic search was performed in four databases: PubMed, Web of Science, Cochrane Library and Scopus, in January 2025. The query and keywords are shown in Supplemental Table 1. The last search was conducted on the 10th of February 2025, without temporal restrictions. Additionally, the references of the included primary studies and relevant available systematic reviews were screened to search for any further articles of possible interest.

Selection Criteria

Included studies were randomized controlled trials (RCTs), non-randomized interventional studies, cohort studies, case-control studies and case series; had EVAR and CO₂ angiography performed, a sample size ≥ 50 patients and the primary outcomes of this review incorporated. Additionally, patients had to be aged ≥ 18 years.

Exclusion criteria comprised any study with less than 50 patients, in vitro studies, editorials, letters to the editor, commentaries, expert opinions, book chapters, guidelines; that were unrelated to the research question, did not define the reported outcomes precisely or did not assess any of the primary outcomes of interest for this review. Duplicates were also excluded. No exclusion criteria based on date were applied.

Data extraction

After duplicates removal, two authors (AFF and JRN) independently participated in study selection. Any disagreement was solved by the intervention of a third author (MD). First, studies were selected by title and abstract, and the remaining ones were eligible for full-text assessment. The selected studies were revised to avoid repeated populations.

Two authors (AFF and JRN) independently retrieved quantitative and descriptive statistical data from the eligible studies, using a standardized data collection form. The data extracted were: journal, publication year, study design, study center, recruitment period, sample size, frequency of CO₂ and ICM usage, participants' mean age, gender distribution, frequency of cardiovascular comorbidities, baseline kidney function, CO₂, ICM and total radiation doses, operative time, fluoroscopy time, urgent vs elective procedures, C-arm vs Hybrid room, procedure-related death, technical success, intra- and post-operative complications, endoleak detection, lowest renal artery (LoRA) and hypogastric Artery Visualization mean length of stay, reinterventions, follow up time and mortality.

Assessment of study quality

Two independent authors (AFF and JRN) systematically evaluated the study methodologies and assessed the risk of bias by applying the National Heart, Lung, and Blood Institute (NHLBI) Study Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (2013). (21) Any divergences between the authors were discussed and resolved. If the disagreement persisted, a third author was consulted. The review process was conducted with unblinded study authorship. ROBvis online tool was employed to visualize the risk of bias registered (mcguinlu.shinyapps.io/robvis/–1/10/2024). The quality of evidence for the included articles was evaluated using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) approach and classified into four levels of quality (high, moderate, low, and very low). (22)

Outcomes assessment and definitions

The primary outcome of interest for safety was AKI occurrence, the definition applied by each study compiled in Supplemental Table 2. Regarding efficacy, the primary endpoint was technical success, as per the definition determined by each study author. These endpoints were assessed during hospitalization, in the immediate post-operative period, or in follow-up visits, as established by each study.

Quantitative synthesis

A random-effects meta-analysis using the restricted maximum likelihood method of log-transformed proportions to calculate the meta-analytical pooled incidence of AKI among participants was performed. Heterogeneity was assessed using the Q-Cochran p -value and the I^2 statistic, with a p -value < 0.10 and an $I^2 \geq 50\%$ considered to

represent substantial heterogeneity. Sources of heterogeneity were assessed by leave-one-out sensitivity analysis and univariable meta-regression models. Assessed covariates included the publication year, participants' mean age, percentage of male participants, percentage of patients with arterial hypertension, dyslipidemia, diabetes mellitus (DM), coronary artery disease (CAD), chronic obstructive pulmonary disease and CKD stage. The covariates used in the adjusted models are available in Supplemental Table 3.

All statistical analysis was performed using software R (metafor package).

RESULTS

Search Results

Twelve studies were eligible for full-text assessment, which culminated in four studies' exclusion (Figure 1), the reasons being unavailability of the primary outcomes of interest (N=2,) and non-performance of CO₂ angiography (N=2). Thus, a total of 8 published articles were included (7, 23-28).

Description of Studies

The 8 studies included were observational, 3 being prospective (24, 27, 29) and 5 retrospective (7, 23, 25, 26, 28). They were performed in 6 different countries within 3 continents – 2 studies from North America (26, 27), 5 studies from European countries (7, 23-25, 29), and 1 study from Asia (28). A total of 1699 patients were assessed, with a minimum of 65 patients (24) and a maximum of 381 patients per study (28). CO₂ angiography was performed on 581 patients, while 1118 patients underwent the procedure with ICM. The identification and summary description of the included studies is shown in Table 1.

The percentage of male participants was 87.1% (n=1479). The mean participants' age was 75.9 years old. The CO₂ population reported older patients across studies, except in (29) and (25), the mean ages ranging from 73.8 (7) to 78 (23); in the ICM population, the range was from 70.6 (7) to 80 (23, 29).

Regarding the incidence of DM, the CO₂ population registered higher rates in three studies (7, 25, 26), ranging from 14% (28) to 35.3% (7). In two studies, a higher

incidence of DM was observed in the ICM group (23), ranging from 12% (26) to 24.8% (7). There was no difference observed in one study. (28).

In most studies, the CO₂ population showed a greater rate of significant CKD disease compared to the ICM population. (7, 23, 25, 26, 28). Serum creatinine values were consistently more elevated in the CO₂ population, ranging from 1.05 mg/dL (24) to 2.02 mg/dL (28), compared to a range of 0.9mg/dL (28) to 1.14 mg/dL (7) in the ICM population. Indeed, eGFR was lower in all CO₂ populations when compared to ICM populations, with minimum values of 30.2 mL/min/1.73m² (28) and maximum of 66.4 mL/min/1.73m² (25) vs 62.7 mL/min/1.73m² (28) and 78.6 mL/min/1.73m² (7) respectively, except for (29), which had a mean of 70 mL/min/1.73m² in the CO₂ population and 63 mL/min/1.73m² in the ICM population (29). A total of 6 patients were already on dialysis: 1 in the CO₂ group and 2 in the ICM group of (25), 2 in the CO₂ group in (27), 1 in the CO₂ group and 1 in the ICM group of (29). Three studies excluded patients undergoing dialysis from the study population. (7, 23, 28), and (27) excluded them from the statistical analysis.

Demographics and comorbidities of the populations included in the studies are available in Table 2.

Procedural details

Considering the 1023 patients solely submitted to ICM, the mean ICM dose administered ranged from 55 mL (28) to 148mL (26). Among the 296 patients receiving both ICM and CO₂, ICM dosage ranged from 4 mL (7) to 700 mL (29) and CO₂ dosage from 50 mL (26) to 990 mL (24). In the 380 patients solely submitted to CO₂, the mean CO₂ dose ranged from 600 mL (29) to 990 mL (24).

The mean total radiation dose was assessed in only 4 studies, with consistently higher values in the CO₂ group (23-26). In the CO₂ group, radiation exposure ranged from 161.3 Gy/cm² (24) to 500.5508 Gy/cm² (25) and in the ICM group, the range was from 159.86 Gy/cm² (23) to 529 Gy/cm² (26). Only 1 (27) performed the procedures with C-arm, (25), (23) and (30) performed in hybrid operation room.

Concerning operative time, all studies, apart from (27) and (29) registered longer durations in the CO₂ group (7, 23, 26, 28), whose operative time ranged from 69.5 minutes (23) to 180 minutes (26), while in the ICM population it varied from 55 minutes (23) to 193 minutes. (27). Both. (28) and (7) reported closely similar operative time between both populations.

Regarding fluoroscopy time, 2 studies observed longer times in the CO₂ population (23, 26) and 4 studies in the ICM population (7, 27-29). Among CO₂ patients, the range was from 14.0 minutes (29) to 46 minutes (26). In the ICM patients, from 12.6 minutes (23) to 49 minutes (28).

Technical success was 100% in the majority of the studies included, with the exception of the ICM populations of (28), (7) and (29), which achieved 99.7% (28), 99.3% (7) and 99.7% (29) technical success, respectively.

Procedural characteristics and contrast doses of each study are available in Table 3.

A total of 77 (13.3%) endoleaks – 9 (11.7%) type I, 62 (80.5%) type II, 1 (1.3%) type III, 2 (2.60%) type IV and 3 (3.40%) not specified - were detected intraoperatively with CO₂ angiography compared to 62 (5.25%) – 28 (45.2%) type I, 33 (53.2%) type II, 1 (1.61%) type III with ICM angiography. In two studies, CO₂ population associated with a higher rate of intraoperative endoleak detection (23, 26). (28) and (29) showed

equal detection rates of 0% in both groups (28, 29). The detection rate of endoleaks intraoperatively ranged from 0% (28, 29) to 63% (26) in the CO₂ population and from 0% (28, 29) to 65.5 (26) in the ICM population.

In the CO₂ group, the rate of LoRA visualization ranged from 69.4% (25) to 100% (27). No data was available for the ICM group. The rate of hypogastric artery visualization ranged from 27% (29) to 100% (27) in the CO₂ group, while in the ICM group (29) reported 83%. (29)

There was 1 procedure-related death registered: in the CO₂ population of (28), one patient (3.3%) died from intestinal necrosis, presumably due to cholesterol embolism. Thus, it was not attributed to the use of CO₂ angiography. (28)

There were 32 reports of adverse effects reported in the CO₂ group, including 13 cases of abdominal pain/nausea (23, 24, 29), 8 cases of nausea and/or vomiting (24, 25, 29), 4 cases of abdominal pain (24), 3 hypotension episodes (25), 2 cases of diarrhea (24), 1 femoral thrombosis (23) and 1 intestinal necrosis (28). The only fatal adverse effect reported was the intestinal necrosis recorded in (28); the femoral thrombosis and distal embolization required surgical intervention and the remaining complications resolved spontaneously. Two studies did not report any CO₂-related adverse effects (7, 27). For the ICM group, 2 contrast-related adverse effects were presented: a case of intestinal necrosis in (28), which was not fatal, and 1 episode of distal embolization in (23).

Postoperative clinical and procedural outcomes and adverse events are available in Table 4.

The mean length of stay was longer in the CO₂ population in 2 studies (7, 26), equal in one study (23) and higher in the ICM population in another study.(25) In the

CO₂ group, length of stay ranged from 3.9 days (26) to 7 days (7), while in the ICM group, it ranged from 2 days (26) to 5 days (25).

Renal function results

A total of 52 cases of AKI were reported among the studies included, with a higher incidence in the ICM population across all studies (7, 23, 25, 29), except for (28). One study did not report any AKI occurrence in the CO₂ group. (25) The AKI occurrence ranged from 0% (25) to 5.8% (23) in the CO₂ group and from 0.8% (25) to 10.3% (7, 26) in the ICM group.

The decrease in eGFR was more pronounced in the ICM population according to two studies (25, 27), (27) reporting the eGFR decrease in the ICM group was 12.7% superior compared to CO₂+ICM and 10.0% superior compared to CO₂ alone. In (7), eGFR decrease was greater in the CO₂ group (44 ml/min/1.73m² to 40 ml/min/1.73m² in the CO₂ population vs 42 ml/min/1.73m² to 41 ml/min/1.73m² in the ICM population). The eGFR reduction varied from 2.09 (25) to 4.0 (7) in the CO₂ population and from 1.0 (7) to 10.6 (25) in the ICM population. Only one study, Vacirca et al (24), registered no decrease in eGFR reduction in the CO₂ group.

Two studies found higher postoperative short-term eGFR values in the CO₂ group compared to the ICM group. (25, 28). Postoperative eGFR ranged from 34.6 mL/min/1.73 m² (28) to 69.2 mL/min/1.73 m² (25) in the CO₂ group and 66.4 mL/min/1.73 m² (28) to 67.2 mL/min/1.73 m² (25) in the ICM group. Chao et al. (26) described the postoperative eGFR as “unchanged”. One study reported eGFR at 1 month, which was 70 ml/min/1.73m² in the CO₂ group and 57 ml/min/1.73m² in the ICM group (29). Only one study determined the eGFR at 3 months, which was 66.4

ml/min/1.73m² in the CO₂ population and 59.3 ml/min/1.73m² in the ICM population.(28)

Postoperative serum creatinine levels were superior in the CO₂ group in most studies (7, 23, 25, 26), apart from (28) and (29). Short-term serum creatinine ranged from 1.02 mg/dL (24) to 1.8 mg/dL (26) in the CO₂ population and from 0.87 mg/dL (28) to 1.21 mg/dL (7) in the ICM population. One study reported serum creatinine values at 1 month, which were 1.0 mg/dL in the CO₂ group and 1.3 mg/dL in the ICM group (29). Two studies measured postoperative serum creatinine at 3 months, which ranged from 1.1mg/dL(23) to 1.81 mg/dL (28) in the CO₂ group and from 0.93 mg/dL (28) to 0.98 mg/dL (23)in the ICM group.

Concerning serum creatinine increase, one study reported a greater increase in the ICM group - 0.17 mg/dL - compared to the CO₂ group - 0.08 mg/dL - (25). On the other hand, another study observed an increase of 0.01 mg/dL in the CO₂ group and a decrease of 0.06 in the ICM group (26). One other study did not determine a difference in creatinine levels in the CO₂ group. (24)

The postoperative renal function outcomes are available in Table 5.

Follow-up results

There were 82 (14.1%) endoleaks detected at discharge – 2 (2.44%) type I, 59 (72.0%) type II, 21 (25.6%) not specified - identified in CO₂ patients postoperatively and 136 (11.5%) – 10 (7.35%) type I, 108 (79.4%) type II, 4 (2.94%) type III, 1 (0.74%) type IV, 13 (9.56%) not specified - in ICM patients. Three studies found a higher incidence of postoperative endoleaks in the CO₂ population (7, 23, 26) and two studies

in the ICM population. (28, 29) Postoperative endoleaks detection ranged from 0% (27) to 26.9% (23) in the CO2 population and 10% (7) to 24% (28) in the ICM population.

Three studies reported data on aneurysm enlargement: 19 cases were recorded, 17 patients (4.8%) in the ICM population and 2 (6.7%) in the CO2 group of (28). Two studies showed no cases of aneurysm enlargement. (7, 24).

Two studies reported data on reintervention: at 24 hours, 13 cases (1.4%) of the population (CO2) from (27). In (7), no need for re-intervention was recorded during total follow up time.

The median follow-up time was 3 months. Fifteen deaths were registered, 9 in ICM population (7, 23, 25, 27, 28). Two studies reported no mortality at all (24, 26). The mortality rate in the CO2 group ranged from 0% (23-26) to 3.3% (28) and from 0% (26, 28, 29) to 1.7% (7) in the ICM group.

Meta-analysis results

There was no statistical difference between the EVAR cohort assessed with CO2 angiography and the ICM angiography cohort regarding AKI risk, with an overall risk ratio of 0.65 (95% CI: 0.27–1.56) (I²=0%) (7, 23, 25, 28, 30), as shown in Figure 1. The test for overall effect was not significant, and the absence of notable heterogeneity indicates uniformity in effect sizes across studies, both in magnitude and direction, as shown in Supplemental Figure 1.

The analysis, performed using a random-effects model with the Mantel-Haenszel method, showed no statistically significant difference in the prevalence of diabetes mellitus (Supplemental Figure 2) or arterial hypertension (Supplemental Figure 4)

between the two cohorts. For DM, the overall risk ratio was 1.45 (95% CI: 0.91–2.31, $p = 0.11$), with significant heterogeneity detected ($p = 0.04$, $I^2 = 61\%$). Similarly, for hypertension, the overall risk ratio was 1.48 (95% CI: 0.95–2.31), with significant heterogeneity observed ($p < 0.01$, $I^2 = 98\%$), indicating that most variability among studies arose from differences in effect sizes rather than random variation. (7, 23, 25, 28, 30) The funnel plot for each co-morbidity is shown in Supplemental Figures 3 and 5, respectively.

Quality of studies

The risk of bias of the selected articles is displayed in Figure 3a. The risk of bias for each observational cohort is individually displayed in figure 3b. All observational cohorts had an overall low risk of bias, except for (27). The items most frequently associated with high risk of bias amongst observational cohorts included key potential confounding variables measurement and statistical adjustment for their impact.

DISCUSSION

This systematic review and meta-analysis aimed to evaluate the clinical efficacy and safety of CO₂ vs ICM angiography in patients submitted to EVAR.

In respect of safety, this meta-analysis does not provide robust evidence to establish a significant difference in AKI risk between CO₂ and ICM in EVAR procedures, as the confidence interval (CI) is wide and non-significant, as shown in Figure 2. AKI incidence was consistently lower in the CO₂ group, reflected in a pooled RR of 0.65 (95% CI: 0.27 to 1.56), suggesting a potential 35% reduction in AKI risk with CO₂. The generally more pronounced eGFR decrease in ICM groups and greater postoperative eGFR values in the CO₂ group further support the potential protective role of CO₂ on renal function, highlighting CO₂ angiography as a potentially safer option for minimizing kidney injury, which is consistent with most studies in current literature (15, 18). A meta-analysis by Ghumman et al from 2017 (15) on the use of CO₂ angiography for peripheral vascular interventions, found a statistically significant lower incidence of AKI with CO₂ angiography (4.3% vs 11.1%; odds ratio [OR] 0.465, 95% confidence interval [CI]: 0.218–0.992; p=0.048). In studies using solely CO₂, AKI incidence was 6.2%. This high value enhances that nephrotoxicity by ICM is not the only contributor to renal impairment in EVAR: ischemia-reperfusion injury from temporary blood flow reduction during the procedure; the disruption of atherosclerotic plaques during the manipulation of the aorta and subsequent release of emboli into the renal arteries; hemodynamic changes; systemic inflammation triggered by the surgical procedure and pre-existing CKD, DM or arterial hypertension (AHT), are other involved factors (18). Our findings could differ from Ghumman et al (15) due to the latter including older studies, which could reflect different clinical practice/diagnostic criteria; smaller sample size studies, potentially lacking statistical power to detect

significant differences and longer follow-up periods, which might detect late-onset renal impairment.

The funnel plot in supplemental Figure 1 demonstrates asymmetry, which could indicate potential selection bias: patients with pre-existing renal impairment, who are at a greater risk of AKI, are more likely to be selected for CO₂ angiography to avoid exacerbating kidney damage. (18) This bias is reflected in the higher prevalence of DM and hypertension in the CO₂ population, described contributors to AKI after ICM, although only a trend ($p < 0.1$) (31). The use of higher ICM loads in patients with already impaired renal function could have resulted in even higher rates of AKI, although this remains speculative.

When considering efficacy, the near-perfect levels of technical success were similar in both populations, which is consistent with literature (12, 32, 33). This validates the reliability of both contrast agents, especially noteworthy in CO₂ due to its unique characteristics and new challenges. However, longer operative times and higher radiation dose are registered in CO₂ angiography, which is closely related the requirement of multiple images of the same area to compensate the lower image quality and the limited familiarity with this technique. (15, 34) It is reasonable to anticipate that these differences will attenuate along the learning curve. Indeed, in Mendes et al (35), experienced professionals conducted the procedures and achieved equal operative times in both groups.

Contrast-related adverse events were predominantly reported in the CO₂ group, which could be due to reporting bias; rapid dispersion and subsequent localized ischemia, irritation or hemodynamic instability because of the gaseous nature of CO₂; and the technique's learning curve, which could cause suboptimal injection methods (15, 18). While mostly were mild and self-limiting, severe complications enhanced the

importance of careful procedural technique and diligent patient monitoring. A low incidence of adverse events was reported in the ICM group, the 2 identified events a case of intestinal necrosis and a distal embolization. This is likely attributable to underreporting minor events given the routine use of ICM and patient selection bias, as patients at higher risk for contrast-induced nephropathy may be preferentially chosen for CO₂ angiography. ICM's adverse effects could be mild, such as itching, fever or flu-like symptoms; or severe, as cardiac arrhythmias, contrast-induced nephropathy and anaphylactic shock. (36, 37).

Studies by Sueyoshi et al (38). and Mascoli et al (39) demonstrated CO₂ angiography's effectiveness in endoleak detection. (38) reported 100% sensitivity and specificity for direct endoleaks (types I and III) detection and (39) had higher agreement with contrast-enhanced ultrasound in detecting type II endoleaks than ICM angiography. However, Huang et al (40) reported poor sensitivity for type II endoleak detection. Our study observed a higher pooled rate of intraoperative endoleak of all types detection in the CO₂ cohort, which suggests that CO₂ angiography may offer superior sensitivity for detecting endoleaks. It could be due to the lower viscosity of CO₂, which allows it detect low-flow endoleaks, and the fact it acts as a negative contrast, facilitating posterior location endoleak's visualization. (39)

Study limitations

This study faced many limitations worth noting. First, few articles (<10) were eligible and the majority had a small sample size without sample sizing and power descriptions, which led to low precision of obtained results. There was severe heterogeneity amongst studies regarding most baseline patient characteristics, study

designs, and methodology. The authors were not able to perform meta-regression models on account of the insufficient number of included primary studies. Few preoperative risk factors were assessed through metanalysis. The lack of long-term follow-up data in most studies limits the ability to evaluate the sustained safety and efficacy of CO₂ angiography and further research is crucial to assess these parameters beyond the perioperative period. The potential for publication bias should be considered, as studies with favorable outcomes may be more likely to be published. Lastly, selection bias must be accounted for, as it could influence the outcome results and impact the generalizability of the findings.

This systematic review exposes the need for large cohorts and RCTs with a primary aim to assess AKI incidence and impact according to contrast agent and the prevention and management of postoperative AKI in EVAR patients. It is crucial to validate the current findings in literature and further uncover the existing gaps of knowledge. The potential impact of CO₂ might predispose clinicians to adapt their strategies for better management of these patients. Proficiency/ Learning curve bias may also be a factor, as poor image resolution increases the need for ICM usage and repeated imaging in the same area. However, this could also result from a more complex case, challenges in CO₂ delivery, the type of vascular access, or the graft used.

CONCLUSION

This meta-analysis demonstrated no statistically significant differences in AKI rates between the EVAR cohorts assessed with CO₂ angiography and ICM angiography, albeit the former had higher prevalence of baseline renal function impairment compared with the latter. In terms of technical success, the rates were almost identical, although operative times and radiation exposure tended to be longer with CO₂ vs ICM, which could be related to a learning curve effect. These findings support the potential equivalence of CO₂ angiography as an alternative to ICM, particularly for patients with contraindications to iodinated contrast agents, while highlighting the need for further research, especially RCTs to address variability and heterogeneity in related outcomes.

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TABLES

Table 1: Identification and summary description of the selected studies from where data was collected

Author	Journal	Publication Year	Study Design	Study Center	Recruitment Time	Sample n	No. CO2	No. ICM	Quality of Evidence (GRADE)
<i>Vacirca et al.</i>	Annals of Vascular Surgery	2022	Retrospective from prospective database	Sant'Orsola-Malpighi Hospital, unicentric, Italy	September 2016 – September 2019 (3 years)	321	72*	249	★★☆☆ Low

<i>Quaglino S. et al.</i>	Annals of Vascular Surgery	2024	Retrospective from prospective database	Mauriziano Umberto I Hospital, unicentric, Italy	2019-2021 (2 years) December 2019 – August 2020 ICM-EVAR; September 2020 – May 2021 CO2 EVAR	101	52	49	★ ★ ☆ ☆ Low
<i>Criado E. et al.</i>	Journal of Vascular Surgery	2012	Prospective observational study	University of Michigan Medicine, unicentric, USA	44 months (years not specified)	114	72	42**	★ ★ ☆ ☆ Low

<i>Takeuchi Y. et al.</i>	Annals of Vascular Surgery	2018	Retrospective from prospective database	Yamaguchi University Hospital and Saiseikai Shimonoseki General Hospital, multicentric, Japan	January 2012 – September 2016 (57 months)	381	30**	351	★ ★ ☆ ☆ Low
<i>Vacirca A. et al.</i>	Journal of Vascular Surgery	2023	Prospective observational study	University Hospital Policlinico S. Orsola - Malpighi, Italy; Hospital of Malmö, St. Franziskus, Sweden; Hospital of Münster, University Hospital of Münster, Germany; Athens	2019 – 2021 (2 years)	65	65**	0	★ ★ ☆ ☆ Low

				Medical Group, Greece, multicentric					
<i>Unal E et al.</i>	European Journal of Vascular and Endovascular Surgery	2023	Retrospective from prospective database	Ufuk University Dr. Ridvan Ege Health, Research and Application Hospital, Bilkent City Hospital, Etlik City Hospital, multicentric, Turkey	January 2019 – January 2022 (3 years)	324	34**	290	★ ★ ☆ ☆ Low
<i>Chao A et al.</i>	The Journal of Vascular Surgery	2007	Retrospective	University of Southern California University Hospital, unicentric, USA	2003-2005 (2 years)	100	16**	84	★ ★ ☆ ☆ Low

<i>Chisci E et. al</i>	European Journal of Vascular & Endovascular Surgery	2024	Prospective	San Giovanni di Dio Hospital, Mauriziano Umberto I Hospital, Hospital Trust of Verona, Santa Maria della Misericordia Hospital, Padova University Hospital, University Hospital Careggi, Sant'Orsola- Malpighi Hospital, multicentric, Italy	January 2023 – January 2024 (1 year)	293	240	53**	 Low
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Table 2: Demographics and comorbidities of the population samples of each study

Author	Contrast Medium	Mean age (years)	Male n(%)		Arterial Hypertension n(%)		Dislipidemia n(%)		Diabetes Mellitus n(%)		Current Smoking n(%)		Coronary Artery Disease n(%)		COPD n (%)		Preoperative eGFR (mL/min/1.73 m²)	CKD stage n (%)		Preoperative Serum Creatinine (mg/dL)	Hemodialysis n(%)	
Vacirca A. et al.	CO2	76.7	67	(93.1)	60	(83.3)	56	(77.8)	16	(22.2)	19	(26.4)	20	(27.8)	32	(44.4)	66.4	NA		1.2	1	(1.4)
	ICM	77.2	223	(89.5)	217	(87.1)	176	(70.6)	41	(16.5)	58	(23.2)	78	(31.3)	106	(42.5)	71.5	NA		1.0	2	(0.8)
Quaglino S. et al.	CO2	78.0	48	(92.3)	46	(88.5)	30	(57.7)	8	(15.4)	28	(53.8)	20	(38.5)	17	(32.7)	NA	16 - 1; 20 - 2; 10 - 3a; 2 - 3b; 3 - 4; 1 - 5	(30.8) – 1; (38.5) – 2; (19.2) – 3a; (3.8) – 3b; (5.8) – 4; (1.9) – 5	NA	NA	

	ICM	77	48	(98)	37	(75.5)	16	(32.7)	10	(20.4)	15	(30.6)	15	(30.6)	10	(20.4)	NA	18 - 1; 25 - 2; 2 - 3a; 2 - 3b; 1 - 4; 1 - 5	(36.7) - 1; (51.0) - 2; (4.1) - 3a; (4.1) - 3b; (2.0) - 4; (2.0) - 5	NA	NA
Criado E. et al.	CO2	72.0	94	(83.3)	NA	NA	NA	NA	22	(19.3)	NA	NA	65	41	16 - 1; 52 - 2; 40 - 3; 4 - 4; 10 - 5	(14.0) - 1; (45.6) - 2; (35.1) - 3; (3.5) - 4; (8.8) - 5	1.4	2	(1.8)		
	CO2 + ICM													43							

	ICM*	NA	NA	NA	NA		NA		NA		NA		NA		NA		39	NA		NA	NA	NA
Takeuchi Y. et al.	CO2	76.0	25	(83)	27	(93)	17	(59)	4	(14)	5	(20)	15	(52)	9	(32)	30.2	0 - 1; 2 - 2; 1 - 3a; 7 - 3b; 18 - 4; 2 - 5	(0) - 1; (6.7) - 2; (3.3) - 3a; (23) - 3b; (60) - 4; (6.7) - 5	2.02	0	(0.0)
	ICM	76.0	282	(80)	279	(81)	153	(46)	46	(14)	253	(83)	95	(29)	75	(23)	62.7	20 - 1; 169 - 2; 106 - 3a; 52 - 3b; 4 - 4; 0 - 5	(5.7) - 1; (48) - 2; (30) - 3a; (15) - 3b; (1.1) - 4; (0) - 5	0.91	0	(0.0)

<i>Vacirca A. et al.</i>	CO2	75.0	55	(84.5)	43	(66.2)	34	(52.3)	11	(17)	15	(23.1)	23	(35.4)	11	(17)	65	6 - 1; 33 - 2; 24 - 3; 2 - 4	(9.2) - 1; (50.8) - 2; (37) - 3; (3) - 4	1.05	0	(0.0)
<i>Unal et al.</i>	CO2	73.8	31	(91.2)	33	(97.1)	7	(20.6)	12	(35.3)	NA		8	(23.5)	7	(20.6)	41.7	NA		1.68	0	(0.0)
	ICM	70.6	266	(91.7)	208	(71.7)	98	(30)	72	(24.8)	NA		119	(41)	88	(30.3)	78.6	NA		1.14	0	(0.0)
<i>Chao A et al</i>	CO2	77	15	(94)	11	(70)	NA		3	(20)	13	(80)	10	(60)	3	(20)	36	1 - 1; 1 - 2; 10 - 3; 4 - 4	(6) - 1; (6) - 2; (63) - 3; (25) - 4	1.8	0	(0.0)

	ICM	76	69	(82)	50	(60)	NA		10	(12)	67	(80)	25	(30)	8	(10)	81	29 - 1; 27 - 2; 25 - 3; 3 - 4	(35) - 1; (32) - 2; (30) - 3; (4) - 4	1.0	0	(0.0)
Chisci E et al	CO2	77	209	(87)	205	(85)	178	(74)	43	(18)	79	(33)	87	(36)	49	(20)	70	66 - 3 to 5	(27)	NA	1	(0.4)
	ICM	80	47	(88)	53	(100)	52	(98)	13	(24)	22	(42)	18	(34)	17	(32)	63	24 - 3 to 5	(45)	NA	1	(2.0)

* a contemporary cohort of 50 comparable patients was used to compare eGFR decrease

Table 3: Procedural characteristics and contrast doses of each study

Author	Contrast Medium	CO2 dose (mL)	ICM dose (mL)	Mean Total Radiation Dose (Gy/cm 2)	Operative Time (minutes)	Fluoroscopy Time (minutes)	Urgent procedures n(%)		Elective procedures n(%)		C-arm vs Hybrid Room	Procedure-related Death n(%)
<i>Vacirca A et al.</i>	CO2	50-100mL*6.8 injections	52.8	500.5508	NA	NA	4	(5.5)	68	(94.5)	Hybrid Room	0 (0)
			0*									
	ICM	NA	88.1	332.3018	NA	NA	21	(8.4)	228	(91.6)	Hybrid Room	0 (0.0)
<i>Quaglino S. et al.</i>	CO2	950	0	311.48	69.5	14.5	NA		NA		Hybrid Room	0 (0.0)

	ICM	0	90	159.86	55	12.60	NA		NA		Hybrid Room	0 (0.0)	
Criado E. et al.	CO2	389	0	NA	165	21	4	(3.5)	110	(96.5)	C-arm	0	(0.0)
	CO2+ICM	430	37		193	32							
	ICM**	0	106	NA	193	28	NA		NA		NA	NA	
Takeuchi Y. et al.	CO2	115	18	NA	172	43	NA		NA		NA	1	(3.3)
	ICM	0	55	NA	171	49	NA		NA		NA	0	(0.0)
Vacirca A. et al.	CO2	990	17	161.3	NA	NA	NA		NA		NA	0	(0.0)
Unal et al.	CO2	80-100***	4	NA	133	16	0	(0.0)	34	(100)	NA	0	(0.0)
	ICM	NA	62	NA	131	17	0	(0.0)	190	(100)	NA	0	(0.0)
Chao A et al.	CO2	50	27	925	180	46	NA		NA		NA	0	(0.0)
	ICM	NA	148	529	140	24	NA		NA		NA	0	(0.0)

<i>Chisci E et. al</i>	<i>CO2</i>	600	0	NA	86	14	13	(5)	227	(95)	Hybrid Room	NA
	<i>ICM</i>	20	700	NA	108	20	5	(9)	33	(62)	Hybrid Room	NA

*in 16 cases (22.2) no ICM was used

** a contemporary cohort of 22 comparable patients was used to compare differences in operative and fluoroscopy time

*** CO2 dose per injection, number of injections not specified

Table 4: Postoperative clinical and procedural outcomes and adverse events of each study

Author	Contrast Medium	Technical Success (%)	Contrast-related adverse events n(%)		Endoleak detected intra-op n(%)		Endoleak postoperative n(%)		LoRA and Hypogastric Artery Visualization (%)	Aneurysm enlargement n(%)	Reintervention n(%)		Mean length of stay (days)	Mortality* n(%)		Follow-up time (months)
<i>Vacirca A. et al.</i>	CO2	100	3 hypotension episodes 2 nausea	(4.1) (2.8)	10 – all type II	(3.8)	8 – all type II	(11.1)	LoRA: 69.4 Hypogastric artery: 100	NA	0**	(0.0)	4	0	(0.0)	1
	ICM	NA	NA		NA		NA		NA	NA	NA		5	4	(1.6)	1
<i>Quaglino S. et al.</i>	CO2	100	8 abdominal pain/nausea episodes 1 femoral thrombosis	(15.4) (1.9)	13 – all type II	(25.0)	14 – all type II	(26.9)	NA	NA	NA		4	0	(0.0)	3
	ICM	100	1 distal embolization	(2.0)	7 – all type II	(14.3)	8 – all type II	(16.3)	NA	NA	NA		4	2	(4.1)	3
<i>Criado E. et al.</i>	CO2 +- ICM	100	0	(0.0)	20 – 2 type I	(17.5)	0	(0.0)	LoRA: 100%	NA	13	(11.4)	NA	2	(1.7)	39

					16 type II 2 type IV	(14.0) (1.8)			Hypogastric artery: 100%								
Takeuchi Y et al.	CO2	100	1 intestinal necrosis***	(3.3)	0	(0.0)	5 1 type Ib; 4 type II	(19) (3.7) (15)	NA	2	(6.7)	no SS		NA	1	(3.3)	20
	ICM	99.7	1 intestinal necrosis****	(0.28)	0	(0.0)	80 1 type Ia, 2 type Ib, 73 type II, 3 type III 1 type IV	(24) (0.28) (0.57) (22.0) (0.88) (0.28)	NA	17	(4.8)	no SS		NA	0	(0.0)	20
Vacirca A. et al.	CO2	NA	4 abdominal pain 2 abdominal pain + nausea 5 nausea + vomiting 2 diarrhea	(4.6) (3.1) (7.7) (3.1)	18 15 type II others not specified	(27.7) (23.1)	10 7 type II, others not specified	(15.4) (10.7)	LoRA: 93.8% Hypogastric artery: 93.8%	0	(0.0)	NA		NA	0	(0.0)	1 day
Unal et al.	CO2	100	0	(0.0)	4 1 type Ib, 2 type II 1 type III	(11.8) (2.9) (5.9) (2.9)	4 1 type Ib 3 type II	(11.8) (2.9) (8.8)	NA	0	(0.0)	0	(0.0)*	7	0	(0.0)	13.3

	ICM	99.3	NA		NA		29 3 type 1a, 5 type Ib, 20 type II 1 type III	(10.0) (1.0) (1.7) (6.9) (0.3)	NA	0	(0.0)	0	(0.0)	3	5	(1.7)	NA
Chao A et. al.	CO2	100	NA		12 4 type Ia 2 type Ib 6 type II	(75.0) (25.0) (12.5) (37.5)	18 - types not specified	(18)	NA	NA		NA		3.9	0	(0.0)	6
	ICM	100	NA		55 24 type Ia, 4 type Ib, 26 type II 1 type III	(65.5) (29.0) (5.0) (31.0) (1.2)	13 - types not specified	(13)	NA	NA		NA		2	0	(0.0)	6
Chisci E et. al	CO2	99.7	3 abdominal pain + nausea; 1 episode of vomiting	(1.0) (0.3)	0	(0.0)	23 – all type II	(10)	LoRA: 81.9 Hypogastric artery: 27	NA		5	(2)	NA	1	(0.4)	1

	ICM		NA	0	(0.0)	7 – all type II	(13)	LoRA: NA Hypogastric artery: 83	NA	2	(4)	NA	0	(0.0)	1
--	-----	--	----	---	-------	--------------------	------	---------------------------------------	----	---	-----	----	---	-------	---

*in total follow-up time

**at 24 hours

***Presumably due to cholesterol embolism, although the possibility of it being a CO2 adverse effect can not be ruled out.

****the other minor complications (buttock claudication, blue toe syndrome, gastric ulcer, stroke and wound infection) were not considered related to ICM use

Words in bold – major adverse effects

Table 5: Postoperative renal function outcomes of each study

Author	Contrast Medium	Postoperative eGFR		eGFR Decrease ml/min/1.73m ²	Postoperative Serum Creatinine (mg/dL)		Serum Creatinine Increase (mg/dL)	CKD Stage postoperative	AKI n(%)	
		Short term (1 day)	Long term (3 months)		Short Term (1 day)	Long Term (3 months)				
<i>Vacirca A et al.</i>	<i>CO2</i>	69.2	NA	2.3	1.2	NA	0.08	NA	0	
	<i>ICM</i>	67.2	NA	10.6	1.15	NA	0.17	NA	2	(0.8)
<i>Quaglino S. et al.</i>	<i>CO2</i>	NA		NA	NA	1.1	NA	NA	3	(5.8)
	<i>ICM</i>	NA		NA	NA	0.98	NA	NA	3	(6.1)
<i>Criado E. et al.</i>	<i>CO2</i>	NA		2.09	NA		NA	NA	2	(1.7)

	<i>C02+ICM</i>			2.04				NA			
	<i>ICM*</i>	NA		2.3	NA		NA	NA		NA	
<i>Takeuchi Y. et al.</i>	<i>CO2</i>	34.6	32.8	NA	1.79	1.81	NA	0 - 1, 2 - 2, 1 -3a, 7 -3b, 18 - 4, 2 - 5	(0.0) (6.7) (3.3) (23.3) (60.0) (6.7)	1	(3.3)
	<i>ICM</i>	66.4	59.3	NA	0.87	0.93	NA	20 - 1,	(5.7)	10	(2.89)

								169 - 2, 106 - 3a, 52 - 3b, 4 - 4, 0 - 5	(48.1) (30.2) (14.8) (1.1) (0.0)		
<i>Vacirca A. et al.</i>	<i>CO2</i>	66	NA	0 (6.5)	1.02	NA	0 (0.08)	NA	NA		
<i>Unal et al.</i>	<i>CO2</i>	42.6	NA	44 to 40***	1.72	NA	NA	NA	1	(2.9)	
	<i>ICM</i>	58.3	NA	42 to 41***	1.21	NA	NA	NA	30	(10.3)	

<i>Chao A et al.</i>	CO2	“unchanged”	NA	NA	1.8	NA	0.01	NA	NA	
	ICM	“unchanged”	NA	NA	0.9	NA	-0.06	NA	NA	
<i>Chisci E et. al</i>	CO2	NA	70****	NA	NA	1****	NA	NA	2	(0.8)
	ICM	NA	57****	NA	NA	1.3****	NA	NA	5	(9)

*cohort of 50 patients with moderate or severe renal insufficiency submitted to EVAR with ICM only

***these results derived from the matched populations comparison

**** at 1-month follow up period

FIGURES

Figure 1: PRISMA 2020 flow diagram

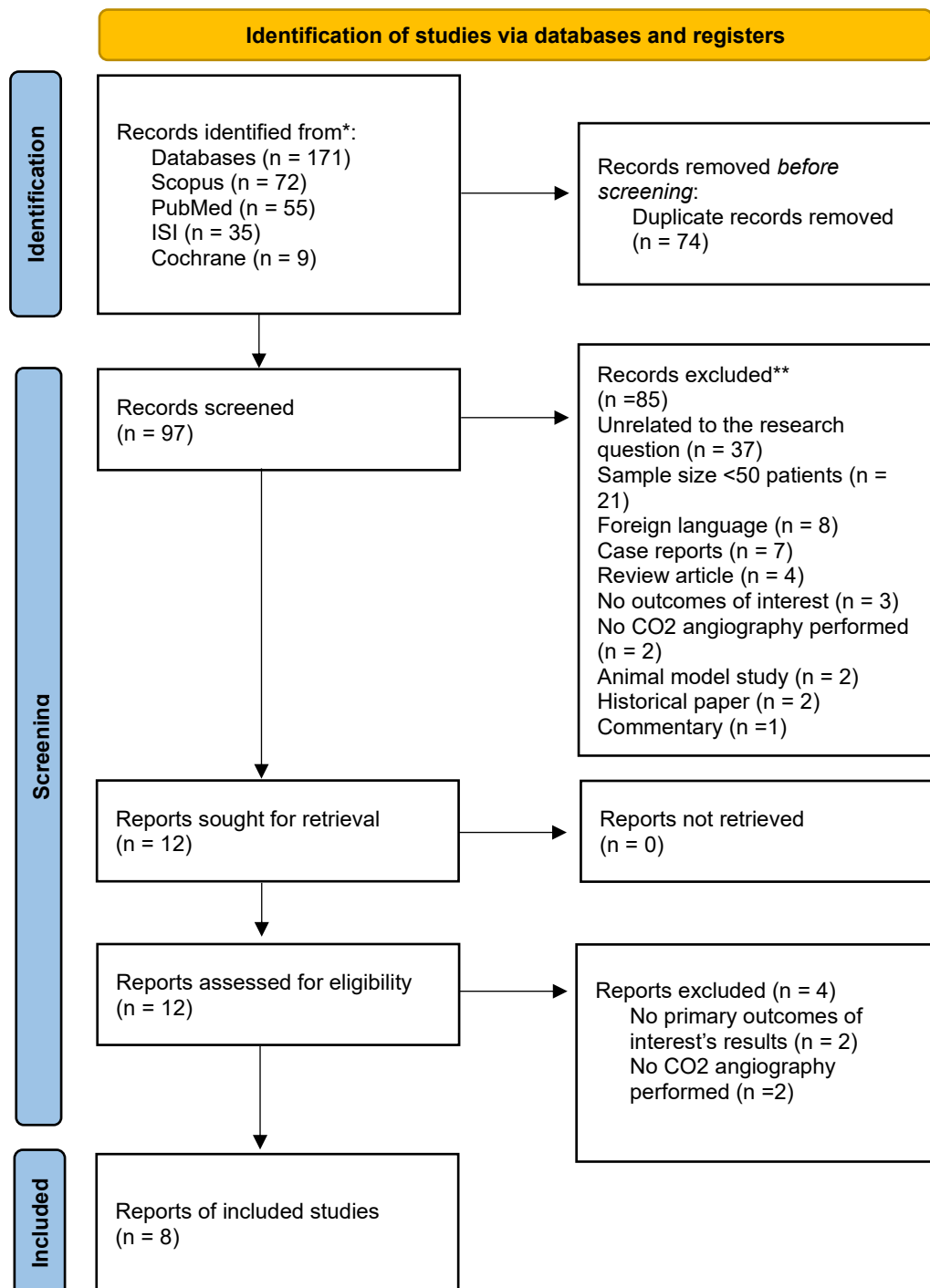


Figure 2: Forest Plot for acute kidney injury – CO2 vs. Iodinated contrast medium

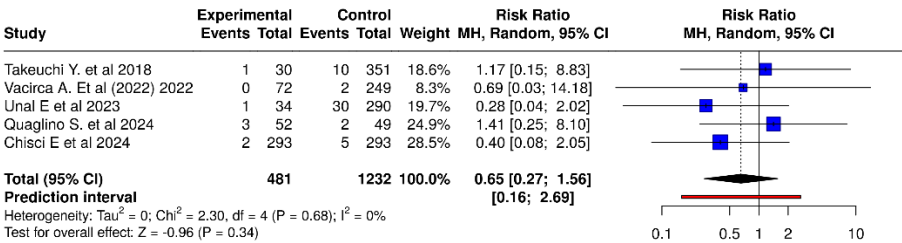


Figure 3a: Risk of bias for each observational cohort individually, using National Heart, Lung, and Blood Institute (NHLBI) Study Quality Assessment Tool.

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	Overall
Vacirca A 2022	+	+	+	+	?	+	+	+	+		+	?	+	×	+
Quaglinos S 2024	+	+	+	+	?	+	×	+	+		+	?	×	×	+
Criado E 2012	+	+	+	+	?	+	+	+	+		+	?	+	×	+
Takeuchi Y 2018	+	+	+	+	?	+	+	+	+		+	?	+	×	+
Vacirca A 2023	+	+	?	+	?	+	+	+	+	+	+	?	?	×	+
Unal E 2023	+	+	+	+	?	+	+		+		+	?	?	+	+
Chao A 2007	+	+	+	+	?	+	+	+	+		+	?	+	×	+
Chisci E 2024	+	+	?	+		+	+	?	+	+	+		+	×	+

D1: Was the research question or objective in this paper clearly stated?

D2: Was the study population clearly specified and defined?

D3: Was the participation rate of eligible persons at least 50%?

D4: Were all the subjects selected or recruited from the same or similar populations?

D5: Was a sample size justification, power description, or variance and effect estimates provided?

D6: For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?

D7: Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?

D8: For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome?

D9: Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?

D10: Was the exposure(s) assessed more than once over time?

D11: Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?

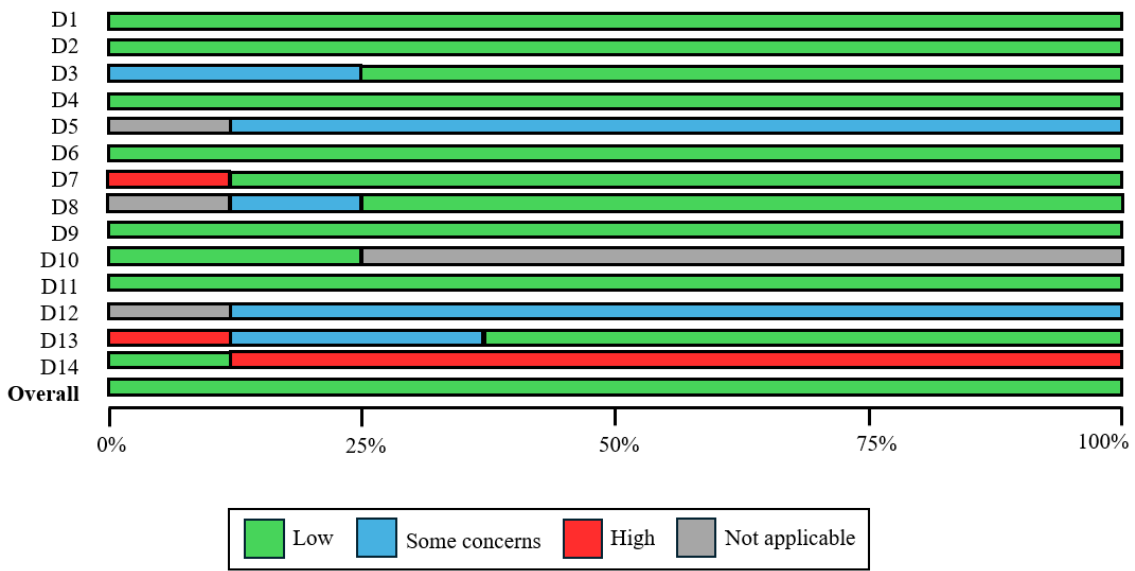
D12: Were the outcome assessors blinded to the exposure status of the participants?

D13: Was loss to follow-up after baseline 20% or less?

D14: Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?



Figure 3b: Overall judgment of bias for each evaluated item regarding observational cohorts, using National Heart, Lung, and Blood Institute (NHLBI) Study Quality Assessment Tool.



SUPPLEMENTARY MATERIALS

Supplemental Table 1: Query and keywords applied

Bibliographic source	Search term	No of reports at February 2025
Pubmed	(“carbon dioxide” OR “CO2” OR “carbon” OR “dioxide” OR “carbondioxide” OR “dioxide of carbon” OR “carbonic acid gas” OR “CO2 DSA” OR “CO2 digital subtraction angiography”) AND (“endovascular aneurysm repair” OR “EVAR” OR “endograft” OR “endovascular procedures” OR “stent” OR “graft” OR “minimally invasive aneurysm repair” OR “blood vessel prosthesis”) AND (“abdominal aneurysm” OR “abdominal aortic aneurysm” OR “AAA”)	55
ISI	(“carbon dioxide” OR “CO2” OR “carbon” OR “dioxide” OR “carbondioxide” OR “dioxide of carbon” OR “carbonic acid gas” OR “CO2 DSA” OR “CO2 digital subtraction angiography”) AND	35

	(“endovascular aneurysm repair” OR “EVAR” OR “endograft” OR “endovascular procedures” OR “stent” OR “graft” OR “minimally invasive aneurysm repair” OR “blood vessel prosthesis”) AND ("abdominal aneurysm" OR “abdominal aortic aneurysm” OR “AAA”)	
Cochrane	(“carbon dioxide” OR “CO2” OR “carbon” OR “dioxide” OR “carbondioxide” OR “dioxide of carbon” OR “carbonic acid gas” OR “CO2 DSA” OR “CO2 digital subtraction angiography”) AND (“endovascular aneurysm repair” OR “EVAR” OR “endograft” OR “endovascular procedures” OR “stent” OR “graft” OR “minimally invasive aneurysm repair” OR “blood vessel prosthesis”) AND ("abdominal aneurysm" OR “abdominal aortic aneurysm” OR “AAA”)	9
Scopus	(“carbon dioxide” OR “CO2” OR “carbon” OR “dioxide” OR “carbondioxide” OR “dioxide of carbon” OR “carbonic acid gas” OR “CO2 DSA” OR “CO2 digital subtraction angiography”) AND	72

	(“endovascular aneurysm repair” OR “EVAR” OR “endograft” OR “endovascular procedures” OR “stent” OR “graft” OR “minimally invasive aneurysm repair” OR “blood vessel prosthesis”) AND ("abdominal aneurysm" OR "abdominal aortic aneurysm" OR "AAA")	
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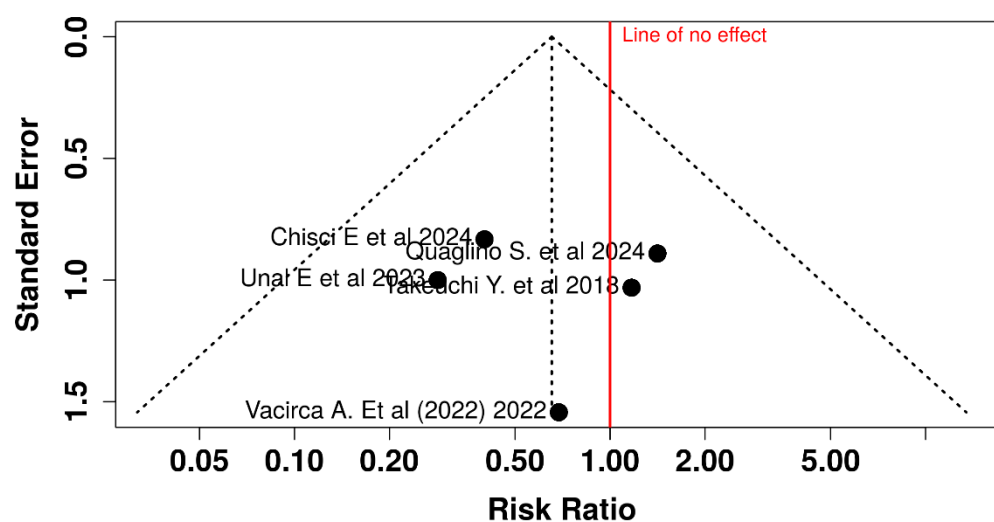
Supplemental Table 2: AKI definition applied in each study

Author	AKI definition
<i>Vacirca et al. (2022)</i>	Postoperative increase in serum creatinine (mg/dL) Postoperative decrease in eGFR (mL/min) Renal function worsening requiring hemodialysis
<i>Quaglino S. et al.</i>	ARISe classification*
<i>Criado E. et al.</i>	Postoperative decrease in eGFR (mL/min)
<i>Takeuchi Y. et al.</i>	RIFLE classification**
<i>Vacirca A. et al. (2023)</i>	An increase in serum creatinine by ≥ 0.3 mg/dL within 48 hours, or an increase in serum creatinine to ≥ 1.5 times baseline within 7 days, or an urine output of < 0.5 mL/kg/h for ≥ 6 hours.
<i>Unal E et al.</i>	A 25% increase in serum creatinine from baseline or a 0.5 mg/dL absolute increase in serum creatinine within 48 hours of intravenous contrast administration
<i>Chao A et al.</i>	NA
<i>Chisci E et al.</i>	Risk/Injury/Failure/Loss/End-stage (RIFLE) classification**

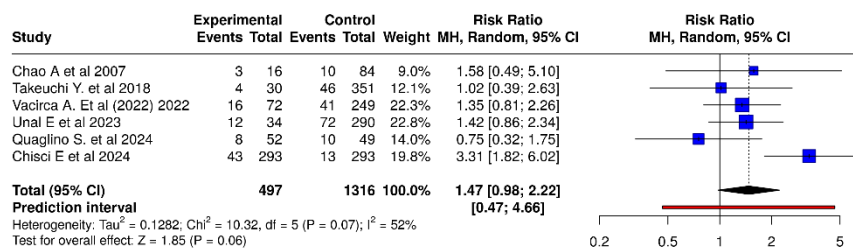
Supplemental Table 3: Covariates used in the adjusted models

Author	Covariables used in adjusted models
<i>Vacirca et al.(2022)</i>	ICM + CO2 dose, ICM dose (univariate)
<i>Quaglini S.et al.</i>	CO2 dose, ICM dose, fluoroscopy, radiation dose, operative time (univariate)
<i>Criado E. et al.</i>	ICM dose (univariate)
<i>Takeuchi Y. et al.</i>	ICM dose, blood transfusion (univariate)
<i>Vacirca A. et al. (2023)</i>	NA
<i>Unal E et a.l</i>	ICM and CO2 dose (univariate)
<i>Chao A et al.</i>	ICM and CO2 dose, fluoroscopy time, radiation dose (univariate)
<i>Chisci E et. al</i>	Operative time, fluoroscopy time, percutaneous EVAR, general anaesthesia, step A*, step B** (univariate)

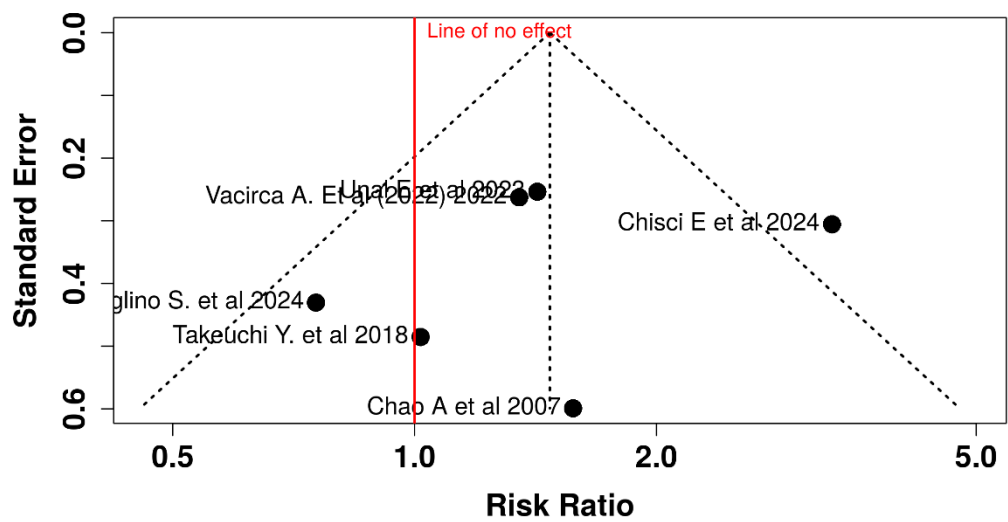
Supplemental Figure 1- Funnel Plot for acute kidney injury – CO2 vs. Iodinated contrast medium



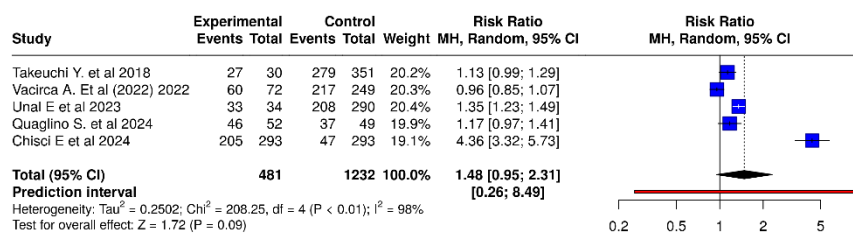
Supplemental Figure 2 - Forest Plot for Diabetes Mellitus – CO2 vs. Iodinated contrast medium



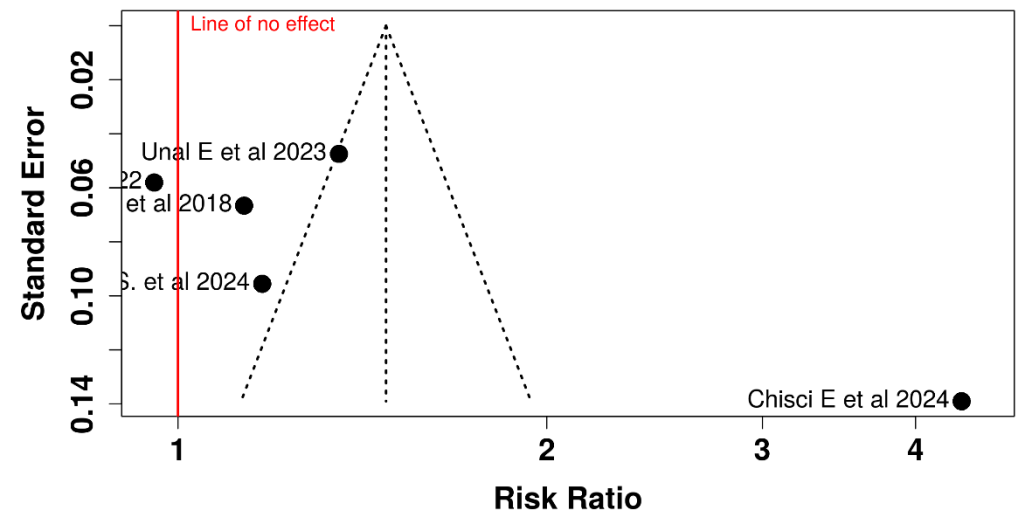
Supplemental Figure 3 - Funnel Plot for Diabetes Mellitus – CO2 vs. Iodinated contrast medium



Supplemental Figure 4 - Forest Plot for Arterial Hypertension – CO2 vs. Iodinated contrast medium



Supplemental Figure 5 - Funnel Plot for Arterial Hypertension – CO2 vs. Iodinated contrast medium



APPENDIX

REPORTING GUIDELINES: PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Title Page
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Page 1 and 2, paragraphs 1 and 2
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Page 2, paragraph 3
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Page 5 paragraph 5 and page 6 paragraph 1
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Page 5, paragraph 3
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Page 6, paragraphs 1 and 2
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Page 6, paragraph 1
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Page 6, paragraph 2
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Page 7, paragraph 2

Section and Topic	Item #	Checklist item	Location where item is reported
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Page 6, paragraph 3
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Page 7, paragraph 1
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Page 7, paragraph 3
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Page 7, paragraph 3
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Page 7, paragraph 3
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Page 7, paragraph 2
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Page 7, paragraphs 3
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Page 7, paragraphs 3
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Page 7, paragraphs 3
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Page 7, paragraphs 3
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Page 7, paragraphs 3
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Page 9, paragraph 1 and Figure 1

Section and Topic	Item #	Checklist item	Location where item is reported
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Page 9, paragraph 1 and Figure 1
Study characteristics	17	Cite each included study and present its characteristics.	Page 9, paragraphs 2, 3 and 4; page 10 paragraph 1; Table 1
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Figure 3a and 3b, Page 16 paragraph 2
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Table 3, 4 and 5; page 11-15
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Pages 11-16
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Page 15, paragraphs 4 and 5
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Page 15, paragraphs 4 and 5
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Page 15, paragraphs 4 and 5
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	NA
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Page 15, paragraphs 4 and 5
DISCUSSION			

Section and Topic	Item #	Checklist item	Location where item is reported
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Pages 17-19 paragraph 1
	23b	Discuss any limitations of the evidence included in the review.	Pages 19 paragraph 3 – page 20 paragraph 1
	23c	Discuss any limitations of the review processes used.	Pages 19 paragraph 3 – page 20 paragraph 1
	23d	Discuss implications of the results for practice, policy, and future research.	Page 20 paragraph 2
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Page 5, paragraph 1
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Page 5 paragraph 1
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Page 5 paragraph 1
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Title page
Competing interests	26	Declare any competing interests of review authors.	Title Page
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Page 6 paragraph 3, page 8 paragraph 2, table 2 to 5

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

For more information, visit: <http://www.prisma-statement.org/>

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(September 13, 2023)

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Committee on Publication Ethics (COPE). Code of conduct and best-practice guidelines for journal editors; Dual publication; Suspected redundant publication in a submitted manuscript (flowchart). Available from: www.publicationethics.org

Council of Science Editors (CSE). White paper on promoting integrity in scientific journal publications. Available from: www.councilscienceeditors.org/

International Society of Managing and Technical Editors (ISMTE). Publishing Ethics 101: A Guide for the Editorial Office. Available from: www.ismte.org/

World Association of Medical Editors (WAME). Duplicate submissions. Available from: www.wame.org/resources

Elsevier's Policy: Multiple, duplicate, and concurrent publications. Available from: www.elsevier.com/editors/perk/multiple-duplicate-concurrent-publication-simultaneous-submission

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translation articles. Text is limited to 1800 words of body text. The order of sections is: Title Page, Introduction, Concept, Relevance, Translation, References (maximum 20, with judicious use of a suggested reading list for online publication), Table, Figure Legends, Figures, Supplementary materials, ICMJE disclosures.

STUDY PROTOCOL DESIGN

Study Protocol Design articles outline prospective clinical trials, studies, and registries with finalized designs that are starting up, actively enrolling, or approved to enroll. Funded studies, such as those supported by the SIR Foundation, NIH, NSF, PCORI, DoD, etc. with relevance in the field of interventional radiology are especially encouraged to publish the study protocol design in JVIR. Study Protocol Design articles are designed to increase awareness, referrals, and enrollment in clinical trials, encourage hypothesis-based prospective research, facilitate feedback to authors prior to completion of studies, allow researchers an early record of development of original ideas and methodologies, and reduce redundancy of research efforts.

All human subject trials must include a registration number with clinicaltrials.gov or equivalent system. The length is limited to 700 words of body text, and should include a succinct (<200 word) Introduction describing the background and purpose of the study. **JVIR** suggests using the [SPIRIT](#) reporting guidelines to create a bulleted list of essential information, including sponsor information, trial design (including randomization process if applicable), study population, interventions, follow-up, sample size calculation, and study endpoints/outcome measures. No abstract is required. References are limited to a maximum of 8. Tables are limited to 1 summary of eligibility (inclusion and exclusion) criteria. Figures are limited to 1 diagram of the trial schema or timeline. Additional information may be supplied as Supplementary materials for online only publication. If the article describes an actively enrolling clinical trial, the contact information for the study coordinator should be included. The order of sections is: Title Page, Introductory text, Bulleted list, References, Table, Figure Legend, Figure, Supplementary materials, ICMJE disclosures.

LESSONS IN IR (Morbidity & Mortality)

Lessons in IR (M&M) articles describe a single clinical case in which an adverse event occurred during interventional radiological care. Cases should have broad educational appeal (including to students and trainees), and thus should be instructive rather than extreme or exceptional. They may portray procedural or post-procedural adverse events or predicaments, mitigative actions, and outcomes. All aspects must be de-identified and compliant with the Health Insurance Portability and Accountability Act (HIPAA), approved or waived by an institutional review board, and free of current and past medicolegal litigation, arbitration, and patient complaints. All Lessons in IR (M&M) articles will have a legal disclaimer attached for publication. Text is limited to 500 words of Case Description body text and Discussion section, plus a maximum of 3 references. The Discussion should consist of 3 subsections entitled “Preparation,” consisting of pre-procedural appraisal and recognition of unique risk factors as well as a possible plan of action to mitigate the adverse event should it occur; “Avoidance,” consisting of procedural best practices to preclude the adverse event; and “Management,” consisting of procedural maneuvers or post-procedural care to mitigate the event. Each subsection should include no more than 2-4 relevant bullet points. Figure descriptions should be included in the text rather than in figure legends, and are limited to 6 figure parts. Each case should be assigned a Society of Interventional Radiology (SIR) adverse event severity assessment (see Baerlocher et al., www.jvir.org/article/S1051-

[0443\(22\)01252-0/fulltext](#)). The order of sections is: Title Page, Case Description, Discussion, SIR adverse event severity assignment, References, Figures, ICMJE disclosures.

EXTREME IR

Extreme IR articles describe a single clinical case in which extraordinary measures were required. Cases may portray severe pathology, unexpected clinical situations, or unanticipated procedural dilemmas demanding creative solutions. Text is limited to 350 words including case description body text and figure legends, and should include no references to allow for high quality, instructive figures or illustrations, limited to 6 figure parts. The order of sections is: Title Page, Text, Figure Legends, Figures, ICMJE disclosures.

IMAGES IN IR

Images in IR articles consist of 1–4 images demonstrating a unique anatomic finding, an unusual diagnosis, or otherwise striking image encountered in clinical interventional radiologic practice. Text is limited to 150 words of figure legends and should include no body text and no references. The order of sections is: Title Page, Figure Captions, Figures, ICMJE disclosures.

Manuscript type	Abstract	Research Highlights	Body text word limit	References maximum	Tables maximum	Figure part maximum	Supplementary Materials
Full length Clinical Study, Laboratory Investigation	Structured, 250-word limit	3–5 bulleted points, 100 word limit	3500	35	6	12	No set limit
Brief Report	Unstructured, 150-word limit	NA	1800	15	4	8	No set limit
Letter to the Editor	NA	NA	800	4	2	6	No set limit
Evidence-based Review	Structured, 250-word limit	3–5 bulleted points, 100 word limit	5000	75	10	12	No set limit
Narrative Review	Unstructured, 150-word limit	3–5 bulleted points, 100 word limit	5000	75	10	12	No set limit
Research in Translation	Unstructured, 150-word limit	NA	1800	20	1	8	No set limit
Study Protocol Design	NA	NA	700	8	1	1	No set limit
Lessons in IR: M&M	NA	NA	500	4	0	6	No set limit

Extreme IR	NA	NA	350 (body text + legends)	0	0	6	No set limit
Images in IR	NA	NA	150 (captions only)	0	0	4	No set limit

IN MEMORIAM

In Memoriam pieces are dedicated to recently deceased personalities of the IR community. Text is limited to 650 words, and a photographic portrait of the memorialized person should be included.

EDITORIAL, COMMENTARY, IR HISTORY, BOOK REVIEW, PERSPECTIVE

Editorial, Commentary, and **IR History** articles are typically invited by the Editor. **Book Reviews** are invited by the Book Review Editor. Authors may also contact the Editor to propose a **Perspective, History** article, or **Book Review**. Specific instructions are provided at the time of invitation. **JVIR** will not accept an unsolicited **Commentary**, but authors are encouraged to submit a **Letter to the Editor** to comment on material already published in **JVIR**.

SUPPLEMENTS, CONFERENCE PROCEEDINGS, MEETING ABSTRACTS

Scientific abstracts (excluding educational posters) presented at the Annual Scientific Meeting of SIR are published as a separate journal supplement. Under special circumstances, abstracts and conference proceedings representing peer-reviewed research from other scientific meetings may be published as supplemental material with prior agreement between the meeting chairs and the Editor.

SIR AND SIR FOUNDATION DOCUMENTS

Official documents originating from SIR or SIR Foundation will be given high profile and expanded access as **JVIR** publications. These include **Clinical Practice Guidelines, Position Statements, Research Reporting Standards**, and **Research Consensus Panel Proceedings**. Special manuscript preparation instructions may be obtained from SIR or SIR Foundation.

ONLINE-ONLY PUBLICATION

SUPPLEMENTARY MATERIALS

To comply with printed word limits, **JVIR** will allow or encourage publication of additional tables, figures, or text (e.g., methodology details, comprehensive data, complementary images,

etc.) in the electronic version of the published manuscript. This material will not be included in the print version but a reference to its availability online will be present in the print version. Supplementary material must meet strict criteria to be included in the electronic version and must not be redundant or irrelevant data. Online-only supplementary material must be marked clearly in the submitted manuscript.

1. Number online-only materials separately, by adding the prefix E (e.g., Fig. E1, Fig. E2).
2. Number the figures and tables sequentially in the order in which they are called out in the text.
3. In-text citations must match the figure/table numbers for print and for online-only E-publication. Citations for print and online-only materials may be interspersed (e.g., Fig. 1, Fig. 2, Fig. E1, Fig. 3).

DATA REPOSITORY

In alignment with the ICMJE and other organizations, **JVIR** supports responsible data-sharing for interventional clinical studies. This practice supports transparency, results verification, and secondary analysis (systematic review and meta-analysis) generation. **JVIR** encourages authors to upload a manuscript's source data and to cite underlying or relevant datasets in manuscripts by citing them in the text and including a data reference in the reference list. Data references should include the following elements: author name(s), dataset title, data repository site, version (where available), year, and global persistent identifier. Add [dataset] immediately before the reference so that it can be properly identified as a data reference. The [dataset] identifier will not appear in the published article.

Mendeley Data is a free-to-use open research data repository designed for this purpose and owned by **JVIR**'s publisher Elsevier. To make a manuscript's data available, authors may create a dataset at Mendeley Data at data.mendeley.com/ and publish it (under embargo if desired). If authors use Mendeley for data deposit, Elsevier will place links between the article and the dataset, making the data easily accessible to readers. Open source code may also be posted on Github (github.com).

MANUSCRIPT SUBMISSION PROCESS

GENERAL INFORMATION

All new manuscripts must be submitted through the **JVIR** online submission site at www.editorialmanager.com/JVIR. Authors are required to upload the title page, text, and tables as Microsoft Word .docx files, and separate figures in electronic form not embedded in the Word file or PDF. Manuscript word count (including main text and references) should be listed on the title page, and the text must have page numbers printed at the bottom of each page starting with the abstract page as page 1. If the study was sponsored, the 6-item study sponsor checklist must be completed and included on the Title page.

NEW SUBMISSIONS

- An optional cover letter may be uploaded as a separate file. Cover letters are seen only by the editors and should only provide information not included in the manuscript text, such as information on the roles played by the funders of externally sponsored trials, and whether any

aspects have been presented or published, or posted as a preprint. Authors may nominate appropriate objective, nonconflicted, expert reviewers.

- Title page
- Research highlights (for full length articles only)
- Blinded manuscript
- Tables
- Figures
- Supplementary material
- ICMJE disclosures

REVISIONS

- Optional cover letter
- Title page
- Research highlights (for full length articles only)
- Point-by-Point Response to Review as a separate document using the Word table template provided at www.jvir.org/content/authorinformation. This document should outline how authors dealt with each of the points raised by the editors and reviewers. Authors need not agree with all of the suggestions or criticisms but must explain the authors' position on every point. Revisions of the manuscript (if performed) must be specified for each comment. Replies to comments will not be published—only the revisions to the manuscript.
- Clean, blinded manuscript that incorporates any changes made during the revision process
- Manuscript with tracked changes. Set the word processing program track changes options to **color only/blue for inserted text** and to **strikethrough/red for deleted text**.
- Tables
- Figures
- Supplementary material
- ICMJE disclosures

FILE NAMES

Files should be labeled with descriptive file names (e.g., Coverletter.docx, Manuscript.docx, Revised_manuscript.docx, Table3.docx, Fig1a.tif). Upload text, tables, and figures as separate files. Do not embed figures or tables into the text document, and do not upload any of the materials as a PDF.

TECHNICAL SPECIFICATIONS FOR TABLES AND FIGURES

TABLES

- Use Microsoft Word's Table feature. Do not construct tables using tabs. Do not use Excel or comparable spreadsheets.
- Do not use vertical/horizontal lines or shading.
- Table title and table legend (if one is necessary) should be included in the same file.
- Tables must be uploaded as individual files, one for each table, and include the table number in the file name (e.g., Table3.docx). Do not embed tables into the text file.

- Do not submit single-column tables. A single column table should be converted into a list or incorporated into the text.

FIGURES (IMAGES)

Graphics software such as Photoshop, Illustrator, BioRender, or InkScape should be used to create camera-ready art. Submit figure images electronically as individual files saved in TIF or EPS file format. Multiple panel figures (e.g., Fig. 1a, 1b, 1c, 1d) must be submitted one panel image per file and not as composite images. Figures submitted embedded in the text file or in presentation software such as PowerPoint, CorelDraw, or Keynote will be rejected. Original art must be prepared and submitted at the proper resolution and size. Editing of images for clarity (cropping, rotation, brightness and contrast, color balance, elimination of artifacts) is encouraged, but manipulation resulting in misrepresentation, removal of legitimate, or introduction of fabricated data is prohibited. If images required extensive alteration, both the source image and the edited image must be submitted.

Step-by-step instructions for art preparation are available at www.elsevier.com/artworkinstructions. Graphics services are also available through the publisher at www.webshop.elsevier.com/illustration-services/. Manuscripts may move into peer review even if the figures do not meet production standards; however, figures of adequate quality are required for publication in **JVIR**, and failure to provide adequate figures will delay or block publication.

COLOR FIGURE POLICY

JVIR publishes in full color. However, reproduction of articles and figures by users and readers may not be in color, so color figures must be prepared so that conversion to grayscale does not compromise their abilities to convey meaning. Color figures should be prepared to be accessible to readers with color vision deficiency; instructions are available at www.elsevier.com/authors/policies-and-guidelines/artwork-and-media-instructions.

TECHNICAL SPECIFICATIONS FOR RADIOGRAPHS, PHOTOGRAPHS, SCANNED IMAGES, AND HALFTONES (DIGITAL IMAGES CHARACTERIZED BY SHADING OR GRADIENTS)

Basic parameters

File Type: TIFF

Resolution: 300 dpi

Color mode: grayscale or RGB

Dimensions (inches): minimum 3.0" (smaller dimension)

File storage size (approximate)

Grayscale: 1–5 MB

RGB: 4–20 MB

TECHNICAL SPECIFICATIONS FOR LINE ART, DIAGRAMS, DRAWINGS, AND GRAPHS (DIGITAL LINE-DRAWN ILLUSTRATIONS WITHOUT GRADIENTS)

Basic parameters

File Type: TIFF or EPS
Resolution: Minimum 1000 dpi
Color mode: grayscale or RGB
Dimensions (inches): minimum 3.0" (smaller dimension)

File storage size (approximate)

Grayscale: 8–40 MB
RGB: 30–50 MB (not recommended; for largest file sizes, preparation as vector format or conversion from raster to vector is preferred)

SIZE, RESOLUTION, LABELS, ARROWS

Figures should be prepared at the expected size of final printing, which is a maximum of full-page width (7.5") and a minimum of one column (3.5"). Most images are appropriate for single-column size (3.5"). Unusually large and complex images may require full page width, while multiple panel figures with small and simple panels may be fit into a row as many as six images across one page. Even for multiple panel figures with expected small panels, each panel should be prepared and submitted individually at 3.5" width. Figures must be composed at full resolution from source data. Low resolution images that are upscaled to higher resolution that remain pixelated and/or with compression artifacts are not acceptable.

Labels such as figure part letters (a, b, c), arrows and arrowheads, asterisks, and axis labels must be large and contrasted enough to be legible after potential minification in the production process if an image is submitted larger than final print size and must be reduced in size for publication. Figure part lettering should be in the lower left corner, lower case in **Arial Bold** font, black or white depending on background, and at least 12 pt size in final printed size. Other labels, including asterisks and other symbols on radiographs, axis labels, graph symbols, and graph symbol keys should be at least 8 pt final printed size. Arrows may be any color, preferably black or white for reproduction quality, at least 3 pt (12 pixels) shaft weight, and at least 300% in arrowhead width and length. Graph axes and other line work should be at least 1 pt weight.

VIDEO FIGURES

Video figures for online electronic publication: **JVIR** will accept relevant video clips with accepted manuscripts for viewing in the online version. A representative thumbnail still image from the video clip should be submitted to embed in the online publication as a visual link to the video file. For video articles or video figures, authors are encouraged to utilize video editing software such as Premiere Pro, Final Cut Pro, iMovie, or Windows Movie Maker.

TECHNICAL SPECIFICATIONS FOR VIDEOS

File format: MP4 (max target 720p), MOV, MPEG-1, MPEG-2, or AVI
Frame rate: 15 frames/second minimum
Video codec: H.264 (+AAC)
Video bit rate: 750 kbps preferred, 260 kbps minimum
Frame size: 492 x 276

Duration: 5 minutes maximum
File size: 150 MB maximum

VIDEO ARTICLES

Video Articles are no longer published by **JVIR**. Instructional videos may be appropriate for the SIRnow video library, such as in the Early Career Section Channel. Please contact education@sirweb.org for information and submissions.

VISUAL ABSTRACTS

Full length Clinical Studies or Laboratory Investigations or Evidence-based Reviews may have a Visual Abstract (graphical abstract, visual synopsis) composed by **JVIR**, in which the research article is summarized diagrammatically. Authors are invited to submit drafts based on the format of previously published **JVIR** Graphical Abstracts. Graphical Abstracts should be a standard 16:9 aspect ratio with 1920 x 1080 pixels at 300 dpi, minimum font size 14 pt, Gotham Narrow font, preferring icons rather than illustrations, submitted in TIFF, PNG, or EPS format.

PROOFS

Authors' pre-proof PDF version will be posted online at www.jvir.org and listed on PubMed upon final acceptance. Corresponding authors will receive an e-mail with a link to the online proofing system, allowing annotation and correction of proofs online for final print and electronic publication. The environment is similar to MS Word: in addition to editing text, authors can also comment on figures/tables and answer questions from the Copy Editor. Web-based proofing provides a faster and less error-prone process by allowing authors to directly type corrections, eliminating the potential introduction of errors. In order to publish articles quickly and accurately in **JVIR**, authors may use this proofing system only for checking the typesetting and editing for completeness and correctness of the text, tables and figures. Significant changes to the article as accepted for publication will only be considered at this stage with special permission from the Editor. All corrections must be returned in one communication only. Please check carefully before replying, since this is the only opportunity to make corrections. Proofreading is solely the authors' responsibility.

UPDATES

MAY 2023

- **[within FIGURES (IMAGES) entry]:** If images required extensive alteration, both the source image and the edited image must be submitted.
- **[within THE USE OF ARTIFICIAL INTELLIGENCE (AI) entry]:** JVIR added Elsevier's AI policy for authors as a reference outline for #3.
- **[within SIR AND SIR FOUNDATION DOCUMENTS entry]:** Official documents originating from SIR or SIR Foundation will be given high profile and expanded access as **JVIR** publications instead of online-only publications.

JUNE 2023

- **[within REDUNDANT (DUPLICATE) PUBLICATIONS, PIRACY, and PLAGIARISM entry]:** A Text Recycling section was added that explains new guidelines of the reuse of materials from authors' own published work.
- **[within DOCUMENT TECHNICAL SPECIFICATIONS entry]:** New entries on line 5 and line 8 provide a detailed guideline for line numbering and image inclusions.
- **[within STUDY PROTOCOL DESIGN entry]:** New entry describes how JVIR suggests using the SPIRIT reporting guidelines to create a bulleted list of essential information, including and added additional sections (Introductory text, Bulleted list) within the order of sections.
- **[within GENERAL INFORMATION entry]:** "Authors will be asked to specify the type of study and level of evidence, and if a clinical trial, the phase or stage of the trial" was removed.
- **[within REVISIONS entry]:** Point-by-Point Response to Review as a separate document using the **Word table** template instead of an excel spreadsheet.

SEPTEMBER 2023

- **[within PREPRINT SERVERS entry]:** JVIR adheres to a double-blind peer review process, and discoverability of the work on a preprint server may jeopardize the confidential review process.