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Research Progress on New Non-invasive Diagnostic Techniques and Long-term Refined Management Strategies for Childhood Asthma

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Abstract: Childhood bronchial asthma has clinical characteristics of strong heterogeneity, prolonged course, and easy recurrence of acute attacks. The atypical symptoms of preschool children and low cooperation with traditional testing have led to prominent problems such as early missed diagnosis, misdiagnosis, and poor long-term management. Traditional invasive and highly cooperative diagnostic methods are difficult to adapt to the physiological characteristics of children. The new non-invasive diagnostic technology, with its advantages of safety, convenience, and repeatable testing, gradually achieves early screening, inflammation classification, and risk prediction of asthma. At the same time, the traditional extensive management model cannot adapt to the individualized diagnosis and treatment needs of children with different phenotypes. Fine, full-cycle, and intelligent management has become the core direction of childhood asthma prevention and control. This article systematically reviews the clinical application value of new non-invasive diagnostic technologies for childhood asthma, covering cutting-edge technologies such as airway inflammation detection, respiratory acoustic monitoring, and intelligent assisted diagnosis. This article summarizes the research progress on refined long-term management strategies such as hierarchical classification, remote home monitoring, and physical and mental collaboration, providing an evidence-based reference for standardized and individualized comprehensive management of pediatric asthma.

Keywords: Childhood bronchial asthma; Non-invasive diagnosis; Precise diagnosis and treatment; Refined management; Disease monitoring

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1. Introduction

Childhood bronchial asthma is the most common chronic respiratory heterogeneity disease in pediatrics. In recent years, the incidence of childhood asthma in China has continued to rise, with the proportion of young children affected increasing year by year, seriously affecting their growth and development, physical

and mental health, and quality of family life. Childhood asthma has become one of the key chronic diseases for prevention and control in pediatrics [1]. Early identification, diagnosis, and long-term management of asthma are key to reducing the incidence of acute attacks, minimizing irreversible damage to lung function, and improving long-term prognosis. At present, the general clinical pulmonary function test has high requirements for the cooperation of young children, and the compliance of invasive detection methods is poor. It is difficult to achieve repeated dynamic monitoring, resulting in some children with atypical asthma and occult airway inflammation unable to be diagnosed and intervened in time. At the same time, the traditional unified management model ignores the individual differences of patients' age, allergic phenotype, inflammation level, and psychological state, resulting in unbalanced long-term control effect and insufficient standardization of primary diagnosis and treatment. With the development of respiratory medicine and intelligent medical technology, various new non-invasive diagnostic technologies have broken through the limitations of traditional diagnosis and treatment. They can accurately assess the state of airway inflammation and the degree of airflow limitation, and provide an objective basis for early diagnosis and classification [2,3]. The long-term refined management strategy based on accurate diagnosis breaks the single drug control mode and realizes the personalized regulation of the whole process of screening, diagnosis, intervention, and follow-up. Based on the research results of core journals at home and abroad in recent years and the latest diagnosis and treatment guidelines, this article systematically summarizes the application advantages and applicable scenarios of new non-invasive diagnostic techniques for childhood asthma. This article outlines the core content and clinical value of a refined long-term management system, analyzes existing problems, and looks forward to future development directions. This article provides theoretical support for optimizing the whole process diagnosis and treatment system of childhood asthma and improving clinical management and control level.

2. New non-invasive diagnostic technology

2.1. Non-invasive detection technology for inflammatory markers in exhaled breath

Fractional exhaled nitric oxide (FeNO) is an indicator for evaluating airway inflammation. Its expression level is positively correlated with airway inflammation and is commonly used in the diagnosis and treatment of respiratory diseases such as asthma. It plays an important role in evaluating therapeutic efficacy and can serve as a basis for improving the condition [4]. Compared to traditional lung function testing, FeNO detection is simple to operate, does not require deliberate cooperation, and can quickly quantify the degree of airway inflammation, distinguish asthma from ordinary wheezing, and cough caused by respiratory infections. Deng Dandan et al.'s research has confirmed that the sensitivity and specificity of FeNO in diagnosing allergic asthma in children can reach over 85%, which can effectively screen for occult asthma and subclinical airway inflammation, providing a basis for early intervention [5]. During long-term follow-up, dynamic FeNO monitoring can predict the risk of acute asthma attacks, guide individualized reduction or maintenance treatment of glucocorticoids, and avoid recurrence of the condition caused by blind discontinuation of medication. In addition to FeNO, exhaled breath condensate (EBC) detection can collect inflammatory factors and oxidative stress indicators in airway secretions, comprehensively evaluate the status of airway microinflammation, and compensate for the limitations of single FeNO detection. It is suitable for auxiliary diagnosis of difficult-to-classify and treat asthma in children, and has gradually been applied in pediatric

clinical research and precision diagnosis and treatment [6].

2.2. Intelligent respiratory acoustic monitoring technology

Intelligent acoustic auscultation and wheezing intelligent recognition technology have become new non-invasive diagnostic breakthroughs for preschool children who cannot cooperate with routine lung function testing. The artificial intelligence acoustic recognition system based on convolutional neural networks and recurrent neural networks can collect children's respiratory sounds through smartphones and smart stethoscopes. It can automatically identify features such as wheezing, stridor, and abnormal respiratory rhythms, and accurately distinguish between physiological wheezing and pathological wheezing [7]. This technology does not require active cooperation from the child and is suitable for early screening of children aged 0-6 years old. It effectively solves the clinical problem of a high missed diagnosis rate of asthma in young children. Research shows that the accuracy of artificial intelligence respiratory acoustic detection in identifying asthma attacks in children is significantly higher than that of artificial auscultation. Artificial intelligence respiratory acoustic detection can capture mild and intermittent wheezing symptoms, enabling real-time screening and dynamic monitoring at home. This provides a convenient means for primary screening of asthma at the grassroots and family levels, greatly expanding the coverage of early diagnosis of childhood asthma [8].

2.3. Simplified non-invasive detection technology for lung function

The traditional forced pulmonary function test requires a high degree of cooperation from children, and the success rate of children is less than 50 %. The new simplified non-invasive lung function technology effectively fills this gap. Tidal respiration lung function testing does not require the child to breathe forcefully. It relies on natural breathing to obtain core indicators such as respiratory rate, tidal volume, and peak time ratio, accurately evaluating the functional status of small airways. This is the core non-invasive technology for asthma screening in preschool children [9]. In addition, the Peak Expiratory Flow (PEF) home dynamic monitoring technology is easy to operate and can be repeatedly tested at home. By using the variation rate of PEF during the day and night to determine airway hyperresponsiveness, this technique can differentiate between exercise-induced asthma and nocturnal asthma. This technology can dynamically track changes in airway ventilation function, compensate for the limitations of single laboratory testing, provide continuous objective data for asthma grading and efficacy evaluation, and adapt to the long-term dynamic diagnosis and treatment needs of children [10].

2.4. Multi-omics non-invasive joint screening technology

With the development of precision medicine, the combined screening system based on non-invasive markers of peripheral blood is gradually improving. It provides a new direction for the classification and diagnosis of asthma in children. Non-invasive indicators such as peripheral blood eosinophil count, total IgE, and specific allergen screening can be combined with airway inflammation detection and lung function indicators to construct a multidimensional diagnostic model for asthma, clarify the allergy phenotype and inflammation classification of children, and distinguish between eosinophilic and non-eosinophilic asthma [11]. Compared to a single detection method, multi-omics combined screening can significantly improve the diagnostic accuracy of childhood asthma while avoiding invasive testing risks [12]. This technology system can accurately identify

high-risk children, predict the severity of the condition and the risk of recurrence, and provide an objective basis for the development of refined and personalized treatment plans in the future. This technology system has been widely applied in the classification, diagnosis, and risk stratification management of childhood asthma.

3. Refined management strategies

3.1. Phenotypic-based hierarchical classification management strategy

Childhood asthma has high heterogeneity, and a unified management plan is difficult to adapt to the disease characteristics of different children. Layered management based on clinical phenotype and inflammation classification is the core of refined diagnosis and treatment. Clinically, patients can be accurately stratified based on their age, triggering factors, type of inflammation, and severity of the condition. We can classify the condition into different management levels, such as mild intermittent, mild persistent, and moderate-to-severe persistent. Based on this, they can develop differentiated plans for medication, monitoring, and intervention [13]. For children with allergic asthma, the plan focuses on strengthening allergen avoidance and desensitization interventions; For infection induced asthma, the plan focuses on respiratory infection prevention and mucosal immune regulation; For exercise-induced asthma, the plan focuses on optimizing exercise programs and preoperative preventive interventions; For children with comorbidities of obesity, anxiety, and allergic rhinitis, it is necessary to carry out collaborative management of comorbidities simultaneously. Hierarchical classification management breaks the traditional "one-size-fits-all" diagnosis and treatment model, achieves precise policy implementation, effectively improves long-term disease control rates, and reduces problems of overtreatment and undertreatment.

3.2. Full-cycle home dynamic monitoring and management

Long-term home monitoring is the foundation of refined management of childhood asthma, which can achieve dynamic tracking of the condition and early risk warning [14]. By relying on non-invasive devices such as PEF instruments, intelligent auscultation equipment, and portable FeNO detectors, a home monitoring system is constructed to guide parents in recording daily respiratory indicators, symptom changes, medication use, and triggering factors of their children, forming continuous disease follow-up data [15]. Medical staff interpret monitoring data in real-time through online platforms and adjust treatment plans in a timely manner. Medical staff intervene in advance for children with abnormal indicators and potential risk of acute attacks to avoid the risk of acute attacks. Compared to traditional quarterly and annual outpatient follow-up, home dynamic monitoring can capture intermittent and hidden fluctuations in medical conditions, solving the problem of one-sidedness in outpatient single evaluation. This can achieve precise, continuous, and dynamic management of asthma throughout the entire process, significantly reducing the frequency of emergency and hospitalization for pediatric patients.

3.3. Standardization of medication use and refined management of compliance

Poor medication adherence and improper inhalation procedures are the main human factors leading to poor control of childhood asthma. Refined medication management is a key link in long-term control [16]. In clinical practice, medical staff should adjust the personalized inhalation device according to the patient's age. For younger children, medical staff give priority to using a spacer device to assist inhalation. For school-

age children, medical staff will regulate the use of dry powder inhalers and correct their incorrect operating techniques one-on-one. At the same time, it is necessary to establish a hierarchical medication guidance system, adjust the dosage and frequency of medication according to the remission period, stable period, and attack period of the disease, and prevent parents from reducing, stopping, and abusing medication on their own. Relying on intelligent inhalation devices and online follow-up systems, medical staff monitor the medication duration and frequency of children in real time, automatically push medication reminders, and carry out personalized health education for children and parents with poor compliance. Multiple studies have confirmed that refined medication management can effectively improve medication adherence in children with asthma and significantly enhance long-term disease control effectiveness [17].

3.4. Multidimensional comprehensive intervention collaborative management

Fine management is not a single medication control, but a multidimensional collaborative intervention system that covers environment, exercise, nutrition, and psychology. In terms of environmental control, based on the screening results of allergens in pediatric patients, doctors develop personalized home environment optimization plans to accurately avoid triggering factors such as dust mites, pollen, and cooking fumes; In terms of exercise intervention, based on the patient's condition tolerance, doctors develop a layered aerobic exercise plan to avoid high-intensity stimulation exercise and improve cardiovascular function and reduce airway hyperresponsiveness through moderate exercise; In terms of nutritional intervention, doctors provide targeted supplementation of anti-inflammatory nutrients to children, correct malnutrition or obesity, and regulate the immune balance of the body [18]. In terms of psychological intervention, doctors alleviate the anxiety and fear emotions of children and parents, and alleviate airway spasms induced by psychological stress. Multidimensional collaborative intervention can reduce asthma triggering factors from the root, establish a long-term management model of drug + non-drug integration, and achieve comprehensive and refined control of asthma [19].

3.5. Intelligent remote follow-up management strategy

Digital intelligent follow-up is an important extension of refined management of childhood asthma in the new era, effectively solving the problems of traditional follow-up gaps and weak grassroots control [20]. Based on the asthma special management mini program, online follow-up platform, and intelligent wearable monitoring devices, medical staff have built a hospital community family three-level linkage follow-up system. Medical staff regularly push personalized health education, rehabilitation guidance, and follow-up reminders. Differentiated follow-up services are provided by medical staff for children of different ages and with different medical conditions. For children with mild stable asthma, they extend the follow-up intervals. For children with moderate-to-severe high-risk asthma, they increase the follow-up frequency. At the same time, they use artificial intelligence algorithms to analyze long-term monitoring data of pediatric patients, automatically predict the trend of disease progression, and develop intervention plans in advance. Intelligent remote follow-up breaks through the limitations of time and space, achieving normalized, precise, and long-term health management, significantly improving the standardization and accessibility of the entire diagnosis and treatment of childhood asthma.

4. Conclusion

The new non-invasive diagnostic technology, with its advantages of safety, convenience, dynamic monitoring, and adaptability to children's physiological characteristics, effectively solves the clinical pain points of difficult early screening, classification diagnosis, and dynamic evaluation of childhood asthma. At present, there are still problems in this field such as inconsistent non-invasive testing standards, insufficient popularization of grassroots technology, poor compliance with long-term family management, and incomplete individualized precision plans, which restrict the comprehensive implementation of the precision diagnosis and treatment system. In the future, it is necessary to optimize further the threshold and operating standards for children's exclusive non-invasive diagnosis, and promote the standardization of primary diagnosis and treatment equipment and technology; It is necessary to improve individualized and precise management models based on AI big data, and build a dynamic control system throughout the entire lifecycle; It is necessary to deepen the interdisciplinary and integrated management model of traditional Chinese and Western medicine, promote the development of early screening, precision, long-term, and intelligent diagnosis and treatment of childhood asthma, and comprehensively improve the standardized and precise diagnosis, treatment, and long-term management level of childhood asthma in China.

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