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Delayed presentation of air embolism after removal of central venous catheters: A systematic review

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ABSTRACT

Purpose: Air embolism is a fatal complication of central venous catheter (CVC) manipulation. Its delayed occurrence after CVC removal is poorly understood and underrecognized. We conducted a systematic review to identify all delayed air embolism following CVC removal.

Material and methods: We included case reports or case series that described venous or paradoxical air embolism occurring ≥10 min after CVC removal. Data extracted included patient demographics, catheter characteristics, removal technique, timing of symptoms onset, clinical presentation, diagnostic tools used, management or treatment and outcomes.

Results: Twenty-eight case reports were identified. Symptoms developed between ten minutes and one hour after removal of CVC in 54% of cases, between one and two hours in 14%, and after more than two hours in 32%. Neurological manifestations occurred in 92% of patients, oxygen desaturation in 90%, and cardiovascular instability in 47%; cardiac arrest was reported in only two cases. In 10 out of the 11 patients in which diagnostic tools were used to identify a cause, a transcutaneous channel was found. Ten patients were investigated for a patent foramen ovale (PFO), and six of them were negative. 18% had permanent neurological impairment and 32% died.

Conclusions: Delayed air embolism after CVC removal is an uncommon but potentially severe complication associated with substantial morbidity and mortality. Persistent venous-to-atmospheric communication was identified by imaging techniques in >90% of cases. Increased vigilance during and after CVC removal is necessary to improve future clinical practice.

1. Introduction

Central venous catheters (CVCs) are inserted in five millions of patients in the United States alone [1] in intensive care units (ICUs), operating rooms and in other departments to facilitate patient management [2]. CVCs may be used in up to 80% ICU patients [3] and are associated with a wide range of complications that may occur at any stage of the catheter's life cycle, such as hemorrhage, thromboembolism, infection, pneumothorax and air embolism [4].

Air embolism is a rare but potentially catastrophic complication of CVC positioning, management and removal, with cardiac, pulmonary, and paradoxical embolism, which can lead to cardiovascular collapse, stroke, and death [5–7]. These severe consequences highlight the critical need for awareness and preventive strategies to mitigate this risk.

The risk of air embolism during CVC positioning, manipulation or removal is well known and easily prevented through specific measures, such as proper patient positioning, breath control, and catheter occlusion [8]. On the contrary, delayed presentation of air embolism

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occurring 10 min to hours after CVC removal is less frequent, less understood and counterintuitive. Delayed presentation of air embolism could occur due several possible causes. Air may have entered at a given time, accumulated in (right) atrium with no or minimal symptoms, and then suddenly spreads into the systemic circulation and becomes symptomatic [9]. Importantly, air passing through a vein-to-dermis fistula with fibrin which had formed around the catheter as the portal of air entry was documented, with echography or CT scan, at least once 24 h after CVC removal [10].

As of today, there is limited data regarding delayed presentation of air embolism after CVC removal. We therefore performed a systematic review of published literature to understand the occurrence rate, the timing of clinical presentations, the associated risk factors, and outcome of this complication. By synthesizing evidence from case reports, we seek to enhance clinical vigilance and inform the development of safer CVC removal protocols.

2. Materials and methods

This systematic review adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [11]. The study protocol was registered on the International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD420251117573. The review question was developed using the SPIDER (Sample, Phenomenon of Interest, Design, Evaluation, and Research type) tool [12]:

- **S (Sample)**: Patients of any age who experienced air embolism after the removal of a CVC in a clinical setting.
- **PI (Phenomenon of Interest)**: The occurrence of air embolism 10 min or more after CVC removal, including venous and paradoxical air embolism.
- **D (Design)**: Case reports, case series, prospective and retrospective studies documenting air embolism post-CVC removal.
- **E (Evaluation)**: Time interval between removal of CVC and onset of symptoms, duration of CVC in place (dwell time); risk factors (e.g., patient position during/after removal, use of gauze or occlusive dressing); clinical presentation (e.g., respiratory system, cardiovascular system, central nervous system, and other symptoms); location of air and affected organ/system; diagnostic methods (e.g., imaging, echocardiography); management strategies (e.g., positioning, oxygen therapy); patient outcomes (e.g., recovery, morbidity, mortality, recovery time).
- **R (Research type)**: Qualitative and Quantitative

2.1. Search strategy

A comprehensive literature search was conducted across Pubmed, Embase and Google Scholar databases, spanning from their inception to December 1, 2025. The search strategy combined keywords and Medical Subject Headings (MeSH) terms, including “air embolism,” “central venous catheter,” “catheter removal,” and “case report,” applied with Boolean operators (‘OR’, ‘AND’, ‘NOT’). The detailed search string is available in the Supplementary Material. Reference lists of included studies were manually reviewed (snowballing) to identify additional relevant reports together with ChatGPT assistance. No language restrictions were imposed to maximize inclusivity. ChatGPT was used to translate one of the manuscripts [13].

2.2. Study selection

Studies were included if they were case reports, case series, prospective and retrospective studies documenting air embolism or symptoms 10 min or more after the removal of a CVC in human subjects, regardless of age. Studies which reported “several minutes” between catheter removal and symptoms onset were included and “several” was arbitrary considered as 10 min [14–18] while the term “overnight” utilized in one manuscript was interpreted as 4 h [19]. Exclusion criteria comprised studies not reporting original data, animal studies, and reports where air embolism occurred during CVC removal or symptoms occurred immediately (<10 min) after CVC removal. Time indicators such as “few minutes”, “shortly after”, “minutes after”, “suddenly”, “immediately” were considered <10 min and the studies were not included in this systematic review (Major exclusion on Table S1 Supplementary material).

Two independent reviewers screened titles and abstracts for relevance using a standardized form. Full texts of potentially eligible studies were then assessed for inclusion. Disagreements were resolved through discussion or by consulting a third reviewer. No language restriction was applied.

2.3. Data extraction

Data were extracted using a standardized form tailored to capture key details from each case report. Extracted information included patient demographics, catheter location, type and size, dwell time (days), and indication for removal; details of CVC removal (e.g., patient position, use of gauze for dressing, occlusive dressing applied, technique/other details) as risk factors; air embolism patient position; primary outcome of time interval between CVC removal and onset of symptoms; clinical presentation (e.g., symptoms related to respiratory system, cardiovascular system, central nervous system, and other symptoms such as diaphoresis); hypothesized mechanism of delayed air embolism; location of air; affected organ/system; diagnostic methods/tools; management strategies/treatment applied; and patient outcomes (e.g., recovery status, morbidity, mortality, recovery time).

Outcomes were summarized using absolute frequencies and percentages. Given the clinical and methodological heterogeneity of the included studies, and the non-uniform reporting of outcomes across case reports, a descriptive approach was adopted for selected variables.

To improve clarity and interpretability, supportive care and resuscitation were defined as follows. Supportive care was considered provided when at least one of the following interventions was reported in the absence of advanced treatments: oxygen supplementation, fluid administration, mechanical ventilation, Trendelenburg positioning, or left lateral decubitus positioning. Resuscitation was considered performed if explicitly reported or if the patient was intubated or received cardiopulmonary resuscitation (CPR). Patients were considered “with permanent sequelae” if the manuscript mentioned at least one between “partial recovery”, “severe sequelae” or other conditions, such as hemianopsia (found in 1 paper) [20].

3. Results

We screened 130 manuscripts and identified 27 manuscripts including 28 overall patients (Fig. 1). All studies focused on the clinical manifestation following CVC removal and were published in peer reviewed journals [10,13–37], except for one [38]. Patients had a median age of 63 (interquartile range [IQR] 50–70) years old and 10/28 (36%) were females (Table 1). The most frequently reported (21/27 = 78%) site of CVC insertion was the right internal jugular vein. Median catheter dwell time was 8 (IQR 4–14) days while the longest dwell time was 2 months.

The use of an occlusive dressing after CVC removal was reported in only one patient, while non-occlusive dressing was used in 18. Only two patients out of 18 were sitting during CVC removal.

In most cases (16/19 = 84%), patients were not lying down at symptoms onset.

Symptoms developed between ten minutes and one hour after removal of CVC in 15 (54%) patients, between one and two hours in four (14%), and after more than 2 h in nine (32%). The most frequent

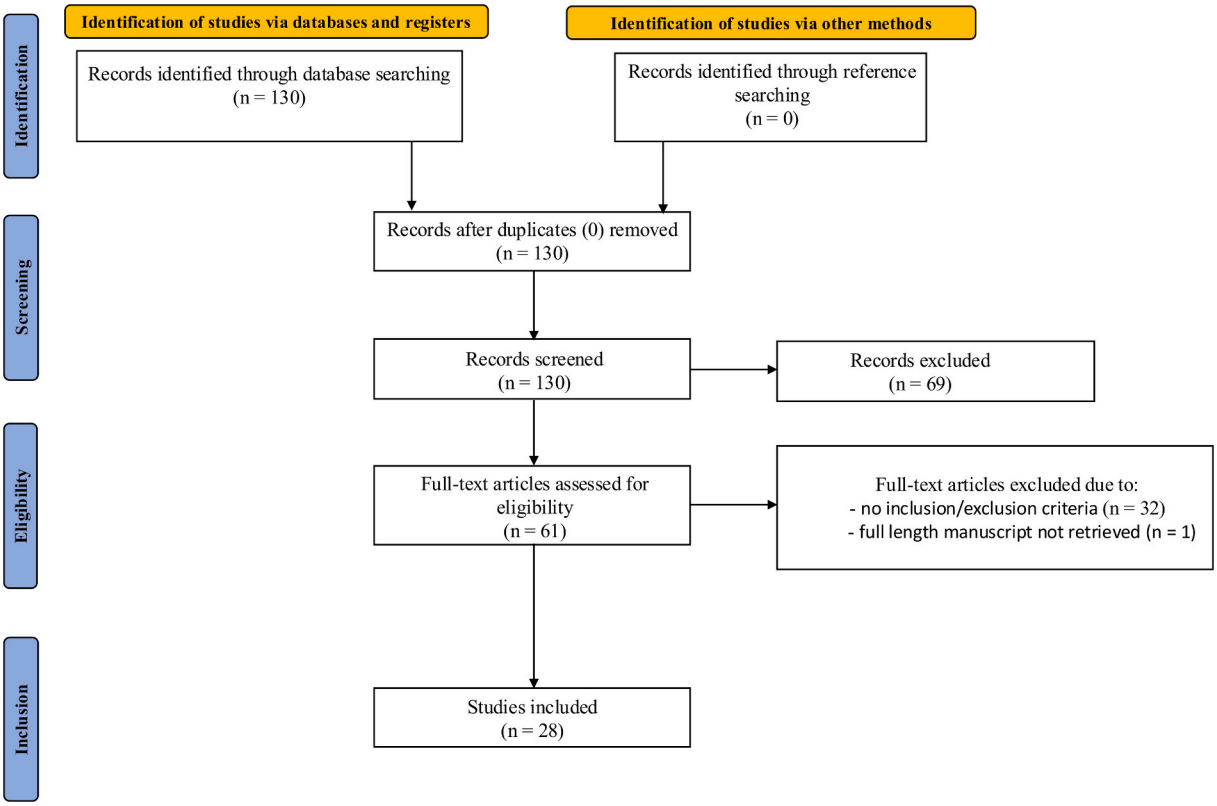

Fig. 1. Flow diagram of the study selection process.

manifestations at onset were neurological impairment (22/24, 92%) and hypoxemia, documented by oxygen desaturation (18/20, 90%) (Table 2). Two patients had cardiac arrest, one at symptoms onset and the other one after 15 min from consciousness alteration.

The diagnostic tools used were echocardiography (57%), CT scan (50%), vascular imaging in 32%, MRI in 25%, Ultrasound in 21%, and autopsy (4%).

Eleven authors investigated the presence of a venous to atmospheric communication through echography and CT scan. A patent transcutaneous channel was found in 10 cases, of which four had a fibrin sheath explicitly identified.

Air bubbles were found in multiple locations: the heart was involved in 12 patients (43%), the brain in 11 (39%) and the pulmonary system in six patients (21%).

Notably 14 patients had air detected in the right circulation only. All patients were symptomatic, with nine presenting neurological manifestations.

In ten studies, the presence ($N = 4$) or absence ($N = 6$) of patent foramen ovale (PFO) was explicitly reported. Within PFO patients, three patients out of four exhibited neurological symptoms and cerebral air localization. Surprisingly, among patients without PFO, all six developed neurological symptoms and showed evidence of cerebral air embolism.

Hyperbaric chamber was described in only one case, while another case required extracorporeal membrane oxygenation.

Full recovery was described in 14 patients (50%), while five (18%) had permanent neurological disabilities and nine (32%) died. When restricting the analysis to the 13 patients with symptoms onset ≥1 h, the results observed across all categories were highly consistent with those reported in the previous analysis (Table S2 Supplementary material). Nine patients (69%) developed neurological symptoms, while one had cardiac arrest. Air was found in the brain in 5 cases (38%). In 7 patients a patent transcutaneous channel was found. Only 7 patients (54%) fully recovered.

4. Discussion

4.1. Key findings

We identified 28 case reports of patients who suffered air embolism 10 min or more after removal of CVC, with almost half of them having symptoms onset ≥1 h. Delayed presentation was most likely due to fibrin sheaths persistence which maintained a patent transcutaneous channel. The most prevalent clinical presentation was neurological, even if more than half of the patients did not have a PFO at echography evaluation. Half of the patients fully recovered.

4.2. Relationship to previous studies

Literature on air embolism related to CVC has focused on complications occurring during or immediately after catheter insertion, with limited attention to post-removal events [1,39].

Evidence addressing air embolism after CVC removal is based on isolated case reports or small case series [5,7,8]. No systematic review has specifically examined delayed air embolism after CVC removal. Current preventive recommendations on removal management are mostly not supported by comparative studies, and generally include patient positioning, use of Valsalva-like maneuvers and application of air-occlusive dressings after catheter removal [7,8,40,41]. However, the optimal duration of post-removal monitoring and occlusive dressing application remains poorly defined.

4.3. Significance of study findings and what this study adds to our knowledge

The findings of this systematic review suggest that delayed air embolism after CVC removal may represent only the “tip of the iceberg,” with milder or unrecognized presentations potentially going undetected. The incidence of this event is unknown.

Table 1
Baseline characteristics, central venous catheter management and symptoms onset of the 28 patients who had delayed presentations of air embolism after central venous catheter removal.

Variables	$N = 28$
Age, median (IQR)	63 (50–70)
Female	10 (36%)
CVC site, n (%)	
Right Internal Jugular vein	21 (78%)
Left Internal Jugular vein	2 (7%)
Subclavian vein	3 (11)
Left side (no specified)	1 (4%)
Femoral vein	0 (0%)
Not available	1
Catheter type, n (%)	
Non-tunneled	9
N/A	19
Catheter size, n (%)	
14 Fr	1 (8%)
12 Fr	5 (42%)
11 Fr	1 (8%)
9 Fr	1 (8%)
7 Fr	2 (17%)
14 G	1 (8%)
6 Fr	1 (8%)
N/A	16
Dwell time, n (days)	
Median	8
Range	1–60
Not reported (n)	3
Gauze dressing, n (%)	
Yes	16 (94%)
No	1 (6%)
N/A	11
Occlusive dressing, n (%)	
Yes	1 (5%)
No	18 (95%)
N/A	9
Patient position upon CVC removal, n (%)	
Supine	9 (53%)
Trendelenburg	4 (23%)
Reverse Trendelenburg	2 (12%)
Sitting	2 (12%)
N/A	11
Patient position at symptoms onset, n (%)	
Sitting	8 (42%)
Upright	8 (42%)
Lying	3 (16%)
N/A	9
Time between CVC removal and symptoms onset	
10 min - 59 min	15 (54%)
60 min - 119 min	4 (14%)
≥120 min	9 (32%)

Abbreviations: CVC: central venous catheter; IQR: interquartile range.

Table 2
Patients presentation, diagnostic and outcomes.

Clinical, diagnostic and outcome variables	Number of patients, n (%)
Complications	
Neurological Impairment	22/24 (92%)
Oxygen Desaturation	18/20 (90%)
Arterial Hypotension	9/19 (47%)
Diaphoresis/agitation	7/9 (78%)
Cardiac ischemia	3 (11%)
Cardiac arrest	2 (7%)
Other symptoms	23 (82%)
Diagnostic tools	
Echocardiography	16 (57%)
Computed Tomography	14 (50%)
Vascular imaging	9 (32%)
Magnetic Resonance Imaging	7 (25%)
Ultrasound	6 (21%)
Autopsy	1 (4%)
Persistent patent catheter tract after CVC removal	
Yes, without specification	10 (91%)
Fibrin sheath, explicitly	4 (36%)
No transcutaneous channel	1 (9%)
Not investigated	17
Air location	
Only cardiac	9 (32%)
Only neurological system	8 (29%)
Only respiratory system	2 (7%)
Two or more sites	9 (32%)
At least one cardiac finding	12 (43%)
At least one cerebral finding	11 (39%)
At least one pulmonary finding	6 (21%)
PFO presence	
Yes	4 (40%)
No	6 (60%)
Not investigated	18
Treatment	
Resuscitation	10 (36%)
Supportive care	12 (43%)
Hyperbaric chamber	1 (4%)
ECMO	1 (4%)
Recovery	
Full recovery	14 (50%)
With permanent sequelae	5 (18%)
Fatal	9 (32%)

Abbreviations: CVC: central venous catheter; PFO: patent foramen ovale; ECMO: extra corporeal membrane oxygenation.

The most important finding of our systematic review is that in most cases (10/11 = 91%) where a soft tissue ultrasound or CT scan was performed, a patent transcutaneous channel connecting the atmosphere to the intravenous space was identified, with fibrin sheath explicitly reported in four cases. The persistency of this channel avoided the collapse of the tissue, permitting air entrance even hours after removal [26] (Fig. S1 Supplementary Material).

Neurological manifestations were observed in 92% of patients, with cerebral air embolism findings in 39% of cases. Three etiopathological pathways can explain brain air embolism, with the most common being a right-to-left intracardiac shunt, namely a PFO, seen in 30% of patients worldwide [7,42]. In our systematic review only four patients showed PFO imaging findings out of the ten who were analyzed. Therefore, other mechanisms may also contribute to neurological symptoms.

The passage of venous air to the arterial bloodstream does not necessarily require an intracardiac shunt. Animal studies show that when the filtering capacity of the pulmonary capillary bed is exceeded, air bubbles may traverse the pulmonary circulation and enter the arterial system [43].

Another mechanism responsible for cerebral air embolism is retrograde air flow into brain circulation. Air bubbles' buoyancy allows larger ones to move backward and overcome venous blood flow [44], in particular when the patient holds an upright position or strains (e.g., during coughing, sneezing, defecation, or Valsalva maneuver) [45]. This would explain, at least in part, the nine patients with air bubbles found in the brain, and particularly the six cases without PFO. To support this hypothesis, four case reports explicitly mentioned air being found in the cerebral venous system.

Since intravascular air is absorbed over time [46], *chances* that delayed neurological manifestations result from the mobilization of residual intracardiac air decreases accordingly. This temporal relationship suggests that alternative pathophysiological mechanisms are more likely responsible.

Overall, this review expands existing knowledge, highlighting the need for development of standardized preventive strategies and monitoring protocols that also take into account prevention of delayed air embolism.

4.4. Strengths and limitations of the study

Limitations of this systematic review should be acknowledged. First, we only identified case reports and one case series, limiting the estimation of true incidence. Conversely, this is the first systematic review

focusing on the delayed nature of air embolism after CVC removal. Second, publication bias is likely: severe cases are reported more often, and additional case reports may be harder to publish once similar cases are already in the literature. It is possible that we may have identified the tip of the iceberg, with most cases likely left unreported. Third, some authors reported incomplete data and reports not mentioning delay between catheter removal and symptoms were not included. Nonetheless, our review was conducted following PRISMA guidelines [11], through a comprehensive search across multiple databases, minimizing the risk of missing relevant reports, and no language restrictions were applied. Fourth, risk factors beyond the development of fibrin sheaths were not identifiable.

4.5. Future perspectives

In the future, delayed air embolism should be considered when discussing best practices for CVC removal. Future studies should investigate risk factors of delayed air embolism such as local thrombosis, CVC bore width and duration of catheter permanence. At present, literature lacks robust evidence for establishment of a standard procedure for CVC removal [47] and post-removal care. It is therefore necessary to better characterize incidence, timing and risk factors of CVC complications to develop structured guidance.

Simple and sustainable acts can be introduced in future clinical practice, such as allowing a small amount of blood to exit the catheter channel before compression to promote channel sealing through blood coagulation to reduce the risk of air entry. Interestingly, sealing the catheter exit tract with bioadhesive materials before gauze dressing (e.g., cyanoacrylate and polyethylene glycol–based hydrogels) [48] may allow a better channel occlusion. We propose PACMAN bundle for CVC removal to limit risks of delayed air embolism (Table 3): P for Position of the patient during catheter removal, ensuring it is supine flat or Trendelenburg position, unless contraindicated [41]; A for Airways block, with patient performing a Valsalva maneuver, or holding his breath when Valsalva maneuver is contraindicated [41]; C for Coagulation of the insertion channel by allowing a small amount of blood to escape before compression; M for Manual compression until hemostasis is achieved [41]; A for Application of gauze dressing and potentially bioadhesive material; N for Neutral decubitus by ensuring that the patient, if possible, stays in a flat or reclined position [41] for 30 min after CVC removal. Finally, it is crucial to raise awareness among clinicians around this fatal complication. Therefore, we suggest to systematically report delays between catheter removal and air embolism, evaluate the presence of fibrin sheaths as a potential source of air, and perform a systematic search of PFO. Surveys, on social media or during conferences, can be determinant to identify the true incidence of this complication.

5. Conclusions

Delayed air embolism after CVC removal is an uncommon but life-threatening complication that may occur hours after the procedure and is frequently associated with respiratory and neurological manifestations. The most plausible etiology is the formation of a transcutaneous fibrin channel, that may avoid tissue collapse allowing continuous air entry, particularly in case of negative intrathoracic pressure or upright position. Simple procedural adjustments, such as allowing a small amount of blood to escape from the catheter tract before compression, may help reduce the risk of delayed air embolism.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the authors used ChatGPT in order to support search strategy and to the translate one of the manuscripts. After using this tool, the authors reviewed and edited the content as needed and takes full responsibility for the content of the published article.

Table 3
Suggested actions to prevent delayed air embolism after central venous catheter removal (The PACMAN bundle).

P	Position of the patient: supine flat or Trendelenburg position during catheter removal.
A	Airways block: be sure that the patient performs Valsalva maneuver, or that holds his breath if Valsalva maneuver contraindicated.
C	Coagulation: allow a small amount of blood to escape from the catheter tract before compression.
M	Manual compression: compress until hemostasis is achieved.
A	Application: gauze dressing and potentially bioadhesive material.
N	Neutral decubitus: be sure that the patient stays in a flat or reclined position for 30 min after removal.

CRediT authorship contribution statement

Emanuele Pacini: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation. **Liliana Alfaroli:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation. **Özgün Ömer Asiller:** Writing – original draft, Methodology, Investigation, Data curation. **Alessandro Belletti:** Writing – review & editing, Conceptualization. **Matteo Borello:** Writing – review & editing, Data curation. **Stefano Fresilli:** Writing – review & editing, Conceptualization. **Giovanni Landoni:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Conceptualization. **Daniel De Backer:** Writing – review & editing, Formal analysis. **Giacomo Monti:** Writing – review & editing, Supervision, Data curation, Conceptualization.

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Declaration of competing interest

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcrc.2026.155606.

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