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Research Article

Etiology of Intracranial Pneumocephalus: A Retrospective Comparative Study of Traumatic and Iatrogenic Causes in Emergency Patients

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Abstract

Aim: The aim of this study was to retrospectively investigate the traumatic and iatrogenic causes of intracranial pneumocephalus (ICnP) in patients presenting to the emergency department (ED). Additionally, the study sought to evaluate the role of venous air embolism during intravenous (IV) line placement in the development of ICnP.

Material and Method: A total of 462 patients who presented to the ED of a tertiary healthcare center between 2018 and 2024 were retrospectively analyzed. Patients included in the study presented with complaints of head trauma or headache but did not have open cranial wounds, evident basal skull fractures, or a history of intracranial surgery. Non-contrast cranial Computed Tomography (CT) scans were performed on all patients, and the anatomical localization of pneumocephalus as well as the IV line placement status were meticulously recorded. Statistical analyses were conducted using SPSS version 26.0, with a significance level of $p<0.05$.

Results: ICnP was most commonly detected in the anterior cranial fossa (62%), followed by the middle fossa (24%) and posterior fossa (10%). Among patients with IV lines, air bubbles were observed in 3.45% of the head trauma group and 2.06% of the headache group. In patients without IV lines, these rates were lower, at 1% and 1.67%, respectively. No statistically significant differences were found between age groups or genders ($p>0.05$). However, a strong association was noted between IV line placement and venous air embolism.

Conclusion: ICnP is commonly associated with venous air embolism occurring during IV line placement and resolves spontaneously within 24 hours in most cases. Our findings indicate that such air bubbles are typically attributed to iatrogenic causes rather than severe pathologies such as basal skull fractures. Avoiding unnecessary further investigations in patients whose air bubbles resolve within the first 24 hours can optimize clinical management and provide a cost-effective approach.

Keywords: Intracranial pneumocephalus, venous air embolism, basal skull fracture, emergency department

INTRODUCTION

Pneumocephalus are a rare clinical condition characterized by the presence of air within the cranial cavity (1). They typically occur following traumatic injuries, surgical interventions, or infections, and these conditions are often associated with skull base fractures (2,3). However, pneumocephalus can also be detected in patients with no history of trauma or apparent cranial pathology (4,5).

According to the literature, pneumocephalus are most commonly localized in the anterior cranial fossa, as indicated by the Mount Fuji radiological sign (6,7). This region is more prone to air leakage due to the proximity of the ethmoid bone and frontal sinuses. Furthermore, the thin dura mater in the anterior cranial fossa, which adheres tightly to the bone, and the arachnoid membranes attaching to the frontal lobes, result in air being trapped within the subdural space of this fossa (8). The thin bony structure of the anterior cranial fossa and its adjacent air cavities further contribute to the accumulation of air bubbles in this area (9).

Venous air embolism is another potential etiology of pneumocephalus. Particularly in emergency departments, air can enter the venous system during intravenous (IV) catheter placement (10). Although the

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exact pathophysiology of venous air embolism remains unclear, the literature agrees that small, low-weight air bubbles can travel retrogradely through the jugular veins against the flow of blood in an upright patient, leading to their occurrence (11).

The aim of this study is to evaluate the etiology of pneumocephalus in patients presenting to the emergency department (ED) with and without head trauma and to investigate the role of intra-venous air leakage. Our hypothesis posits that pneumocephalus are not solely associated with skull base fractures but may also result from venous air leakage during IV catheterization.

MATERIAL AND METHOD

This study was conducted as a retrospective analysis of patients presenting to the ED of a tertiary care center between 2018 and 2024. A total of 462 patients with complaints of head trauma and headache were included. Inclusion criteria were defined as patients aged 18-95 years presenting with clinical complaints of head trauma or headache. Patients with open cranial injuries, evident skull base fractures, intracranial hemorrhage, or a history of intracranial surgery were excluded. Additionally, cases with incomplete clinical or radiological data were not included in the analysis.

All patients underwent an emergency non-contrast cranial Computed Tomography (CT) scan upon admission. Demographic information, including age and gender, clinical conditions, venous access placement status, and the localization of pneumocephalus, were meticulously recorded. Patients' ages were categorized into three groups: 18-40 years, 41-65 years, and over 66 years. The anatomical localization of pneumocephalus was classified into anterior, middle, and posterior cranial fossae. Venous access placement was evaluated based on hospital records, and patients with venous access were analyzed as a separate group (Table 1).

Patients with detected air bubbles on cranial CT scans were admitted for follow-up. A control CT scan was performed 24 hours later. Patients whose air bubbles did not resolve within 24 hours were excluded from the study.

Radiological evaluations were conducted by two independent and experienced neuroradiologists, and consensus was reached on the localization and dimensions of air bubbles. Initial cranial CT scans were retrospectively reviewed through the digital archive system, with detailed documentation of the visibility and localization of pneumocephalus. CT scans were performed with slice thicknesses ≤5 mm, in accordance with established standards in the literature for air bubble detection (12).

Statistical analysis of the data was performed using Statistical Package for the Social Sciences (SPSS) version 26.0 software. Continuous variables were expressed as mean±standard deviation, while categorical variables were presented as frequencies and percentages. Independent sample t-tests were used to assess significant differences between patients with and without head trauma, while chi-square tests were applied to evaluate relationships between categorical variables. A significance level of $p<0.05$ was considered statistically significant.

This study was approved by the Ordu University Non-Interventional Scientific Research Ethics Committee (Approval number: E-14647249-000-110429, Decision number: 2025/35, Date: 07.02.2025). The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and approved institutional guidelines.

Statistical Analysis

This study utilized SPSS version 26.0 for the analysis of intracranial air bubble distribution and etiology. Continuous variables were expressed as mean±standard deviation (SD), while categorical variables were presented as frequencies and percentages. Chi-square tests were employed for comparisons between groups to evaluate the relationships between the occurrence of pneumocephalus and factors such as IV access status, clinical conditions (head trauma and headache), and anatomical localization. A significance threshold of $p<0.05$ was applied, and the results were summarized in tables and figures. However, no significant differences were found between patients with and without IV access or among different anatomical localizations.

RESULTS

Statistical analyses revealed no significant differences in the prevalence of pneumocephalus across age groups or between genders ($p=0.903$). However, the analysis suggested a potential increase in prevalence with advancing age, although this trend was not statistically significant. Similarly, while air bubbles were observed more frequently in male patients compared to females, this difference did not reach statistical significance (Table 1).

Comparisons between patients with and without IV access showed no statistically significant differences in the frequency of pneumocephalus in trauma and headache groups ($p=0.590$). Nevertheless, in patients with IV access, air bubbles were detected at a rate of 3.45% in the trauma group and 2.06% in the headache group. In contrast, these rates were 1% and 1.67% respectively in patients without IV access. These findings suggest a potential association between air bubbles and venous air embolism, although no significant relationship was established between clinical groups (Table 2, Figure 1).

The anatomical localization analysis indicated that air bubbles were most commonly found in the anterior cranial fossa (62%), followed by the middle cranial fossa (24%) and the posterior cranial fossa (10%). However, no significant differences were detected between these anatomical regions ($p=0.188$) (Table 3, Figure 2).

Table 1. Distribution of demographic characteristics by age groups				
Age group	**Total number of patients**	**Male patients (%)**	**Female patients (%)**	**p-value**
18-40	138	83 (60.1)	55 (39.9)	0.903
41-65	184	110 (59.8)	74 (40.2)	0.903
66+	140	87 (62.1)	53 (37.9)	0.903

This table presents the gender distribution across different age groups; Statistical Test: Chi-Square Test was applied; p-Values: No significant difference was found in gender distribution across all age groups (p=0.903)

Table 2. Air bubble detection rates by clinical condition and venous access status					
Clinical condition	**Venous access status**	**Total number of patients**	**Number of air bubble detections**	**Detection rate (%)**	**p-value**
Head trauma	**IV line placed**	145	5	3.45	0.590
	IV line not placed	100	1	1.00	0.590
Headache	**IV line placed**	97	2	2.06	0.590
	IV line not placed	120	2	1.67	0.590

This table displays the rates of intracranial air bubble detection based on clinical conditions (head trauma and headache) and the presence or absence of venous access; Statistical Test: Chi-Square Test was applied; p-Values: No significant differences were found between patients with and without venous access (p=0.590)

Table 3. Anatomical localization of air bubbles				
Localization	**Total number of detections**	**Male detection (%)**	**Female detection (%)**	**p-value**
Anterior fossa	162 (62%)	70	60	0.188
Middle fossa	62 (24%)	30	20	0.188
Posterior fossa	26 (10%)	15	5	0.188

This table illustrates the distribution of air bubbles based on anatomical localization Statistical Test: Chi-Square Test was applied; p-Values: No significant differences were found among the anatomical localizations (p=0.188)

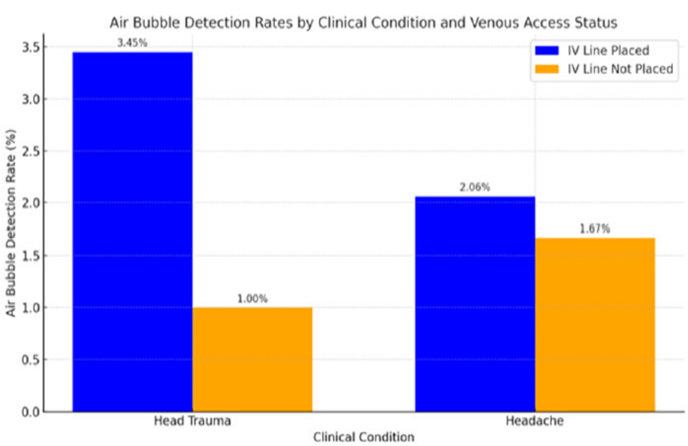

Figure 1. Air bubble detection rates by clinical condition and venous access status; This bar chart illustrates the detection rates of pneumocephalus across two clinical conditions: trauma and headache, stratified by IV access status; Detection rates were higher in cases with IV access (3.45% for trauma, 2.06% for headache) compared to cases without IV access (1.0% and 1.67%, respectively); No significant differences between the groups (p=0.590)

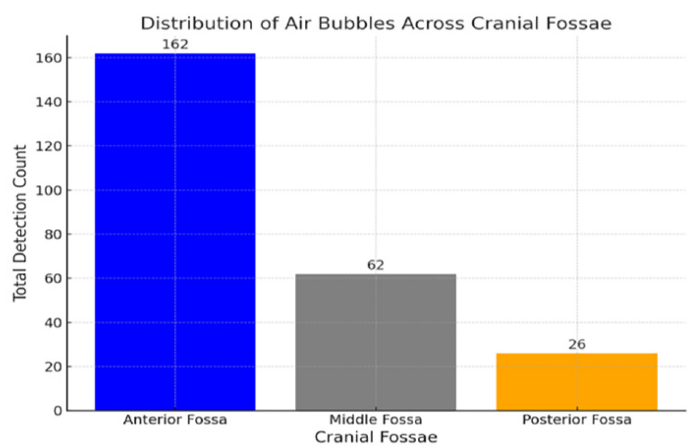

Figure 2. Distribution of pneumocephalus across cranial fossae; This bar chart shows the distribution of pneumocephalus across the cranial fossae; The anterior fossa exhibited the highest prevalence (162 cases, 62%), followed by the middle fossa (62 cases, 24%) and posterior fossa (26 cases, 10%); While the anterior fossa demonstrated a higher frequency, the differences between the fossae were not statistically significant (p=0.188)

DISCUSSION

This study retrospectively investigated the etiology of pneumocephalus in patients presenting to the ED with complaints of closed head trauma and headache, demonstrating that this phenomenon predominantly arises from iatrogenic causes. Our findings indicate that while the occurrence of pneumocephalus shows some variation in patients with IV lines, these differences are not statistically significant. The disappearance of most of these air bubbles within 24 hours in short-term follow-up is considered an important indicator to rule out the possibility of a basal skull fracture (Figure 3).

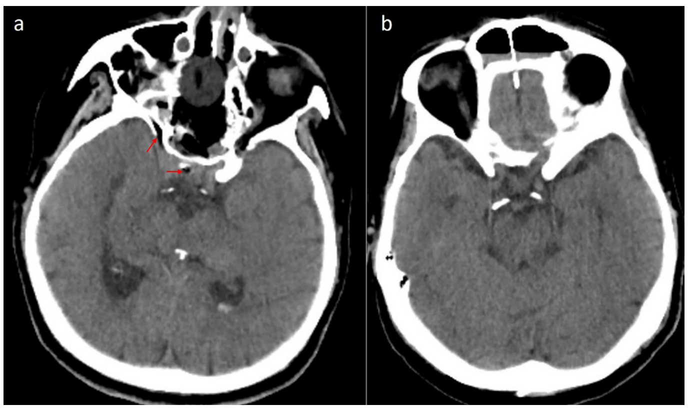

Figure 3. A. A brain computed tomography (CT) scan of a patient with blunt head trauma who was admitted to the emergency department; The scan shows pneumocephalus within the cranial cavity, indicated by red arrows; **B.** A follow-up brain CT scan taken 24 hours later demonstrates the spontaneous disappearance of the previously observed air bubbles

Detecting basal skull fractures using cranial CT imaging is often challenging (13). The structural characteristics of the anterior cranial fossa, including its predisposition to air leakage, may contribute to the accumulation of air bubbles in this region. In patients with traumatic basal skull fractures, two prominent symptoms are commonly observed: rhinorrhea and periorbital ecchymosis (14,15). Among patients presenting these symptoms, 80% and 76%, respectively, were found to have basal skull fractures (16,17). However, basal skull fractures were detected in only 19%-48% of patients with periorbital ecchymosis and 10%-30% of those with rhinorrhea (18-20). Thus, the presence of symptoms or cranial CT imaging alone may not suffice for diagnosing basal skull fractures. The literature emphasizes the importance of considering air bubbles detected on cranial CT scans (21).

Although air bubbles may serve as an indicator, their presence does not necessitate immediate and unnecessary further investigations, as air bubbles do not always indicate basal skull fractures (22,23). In our study, air bubbles were detected in 3.45% of patients with trauma and IV lines and 2.06% in headache patients with IV lines. Conversely, these rates were 1% and 1.67%, respectively, in patients without IV lines. These data suggest that head trauma alone is insufficient to cause pneumocephalus, which are more likely associated with venous air embolism occurring during IV placement. The literature notes that venous air embolisms are typically harmless and resolve completely within 1-3 days, sometimes within hours or up to a week (24-26). This can be attributed to the reabsorption of air through the venous circulation or its transfer into pulmonary circulation (27). Small venous air embolisms are generally eliminated via the pulmonary circulation and follow a clinically benign course (28).

In our study, air bubbles were found to disappear on follow-up CT scans conducted 24 hours after the initial cranial CT in patients with IV lines. Although further investigations were performed in some patients despite the disappearance of air bubbles, no significant findings were observed. Therefore, deferring further tests in patients whose air bubbles disappear within 24 hours and who do not develop new symptoms is recommended. However, additional evaluations should be performed in cases where air bubbles persist. The disappearance of air bubbles within 24 hours and the absence of additional findings related to basal skull fractures in further investigations have allowed for the safe discharge of such patients.

One of the strengths of this study is the retrospective analysis of a large patient group (n=462) with detailed evaluations of these groups. However, the study has certain limitations. For instance, the lack of cases developing new symptoms within 24 hours has limited our ability to distinguish between harmless and harmful air embolisms. Furthermore, advanced imaging techniques were not used to directly demonstrate venous air embolism, and the small sample size of patients without IV lines restricts the generalizability of the findings. These limitations highlight the need for larger-scale prospective studies.

Additionally, our study provided short-term follow-up of cerebral venous air embolism up to 24 hours but did not evaluate the long-term effects of air bubbles. While the literature generally agrees that small venous air embolisms do not pose significant short-term problems, long-term follow-up could have provided a more precise understanding of the extent to which the rapid resolution of air bubbles reduces the likelihood of basal skull fractures (29). Although methods such as hyperbaric oxygen therapy and Trendelenburg positioning have been suggested to accelerate air bubble absorption, there is no consensus in the literature regarding their clinical benefits (30,31). Furthermore, adequate training of ED personnel on IV line placement and air evacuation can reduce the risk of venous air embolism, improve patient care, and enhance efficiency in healthcare systems (32).

CONCLUSION

Intracranial pneumocephalus (ICnP) is associated with iatrogenic venous air embolism, particularly during IV line placement. This phenomenon typically resolves spontaneously within 24 hours, does not require additional treatment, and follows a benign clinical course. Avoiding unnecessary further investigations in cases where air bubbles resolve within the first 24 hours offers a cost-effective approach, optimizing patient management and improving resource utilization within the healthcare system.

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Ethical approval: *This study was approved by the Ordu University Non-Interventional Scientific Research Ethics Committee (Approval number: E-14647249-000-110429, Decision number: 2025/35, Date: 07.02.2025).*

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