doi.org/10.36721/PJPS.2026.39.6.163.1

Collaborative management model combined with inhaled corticosteroids in CPAP treatment of acute exacerbations of pediatric bronchial asthma: A retrospective cohort study

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Abstract: **Background**: Continuous positive airway pressure (CPAP) for treating acute pediatric bronchial asthma exacerbations rises yearly. Inhaled corticosteroids (ICS) are key for controlling asthma-related inflammation, but research on ICS combined with the collaborative management model (CMM) remains incomplete. **Objectives**: This study aims to explore the effect of CMM combined with ICS in CPAP treatment for children with acute bronchial asthma exacerbations. **Methods**: 107 children with acute bronchial asthma exacerbations receiving CPAP in our hospital's Respiratory Department (Jan 2023-Jan 2025) were screened; 104 were included after exclusions. Based on the records of medical record treatment, they were divided into ICS group (51 cases) and CMM+ICS group (combined group, 53 cases). Primary outcomes: pulmonary function [forced expiratory volume in 1 second (FEV1), peak expiratory flow (PEF)], arterial blood gas [Arterial partial pressure of oxygen (PaO_2), arterial partial pressure of carbon dioxide ($PaCO_2$), oxygen saturation (SaO_2)] and CPAP-related complication incidence. Secondary outcomes: vital signs [respiratory rate (RR), heart rate (HR), blood pressure (BP)], hospital stay length, duration of a single management session, incremental cost-effectiveness ratio (ICER), pediatric asthma quality of life questionnaire (PAQLQ) scores and parental self-rating anxiety scale (SAS) anxiety levels. **Results**: Results showed that the combined group had significantly higher FEV1, PEF, PaO_2 and SaO_2 than the ICS group (all $p<0.05$), whereas $PaCO_2$ ($p<0.001$) and CPAP complication incidence ($p=0.024$) were lower than the ICS group. Additionally, the combined group had significantly lower RR, HR, SBP and DBP (all $p<0.05$), significantly shorter hospital stay and duration of a single management session (both $p<0.001$) and a significantly favorable ICER (-225.13 yuan/day) than the ICS group. Moreover, it had significantly higher PAQLQ scores ($p<0.001$) and lower parental SAS scores ($p<0.001$) compared with the ICS group. **Conclusion**: CMM combined with ICS in CPAP improves pediatric acute asthma exacerbations, has high clinical value, worthy of respiratory promotion.

Keywords: Acute exacerbation phase; Childhood bronchial asthma; Collaborative management model; Continuous positive airway pressure; Inhaled corticosteroids

Submitted on 03-11-2025 – Revised on 26-12-2025 – Accepted on 09-01-2026

INTRODUCTION

Pediatric bronchial asthma, one of the most prevalent chronic respiratory disorders among children globally, has witnessed a steady rise in incidence over the past decades, imposing a substantial burden on children's physical and mental health, family quality of life (QoL) and social medical resources (Qian *et al.*, 2023, Rosas-Salazar *et al.*, 2023). Relevant statistics from the World Health Organization (WHO) reveal that the prevalence of asthma in children under 5 years old worldwide has surpassed 10%, reaching as high as 15% in certain developed countries and regions (Fainardi *et al.*, 2022). Clinical studies have demonstrated that without timely and effective intervention, children experiencing acute asthma exacerbations may face hospitalization durations extended to 7-10 days, with a 40% risk of recurrence within 3 months (Abdelgadir *et al.*, 2025). Additionally, such cases are often accompanied by complications including growth retardation and psychobehavioral disorders, which not only elevate family management giving pressure and economic costs but also consume significant volumes of high-quality medical resources (Shipp *et al.*, 2023). Therefore, exploring safe, efficient and cost-effective therapeutic strategies for acute exacerbation of pediatric asthma has become a prioritized research direction in the field of pediatric respiratory medicine (Comite Nacional de *et al.*, 2021).

Continuous positive airway pressure (CPAP), a non-invasive ventilatory modality, functions by sustaining a steady positive airway pressure during the expiratory phase (Nagata *et al.*, 2024). This mechanism effectively distends the airways, alleviates airway collapse, optimizes the ventilation/perfusion ratio, thereby remediating hypoxemia and diminishing the consumption of respiratory work (Nagata *et al.*, 2024). Since the late 20th century, it has been progressively employed in the treatment of acute exacerbation of pediatric bronchial asthma (Nolasco *et al.*, 2022). Pertinent clinical practice guidelines indicate that

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for pediatric patients with moderate-to-severe acute asthma exacerbations-where standard oxygen therapy and bronchodilator interventions fail to yield satisfactory therapeutic efficacy-timely initiation of CPAP can yield a 25-30% reduction in hospitalization rates and cut the incidence of respiratory failure by 15-20% (Korang *et al.*, 2024). Consequently, it has evolved into a pivotal respiratory support modality for acute exacerbation of pediatric bronchial asthma (Almogarry *et al.*, 2023).

Inhaled corticosteroids (ICS), widely acknowledged in clinical practice as the first-line agent for managing asthmatic airway inflammation, boasts potent local anti-inflammatory activity with minimal systemic adverse events (Zhu *et al.*, 2023, Jones *et al.*, 2022). Multiple randomized controlled trials (RCTs) have demonstrated that, in the context of acute exacerbation of pediatric asthma, early administration of ICS can reduce the duration of airway inflammation control by 30-40%, expedite the rate of symptom alleviation by 20-25% and lower the risk of subsequent acute exacerbations (Dubin *et al.*, 2024). Clinical guidelines recommend that for children with acute asthma exacerbations, adjunctive ICS therapy to bronchodilator interventions can substantially enhance pulmonary function parameters, shorten the length of hospital stay and decrease readmission rates (Rayner *et al.*, 2025, Maspero *et al.*, 2024). Nevertheless, to date, most research investigating the combined use of ICS with CPAP in the treatment of acute exacerbation of pediatric asthma has predominantly centered on the therapeutic effects of the drug alone (Korang *et al.*, 2024). It lacks systematic exploration integrated with management modalities, failing to fully unlock the synergistic potential of pharmacological therapy and management support. Consequently, some pediatric patients still experience suboptimal therapeutic outcomes and elevated complication rates (Bodum *et al.*, 2022).

The collaborative management model (CMM), a novel interdisciplinary management modality, it achieves holistic and systematic management of patients (Wei *et al.*, 2022). In the management of pediatric asthma, CMM effectively addresses the limitations of traditional management-such as fragmented management and inadequate interprofessional coordination-through multidisciplinary team collaboration (Tveit *et al.*, 2023). Clinical studies have illustrated that the application of CMM in the long-term management of pediatric asthma can elevate the asthma control rate among pediatric patients by 35-40%, reduce the frequency of acute exacerbations by 25-30% and significantly improve parents' disease-related knowledge and management satisfaction (Gray *et al.*, 2023). Nonetheless, research on the application of the CMM in CPAP treatment for acute exacerbation of pediatric asthma remains scarce to-date. A mature clinical application protocol has yet to be established and robust systematic clinical evidence to endorse the efficacy, safety and cost-effectiveness of its combined use with ICS is still lacking (Tong *et al.*, 2022).

Against the backdrop of the aforementioned clinical context, this study, adopting a retrospective cohort study design, aims to explore the application efficacy of CMM combined with ICS in CPAP treatment for acute exacerbation of pediatric asthma. In terms of clinical practice, it is expected to provide a novel therapeutic regimen integrating the synergy of pharmacotherapy and management for CPAP treatment of acute pediatric asthma exacerbations. This regimen will contribute to enhancing therapeutic outcomes, diminishing the incidence of complications, curtailing the hospital stay duration and alleviating the economic burden and psychological stress on families. Furthermore, it will optimize management workflows, improve management efficiency and offer direct evidence-based support for clinical practice in pediatric respiratory medicine. From an academic research perspective, the study intends to enrich the evidence base for the comprehensive management of acute pediatric asthma exacerbations, laying the groundwork for subsequent prospective studies, multicenter researches and the formulation of standardized therapeutic protocols. In terms of social value, it will help reduce the disease burden associated with acute pediatric asthma exacerbations, alleviate the consumption of healthmanagement resources, and enhance children's health status and family QoL, holding profound significance for advancing the diagnostic and therapeutic capabilities in pediatric respiratory medicine.

MATERIALS AND METHODS

Study design

Based on the medical records of pediatric patients with acute exacerbation of bronchial asthma who received CPAP treatment in the Respiratory Department of our hospital between January 2023 and January 2025, an initial pool of 107 patients was identified. Among them, 2 patients were excluded for incomplete clinical data, and 1 for concomitant pulmonary tuberculosis, for a total of 3 exclusions. Ultimately, data from 104 patients were included for analysis. Stratified by the therapeutic modalities documented in their medical records, the patients were divided into two groups: one group was administered ICS monotherapy (ICS group, n=51), while the other received CMM combined with ICS (combined group, n=53) (Fig. 1).

Study duration

Patients with acute exacerbation of bronchial asthma who were treated in the Respiratory Department of our hospital from January 2023 to January 2025 were retrospectively enrolled in this study.

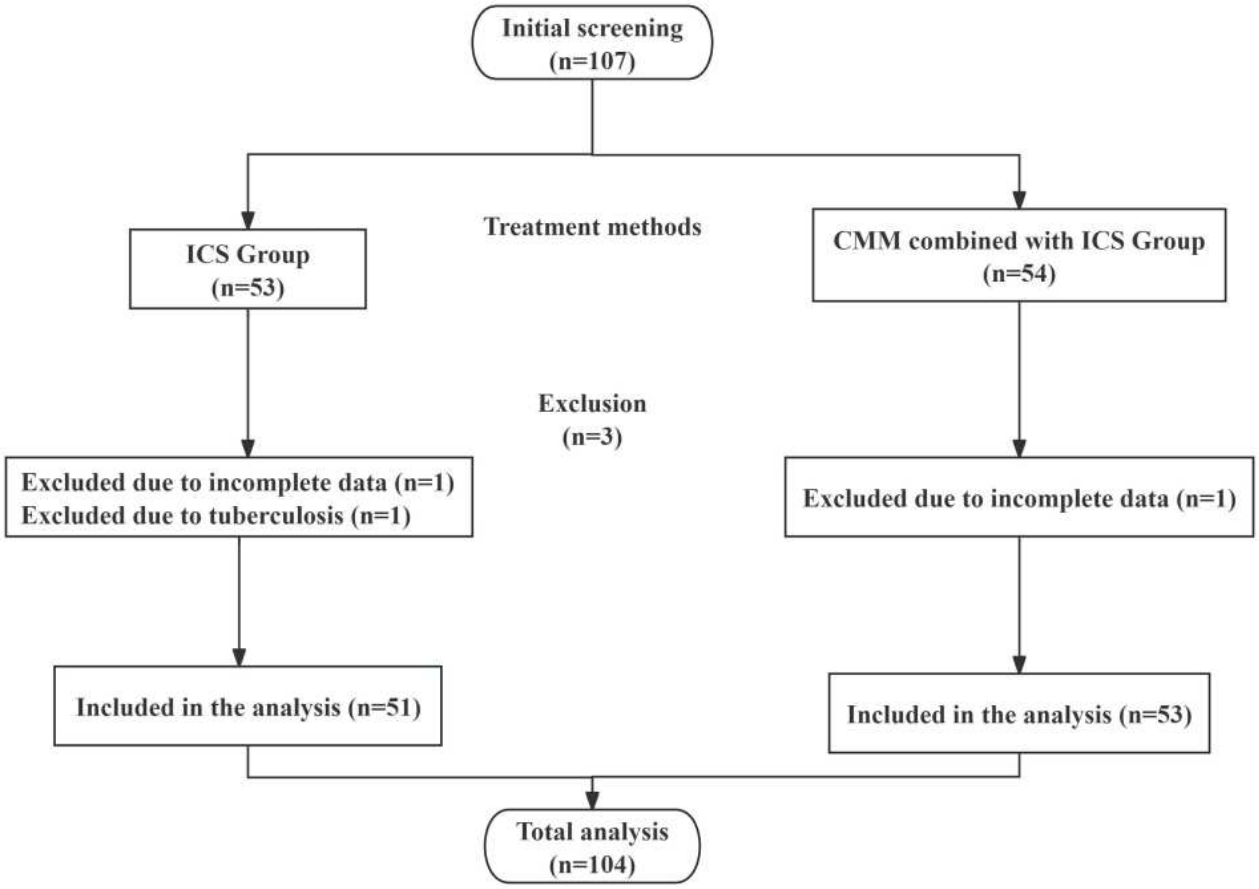

Fig. 1: Research flowchart
Note: ICS: inhaled corticosteroids; CMM: collaborative management model. A total of 107 patients were initially screened in this study, after exclusion, 104 cases were included in the analysis, with 51 in ICS group and 53 in combined group.

Place of study
The study was conducted in the Respiratory Department, Children's Hospital of Hebei.

Inclusion criteria
(1) Meeting the diagnostic criteria for acute exacerbation of pediatric bronchial asthma as specified in the Diagnostic and Therapeutic Guidelines for Pediatric Bronchial Asthma (2023 Edition), specifically characterized by: sudden exacerbation of pre-existing asthmatic symptoms (wheezing, coughing, dyspnea, chest tightness), audible wheezes on lung auscultation and clinically assessed as moderate-to-severe acute exacerbation; (2) Required CPAP therapy based on clinical condition(The Subspecialty Group of Respiratory, 2025); (3) Aged 6 to 14 years; (4) The guardians of the pediatric patients provided informed consent to the study content, with documented records of treatment plan selection retained in the medical charts.

Exclusion criteria
(1) Comorbid with other severe respiratory disorders, cardiovascular diseases, immune system disorders, hematological diseases, or severe hepatic/renal insufficiency; (2) Duration of CPAP therapy < 24 hours; (3) Had undergone systemic glucocorticoid therapy within 1 week prior to hospital admission; (4) Required modification of the therapeutic regimen due to changes in clinical condition during treatment; (5) Presence of cognitive impairment or communication deficits; (6) Incomplete medical records with missing key outcome measures; (7) Readmission of the same pediatric patient due to acute asthma exacerbation during the study period (Maspero *et al.*, 2024, Bodum *et al.*, 2022).

Therapeutic regimens
Medical chart reviews indicated that pediatric patients in both groups received basic treatment in accordance with the Diagnostic and Therapeutic Guidelines for Pediatric Bronchial Asthma (2023 Edition)(The Subspecialty Group of Respiratory, 2025), with CPAP therapy utilizing a CPAP ventilator (Mindray, Model NB350, China).

(1) *ICS group*: Medical records documented that on the basis of routine basic treatment and CPAP therapy, the patients were administered only ICS therapy. Budesonide suspension for inhalation was used 2mg per administration.

The medication was diluted in 2-3ml of normal saline prior to nebulized inhalation, administered twice daily at 12-hour intervals for 7 consecutive days, with a conventional management model implemented (Kew *et al.*, 2022).

(2) *Combined group*: In addition to routine basic treatment, CPAP therapy and the same ICS regimen as the ICS group, the patients received supplementary CMM interventions. A collaborative management team was established, consisting of respiratory physicians, pediatric specialist nurses, respiratory therapists, psychological counselors and clinical dietitians. Respiratory therapists instructed pediatric patients on proper breathing techniques and assessed CPAP device parameters; specialist nurses monitored vital signs, documented CPAP adherence and prevented management-related complications; psychological counselors alleviated pediatric patients' anxiety via game-based interactions once daily and addressed parents' queries through one-on-one communications; dietitians formulated individualized dietary plans based on each patient's specific conditions (Russi *et al.*, 2024, Sharma *et al.*, 2025).

Ethical statement

It adheres strictly to the Declaration of Helsinki and ethical norms for pediatric medical research. As a retrospective cohort design, all data were extracted from archived medical records of pediatric patients in the hospital information system. All information underwent de-identification processing, with only clinically relevant diagnostic and therapeutic data required for the study retained-effectively safeguarding the privacy and personal information security of pediatric patients. No additional intervention measures were implemented on the patients during the study; the therapeutic regimens for both groups were routine clinical practices, with no violations of medical norms or impairments to the rights and interests of pediatric patients.

Observation indicators

Primary observation indicators

Pulmonary function indicators

Forced expiratory volume in 1 Second (FEV1) and peak expiratory flow (PEF) were measured using a pulmonary function testing system (MasterScreen, CareFusion Germany234GmbH, Germany).

Arterial blood gas indicators

Arterial partial pressure of oxygen (PaO_2), arterial partial pressure of carbon dioxide ($PaCO_2$) and oxygen saturation (SaO_2) were detected with a blood gas analyzer (cobas b 123POC system, Roche Diagnostics, Germany).

Incidence of CPAP-related complications

Common CPAP-related complications in pediatric patients include facial skin lesions, gastrointestinal distension, nasal mucosal irritation, mask-related issues, respiratory discomfort and other rare complications (Wang *et al.*, 2022). The incidence of CPAP-related complications was analyzed using documentation in pediatric patients' medical records.

Secondary observation indicators

Vital signs

Respiratory rate (RR), heart rate (HR) and blood pressure (BP) were monitored using a monitor (ePM 10, Mindray, China).

Hospitalization duration, duration of a single management session and incremental cost-effectiveness ratio (ICER)

Hospitalization duration was extracted from the hospital's inpatient management system. Admission time was defined as the time when the pediatric patient completed hospitalization procedures and was formally admitted to the ward, while discharge time was determined by the time when the physician issued discharge orders and the patient completed discharge formalities (Kuitunen *et al.*, 2022).

Only management items directly associated with CPAP therapy and with clear operational procedures were included in the statistical analysis, excluding routine basic management. CPAP-related management sessions included CPAP mask fitting and parameter adjustment, condition monitoring during CPAP therapy, management for CPAP-related complications and CPAP discontinuation with equipment arrangement-all based on documented management session records (Shetty *et al.*, 2022).

The ICER was defined as the ratio of the incremental medical cost difference to the incremental treatment effect difference between the two groups. Medical costs in this study referred to direct medical costs, extracted from patients' hospitalization settlement bills, including CPAP-related equipment costs, diagnostic and therapeutic management costs and complication management costs. The treatment effect indicator was defined as the number of days saved in hospitalization (Liu *et al.*, 2023).

Pediatric asthma quality of life questionnaire (PAQLQ) and self-rating anxiety scale (SAS)

The PAQLQ is an internationally recognized asthma-specific tool for assessing QoL in children. The PAQLQ comprises 23 items, categorized into 3 dimensions (symptom dimension, activity limitation dimension and emotional function dimension). Total scores span a range of 1.0 to 7.0, with higher scores indicating less impairment to QoL (Zhou and Xu, 2023).

In this study, the SAS was employed to assess the anxiety levels of pediatric patients' guardians resulting from their children's acute asthma exacerbations. The scale includes 20 items, with standardized scores ranging from 25 to 100; higher scores correspond to more severe anxiety (Campo-Arias *et al.*, 2022).

Sample size calculation method

Based on a single-center retrospective study of asthmatic children aged 6-11 years conducted by (Gao *et al*., (Gao *et al.*, 2021), Cohen's d was estimated at 0.64 according to changes in lung capacity parameters. Using this value, with a significance level (α) of 0.05, statistical power (1-β) of 85% and a two-tailed test, the required sample size per group was calculated as 45 (via G*Power 3.1.9.7 software), resulting in a total sample size of 90. Considering potential data loss inherent to retrospective studies, a total of 104 patients were enrolled in this study (51 in the ICS group and 53 in the combined group) to ensure the stability of the results.

Statistical methods

For quantitative data, the Kolmogorov-Smirnov test was applied to verify normality. Normally distributed data were expressed as mean±standard deviation (SD), with intergroup comparisons performed using the independent samples t-test and intragroup pre- and post-treatment comparisons using the paired t-test. Non-normally distributed quantitative data were presented as median (interquartile range) [M(IQR)] and compared between groups via the Mann-Whitney U test. Categorical data were expressed as counts and percentages [n(%)], with intergroup comparisons conducted using the Chi-Square test. A *p*-value < 0.05 was considered statistically significant for all outcomes.

Classification of pediatric bronchial asthma

The severity grading of acute asthma exacerbations in children is based on the Global Initiative for Asthma (GINA) 2025(Venkatesan, 2025). This guideline specifies the severity grading criteria for acute pediatric asthma exacerbations, which are primarily determined by symptoms, physical signs and objective examination indicators. The severity is categorized into four levels: mild, moderate, severe and life-threatening.

Mild acute asthma exacerbation

Symptoms:
Classic asthma symptoms such as wheezing, coughing, chest tightness and shortness of breath.
Symptoms are intermittent or mildly persistent.
Signs:
Normal or slightly increased RR.
Normal or slightly increased HR.
Scattered wheezes are audible on auscultation.
Objective examination:
$FEV_1 \geq 80\%$ of predicted value.
After administration of a short-acting bronchodilator, FEV_1 improvement ≥ 12% or absolute increase ≥ 200ml.

Moderate acute asthma exacerbation

Symptoms:
Worsening symptoms affecting daily life and activities.
More frequent wheezing, coughing, chest tightness and shortness of breath.
Signs:
Markedly increased RR (children: >30 breaths/min for 2-5 years old; >25 breaths/min for 5-12 years old).
Markedly increased HR (children: >120 beats/min for 2-5 years old; >110 beats/min for 5-12 years old).
Diffuse wheezes are audible on auscultation.
Objective examination:
FEV_1 60%-79% of predicted value.
After administration of a short-acting bronchodilator, FEV_1 improvement ≥ 12% or absolute increase ≥ 200ml.

Severe acute asthma exacerbation

Symptoms:
Severe symptoms, inability to speak normally or perform activities.
Symptoms such as anxiety, restlessness and sweating.
Signs:
Significantly increased RR (children: >40 breaths/min for 2-5 years old; >35 breaths/min for 5-12 years old).
Significantly increased HR (children: >140 beats/min for 2-5 years old; >130 beats/min for 5-12 years old).
Presence of accessory muscle retractions (suprasternal, supraclavicular, intercostal).
Wheezes are diminished or absent (indicating critical condition).
Objective examination:
$FEV_1 < 60\%$ of predicted value.
After administration of a short-acting bronchodilator, FEV_1 improvement < 12% or absolute increase < 200ml.
Arterial blood gas analysis shows hypoxemia (PaO_2 < 60mmHg) or hypercapnia ($PaCO_2$ > 45mmHg).

Life-threatening acute asthma exacerbation

Symptoms:
Sense of impending death, altered mental status (e.g., lethargy, coma).
Inability to breathe spontaneously or only shallow breathing.
Signs:
Extremely rapid or slow RR, or abnormal respiratory rhythm.
Extremely rapid (>160 beats/min) or extremely slow (<100 beats/min) HR.
Cyanosis (cyanotic lips and nail beds).
Marked accessory muscle retractions.
Objective examination:
FEV_1: Severely reduced (<40% of predicted value).
Response to inhaled short-acting bronchodilator: FEV_1 improvement rate <12% or absolute increase <200 ml.
Arterial blood gas analysis: Shows severe hypoxemia (PaO_2 <50 mmHg) or severe hypercapnia ($PaCO_2$ >60 mmHg).

Signs of arrhythmia or myocardial ischemia

The occurrence, duration and severity of asthma exacerbations were assessed according to the GINA

guidelines. An asthma exacerbation was defined as a clinical event in which asthma patients experienced a significant worsening of symptoms, including wheezing, coughing, chest tightness and shortness of breath, after a stable period, leading to the need for increased medication or hospitalization. The duration of an exacerbation was defined as the number of days from the onset of symptom worsening until symptom relief or achievement of a stable state. The severity of exacerbations was evaluated using the grading criteria established by the GINA guidelines, which were categorized into two levels: moderate exacerbation, defined as a significant worsening of symptoms requiring an increase in medication dose; and severe exacerbation, defined as severe symptoms with respiratory failure requiring intravenous corticosteroids or hospitalization.

RESULTS

Comparison of baseline clinical characteristics between the two groups

Baseline clinical characteristics of the pediatric patients in the two groups were compared (Table 1). As indicated by the results, no statistically significant differences were observed across all variables between the two groups (all $p > 0.05$). This demonstrates that the baseline profiles of the two groups were highly comparable, thereby supporting the subsequent comparison of outcome measures.

Comparison of pulmonary function indicators between the two groups

Pulmonary function indicators, including FEV1 and PEF, were compared between the two groups of pediatric patients (Table 2). Following treatment, FEV1 and PEF were elevated in both groups (all $p > 0.05$). Subsequent comparison of the two indicators post-treatment revealed that the elevations in FEV1 and PEF in the combined group were significantly more pronounced than those in the ICS group (*95% CI*: -0.37, -0.01, $p = 0.038$; *95% CI*: -54.93, -0.85, $p = 0.043$). These findings demonstrate that pulmonary function was ameliorated in both groups after treatment and the therapeutic effect of CMM combined with ICS was more substantial in improving pulmonary function.

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Comparison of arterial blood gas parameters between the two groups

Arterial blood gas parameters of the two groups of pediatric patients were contrasted. Post-treatment, PaO_2 and SaO_2 were elevated, while $PaCO_2$ was reduced in both groups (all $p < 0.05$). Additionally, post-treatment comparative analysis revealed that compared with the ICS group, the combined group exhibited more prominent elevations in PaO_2 and SaO_2 (*95% CI*: -3.77, -0.36, $p = 0.018$; *95% CI*: -1.01, -0.11, $p = 0.016$), along with a more substantial reduction in $PaCO_2$ (*95% CI*: 1.02, 2.67, $p < 0.001$) (Table 3). These results collectively illustrate that respiratory function, acid-base balance and oxygenation status were ameliorated in both groups following treatment and the combined therapy of CMM with ICS yielded superior improvement effects.

Incidence of CPAP-related complications in the two groups

Detailed data on the incidence of CPAP-related complications in both groups are presented in table 4. In the ICS group, 5 cases of facial pressure ulcers were reported (incidence rate: 9.8%), along with 3 cases of nasal dryness/bleeding, 2 cases of gastrointestinal distension and 2 cases of intolerance-related agitation. A total of 12 complications were recorded in the ICS group (overall incidence rate: 23.5%), none of which were severe; all were managed symptomatically. In the combined group, 2 cases of facial pressure ulcers, 1 case of nasal dryness/bleeding and 1 case of gastrointestinal distension were documented; no cases of intolerance-related agitation occurred. The total number of complications in the combined group was 4 (overall incidence rate: 7.5%), which was significantly lower than that in the ICS group ($p = 0.024$). Additionally, the severity of complications in the combined group was milder, with no persistent unrelieved symptoms following symptomatic management. These findings indicate that the combined therapy of CMM with ICS can reduce the incidence of CPAP-related complications.

Comparison of vital sign parameters between the two groups

Vital signs, including RR, HR, systolic blood pressure (SBP), and diastolic blood pressure (DBP), were compared between the two pediatric patient groups. Following treatment, all four parameters were reduced in both groups (all $p < 0.04$). Post-treatment intergroup comparison revealed that the combined group exhibited more pronounced reductions in RR, HR, SBP and DBP compared with the ICS group, with values closer to the normal reference range (*95% CI*: 1.64, 3.31, $p < 0.001$; *95% CI*: 1.21, 7.16, $p = 0.006$; *95% CI*: 0.21, 6.12, $p = 0.036$; *95% CI*: 0.17, 4.54, $p = 0.035$) (Table 5). These

results demonstrate that the patients' respiratory and circulatory functions were improved and their clinical condition was ameliorated after treatment; additionally, the combined therapy of CMM with ICS yielded superior therapeutic effects.

Comparison of hospitalization duration and duration of a single management session between the two groups

Data regarding hospitalization duration and duration of a single management session in the two groups of pediatric patients are summarized in table 6. In the ICS group, the hospitalization duration was 9.52±1.63 days, whereas in the combined group, it was 6.92±1.17 days, significantly shorter than that in the ICS group (*95% CI*: 2.05, 3.16, $p < 0.001$). During a single management session, the ICS group recorded 18.58±2.86 minutes, whereas the combined group recorded 13.14±2.38 minutes. This duration was also significantly shorter in the combined group compared with the ICS group (95% CI: 4.42, 6.46, $p < 0.001$). These data suggest that combined therapy with CMM and ICS resulted in reduced hospitalization duration and a shorter duration of a single management session.

Comparison of ICER between the two groups

The average medical cost per case in the ICS group was 8998.04±760.98 yuan, which was significantly lower than 9583.96±806.01 yuan in the combined group (95%CI: -1501.31, -280.79, $p<0.001$). In terms of the average length of hospital stay, the ICS group had a significantly longer duration of 9.52±1.63 days compared to 6.92±1.17 days in the combined group (95%CI: 1.88, 2.22, $p<0.001$). The ICER was computed as -225.13 yuan/day. This value demonstrates that for each additional day of hospitalization shortened for patients in the combined group, not only is no additional investment required, but the medical costs can also be reduced by 225.13 yuan (Table 7).

Comparison of PAQLQ scores in pediatric patients and sas scores in their guardians between the two groups

PAQLQ scores in pediatric patients and SAS scores in their guardians were compared between the two groups. Post-treatment, PAQLQ scores of the pediatric patients were elevated, while SAS scores of the guardians were reduced (all $p < 0.05$). Furthermore, post-treatment comparative analysis revealed that compared with the ICS group, the combined group exhibited more substantial elevations in pediatric patients' PAQLQ scores (*95% CI*: -0.81, -0.47, $p < 0.001$) and more significant reductions in guardians' SAS scores (*95% CI*: 5.35, 8.56, $p < 0.001$) (Table 8). These data collectively confirm that after treatment, QoL of pediatric patients was enhanced and the anxiety levels of their guardians were alleviated in both groups. Additionally, the combined therapy of CMM with ICS yielded superior improvements in pediatric patients' QoL and guardians' anxiety compared with ICS monotherapy.

DISCUSSION

Pediatric bronchial asthma, a highly prevalent chronic respiratory disorder worldwide, poses a significant threat to pediatric patients' health while escalating the medical burden on families. CPAP, a pivotal technology for improving respiratory function, can reduce the endotracheal intubation rate and mortality; ICS, meanwhile, serves as the cornerstone drug for controlling airway inflammation. CMM, by establishing a multidisciplinary closed-loop management system, has demonstrated remarkable efficacy in chronic disease management (Pardo-Manrique *et al.*, 2024, Ashrafizadeh, 2024, Almogarry *et al.*, 2023). Nevertheless, research on its combined application in CPAP treatment for acute asthma exacerbations remains scarce, with a lack of systematic evaluation of multi-dimensional outcomes. Thus, this study addresses key clinical challenges, exploring the application value of CMM combined with ICS to provide evidence for the optimization of therapeutic regimens for acute pediatric asthma exacerbations.

Through systematic analysis of clinical data from 104 pediatric patients with acute exacerbation of bronchial asthma undergoing CPAP therapy, this retrospective cohort study comprehensively evaluated the interventional efficacy of CMM combined with ICS. The findings revealed that this combined regimen exhibited advantages across multiple dimensions, including physiological function improvement, clinical management optimization, enhanced patient outcomes and health economic benefits. At the core physiological indicator level, pulmonary function was markedly improved in the combined group post-treatment, with pronounced optimization effects observed in arterial blood gas parameters. In terms of clinical management and safety, the combined group demonstrated superior vital sign stability compared with the ICS group. Furthermore, the incidence of CPAP-related complications was reduced in the combined group, accompanied by a significant shortening of hospitalization duration and a single management session, resulting in concurrent improvements in management safety and efficiency. In the realm of patient-reported outcomes and health economics, the combined regimen realized synergistic improvement in pediatric patients' physical health and guardians' anxiety levels. Notably, while attaining superior therapeutic efficacy, the combined regimen also reduced medical costs, demonstrating favorable cost-effectiveness advantages. These results collectively confirm that the CMM combined with ICS regimen can effectively optimize the clinical efficacy and management quality of CPAP therapy for acute exacerbation of pediatric bronchial asthma.

Table 1: Baseline data [mean ±SD, n(%)]

Variables	ICS group (n=51)	Combined group (n=53)	*Difference 95%CI*	*p*	*Effect size*
Age (years)	8.23±2.49	7.98±2.55	-0.73,1.23	0.619	Cohen's D=0.098
BMI (kg/m^2)	18.44±1.65	18.33±1.75	-0.56,0.77	0.753	Cohen's D=0.062
Height (cm)	131.08±18.87	131.72±19.60	-8.13,6.85	0.865	Cohen's D=-0.033
Weight (kg)	28.45±8.24	28.89±8.81	-3.75,2.36	0.797	Cohen's D=-0.051
Gender	-	-	-	0.720	Phi=-0.035
Male	30 (58.8%)	33 (62.3%)	-	-	-
Female	21 (41.2%)	20 (37.7%)	-	-	-
Course of disease (years)	4.44±1.65	4.48±1.75	-0.70,0.62	0.909	Cohen's D=-0.022
Continuous aggravation time (days)	3.18±1.15	3.20±1.22	-0.48,0.44	0.940	Cohen's D=-0.015
Acute exacerbation severity (GINA)	-	-	-	0.444	Phi=0.075
Moderate	39 (76.5%)	37 (69.8%)	-	-	-
Severe	12 (23.5%)	16 (30.2%)	-	-	-
Acute exacerbation trigger	-	-	-	0.684	Cramer's V=0.085
Respiratory tract infection	36 (68.6%)	34 (64.2%)	-	-	-
Exposure to allergens	10 (19.6%)	11 (20.8%)	-	-	-
Others (strenuous exercise, emotional fluctuations, hormonal changes, etc.)	5 (9.8%)	8 (15.1%)	-	-	-

Note: BMI: body mass index; GINA: Global Initiative for Asthma.

Table 2: Comparison of FEV1 and PEF [mean ±SD]

Variables	Time	ICS group (n=51)	Combined group (n=53)	*Difference 95%CI*	*p*	*Effect size* (Cohen's D)
FEV1 (L)	*Before treatment*	1.93±0.41	1.95±0.44	-0.18,0.15	0.869	-0.032
	After treatment	2.43±0.43*	2.62±0.48*	-0.37,-0.01	0.038	-0.411
PEF (L/min)	*Before treatment*	304.39±65.23	306.00±68.14	-27.57,24.35	0.902	-0.024
	After treatment	357.37±65.89*	385.26±72.81*	-54.93,-0.85	0.043	-0.401

Note: *P<0.05 vs. before treatment; FEV_1: forced expiratory volume in one second; PEF: peak expiratory flow.

Table 3: Comparison of PaO2, PaCO2 and SaO2 [mean ±SD]

Variables	Time	ICS group (n=51)	Combined group (n=53)	*Difference 95%CI*	*p*	*Effect size* (Cohen's D)
PaO2 (mmHg)	*Before treatment*	66.52±3.69	66.44±3.85	-1.39,1.55	0.914	0.021
	After treatment	80.91±4.32*	82.98±4.43*	-3.77,-0.36	0.018	-0.471
PaCO2 (mmHg)	*Before treatment*	42.26±2.58	42.19±2.66	-0.95,1.09	0.889	0.028
	After treatment	39.60±2.25*	37.75±1.99*	1.02,2.67	<0.001	0.871
SaO2 (%)	*Before treatment*	91.92±1.44	91.78±1.50	-0.44,0.71	0.637	0.093
	After treatment	95.70±1.15*	96.26±1.17*	-1.01,-0.11	0.016	-0.482

Note: *P<0.05 vs. before treatment; PaO_2: partial pressure of oxygen in arterial blood; PaCO2: partial pressure of carbon dioxide in arterial blood; SaO_2: oxygen saturation in arterial blood.

Table 4: Comparison of complications [n(%)]

Variables	ICS group (n=51)	Combined group (n=53)	*p*	*Effect size* (Phi)
Facial pressure ulcer	5 (9.8%)	2 (3.8%)	-	-
Dry nasal cavity/nasal bleeding	3 (5.9%)	1 (1.9%)	-	-
Gastrointestinal distension	2 (3.9%)	1 (1.9%)	-	-
Intolerance and restlessness	2 (3.9%)	0 (0.0%)	-	-
Total	12 (23.5%)	4 (7.5%)	0.024	0.221

Table 5: Comparison of RR, HR, SBP and DBP [mean ±SD]

Variables	Time	ICS group (n=51)	Combined group (n=53)	*Difference 95%CI*	*p*	*Effect size* (Cohen's D)
RR (BPM)	*Before treatment*	33.82±3.39	32.98±3.42	-0.48,2.17	0.210	0.247
	After treatment	25.61±2.32*	23.13±1.98*	1.64,3.31	<0.001	1.148
HR (BPM)	*Before treatment*	130.20±9.67	128.87±9.82	-2.46,5.12	0.489	0.136
	After treatment	105.47±8.21*	101.28±9.82*	1.21,7.16	0.006	0.548
SBP (mmHg)	*Before treatment*	114.16±9.40	113.75±9.49	-3.27,4.08	0.829	-0.342
	After treatment	108.33±8.14*	105.17±7.02*	0.21,6.12	0.036	0.027
DBP (mmHg)	*Before treatment*	74.80±6.13	74.60±6.43	-2.25,2.65	0.871	0.032
	After treatment	70.45±5.84*	68.09±5.38*	0.17,4.54	0.035	0.420

Note: *P<0.05 vs. before treatment; RR: respiratory rate; HR: heart rate; SBP: systolic blood pressure; DBP: diastolic blood pressure; BPM: breaths per minute; BPM: beats per minute.

Table 6: Comparison of length of hospital stay and duration of a single management session [mean ±SD]

Variables	ICS group (n=51)	Combined group (n=53)	*Difference 95%CI*	*p*	*Effect size* (Cohen's D)
Length of hospital stay (days)	9.52±1.63	6.92±1.17	2.05,3.16	<0.001	1.842
Duration of a single management session (minutes)	18.58±2.86	13.14±2.38	4.42,6.46	<0.001	2.070

Table 7: Comparison of ICER [mean ±SD]

Variables	ICS group (n=51)	Combined group (n=53)	*Difference 95%CI*	*p*	*Effect size* (Cohen's D)
Average medical cost per case (yuan)	8998.04±760.98	9583.96±806.01	-891.05,-280.79	<0.001	-0.747
Average length of hospital stay (days)	9.52±1.63	6.92±1.17	2.05,3.16	<0.001	1.842
ICER(yuan/day)	-225.13		-	-	-

Note: ICER: incremental cost-effectiveness ratio.

Table 8: Comparison of PAQLQ scores and SAS scores [mean ±SD]

Variables	Time	ICS group (n=51)	Combined group (n=53)	*Difference 95%CI*	*p*	*Effect size* (Cohen's D)
PAQLQ (scores)	*Before treatment*	4.04±0.42	3.93±0.42	-0.06,0.27	0.196	0.255
	After treatment	5.40±0.46*	6.04±0.43*	-0.81,-0.47	<0.001	-1.449
SAS (scores)	*Before treatment*	60.37±4.16	59.47±4.23	-0.73,2.53	0.276	0.215
	After treatment	50.37±4.16*	43.42±4.09*	5.35,8.56	<0.001	1.687

Note: *P<0.05 vs. before treatment; PAQLQ: pediatric asthma quality of life questionnaire; SAS: self-rating anxiety scale.

The improvement in pulmonary function and arterial blood gas parameters in the combined group stems primarily from the pathophysiological synergy between CMM and ICS. Airway obstruction during acute asthma exacerbations results from multiple factors, including smooth muscle spasm, mucosal edema and inflammatory infiltration (Rajvanshi *et al.*, 2024). As a first-line anti-inflammatory agent, ICS mitigates airway hyperresponsiveness at the source by suppressing airway inflammatory responses, reducing eosinophilic infiltration and alleviating mucosal edema-thereby laying the groundwork for the recovery of ventilatory function (Schindel *et al.*, 2021). In contrast, CMM achieves precision and individualization of therapeutic interventions through the establishment of a multidisciplinary collaborative team. Dedicated nurses continuously monitor pediatric patients' respiratory rhythms and CPAP pressure compatibility, dynamically adjusting ventilation parameters to ensure that positive airway pressure support effectively counteracts airway collapse, enhances alveolar

ventilation efficiency and promotes PaO_2 elevation and $PaCO_2$ elimination. Concurrently, by standardizing ICS inhalation guidance, CMM avoids insufficient drug deposition caused by poor pediatric compliance, ensuring targeted delivery of medications to airway target organs and reinforcing anti-inflammatory efficacy (Kumar Reddy, 2023). Ultimately, this translates to improved pulmonary function indicators such as FEV1 and PEF (Tang *et al.*, 2021). Such a synergetic model effectively addresses the dual predicament of diminished drug efficacy and mismatched ventilation parameters inherent in monotherapy.

Common complications of CPAP therapy are closely linked to the degree of management refinement. The CMM implemented in the combined group significantly reduced the risk of complications through full-cycle management encompassing preoperative assessment, intraoperative intervention and postoperative management: preoperatively, well-fitted masks were selected based on children's facial contours with concurrent pressure ulcer prophylaxis; intraoperatively, postural adjustment and emotional reassurance minimized airway pressure fluctuations caused by crying, thereby preventing barotrauma; postoperatively, warm saline nasal management was administered to alleviate dryness symptoms, forming a systematic protection system (Wang *et al.*, 2022). Furthermore, the CMM defined the division of roles and responsibilities among physicians, nurses and rehabilitation therapists, establishing a rapid response protocol. This avoided work overlap and delays inherent in conventional management, resulting in shortened duration of a single management session. The reduction in hospitalization duration stems from the synergistic interplay of multiple factors: improved pulmonary function expedited the symptom relief process, reduced complications decreased the need for additional treatments (Tveit *et al.*, 2023) and personalized management interventions promoted overall recovery, all of which aligns closely with the core objectives of asthma treatment: symptom control and risk prevention.

During acute exacerbations of pediatric asthma, impairment in QoL encompasses multifaceted issues such as symptom distress, activity restriction and emotional impact. Meanwhile, guardians' anxiety primarily stems from concerns about disease prognosis and management giving burden. The combined group achieved dual improvements through the three-dimensional system developed by the CMM model, encompassing physiological intervention, psychological support and health education. For pediatric patients, improved pulmonary function alleviates wheezing and dyspnea, increases symptom-free days, enhances activity tolerance and consequently improves PAQLQ scores. For guardians, disease management education enables them to master exacerbation warning signals and emergency response strategies, reducing fears associated with disease fluctuations. Concurrently, management guidance provided by the dedicated management team alleviates the burden of management and mitigates anxiety (Sommanus *et al.*, 2022) This virtuous cycle of improved physical health in children and psychological relief in guardians fully reflects the application value of the bio-psycho-social medical model in pediatric asthma management.

The negative ICER value in the combined group reflects a cost optimization structure characterized by incremental dedicated input yet substantial overall savings. While CMM incurs additional dedicated costs-such as those for specialized management and psychological interventions-the reduction in hospitalization duration curtails daily recurring fixed costs, including bed fees, management fees and routine monitoring fees(Ontario, 2024). Concurrently, the decreased incidence of complications eliminates expenditures on additional treatments, forming a cost offset mechanism. This economic advantage holds significant implications for high-prevalence diseases like pediatric asthma, aligning particularly with the current demand for optimal allocation of medical resources. It provides practical evidence for the promotion of high-efficacy and cost-effective therapeutic regimens in primary hospitals.

The findings of this study are highly congruent with the conclusions of multiple prior studies. Regarding the interventional value of CMM, a school-based telemedicine asthma management study (SB-TEAM) demonstrated that a combined management model significantly reduced the hospitalization rate of asthmatic children (7% vs. 15%) and increased symptom-free days, consistent with the shortened hospitalization duration and improved QoL observed in the combined group of this study (Crabtree-Ide *et al.*, 2021). This confirms the generalizable value of multi-scenario collaborative management in asthma management. By integrating telemedicine with in-school management, the SB-TEAM study enhanced continuity of management, which shares the same conceptual origin as the multidisciplinary collaboration of CMM in this study, both highlighting the crucial role of extended management services in asthma management. Furthermore, a retrospective study indicated that child-friendly psychological interventions significantly improved pulmonary function, QoL and management giver satisfaction in children with bronchial asthma (all $p < 0.05$) (Wang *et al.*, 2025). The integration of child-friendly psychological interventions with family management in that study aligns with the game-based interaction approach implemented by psychological counselors in this research, underscoring the importance of psychological interventions in pediatric asthma management. Notably, some studies differ from the current research, which primarily focuses on the impact of CPAP on airway responsiveness. Another meta-analysis, which analyzed 27 RCTs, reported that compared with standard oxygen

therapy, CPAP shortened hospitalization duration, reduced RR, $PaCO_2$ and HR, decreased the need for mechanical ventilation and increased PaO_2; however, no improvements were observed in SpO_2 or pH[32]. The lack of significant improvement in SpO_2 following CPAP therapy in this meta-analysis contrasts with the findings of the current study. The core reason lies in the fact that the baseline SpO_2 of most children included in the meta-analysis was in the plateau phase of the oxygen-hemoglobin dissociation curve. While CPAP could still increase PaO_2, SpO_2 was already close to the normal range, leaving minimal room for further elevation and thus failing to yield a statistically significant difference.

This study systematically explored the application of CMM combined with ICS in CPAP therapy for acute exacerbation of pediatric asthma. It not only aligns with the pathophysiological demands of asthma treatment but also adapts to the practical scenarios of pediatric clinical management, providing a directly scalable intervention regimen for clinical practice. Compared with mono-intervention studies, this regimen more comprehensively encompasses multiple dimensions, including physiological treatment, management and psychological support, embodying the modern medical philosophy of multidisciplinary collaboration. Additionally, the study incorporated physiological function indicators, clinical management metrics, patient-reported outcomes and health economic parameters to form a multi-dimensional evaluation system. It not only focuses on short-term clinical efficacy but also integrates long-term QoL and medical costs, rendering the evaluation results more clinically referable and consistent with the current patient-centered orientation of clinical research (Rosas-Salazar *et al.*, 2023).

Targeting the clinical predicaments of limited efficacy of monotherapy and inadequate safety management in CPAP therapy for acute exacerbation of pediatric bronchial asthma, this study innovatively integrates CMM with ICS-providing a novel synergistic therapeutic pathway for clinical practice. Furthermore, it enriches the evidence base for comprehensive management of acute pediatric asthma exacerbations and offers direct evidence for the clinical promotion of standardized combined therapeutic regimens in respiratory departments. Particularly, it holds significant guiding value for optimizing the CPAP treatment workflow and improving management efficiency in acute pediatric asthma exacerbations, thereby facilitating the transformation of therapeutic strategies for this condition from mono-intervention to multi-dimensional collaborative management.

Study limitations

Given its retrospective cohort design, although intergroup balance was ensured through strict screening, selection bias could not be fully eliminated. The completeness of medical record documentation may have affected the accuracy of some data-for instance, potential human error might exist in the recording of management duration. The lack of randomized grouping meant that confounding factors could not be completely ruled out, which may have had potential impacts on the results. This study only enrolled 104 pediatric patients from a single center, resulting in a relatively limited sample size. Additionally, patients from the same medical center may exhibit homogeneity in terms of disease severity and treatment adherence, leading to limited external validity of the findings. The results are difficult to generalize to pediatric populations across different regions and hospital levels, particularly failing to reflect the application effects in resource-constrained regions (Sharma *et al.*, 2025). The study focused on short-term efficacy assessment during hospitalization and at discharge, with no long-term follow-up of patients. Thus, it was unable to clarify the role of the combined regimen in long-term outcomes such as asthma recurrence rate, long-term pulmonary function protection and impact on growth and development. The implementation of the CMM relies on the professional competence of the management team. Differences may exist in operational standardization and the quality of health education among individuals. Although this study attempted to unify the intervention process, quantitative evaluation of each measure in the CMM was not conducted, reducing the reproducibility of the intervention regimen and hindering accurate replication and promotion in other hospitals. Furthermore, the study did not consider the participation of external management resources such as schools and communities, resulting in a gap from the ideal multi-scenario CMM. Future research could conduct multi-center, large-sample RCTs to further verify the efficacy and safety of the combined regimen, thereby improving the external validity of the results. Extending the follow-up period to evaluate the impact of the regimen on long-term outcomes, such as asthma recurrence rates and long-term pulmonary function, is also recommended. Refining the CMM intervention process and formulating standardized operating procedures will enhance the reproducibility of the regimen. Additionally, integrating telemedicine technology to expand the application scenarios of collaborative management, especially focusing on the feasibility of implementation in resource-constrained regions, will promote the homogeneous improvement of pediatric asthma management quality (Shipp *et al.*, 2023).

CONCLUSION

Multi-dimensional evaluation confirms that the application of CMM combined with ICS in CPAP therapy for acute exacerbation of pediatric bronchial asthma can effectively improve patients' pulmonary function and oxygenation status, reduce complications, shorten hospitalization duration, enhance pediatric patients' QoL and alleviate guardians' anxiety. It exhibits favorable clinical efficacy

and cost-effectiveness. Its core value lies in constructing an integrated intervention system that addresses the deficiency of emphasizing treatment over management in traditional therapy. This study provides a new direction for optimizing the clinical management of acute exacerbations of pediatric bronchial asthma.

Acknowledgments
None

Authors' contributions
Yuxiao Hu and Yajuan Chu: Developed and planned the study, performed experiments and interpreted results. Edited and refined the manuscript with a focus on critical intellectual contributions; Qianli Guo, Wenshan Lv and Linlin Liu: Participated in collecting, assessing and interpreting the data. Made significant contributions to date interpretation and manuscript preparation; Yuxiao Hu and Yajuan Chu: Provided substantial intellectual input during the drafting and revision of tahe manuscript. All authors have read and approved the final manuscript.

Funding
Application of Collaborative Care in CPAP Treatment for Acute Episodes of Pediatric Bronchial Asthma (No. 20231139).

Data availability statement
The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethical approval
This study was approved and a waiver of informed consent has been granted by the Ethics Committee of Children's Hospital of Hebei Province (Approval No: 202222-20).

Conflict of interest
The authors declare that they have no conflicts of interest.

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