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Effectiveness of Self-Administered Non-Pharmacological Interventions for the Prevention and Relief of Middle Ear Barotrauma During Air Travel: A Systematic Review

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Abstract

Middle ear barotrauma is a common complication of air travel caused by failure of adequate pressure equalization across the tympanic membrane. This systematic review evaluated the effectiveness of self-administered non-pharmacological interventions for the prevention and relief of middle ear barotrauma associated with air travel. PubMed, Scopus, ScienceDirect, and the Cochrane Library were searched without publication date restrictions. Studies assessing self-administered mechanical interventions during actual or simulated aviation-related pressure exposure were included. Three studies met the eligibility criteria, comprising one prospective controlled study, one prospective non-randomized controlled interventional study, and one double-blind randomized crossover trial. Nasal balloon autoinflation was associated with lower rates of barotitis and improved middle ear pressure equalization. In one study, barotitis occurred in 6% of compliant autoinflation users compared with 15% of controls, while another reported delayed barotrauma in 38.6% versus 68.2%, respectively. Nasal balloon use also restored normal pressure in 69% of participants who failed valsalva maneuver. Pressure-regulating earplugs did not significantly improve Eustachian tube function or pressure-equalization performance but significantly reduced subjective discomfort. Overall, self-administered non-pharmacological interventions, particularly nasal balloon autoinflation, may provide practical benefit in preventing or relieving middle ear barotrauma, although the limited and heterogeneous evidence warrants further high-quality randomized studies.

Keywords: Middle ear barotrauma; Air travel; Self-administered interventions; Non-pharmacological interventions; Prevention

Introduction

Air travel has become a fundamental pillar of modern global mobility; however, it imposes significant physiological demands due to periodic exposure to rapid changes in atmospheric pressure [1] [2]. The take-off phase and, more critically, the aircraft descent phase force the human auditory system to adapt drastically to shifting cabin barometric pressures [3]. When the Eustachian tube fails to execute its mechanical ventilation and equalization functions between the middle ear cavity and the external environment, negative intra-tympanic pressure develops rapidly [4]. This progressive functional failure triggers mucosal inflammation and structural strain on the tympanic membrane—a clinical aviation manifestation widely known as middle ear barotrauma or *airplane ear* [5].

Clinically, the manifestations of middle ear barotrauma vary from mild discomfort to severe structural complications [6]. Initial symptoms typically include a sensation of fullness or blockage (*blockage*), acute otalgia caused by membrane distortion, and tinnitus [7]. If the pressure gradient continues to rise beyond the tolerance threshold of the ear's barostructure, it can induce mucosal transudate effusion, hemotympanum, or even tympanic membrane perforation, potentially leading to long-term conductive hearing loss [8]. Epidemiological studies indicate that this condition affects approximately 20% of adult passengers and up to

40% of pediatric passengers [4]. Furthermore, among high-flying commercial cabin crews, the prevalence of middle ear barotrauma reaches a striking 85% at some point during their careers [9].

To date, preventive approaches for barotrauma are divided into pharmacological interventions and self-administered non-pharmacological methods [10]. Pharmacological protocols utilizing oral or topical decongestants, such as pseudoephedrine, are frequently selected to reduce nasopharyngeal mucosal edema [4]. Unfortunately, these chemical agents carry risks of systemic adverse effects, including tachycardia, somnolence, and rebound congestion, requiring careful clinical consideration prior to flight [10]. Alternatively, *self-administered non-pharmacological interventions* offer safe, cost-free, and universally accessible active and passive equalization modalities for passengers [5]. Mechanical techniques such as the Valsalva maneuver, the Toynbee maneuver, physiological stimulation through swallowing or chewing, the use of pressure-regulating earplugs (*pressure-regulating earplugs*), and nasal balloon autoinflation (*nasal balloon auto-inflation*) have become primary recommendations within civil aviation safety protocols [4], [11].

Although these self-administered methods are widely practiced, the underlying scientific evidence evaluating their comparative clinical efficacy remains highly fragmented and plagued by inconsistent study outcomes [10]. Some clinical trials demonstrate superior efficacy for mechanical autoinflation techniques, whereas other systematic reviews report limited robust empirical evidence regarding the reliability of specialized cabin earplugs [4], [11]. The lack of standardized educational guidelines from aerospace safety authorities often leads passengers to perform equalization maneuvers incorrectly, inadvertently increasing the risk of secondary barotrauma or micro-otic injuries [5]. To date, comprehensive evaluations utilizing a *systematic review* framework to synthesize clinical efficacy data across all self-administered non-pharmacological interventions remain remarkably scarce.

This *systematic review* was established to address this prominent knowledge gap. Utilizing an evidence-based framework, this study aims to evaluate, critically analyze, and synthesize the efficacy of various self-administered non-pharmacological interventions performed by passengers to prevent and alleviate middle ear barotrauma during air travel. The synthesized data from this review is intended to provide a robust foundation for establishing aviation medicine clinical guidelines, practical safety recommendations for commercial airlines, and strategic directions for future aerospace research.

Methods

This systematic review was conducted based on the Preferred Reporting Items for Systematic Reviews.

2.1 Eligibility Criteria

Inclusion and exclusion criteria were determined before the literature search to improve the specificity of the review. Studies involving individuals exposed to pressure changes related to air travel, including actual flights and simulated aviation-related pressure exposure, were included. The interventions of interest were self-administered non-pharmacological interventions intended to prevent, relieve, or correct middle ear barotrauma or pressure-equalization difficulties, including the Valsalva maneuver, nasal balloon autoinflation, pressure-regulating or pressure-equalizing earplugs, and other self-applied mechanical interventions.

The PICOS framework was used to determine the inclusion criteria, consisting of: 1) Population: children or adults exposed to actual air travel or simulated aviation-related pressure changes; 2) Intervention: self-administered non-pharmacological interventions for the prevention or relief of middle ear barotrauma; 3) Comparison: no intervention, usual care, placebo or sham intervention, or another self-administered non-pharmacological intervention; 4) Outcome: incidence or severity of middle ear barotrauma, ear pain or discomfort, middle ear pressure equalization, Eustachian tube function, and related clinical outcomes; and 5) Study design: randomized controlled trials, crossover trials, prospective controlled studies, non-randomized controlled interventional studies, or prospective interventional studies. The exclusion criteria were: 1) studies irrelevant to the aim of the review; 2) barotrauma caused by diving, hyperbaric oxygen therapy, or other non-aviation-related pressure exposure; 3) studies evaluating pharmacological, surgical, or other non-self-administered interventions; 4) observational studies without evaluation of an intervention; 5) case reports, reviews, editorials, and conference abstracts without sufficient data; and 6) non-human or in vitro studies.

2.2 Search Strategy

Independent researchers searched the relevant literature using PubMed, Scopus, ScienceDirect, and the Cochrane Library, without publication date restrictions. The search terms were adapted according to the requirements of each database and were based on three main concepts: middle ear barotrauma, air travel, and non-pharmacological interventions. The principal keywords included:

("barotrauma" OR "barotitis" OR "middle ear barotrauma" OR "otic barotrauma" OR "ear pain") AND ("air travel" OR "aviation" OR "aircraft" OR "flight" OR "cabin pressure") AND ("Valsalva" OR "Toynbee" OR "autoinflation" OR "Otovent" OR "nasal balloon" OR "earplug" OR "pressure equalization"). The search strategy was modified when necessary to comply with the search limitations and syntax of each database.

2.3 Data Extraction and Analysis

The included studies were independently extracted by two reviewers using a standardized data extraction sheet. Extracted information included the first author, year of publication, study design, study location, participant characteristics, sample size, intervention and comparator groups, intervention protocol, and reported outcomes. The two reviewers subsequently evaluated the extracted data for accuracy and study eligibility. Any disagreements arising during the study selection or data extraction process were resolved through discussion and consensus.

Due to differences in study populations, interventions, exposure settings, and outcome measurements, the findings were primarily synthesized descriptively. Results were grouped according to clinically relevant outcomes, including the incidence and severity of middle ear barotrauma, middle ear pressure equalization and Eustachian tube function, and ear pain or subjective discomfort.

2.4 Risk of Bias Assessment

The risk of bias of the included studies was assessed according to study design. The Cochrane Risk of Bias 2 (RoB 2) tool for crossover randomized trials was used for randomized crossover studies, while the Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool was used for prospective controlled non-randomized studies.

RoB 2 assesses bias arising from the randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result, with additional consideration of period and carryover effects in crossover trials. The overall risk of bias was categorized as low risk, some concerns, or high risk. ROBINS-I evaluates bias due to confounding, participant selection, classification of interventions, deviations from intended interventions, missing data, measurement of outcomes, and selection of the reported result. Judgments were categorized according to the recommendations of the respective assessment tool. Disagreements between reviewers were resolved through discussion.

2.5 Intervention of Interest

Self-administered non-pharmacological interventions provide a practical approach for preventing or relieving middle ear pressure-related symptoms during changes in ambient pressure associated with air travel. These interventions aim to facilitate pressure equalization between the middle ear and the surrounding environment without the use of pharmacological or invasive treatment. The interventions evaluated in this review included pressure-equalization maneuvers such as the Valsalva maneuver, nasal balloon autoinflation, pressure-regulating or pressure-equalizing earplugs, and other self-applied mechanical approaches. Therefore, this review focused on evaluating the effectiveness of these self-administered non-pharmacological interventions in preventing and relieving middle ear barotrauma associated with air travel or simulated aviation-related pressure exposure.

2.6 Outcome of Interest

The primary outcomes of this review were the incidence and severity of middle ear barotrauma, ear pain or subjective discomfort, and successful middle ear pressure equalization. Middle ear barotrauma was assessed using reported clinical or otoscopic findings, including barotitis severity and tympanic membrane changes.

Secondary outcomes included middle ear pressure or tympanometric findings, Eustachian tube function, the number or success of pressure-equalizing maneuvers, ear fullness or blockage, hearing-related symptoms, and other intervention-related clinical outcomes. Multiple outcomes were assessed to provide a comprehensive evaluation of the effectiveness of self-administered non-pharmacological interventions for the prevention and relief of middle ear barotrauma during air travel.

Results

3.1 Study selection and identification

After the literature search, a total of 77 records were identified from four databases: PubMed (n = 33), ScienceDirect (n = 2), Scopus (n = 38), and Cochrane (n = 4). After removing 32 duplicate records, 45 records remained for title and abstract screening. Of these, 37 records were excluded, leaving eight reports sought for retrieval. Two reports could not be retrieved, resulting in six reports assessed for eligibility. Three reports were subsequently excluded due to wrong publication type (n = 1) and wrong study design (n = 2). **Fig. 1** shows the PRISMA flowchart. Thus, three studies were included in the systematic review for qualitative analysis.

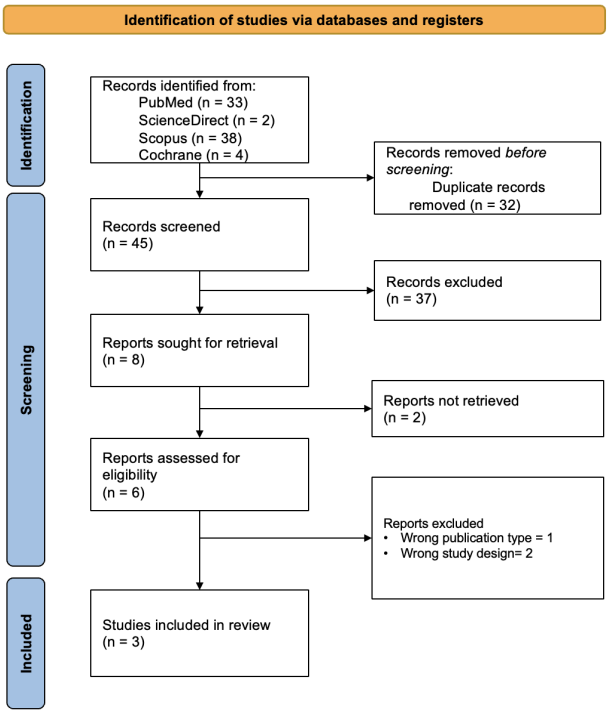


Figure 1. PRISMA Flowchart

3.2. Risk of Bias

The risk of bias varied across the included studies. Jumah et al. (2010) was judged to have an overall low risk of bias, although some concerns were identified in the randomization process. Stangerup et al. (2004) was judged to have some concerns overall, mainly due to concerns regarding deviations from the intended intervention and missing outcome data. Using ROBINS-I, Landolfi et al. (2010) was judged to have an overall serious risk of bias, primarily due to serious concerns related to confounding, participant selection, and outcome measurement.

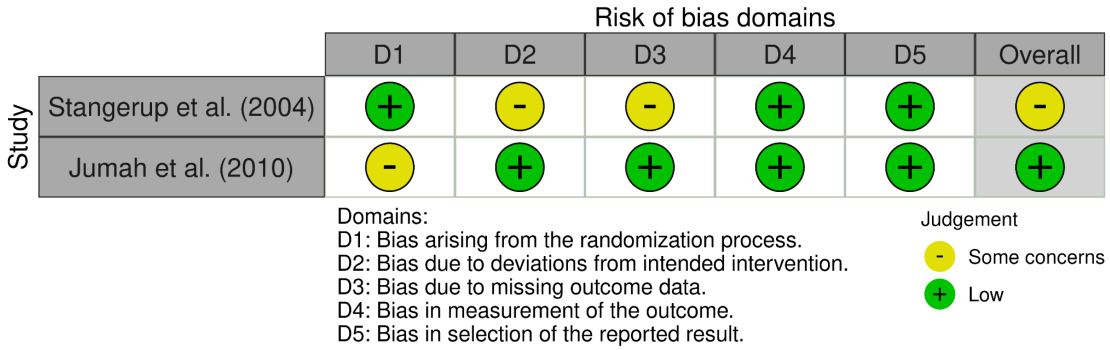


Figure 2. Risk of Bias 2

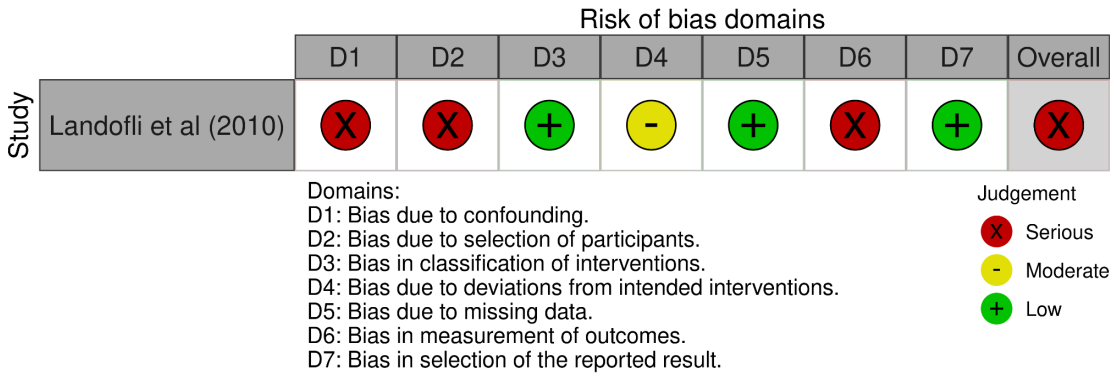


Figure 2. Risk of Bias Robins I

3.3 Summaries of the Included Studies

Across the three included studies, study designs comprised one prospective controlled study, one prospective non-randomized controlled interventional study, and one double-blind randomized crossover trial. Stangerup et al. (2004) evaluated 134 commercial airline passengers aged ≥18 years on a Copenhagen–London flight, comparing nasal balloon autoinflation during descent with standard pressure-equalization instructions, including the Valsalva maneuver. Landolfi et al. (2010) included 88 healthy Italian Air Force jet pilots following hypobaric chamber exposure with 100% oxygen and compared repeated nasal balloon autoinflation with Valsalva maneuver alone. Jumah et al. (2010) enrolled 21 patients with a history of pressure-equalization difficulties during flying in a double-blind randomized crossover trial comparing pressure-regulating earplugs with placebo earplugs during controlled pressure-chamber exposure. Overall, the included studies investigated self-administered non-pharmacological strategies across both actual flight and simulated aviation-related pressure exposures, with interventions primarily involving nasal balloon autoinflation and pressure-regulating earplugs.

3.4 Effectiveness of Self Administered Non-Pharmacological Interventions

3.4.1 Incidence and Severity of Middle Ear Barotrauma

Nasal balloon autoinflation was associated with a lower incidence of middle ear barotrauma across the included studies. In one study, otoscopic signs of barotitis defined as Teed grade ≥2 were observed in 6% of participants who complied with autoinflation compared with 15% of controls ($p<0.05$). In another study evaluating delayed ear barotrauma after hypobaric exposure, the overall prevalence on Day 2 was 53.4% (47/88). However, delayed barotrauma occurred less frequently in the nasal balloon group than in the control group (38.6% [17/44] vs 68.2% [30/44], $p<0.01$). Abnormal tympanograms with a C1 curve were also observed less frequently in the nasal balloon group, affecting five participants compared with nine in the control group.

3.4.2 Middle Ear Pressure Equalization and Eustachian Tube Function

Nasal balloon autoinflation showed beneficial effects on middle ear pressure restoration. Pathological negative middle ear pressure of ≤−200 dPa was observed in 3% of compliant participants using autoinflation compared with 15% of controls ($p<0.05$). Following air travel, the Valsalva maneuver successfully normalized middle ear pressure in 46% of affected participants (48/105). Among those who failed to achieve normalization with Valsalva, subsequent nasal balloon use restored normal pressure to 69% (36/52). Pressure-Regulating Earplugs (PREP) altered pressure dynamics within the external auditory canal by delaying the attainment of maximum pressure by approximately seven minutes. However, PREP did not significantly improve Eustachian tube function or pressure-equalization performance. No significant differences were observed in impedance-based Eustachian tube function ($p=0.57$), the number of pressure-equalizing maneuvers (8.0 vs 9.68, $p=0.088$), or the success rate of Eustachian tube opening (23.4% vs 27.1%, $p=0.263$).

3.4.3 Ear Pain and Subjective Discomfort

Self-administered non-pharmacological interventions also showed effects on subjective symptoms. After hypobaric exposure, 61.4% (27/44) of participants in the nasal balloon group remained symptom-free on Day 2 compared with 31.8% (14/44) in the control group ($p<0.01$). Pressure-regulating earplugs were also associated with significantly lower subjective pain and discomfort scores, with a mean VAS score of 2.19 ± 1.50 during PREP use compared with 3.38 ± 2.33 without PREP ($p=0.003$).

Discussion

The primary objective of this systematic review was to evaluate, critically analyze, and synthesize the clinical efficacy of self-administered non-pharmacological interventions in preventing and mitigating middle ear barotrauma (MEB) during flight, directly addressing the critical knowledge gap identified in the literature. As outlined in the introduction, atmospheric pressure changes during aircraft take-off and, more severely, descent, force the human auditory system to adapt to drastic barometric shifts. When the Eustachian tube fails to maintain its mechanical ventilation and equalization function, negative intra-tympanic pressure builds rapidly, leading to the documented clinical manifestations of "airplane ear," ranging from mild blockage and acute otalgia to mucosal effusion and tympanic membrane perforation.

The high epidemiological burden of MEB—affecting up to 20% of adult passengers, 40% of pediatric flyers, and a staggering 85% of commercial aircrew throughout their careers [1] underscores the urgent need for reliable preventive modalities. While pharmacological options such as oral or topical decongestants are widely utilized to reduce nasopharyngeal mucosal edema, their clinical utility is severely hampered by systemic adverse effects, including tachycardia, somnolence, and rebound congestion. Consequently, the self-administered non-pharmacological interventions analyzed in this review present a crucial, safe, cost-free, and universally accessible alternative for passenger self-care.

The synthesized data demonstrates that active mechanical autoinflation techniques and passive behavioral maneuvers exhibit varying degrees of clinical success, helping to resolve the fragmented and inconsistent findings reported in previous trials. Active mechanical autoinflation, specifically the valsalva maneuver remains the most widely recommended baseline technique in civil aviation safety protocols. By forcefully pushing air through the nasopharynx to clear the Eustachian tube, the Valsalva maneuver successfully equalizes middle ear pressure in nearly half of affected adult passengers. However, a significant subset of flyers remains symptomatic due to improper execution or underlying physiological barriers. For these resistant cases, mechanical autoinflation devices such as nasal balloons offer a superior clinical adjunct, significantly clearing persistent negative pressure and dropping the incidence of barotitis by facilitating managed tubal opening.

In contrast, passive behavioral strategies, including continuous swallowing, yawning, and chewing gum, serve as effective physiological maintenance tools. These actions trigger the dynamic contraction of the *tensor veli palatini* muscle to open the Eustachian tube orifice. However, as synthesized from the literature, the efficacy of these passive habits drops drastically when passengers suffer from acute upper respiratory tract infections or pre-existing Eustachian tube dysfunction. Furthermore, pressure-regulating earplugs (PREP) provide a passive physical buffer by utilizing specialized ceramic filters to slow the rate of ambient air pressure shifts within the external auditory canal. While PREPs grant the Eustachian tube more time to adapt naturally, the evidence isolating their standalone efficacy remains limited compared to active mechanical equalizing maneuvers.

Several limitations and systemic gaps emerged from this review. First, the lack of standard methodologies and a heavy reliance on subjective post-flight questionnaires—rather than objective pre- and post-flight tympanometry—contribute to the historical inconsistencies in data. Second, despite the alarming 40% prevalence rate among pediatric flyers, there is a profound scarcity of high-level evidence tailored to children. Pediatric passengers have a distinct anatomical vulnerability (shorter, more horizontal Eustachian tubes) and frequently lack the coordination to properly execute active maneuvers like the Valsalva, often leading to secondary micro-injuries or ineffective equalization. Finally, the absence of standardized educational guidelines from aerospace safety authorities leaves many flyers executing these techniques incorrectly, compounding the risk of barotrauma.

Conclusion

Self-administered non-pharmacological interventions provide a safe, viable, and highly accessible first-line framework for the prevention and relief of middle ear barotrauma during air travel, successfully mitigating the systemic risks and side effects associated with traditional pharmacological decongestants. Active mechanical autoinflation techniques—particularly the valsalva maneuver and targeted nasal balloon devices—demonstrate the strongest clinical capability to clear negative intra-tympanic pressure and minimize barotitis during aircraft descent. Meanwhile, passive behaviors (swallowing, yawning, chewing gum) and pressure-regulating earplugs offer excellent baseline protection for healthy passengers experiencing mild pressure fluctuations.

This systematic review successfully resolves the knowledge gap by establishing that mechanical autoinflation methods yield superior pressure equalization compared to purely passive behavioral strategies. However, the current body of literature remains fragmented by methodological limitations and a lack of objective diagnostic criteria. Future randomized controlled trials utilizing pre- and post-flight otoscopy or tympanometry are critically required to deliver high-level empirical data. Ultimately, these findings should serve as a foundational baseline for aerospace medicine authorities and commercial airlines to develop standardized, clear, and age-appropriate passenger education guidelines to reduce the global burden of airplane ear.

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