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Review

Wheat Allergy: Clinical Phenotypes, Diagnostic Approaches, and Management Strategies

Jung-Won Park,* **Kyung Hee Park**, **Jae-Hyun Lee**

Division of Allergy and Immunology, Department of Internal Medicine, Yonsei University College of Medicine, Seoul, Korea

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Correspondence to
Jung-Won Park, MD, PhD
Division of Allergy and Immunology, Department of Internal Medicine, Yonsei University College of Medicine, 50-1 Yonsei-ro, Seodaemun-gu, Seoul 03722, Korea.
Tel: +82-2-2228-1961
Fax: +82-2-393-6884
Email: parkjw@yuhs.ac

ORCID iDs
Jung-Won Park
https://orcid.org/0000-0003-0249-8749
Kyung Hee Park
https://orcid.org/0000-0003-3605-5364
Jae-Hyun Lee
https://orcid.org/0000-0002-0760-0071

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ABSTRACT

Wheat triggers a broad spectrum of allergic diseases, with prevalence varying across regions. In adults, it is the leading cause of food-induced anaphylaxis, most often as wheat-dependent exercise-induced anaphylaxis (WDEIA), while occupational exposure causes baker's asthma. In children, wheat allergy manifests as immediate-type reactions, including anaphylaxis, and contributes to atopic dermatitis. Recently, wheat is known as one of key triggers of eosinophilic esophagitis across all age groups. Wheat proteins are classified into water/salt-soluble and -insoluble fractions, with distinct physiochemical profiles. Among insoluble proteins, ω-5 gliadin and high- and low-molecular weight glutenins are well recognized as major allergens in WDEIA. Conversely, both gluten proteins and water–salt soluble allergens, such as α-amylase inhibitors and lipid-transfer proteins, are key allergens in pediatric wheat allergy and baker's asthma. Accurate diagnosis requires component-resolved diagnostics (CRD), given the complex physicochemical properties of wheat proteins. However, conventional skin prick testing and some multiplex specific immunoglobulin E assays lack full CRD integration, likely underestimating true prevalence. Management primarily relies on avoidance, but strict elimination is difficult due to wheat's ubiquity. In WDEIA, cofactors such as exercise, alcohol, or nonsteroidal anti-inflammatory drugs commonly precipitate reactions, with provoking doses varying widely, necessitating individualized strategies. Oral immunotherapy has been attempted for pediatric wheat allergy but demonstrated lower efficacy than for other foods, underscoring the need for patient-tailored strategies. Baker's asthma management focuses on work-place control, personal respiratory protective equipment, and pharmacotherapy. Overall, improved CRD-based diagnostics and novel therapeutic approaches are needed to enhance care for this diverse spectrum of wheat-related allergic diseases.

Keywords: Baker's asthma; eosinophilic esophagitis; gluten; wheat allergy; exercise-induced anaphylaxis; occupational exposure; pharmacotherapy

INTRODUCTION

Wheat, one of the most widely consumed staple cereals worldwide, can elicit a broad spectrum of allergic diseases, including immunoglobulin E (IgE)-mediated immediate

hypersensitivity, across all age groups: occupational baker's asthma and rhinitis, type 2 inflammation–associated eosinophilic esophagitis (EoE), mixed-type atopic dermatitis in children, and non-allergic inflammatory cell–mediated celiac disease.[1,2] The prevalence of wheat allergy has risen markedly over the past decade, paralleling global increases in wheat consumption.[3,4] In contrast, celiac disease is strongly linked to human leukocyte antigen (HLA)-DQ2 or HLA-DQ8 alleles and intestinal tissue transglutaminase activity.[5] Notably, these HLA alleles are largely absent in the traditional Korean population, and celiac disease has rarely been reported in Korea.[6]

Compared with other common food allergens, wheat exhibits unique immunologic properties driven by the distinct physicochemical characteristics of its proteins. Wheat proteins are categorized into four Osborne fractions: water-soluble albumins, salt-soluble globulins, alcohol-soluble gliadins, and glutenins, which require alcohol plus reducing agents such as dithiothreitol for solubilization.[7]

Through IgE-mediated pathways, wheat can induce diverse clinical phenotypes, including immediate anaphylaxis, urticaria in children, wheat-dependent exercise-induced anaphylaxis (WDEIA), atopic dermatitis, and baker's asthma and allergic rhinitis, following respiratory, gastrointestinal, or cutaneous exposure (**Table**).[8-11] The importance of cutaneous exposure in IgE-mediated wheat allergy is well illustrated by the epidemics of hydrolyzed wheat protein (HWP) soap-induced wheat allergy in Japan.[12] Clinical manifestations of HWP allergy can be broadly categorized into skin symptoms, including urticaria, pruritus, and eyelid angioedema, occurring during or shortly after use of the soap, and systemic allergic reactions following ingestion of wheat products, such as urticaria, dyspnea, gastrointestinal symptoms, and anaphylaxis, most commonly presenting as WDEIA.[12] EoE represents a distinct entity from classic IgE-mediated allergy. Although often associated with atopic comorbidities, its pathogenesis is primarily by Th2 cell and eosinophilic inflammation rather than IgE-driven mechanisms.[13,14] Importantly, the prevalence of EoE has increased rapidly across all age groups, with wheat recognized as one of its most important dietary triggers.[15]

The heterogeneity of wheat-related allergic disease is largely attributable to specific allergenic components. Accurate diagnosis therefore requires component-resolved diagnostics (CRD) employing well-defined major allergens.[16,17] This diagnostic complexity may contribute

Table. Clinical features of wheat allergy phenotypes

	Onset ages	Exposure route	Major allergens, provocation factors	Pathogenesis	Diagnosis
WDEIA	Mainly adults, but occasionally children	Oral, skin	Water-salt insoluble gluten (ω-5 gliadin, glutenins) with provoking factors (exercise, NSAIDs, alcohol)	IgE-mediated	SPT or sIgE to ω-5 gliadin, gluten. If needed, food challenge test
Immediate allergic reactions of wheat allergy	Mainly children	Oral	Water-salt soluble α-amylase inhibitors, lipid transfer proteins; and water-salt insoluble gluten (ω-5 gliadin, glutenins) without provoking factors	IgE-mediated	SPT or sIgE total extract of wheat, ω-5 gliadin, gluten. If needed, food challenge test
Atopic dermatitis with wheat sensitization	Neonates to children	Oral, skin	Water-salt soluble α-amylase inhibitors, lipid transfer proteins; water-salt insoluble gluten (gliadins, glutenins)	IgE and type 2 inflammation	SPT or sIgE to total extract of wheat, ω-5 gliadin, gluten. If needed, food challenge test
Eosinophilic esophagitis	Children to adults	Oral	Milk, wheat, egg, soy, fish, shellfish, peanut, tree nuts	Type 2 inflammation	Elimination diet
Baker's occupational asthma and rhinitis	Adults	Inhalation	Water-salt soluble α-amylase inhibitors, lipid transfer proteins, gliadins, aspergillus α-amylase, other cereals	IgE and type 2 inflammation	SPT or sIgE total extract of wheat, rye. Methacholine challenge test. If needed, bronchial provocation test

WDEIA, wheat-dependent exercise-induced anaphylaxis; NSAID, nonsteroidal anti-inflammatory drug; IgE, immunoglobulin E; SPT, skin prick test; sIgE, specific immunoglobulin E.

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to underestimating the true prevalence of wheat allergy. In this review, we summarize the distinctive clinical phenotypes of IgE-mediated immediate reactions, type 2 allergic inflammatory cell-mediated, and mixed phenotype wheat allergy diseases, and describe the principal culprit allergens as well as current and emerging treatment strategies tailored to these conditions.

WDEIA

Wheat allergy manifests differently across age groups. In adults, it most commonly presents as WDEIA, a phenotype distinct from pediatric wheat allergy,[4,18,19] although its overall prevalence remains poorly defined. WDEIA is typically triggered by cofactors, most frequently physical exercise, followed by nonsteroidal anti-inflammatory drugs (NSAIDs) and alcohol, which act synergistically with wheat ingestion to provoke anaphylaxis. Notably, many patients with WDEIA tolerate wheat products in the absence of these cofactors. Because of this atypical presentation, WDEIA is often misdiagnosed as idiopathic anaphylaxis, resulting in delayed diagnosis. Therefore, WDEIA should always be considered and excluded in adult patients presenting with recurrent anaphylaxis of uncertain etiology.[3,20,21]

Major allergens of WDEIA

Gliadins and glutenins, collectively referred to as gluten, constitute approximately 70% of total wheat protein and serve as the principal storage proteins. Quantitative analysis of 13 wheat cultivars demonstrated notable variability in protein composition: water- and salt-soluble proteins (10%–34%), gliadins (48%–62%), and glutenins (15%–48%).[7,22] Within gluten, ω-5 gliadin and both high- and low-molecular-weight glutenins are recognized as the major allergens responsible for WDEIA.[23-27]

Among gluten proteins, gliadins generally exhibit stronger allergenicity than glutenins, with significant cross-reactivity reported between them.[28] Gliadins are subdivided into α/β, γ, and ω types. The α/β and γ fractions are predominant, comprising 28%–33% and 23%–31% of total gliadins, respectively, whereas ω-gliadins are less abundant, with ω-1/2 and ω-5 gliadins representing 4%–7% and 3%–6% of the gliadin fraction.[22,29] Despite its lower abundance, ω-5 gliadin is clinically critical as the dominant major allergen in WDEIA.

Gluten possesses unique biochemical properties: they are insoluble in water or salt as well as rich in glutamine and proline.[28,30] In the digestive tract, gliadins are is poorly degraded by gastric and pancreatic enzymes, as well as intestinal brush border membrane proteases.[30] Consequently, gluten peptides are rarely absorbed under normal circumstances.[5] However, during conditions that increase intestinal permeability, such as exercise, NSAIDs exposure, or intestinal infection, these peptides may cross the intestinal epithelial barrier.[5,31] This may explain the characteristic link between WDEIA and such provocative cofactors. Although the exact mechanism by which exercise enhances absorption remains unclear,[31] aspirin and NSAIDs are known to disrupt the phospholipid monolayer of mucus and the phospholipid bilayer of the intestinal epithelium, while impairing mitochondrial oxidative phosphorylation, thereby increasing intestinal permeability.[32] Furthermore gluten has repetitive peptide motifs consist of glutamine (Q) and proline (P) (*e.g.,* QQIPQQQ and QQFPQQQ, QQSPQQQ).[8] These repetitive peptide motifs resist enzymatic digestion and can lead to repeated IgE-binding allowing multivalent immune engagement, allowing cross-linking of multiple IgE-FcεR1 on mast cells and basophils.

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Ethnic difference of WDEIA

The incidence of WDEIA varies among ethnicities and geographic regions. In East Asian countries, WDEIA represents the most frequent cause of food-induced anaphylaxis[3,18,33]; in contrast, while in Europe, it is the most common adult-onset food induced anaphylaxis in Central Europe, it occurs less frequently in Southern European population.[4] These differences may partly reflect variation in clinical awareness and diagnostic focus, but they also suggest a potential role of genetic susceptibility in disease development. A genome-wide association study conducted in a Japanese cohort identified HLA-DPB1*02:01:02 allele as an allele associated with WDEIA.[34] However, the prevalence of this allele shows only modest variation across populations—Japanese (22.0%), Chinese (18.4%), Swedish (14.0%), European American (13.8%), and Mexican (10.3%).[34]—This suggests that other factors, such as dietary wheat consumption and environmental exposures may also influence disease risk.

In another Japanese study involving 452 patients with HWP soap-induced wheat allergy, including WDEIA manifestations, an association was observed with amino acid sequence variation in pocket 4 of HLA-DQ allele.[35] This finding may not align with the HLA-DPB1 association observed in classic WDEIA, possibly reflecting differences in allergenic epitopes. The major allergen of HWP soap-induced allergy, known as glupearl 19S, is a high-molecular-weight gluten fraction generated by acid hydrolysis of gluten at 95°C for 40 minutes.[36] Further replication studies across diverse ethnic groups are warranted to clarify the genetic basis of WDEIA and to better understand interactions between genetic predisposition, wheat protein structure, and environmental cofactors in disease expression.

Diagnosis of WDEIA

Measurement of specific immunoglobulin E (sIgE) to ω-5-gliadin is essential for diagnosing WDEIA.[31] In most cases, a compatible history together with ω-5-gliadin sensitization is sufficient for diagnosis. However, some WDEIA patients may show IgE reactivity to high molecular weight (HMW) glutenin subunit rather than ω-5-gliadin.[25] The ThermoFisher ImmunoCAP system provides sIgE measurement of total extract of wheat, ω-5-gliadin, and gluten. The skin prick test (SPT) is a standard diagnostic tool for identifying culprit allergens. SPT using wheat gluten or gliadin extracts is particularly useful for the diagnosis of WDEIA, whereas the SPT response to water-soluble or salt-soluble wheat extracts is often weak or disappointing. In Korea, the multiple allergen simultaneous test (MAST) system is widely used for sIgE measurement. Earlier versions of the MAST system did not include ω-5-gliadin or gluten, representing a significant limitation in the diagnosis of WDEIA.[37] Recently, upgraded MAST products, incorporating both ω-5-gliadin and gluten have become available, effectively filling this diagnostic gap. The overall agreement rate for gluten-specific IgE between ImmunoCAP and Advensure™ MAST (Invitros, Seoul, Korea) was 0.91 (manuscript in preparation).

Confirmation of WDEIA by provocation test is often required in Korea. Because young Korean men are candidates for military service, an official diagnosis of WDEIA is necessary for final recruitment decision. Moreover, oral provocation testing helps patients determine their individual threshold of wheat intake that induces WDEIA symptoms. Provocation tests using pure gluten have shown that ingestion of 10 to 80 g of gluten is required to elicit a positive reaction, with or without prevocational cofactors, such as exercise. In Korea, where bread flour contain 13% gluten, this amount is equivalent to 80–640 g of conventional wheat.[38] In Korea, pure gluten products are not readily available, so conventional bread is typically used for oral provocation test. We administer maximum 240 g of conventional bread

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and let treadmill exercise for 10 minutes with or without aspirin. The relatively high threshold of gluten required to induce WDEIA may be explained by the physicochemical characteristics of gluten proteins.

Treatment of WDEIA

The cornerstone of management is strict avoidance of wheat, particularly when exposure may coincide with known cofactors.[39] However, complete elimination is often difficult, and inadvertent or intentional wheat consumption is common. WDEIA poses particular management challenges because affected individuals frequently tolerate wheat in the absence of cofactors.[1] Some patients with mild WDEIA can even tolerate wheat when taking regular antihistamine administration.[40,41] These findings may underscore the need for tailored approaches to both prevention and treatment. However, in clinical practice, it is difficult to define a range of exercise that does not provoke anaphylaxis, and the degree of tolerance is highly variable and unpredictable. Therefore, avoidance of cofactor alone or regular administration antihistamine cannot currently be recommended as a universally safe management strategy. This clinical uncertainty is also relevant to the use of omalizumab, which may offer potential benefit in patients with WDEIA. Omalizumab has been shown to increases the threshold of the eliciting dose for several food allergens, including peanut, egg, milk and cashew. Nevertheless, this protective effect was not observed in 17% of peanut allergy patients, underscoring the need for continued strict allergen avoidance even in patients receiving omalizumab.[42] Based on these findings, the US FDA approved omalizumab for reducing the risk of severe allergic reactions to multiple foods following accidental exposure. Importantly, this approval does not imply that patient can consume food allergens freely.[43]

Gluten-free wheat substitutes are commercially available; however, gluten is the principal protein conferring dough elasticity and viscosity, and its removal inevitably alters texture and taste.[44] Most gluten-free wheat flours are based on rice, corn, or purified wheat starch, which lack gluten but cannot replicate the sensory properties of true wheat. Although the gluten content varies among *Triticum aestivum* cultivar,[22] these differences are insufficient to ensure safety for WDEIA patients.

Recent studies have explored the development of ω-5 gliadin-deficient or low-molecular weight glutenin-deficient wheat cultivars, which demonstrate markedly reduced allergenicity *in vitro* and in sensitized patients.[28,45,46] However, oral provocation studies are still needed to validate their clinical safety and tolerability before these hypoallergic cultivars can be recommended for consumption.

Prognosis of WDEIA

The prognosis of WDEIA has not been well characterized, and spontaneous remission in adult appears uncommon.[33] In one study involving 10 adult patients wheat allergy confirmed by double-blind placebo-controlled food challenge, a favorable prognosis was reported; however, the clinical characteristics of these patients were not consistent with typical WDEIA, limiting the applicability of the finding.[47] In contrast, some patients who developed WDEIA following the use of HWP containing soap experienced remission after discontinuing HWP exposure, while continued oral consumption of wheat products did appear to influence remission.[48] These observations suggest that the natural course of WDEIA may differ depending on the route of sensitization, and that long-term avoidance of relevant allergens remains essential for management.

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PEDIATRIC WHEAT ALLERGY

Pediatric wheat allergy patients present with a broad spectrum of clinical symptoms compared with adult wheat allergy patients. In adults, the predominant phenotype is WDEIA,[4,18] whereas in children, wheat exposure may exacerbate atopic dermatitis, often with delayed onset, or induce immediate allergic reactions, such as urticaria, or anaphylaxis with or without cofactor like exercise.

Immediate allergic reactions of pediatric wheat allergy

Both water/salt-soluble and insoluble proteins have been identified as major allergens in children with immediate-type wheat allergy. The water/salt-soluble proteins, which contain metabolic proteins, include α-amylase inhibitors and lipid transfer proteins (LTPs). These molecules are well-recognized allergens implicated not only in pediatric wheat allergy but also in occupational wheat flour asthma/allergic rhinitis.[16,17,49]

Among the insoluble proteins, the ω-5 gliadin has been established as a major allergen of immediate- onset pediatric wheat allergy patients.[27,50,51] In addition, other gliadin components (α-, β-, and γ-gliadins) and both HMW- and low molecular weight (LMW)-molecular-weight glutenins have been reported as the major allergens.[16,52] Collectively, these findings suggest that no single dominant major allergen is responsible for pediatric immediate-type wheat allergy.[16,52] This contrasts with WDEIA, where ω-5 gliadin, as well as HMW- and LMW-glutenins, are the clearly predominant allergens.[8,25]

In a Korean study, Hwang *et al.*[11] reported the optimal cut-off value for sIgE to whole wheat extract (10.2 KU/L) and ω-5 gliadin (0.69 KU/L) in predicting positive oral wheat challenge results among children with immediate-type reactions. The corresponding area under the curve values of 0.753 and 0.751 indicated that both whole wheat extract and ω-5 gliadin sIgE measurements are useful diagnostic markers.[11] However, compared with CRD, sIgE to whole wheat extract is more prone to false positive results in regions where grass pollinosis is prevalent, owing to cross-reactivity between water/salt soluble wheat protein and grass pollen allergens.[53] This limitation is less significant in region, such as East Asia, where grass pollinosis is relatively uncommon.

Atopic dermatitis with wheat sensitization

Several major wheat allergens have been implicated in pediatric atopic dermatitis associated with wheat sensitization. In these patients, unclassified gliadins, α-amylase/trypsin inhibitors have been identified as key major allergens.[54,55] Importantly, the difference in IgE epitope recognition appear to distinguish immediate type allergic reactions from wheat sensitized atopic dermatitis. WDEIA or immediate-type allergic reactions to wheat typically produce sIgE to linear continuous epitopes of αβ-, γ-, ω-2/5-gliadines, whereas children with wheat-sensitized atopic dermatitis tend to recognize conformational epitopes of these same these gliadins.[56] This suggests that the structural nature of IgE-binding epitopes may contribute to different clinical phenotypes of wheat allergy between immediate-type allergic reactions and chronic eczematous inflammation.

Treatment of pediatric wheat allergy

Strict avoidance remains the cornerstone of management in pediatric wheat allergy patients. As wheat belongs to Triticeae tribe of the Poaceae (grass) family, *in vitro* studies have demonstrated IgE cross-reactivity between wheat and grass pollen,[53] as well as with

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other Triticeae tribe cereals, such as barley, rye, and oat. However, clinical cross-reactivity with these related cereals is uncommon among pediatric wheat allergy patients[57]; therefore, routine avoidance of other Triticeae grains is not recommended.[58] Nevertheless, clinicians should consider the possibility of cross-reactivity. If patients with wheat allergy also report allergic symptoms after ingestion of other cereals (*e.g.*, barley, rye, and oat), strict avoidance to the offending cereals should be advised.

Oral allergen-specific immunotherapy (OIT) has emerged as a promising strategy for desensitization and tolerance induction in pediatric food allergy patients.[59] There are limited clinical trials of wheat OIT, and the enrolled patients were small. In addition, the protocols and efficacy endpoints varied considerably across studies, making direct head-to-head comparison difficult. Most of the reported wheat OIT achieved successful desensitization. However, the targeted maintenance doses differed widely, ranging from 52 to 5,200 mg of wheat protein (the latter equivalent to approximately 200 g of boiled noodles). Higher maintenance doses administered over longer durations appear to be associated with higher success rates for induction of immune tolerance.[60-64] In contrast, patients with WDEIA demonstrated the modest success rate for desensitization and sustained immune tolerance compared to other forms of food allergy.[65-68] Furthermore, OIT carries the risk of EoE as an adverse reaction.[69]

Due to the indigestible and insoluble nature of gluten, maintaining consistent and predictable gluten absorption *via* the gastrointestinal tract remains a major challenge. This unpredictable absorption kinetics often necessitate higher doses of wheat protein to achieve effective desenstization,[61,65] which can compromise the adherence and increase the risk of adverse effects, including exercise-induced anaphylaxis.[62,66,67] To mitigate this problem, some investigators have employed a 70% purified wheat protein extract containing gluten, thereby reducing the total amount of wheat-based products required during maintenance phase of OIT.[63]

Given these limitations, alternative immunotherapy approaches that provide controlled and reproducible allergen delivery are under investigation. Epicutaneous immunotherapy (EPIT), which deliver allergens *via* a transdermal patch, has been studied extensively for food allergies.[70] In a phase III study, a peanut protein patch (Viaskin®) containing 250 μg of peanut protein achieved significant desensitization and increased tolerance thresholds in children with peanut allergy.[71] However, a phase IIb study in adults demonstrated limited efficacy,[72] likely attributable to interindividual variability in skin barrier integrity and differences in allergen penetration across skin sites.[73]

To overcome these limitations of EPIT, transdermal immunotherapy (TDIT) using a dissolving microarray patch (dMAP) technology has been developed and has shown promising results in preclinical murine models.[74,75] The dMAP-based TDIT platform offers several advantages over EPIT with the electrostatic vacuum patch. The dissolving microneedle enable precise and consistent allergen delivery directly into the epicutaneous and upper dermis layers, effectively bypassing the stratum corneum,[76-78] which otherwise restricts macromolecular allergen penetration and necessitates prolonged application of EPIT application. Consequently, dMAP-based TDIT may require lower allergen doses and shorter application times to achieve comparable immunologic responses, potentially improving patient adherence and safety.

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Nevertheless, robust comparative evidence demonstrating the superiority of dMAP-based TDIT over EPIT both in animal and human studies remain limited. Future research, particularly well-designed trials across diverse age groups, is essential for evaluating the efficacy, safety, and long-term immunologic outcomes of this novel approach as well as determining its potential to address the inherent limitations of EPIT.

Prognosis of pediatric wheat allergy

The natural course of pediatric wheat allergy is generally favorable, with most children developing clinical tolerance during middle childhood and adolescence. Longitudinal cohort studies have reported that approximately 50%–70% of affected children achieve tolerance by school age, although sensitization to ω-5 gliadin **or** high wheat-sIgE levels are associated with persistent allergy into adolescence or adulthood,[79-81] and severity of wheat allergy.[51] Recent studies have suggested that OIT accelerates tolerance induction in children with persistent wheat allergy; however its efficacy appears lower than that for other foods, and adverse reactions remain common.[65,66] These findings underscore the need for patient-tailored strategies and careful monitoring during desensitization.

EoE TRIGGERED BY WHEAT

EoE is a non-IgE-mediated, Th2 dependent inflammatory disease characterized clinically by vomiting, dysphagia, and food impaction, as well as histologically by dense intraepithelial eosinophilic infiltration of esophageal mucosa. EoE typically shows a poor response to proton pump inhibitors. This disease is first described in 1980–1990's, and its prevalence has since risen sharply worldwide.[82,83] EoE occur both in children and adults with a high rate of comorbidity with other allergic diseases. Approximately 40% of pediatric EoE patients have concurrent IgE-mediated food allergy.[84] Interestingly, cases have been reported in which patients outgrow IgE-mediated food allergy but later develop EoE to the same trigger food,[85] as well as cases showing the reverse sequence, where EoE is followed by the new-onset odf an IgE-mediated food allergy to the same food.[86] These observations underscore the close immunology interplay between IgE- and non-IgE-mediated food allergic mechanism. Moreover, EoE has been identified as an adverse effect in 0.23% per year undergoing sublingual immunotherapy to inhalant allergens[87] and 2.7% of OIT,[88] suggesting that local Th2-driven mucosal inflammation can be triggered by chronic allergen exposure in susceptible individuals.

Wheat is the most important trigger of EoE in adults,[89] and the second most common trigger after milk in children.[90] Because EoE is non-IgE-mediated, identification of causative relies primarily on clinical and histologic responses to an elimination diet, while skin testing and serum sIgE measurement have limited diagnostic utility.[13] A meta-analysis of dietary therapy demonstrated a histological remission rate of 72.1% with empiric six- to eight-food elimination diets (milk, wheat, egg, soy, fish, shellfish, peanut, and tree nuts), compared with 45.5% for SPT-based elimination approaches.[15] Notably, single-food elimination targeting milk or gluten-containing foods achieved 68.7% and 58.7% histologic remission rates, respectively, reaffirming that milk and wheat are the predominant EoE triggers.[15]

Because barley and rye also contain gluten and also because cross reactivity among these cereals has been documented, some clinicians advocate a strict gluten-free diet that eliminates barley, oat, and rye in addition to wheat, especially when patients complain

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of aggravation of allergic manifestations after consuming these cereals. However, many patients of IgE-mediated wheat allergy tolerate these cereals without reactions, while others may exhibit variable sensitivity.[91] Implementing a strict gluten-free regimen is considerably more challenging than wheat avoidance alone. To date, no controlled studies have directly compared the efficacy of wheat-only versus strict gluten elimination diets in EoE. Thus, the optimal dietary strategy for managing wheat-triggered EoE remains uncertain.[13]

BAKER'S OCCUPATIONAL ASTHMA AND RHINITIS

Baker's asthma and rhinitis are among the most common IgE-mediated occupational respiratory diseases caused by inhalation of wheat or other cereal flours.[92,93] In Korea, baker's asthma ranks as the second most frequent cause of occupational asthma.[94] The incidence among young bakers has been reported as 0.3–7.3 cases per 1,000 person-years,[2,93] reflecting substantial variability, depending on exposure levels, working conditions, and regional occupational safety practices.

Causative allergen of Baker's occupational asthma and rhinitis

Multiple wheat-derived allergens have been implicated in baker's occupational asthma, including thiol reductase (Tri a 27), dimeric wheat α-amylase inhibitor (Tri a 28), tetrameric wheat α-amylase inhibitor CM2 (Tri a 29.02), serine protease inhibitor like allergen (Tri a 39), and total gliadins.[95,96] Despite these identifications, no single allergen component has demonstrated sufficient diagnostic performance for clinical use. In fact, sIgE measurement for total wheat extract generally exhibits higher diagnostic sensitivity than CRD approaches using combinations of these major allergenic components.[95]

Many patients with baker's asthma show co-sensitization to other cereals, such as barley, rye, oat, rice, maize, soybean, buckwheat, fungal α-amylase. Among cereals, wheat, rye, and barley all belong to the Triticeae tribe of the Poaceae (grass) family, whereas oats and rice also belong to the broader Poaceae family but to different tribes. This taxonomic relationship explain the shared structural homology and cross-reactivity observed among these cereals.[97]

However, about 10%–29% of flour challenge positive baker's asthma patients lack detectable sIgE to wheat,[92,98] indicating that the absence of wheat- or rye-sIgE does not exclude the diagnosis. These findings suggest that other cereal flours or non-cereal allergens may act as primary sensitizers in some individuals. Indeed, buckwheat, soybean, rice, Aspergillus α-amylase show minimal cross-reactivity with wheat,[92] implicating them as potential independent culprit allergens in certain cases.

Aspergillus α-amylase, widely used as a flour improver, is a well-established occupational allergen responsible for baker's asthma.[99] In Korea, the increasing use of rice-supplemented bread—containing 10%–30% rice flour to enhanced softness, moisture, and texture—has raised interest in rice-induced occupational asthma. Some Korean bakers show dual sensitization to wheat and rice. Although rice allergens are heat-labile, inhalation of rice flour dust may provoke respiratory allergies.[98] Confirmation of rice as a causative allergen require cross-reactivity testing between wheat and rice extracts, along with specific bronchial challenge testing.

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Diagnosis of baker's occupational asthma and rhinitis

Diagnosis of baker's asthma is based on a combination of occupational exposure history, sIgE testing and objective assessment of airway hyperresponsiveness, including bronchodilator reversibility and methacholine challenge tests. In patients with a compatible occupational history but negative sIgE results to wheat or rye, a specific flour provocation test may be necessary to confirm or exclude he diagnosis. Wheat flour is recognized as the primary causative allergen in Baker's occupational asthma and rhinitis. Elevated sIgE level to whole wheat extract (≥ 5.1 KU/L) or rye whole extract IgE (≥ 6.2 KU/L) strongly support the diagnosis of baker's occupational asthma and may eliminate the need for further confirmatory testing.[98]

Treatment of Baker's asthma and rhinitis

The incidence and severity of baker's asthma/rhinitis are closely correlated with airborne flour dust concentration in the workplace.[2] Therefore, workplace modification is a crucial component of management. Improving bakery ventilation systems and implementing effective dust extraction or containment measures can substantially reduce allergen exposure, thereby improving symptoms and preventing new cases among exposed workers.

The use of disposable personal protective equipment, particularly FFP3 respiratory masks, is strongly recommended for affected workers. FFP3 mask can remove more than 99% of 0.3 μm airborne particle, and protect workers from wheat flour exposure at concentrations of up-to 25 mg/m^3, which is sufficient for most major workplace setting.[100] If symptoms persist despite environmental interventions, consistent mask use, and standard pharmacological treatment according to the Global Initiative for Asthma guidelines, a referral to an occupational medicine specialist is warranted.

For patients with poorly controlled disease despite these measures, further steps—such as formal workplace evaluation, worker's compensation assessment, and job retraining or reassignment—may be necessary for preventing ongoing exposure and long-term respiratory disability.

CONCLUSION

Wheat-induced allergic diseases represent a heterogeneous spectrum of disorders sharing common allergenic components, IgE and/or type 2 inflammation, but differing in the route of exposure, immune effector mechanisms, and clinical manifestations. Pediatric wheat allergy typically involves cutaneous and gastrointestinal sensitization, whereas WDEIA arises from oral ingestion coupled with cofactors that enhance allergen absorption. In contrast, baker's asthma and rhinitis result from inhalational exposure to wheat flour in occupational settings.

Despite these phenotypic differences, all forms except EoE are unified by IgE-mediated sensitization to gluten (particularly ω-5 gliadin and glutenins), and non-gluten proteins (α-amylase inhibitors, LTP) highlighting the multifaceted allergenicity of wheat. Understanding these overlapping yet distinct immunopathologic mechanisms is essential for accurate diagnosis, tailored management, and preventive strategies across age groups and exposure contexts.

Recently, omalizumab and OIT have been introduced as plausible treatment option for food allergy and may also be applicable to wheat allergy. Some patients with WDEIA can tolerate

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adequate amounts of wheat in the absence of provoking cofactors. However, the efficacy of these therapeutic approaches is limited in a subset of patients, and substantial clinical uncertainty on the efficacy remains. Therefore, strict dietary avoidance continues to be the mainstay of management. Although the presence of cross-reactivity of gluten among staple cereals has been reported in some patients, routine avoidance of these cross-reactive cereals is not recommended.

Future research integrating CRD and novel immunotherapeutic approaches may ultimately guide personalized treatment strategies for patients with wheat-related allergic disorders.

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REFERENCES

1. Scherf KA, Brockow K, Biedermann T, Koehler P, Wieser H. Wheat-dependent exercise-induced anaphylaxis. Clin Exp Allergy 2016;46:10-20. PUBMED | CROSSREF
2. Brisman J, Järvholm B, Lillienberg L. Exposure-response relations for self reported asthma and rhinitis in bakers. Occup Environ Med 2000;57:335-40. PUBMED | CROSSREF
3. Jiang N, Yin J, Wen L, Li H. Characteristics of anaphylaxis in 907 Chinese patients referred to a tertiary allergy center: a retrospective study of 1,952 episodes. Allergy Asthma Immunol Res 2016;8:353-61. PUBMED | CROSSREF
4. Kraft M, Dölle-Bierke S, Renaudin JM, Ruëff F, Scherer Hofmeier K, Treudler R, et al. Wheat anaphylaxis in adults differs from reactions to other types of food. J Allergy Clin Immunol Pract 2021;9:2844-2852.e5. PUBMED | CROSSREF
5. Green PH, Cellier C. Celiac disease. N Engl J Med 2007;357:1731-43. PUBMED | CROSSREF
6. Makharia GK. Celiac disease screening in southern and East Asia. Dig Dis 2015;33:167-74. PUBMED | CROSSREF
7. DuPont FM, Chan R, Lopez R, Vensel WH. Sequential extraction and quantitative recovery of gliadins, glutenins, and other proteins from small samples of wheat flour. J Agric Food Chem 2005;53:1575-84. PUBMED | CROSSREF
8. Matsuo H, Morita E, Tatham AS, Morimoto K, Horikawa T, Osuna H, et al. Identification of the IgE-binding epitope in omega-5 gliadin, a major allergen in wheat-dependent exercise-induced anaphylaxis. J Biol Chem 2004;279:12135-40. PUBMED | CROSSREF
9. Quirce S, Diaz-Perales A. Diagnosis and management of grain-induced asthma. Allergy Asthma Immunol Res 2013;5:348-56. PUBMED | CROSSREF
10. Yokooji T, Kurihara S, Murakami T, Chinuki Y, Takahashi H, Morita E, et al. Characterization of causative allergens for wheat-dependent exercise-induced anaphylaxis sensitized with hydrolyzed wheat proteins in facial soap. Allergol Int 2013;62:435-45. PUBMED | CROSSREF
11. Hwang Y, Kim J, Ahn K, Jeong K, Lee S, Hong SJ, et al. Diagnostic decision point for IgE-mediated wheat allergy in children. Allergy Asthma Immunol Res 2024;16:555-61. PUBMED | CROSSREF
12. Yagami A, Aihara M, Ikezawa Z, Hide M, Kishikawa R, Morita E, et al. Outbreak of immediate-type hydrolyzed wheat protein allergy due to a facial soap in Japan. J Allergy Clin Immunol 2017;140:879-881.e7. PUBMED | CROSSREF
13. Burk CM, Shreffler WG. Triggers for eosinophilic esophagitis (EoE): the intersection of food allergy and EoE. J Allergy Clin Immunol 2024;153:1500-9. PUBMED | CROSSREF
14. Clayton F, Fang JC, Gleich GJ, Lucendo AJ, Olalla JM, Vinson LA, et al. Eosinophilic esophagitis in adults is associated with IgG4 and not mediated by IgE. Gastroenterology 2014;147:602-9. PUBMED | CROSSREF

15. Arias A, González-Cervera J, Tenias JM, Lucendo AJ. Efficacy of dietary interventions for inducing histologic remission in patients with eosinophilic esophagitis: a systematic review and meta-analysis. Gastroenterology 2014;146:1639-48. PUBMED | CROSSREF
16. Pastorello EA, Farioli L, Conti A, Pravettoni V, Bonomi S, Iametti S, et al. Wheat IgE-mediated food allergy in European patients: alpha-amylase inhibitors, lipid transfer proteins and low-molecular-weight glutenins. Allergenic molecules recognized by double-blind, placebo-controlled food challenge. Int Arch Allergy Immunol 2007;144:10-22. PUBMED | CROSSREF
17. Srisuwatchari W, Kanchanapoomi K, Pacharn P. Molecular diagnosis to IgE-mediated wheat allergy and wheat-dependent exercise-induced anaphylaxis. Clin Rev Allergy Immunol 2025;68:47. PUBMED | CROSSREF
18. Lee SC, Kim SR, Park KH, Lee JH, Park JW. Clinical features and culprit food allergens of Korean adult food allergy patients: a cross-sectional single-institute study. Allergy Asthma Immunol Res 2019;11:723-35. PUBMED | CROSSREF
19. Du Z, Li L, Liu J, Xu Y, Cui L, Yin J. Clinical profiles of patients with wheat-induced anaphylaxis at various ages of onset. World Allergy Organ J 2023;16:100767. PUBMED | CROSSREF
20. Kennard L, Thomas I, Rutkowski K, Azzu V, Yong PFK, Kasternow B, et al. A multicenter evaluation of diagnosis and management of omega-5 gliadin allergy (also known as wheat-dependent exercise-induced anaphylaxis) in 132 adults. J Allergy Clin Immunol Pract 2018;6:1892-7. PUBMED | CROSSREF
21. Xu YY, Jiang NN, Wen LP, Li H, Yin J. Wheat allergy in patients with recurrent urticaria. World Allergy Organ J 2019;12:100013. PUBMED | CROSSREF
22. Koenig A, Konitzer K, Wieser H, Koehler P. Classification of spelt cultivars based on differences in storage protein compositions from wheat. Food Chem 2015;168:176-82. PUBMED | CROSSREF
23. Palosuo K, Alenius H, Varjonen E, Koivuluhta M, Mikkola J, Keskinen H, et al. A novel wheat gliadin as a cause of exercise-induced anaphylaxis. J Allergy Clin Immunol 1999;103:912-7. PUBMED | CROSSREF
24. Snégaroff J, Branlard G, Bouchez-Mahiout I, Laudet B, Tylichova M, Chardot T, et al. Recombinant proteins and peptides as tools for studying IgE reactivity with low-molecular-weight glutenin subunits in some wheat allergies. J Agric Food Chem 2007;55:9837-45. PUBMED | CROSSREF
25. Takahashi H, Matsuo H, Chinuki Y, Kohno K, Tanaka A, Maruyama N, et al. Recombinant high molecular weight-glutenin subunit-specific IgE detection is useful in identifying wheat-dependent exercise-induced anaphylaxis complementary to recombinant omega-5 gliadin-specific IgE test. Clin Exp Allergy 2012;42:1293-8. PUBMED | CROSSREF
26. Bouchez-Mahiout I, Snégaroff J, Tylichova M, Pecquet C, Branlard G, Laurière M. Low molecular weight glutenins in wheat-dependant, exercise-induced anaphylaxis: allergenicity and antigenic relationships with omega 5-gliadins. Int Arch Allergy Immunol 2010;153:35-45. PUBMED | CROSSREF
27. Palosuo K, Varjonen E, Kekki OM, Klemola T, Kalkkinen N, Alenius H, et al. Wheat ω-5 gliadin is a major allergen in children with immediate allergy to ingested wheat. J Allergy Clin Immunol 2001;108:634-8. PUBMED | CROSSREF
28. Lee J, Kim SR, Park JH, Park KH, Jeong KY, Lee JH, et al. Evaluation of allergenicity on a ω-5 gliadin-deficient cultivar in wheat-dependent exercise-induced anaphylaxis. Allergy Asthma Immunol Res 2022;14:379-92. PUBMED | CROSSREF
29. Jang YR, Kang CS, Lim SH, Lee JY. Screening and identification of omega-5 gliadin mutants in wheat doubled-haploid lines. Yugjong Haghoeji 2018;50:181-92. CROSSREF
30. Shan L, Molberg Ø, Parrot I, Hausch F, Filiz F, Gray GM, et al. Structural basis for gluten intolerance in celiac sprue. Science 2002;297:2275-9. PUBMED | CROSSREF
31. Matsuo H, Morimoto K, Akaki T, Kaneko S, Kusatake K, Kuroda T, et al. Exercise and aspirin increase levels of circulating gliadin peptides in patients with wheat-dependent exercise-induced anaphylaxis. Clin Exp Allergy 2005;35:461-6. PUBMED | CROSSREF
32. Bjarnason I, Scarpignato C, Holmgren E, Olszewski M, Rainsford KD, Lanas A. Mechanisms of damage to the gastrointestinal tract from nonsteroidal anti-inflammatory drugs. Gastroenterology 2018;154:500-14. PUBMED | CROSSREF
33. Du Z, Gao X, Li J, Li L, Liu J, Yin J. Clinical features and outcomes of patients with wheat-dependent exercise-induced anaphylaxis: a retrospective study. Allergy Asthma Clin Immunol 2022;18:61. PUBMED | CROSSREF
34. Fukunaga K, Chinuki Y, Hamada Y, Fukutomi Y, Sugiyama A, Kishikawa R, et al. Genome-wide association study reveals an association between the HLA-DPB1(*)02:01:02 allele and wheat-dependent exercise-induced anaphylaxis. Am J Hum Genet 2021;108:1540-8. PUBMED | CROSSREF
35. Noguchi E, Akiyama M, Yagami A, Hirota T, Okada Y, Kato Z, et al. HLA-DQ and RBFOX1 as susceptibility genes for an outbreak of hydrolyzed wheat allergy. J Allergy Clin Immunol 2019;144:1354-63. PUBMED | CROSSREF

36. Liu X, Wang C, Zhang X, Zhang G, Zhou J, Chen J. Application prospect of protein-glutaminase in the development of plant-based protein foods. Foods 2022;11:440. PUBMED | CROSSREF

37. Park JS, Yoo Y, Kwon JW. Multiple allergen simultaneous test for food allergens cannot screen wheat-dependent, exercise-induced anaphylaxis and α-gal syndrome. Yonsei Med J 2025;66:58-62. PUBMED | CROSSREF

38. Brockow K, Kneissl D, Valentini L, Zelger O, Grosber M, Kugler C, et al. Using a gluten oral food challenge protocol to improve diagnosis of wheat-dependent exercise-induced anaphylaxis. J Allergy Clin Immunol 2015;135:977-984.e4. PUBMED | CROSSREF

39. Cianferoni A. Wheat allergy: diagnosis and management. J Asthma Allergy 2016;9:13-25. PUBMED | CROSSREF

40. Kato Y, Nagai A, Saito M, Ito T, Koga M, Tsuboi R. Food-dependent exercise-induced anaphylaxis with a high level of plasma noradrenaline. J Dermatol 2007;34:110-3. PUBMED | CROSSREF

41. Choi JH, Lee HB, Ahn IS, Park CW, Lee CH. Wheat-dependent, exercise-induced anaphylaxis: a successful case of prevention with ketotifen. Ann Dermatol 2009;21:203-5. PUBMED | CROSSREF

42. Wood RA, Togias A, Sicherer SH, Shreffler WG, Kim EH, Jones SM, et al. Omalizumab for the treatment of multiple food allergies. N Engl J Med 2024;390:889-99. PUBMED | CROSSREF

43. FDA. FDA approves first medication to help reduce allergic reactions to multiple foods after accidental exposure [Internet]. Silver Spring (MD): FDA; 2024 [cited 2025 Dec 28]. Available from: https://www.fda.gov/news-events/press-announcements/fda-approves-first-medication-help-reduce-allergic-reactions-multiple-foods-after-accidental?utm_source=chatgpt.com.

44. Thompson T. Wheat starch, gliadin, and the gluten-free diet. J Am Diet Assoc 2001;101:1456-9. PUBMED | CROSSREF

45. Kohno K, Takahashi H, Endo TR, Matsuo H, Shiwaku K, Morita E. Characterization of a hypoallergenic wheat line lacking ω-5 gliadin. Allergol Int 2016;65:400-5. PUBMED | CROSSREF

46. Morita E, Matsuo H, Kohno K, Yokooji T, Yano H, Endo T. A narrative mini review on current status of hypoallergenic wheat development for IgE-mediated wheat allergy, wheat-dependent exercise-induced anaphylaxis. Foods 2023;12:954. PUBMED | CROSSREF

47. Scibilia J, Rossi Carlo M, Losappio Laura M, Mirone C, Farioli L, Pravettoni V, et al. Favorable prognosis of wheat allergy in adults. J Investig Allergol Clin Immunol 2019;29:118-23. PUBMED | CROSSREF

48. Hiragun M, Ishii K, Hiragun T, Shindo H, Mihara S, Matsuo H, et al. The sensitivity and clinical course of patients with wheat-dependent exercise-induced anaphylaxis sensitized to hydrolyzed wheat protein in facial soap - secondary publication. Allergol Int 2013;62:351-8. PUBMED | CROSSREF

49. James JM, Sixbey JP, Helm RM, Bannon GA, Burks AW. Wheat alpha-amylase inhibitor: a second route of allergic sensitization. J Allergy Clin Immunol 1997;99:239-44. PUBMED | CROSSREF

50. Daengsuwan T, Palosuo K, Phankingthongkum S, Visitsunthorn N, Jirapongsananuruk O, Alenius H, et al. IgE antibodies to omega-5 gliadin in children with wheat-induced anaphylaxis. Allergy 2005;60:506-9. PUBMED | CROSSREF

51. Ito K, Futamura M, Borres MP, Takaoka Y, Dahlstrom J, Sakamoto T, et al. IgE antibodies to omega-5 gliadin associate with immediate symptoms on oral wheat challenge in Japanese children. Allergy 2008;63:1536-42. PUBMED | CROSSREF

52. Mäkelä MJ, Eriksson C, Kotaniemi-Syrjänen A, Palosuo K, Marsh J, Borres M, et al. Wheat allergy in children - new tools for diagnostics. Clin Exp Allergy 2014;44:1420-30. PUBMED | CROSSREF

53. Jones SM, Magnolfi CF, Cooke SK, Sampson HA. Immunologic cross-reactivity among cereal grains and grasses in children with food hypersensitivity. J Allergy Clin Immunol 1995;96:341-51. PUBMED | CROSSREF

54. Varjonen E, Vainio E, Kalimo K. Antigliadin IgE--indicator of wheat allergy in atopic dermatitis. Allergy 2000;55:386-91. PUBMED | CROSSREF

55. Kusaba-Nakayama M, Ki M, Iwamoto M, Shibata R, Sato M, Imaizumi K. CM3, one of the wheat α-amylase inhibitor subunits, and binding of IgE in sera from Japanese with atopic dermatitis related to wheat. Food Chem Toxicol 2000;38:179-85. PUBMED | CROSSREF

56. Battais F, Mothes T, Moneret-Vautrin DA, Pineau F, Kanny G, Popineau Y, et al. Identification of IgE-binding epitopes on gliadins for patients with food allergy to wheat. Allergy 2005;60:815-21. PUBMED | CROSSREF

57. Srisuwatchari W, Piboonpocanun S, Wangthan U, Jirapongsananuruk O, Visitsunthorn N, Pacharn P. Clinical and in vitro cross-reactivity of cereal grains in children with IgE-mediated wheat allergy. Allergol Immunopathol (Madr) 2020;48:589-96. PUBMED | CROSSREF

58. Kliewer KL, Venter C, Cassin AM, Abonia JP, Aceves SS, Bonis PA, et al. Should wheat, barley, rye, and/or gluten be avoided in a 6-food elimination diet? J Allergy Clin Immunol 2016;137:1011-4. PUBMED | CROSSREF

59. Mousallem T, Burks AW. Immunology in the clinic review series; focus on allergies: immunotherapy for food allergy. Clin Exp Immunol 2012;167:26-31. PUBMED | CROSSREF

60. Leeds S, Liu EG, Nowak-Wegrzyn A. Wheat oral immunotherapy. Curr Opin Allergy Clin Immunol 2021;21:269-77. PUBMED | CROSSREF

61. Sato S, Utsunomiya T, Imai T, Yanagida N, Asaumi T, Ogura K, et al. Wheat oral immunotherapy for wheat-induced anaphylaxis. J Allergy Clin Immunol 2015;136:1131-1133.e7. PUBMED | CROSSREF

62. Nagakura KI, Yanagida N, Sato S, Nishino M, Takahashi K, Asaumi T, et al. Low-dose-oral immunotherapy for children with wheat-induced anaphylaxis. Pediatr Allergy Immunol 2020;31:371-9. PUBMED | CROSSREF

63. Nowak-Węgrzyn A, Wood RA, Nadeau KC, Pongracic JA, Henning AK, Lindblad RW, et al. Multicenter, randomized, double-blind, placebo-controlled clinical trial of vital wheat gluten oral immunotherapy. J Allergy Clin Immunol 2019;143:651-661.e9. PUBMED | CROSSREF

64. Koosakulchai V, Miura Y, Nagakura KI, Fusayasu N, Yanagida N, Sato S, et al. Six-year follow-up of low-dose oral immunotherapy for children with wheat-induced anaphylaxis. J Allergy Clin Immunol Pract 2024;12:2865-2867.e1. PUBMED | CROSSREF

65. Furuta T, Tanaka K, Tagami K, Matsui T, Sugiura S, Kando N, et al. Exercise-induced allergic reactions on desensitization to wheat after rush oral immunotherapy. Allergy 2020;75:1414-22. PUBMED | CROSSREF

66. Kulmala P, Pelkonen AS, Kuitunen M, Paassilta M, Remes S, Schultz R, et al. Wheat oral immunotherapy was moderately successful but was associated with very frequent adverse events in children aged 6–18 years. Acta Paediatr 2018;107:861-70. PUBMED | CROSSREF

67. Makita E, Yanagida N, Sato S, Asaumi T, Ebisawa M. Long-term prognosis after wheat oral immunotherapy. J Allergy Clin Immunol Pract 2020;8:371-374.e5. PUBMED | CROSSREF

68. Pacharn P, Witeetanavanich S, Srisuwatchari W, Rutrakool N, Wongteerayanee C, Tanticharoenwiwat P, et al. Treatment difficulties in wheat oral immunotherapy and the predictive value of wheat-specific IgE. Asian Pac J Allergy Immunol 2025;43:873-80. PUBMED | CROSSREF

69. Jin H, Trogen B, Nowak-Wegrzyn A. Eosinophilic esophagitis as a complication of food oral immunotherapy. Curr Opin Allergy Clin Immunol 2020;20:616-23. PUBMED | CROSSREF

70. Kim EH, Burks AW. Food allergy immunotherapy: oral immunotherapy and epicutaneous immunotherapy. Allergy 2020;75:1337-46. PUBMED | CROSSREF

71. Fleischer DM, Greenhawt M, Sussman G, Bégin P, Nowak-Wegrzyn A, Petroni D, et al. Effect of epicutaneous immunotherapy vs placebo on reaction to peanut protein ingestion among children with peanut allergy: the PEPITES randomized clinical trial. JAMA 2019;321:946-55. PUBMED | CROSSREF

72. Sampson HA, Shreffler WG, Yang WH, Sussman GL, Brown-Whitehorn TF, Nadeau KC, et al. Effect of varying doses of epicutaneous immunotherapy vs placebo on reaction to peanut protein exposure among patients with peanut sensitivity: a randomized clinical trial. JAMA 2017;318:1798-809. PUBMED | CROSSREF

73. Landers JJ, Janczak KW, Shakya AK, Zarnitsyn V, Patel SR, Baker JR Jr, et al. Targeted allergen-specific immunotherapy within the skin improves allergen delivery to induce desensitization to peanut. Immunotherapy 2022;14:539-52. PUBMED | CROSSREF

74. Shakya AK, Gill HS. A comparative study of microneedle-based cutaneous immunization with other conventional routes to assess feasibility of microneedles for allergy immunotherapy. Vaccine 2015;33:4060-4. PUBMED | CROSSREF

75. Liang L, Hwang AR, Guon TE, Park KH, Park CO, Lee JH, et al. Microarray patch based transdermal allergen immunotherapy prevents gliadin-induced anaphylaxis in a murine model. Allergy Asthma Immunol Res 2025;17:330-48. PUBMED | CROSSREF

76. Fernando GJP, Chen X, Primiero CA, Yukiko SR, Fairmaid EJ, Corbett HJ, et al. Nanopatch targeted delivery of both antigen and adjuvant to skin synergistically drives enhanced antibody responses. J Control Release 2012;159:215-21. PUBMED | CROSSREF

77. Park KH, Oh EY, Han H, Kim JD, Kim SJ, Jeong KY, et al. Efficacy of transdermal immunotherapy with biodegradable microneedle patches in a murine asthma model. Clin Exp Allergy 2020;50:1084-92. PUBMED | CROSSREF

78. Park CO, Kim HL, Park JW. Microneedle transdermal drug delivery systems for allergen-specific immunotherapy, skin disease treatment, and vaccine development. Yonsei Med J 2022;63:881-91. PUBMED | CROSSREF

79. Keet CA, Matsui EC, Dhillon G, Lenehan P, Paterakis M, Wood RA. The natural history of wheat allergy. Ann Allergy Asthma Immunol 2009;102:410-5. PUBMED | CROSSREF

80. Koike Y, Yanagida N, Sato S, Asaumi T, Ogura K, Ohtani K, et al. Predictors of persistent wheat allergy in children: a retrospective cohort study. Int Arch Allergy Immunol 2018;176:249-54. PUBMED | CROSSREF

81. Kotaniemi-Syrjänen A, Palosuo K, Jartti T, Kuitunen M, Pelkonen AS, Mäkelä MJ. The prognosis of wheat hypersensitivity in children. Pediatr Allergy Immunol 2010;21:e421-8. PUBMED | CROSSREF
82. Biller JA, Winter HS, Grand RJ, Allred EN. Are endoscopic changes predictive of histologic esophagitis in children? J Pediatr 1983;103:215-8. PUBMED | CROSSREF
83. Brown LF, Goldman H, Antonioli DA. Intraepithelial eosinophils in endoscopic biopsies of adults with reflux esophagitis. Am J Surg Pathol 1984;8:899-905. PUBMED | CROSSREF
84. Gabryszewski SJ, Dudley J, Shu D, Faerber JA, Grundmeier RW, Fiks AG, et al. Patterns in the development of pediatric allergy. Pediatrics 2023;152:e2022060531. PUBMED | CROSSREF
85. Maggadottir SM, Hill DA, Ruymann K, Brown-Whitehorn TF, Cianferoni A, Shuker M, et al. Resolution of acute IgE-mediated allergy with development of eosinophilic esophagitis triggered by the same food. J Allergy Clin Immunol 2014;133:1487-9. PUBMED | CROSSREF
86. Hill DA, Shuker M, Cianferoni A, Wong T, Ruchelli E, Spergel JM, et al. The development of IgE-mediated immediate hypersensitivity after the diagnosis of eosinophilic esophagitis to the same food. J Allergy Clin Immunol Pract 2015;3:123-4. PUBMED | CROSSREF
87. Zeiger RS, Schatz M, Pomichowski ME, Li Q, Slezak JM, Nolte H, et al. Real-world assessment of anaphylaxis and eosinophilic esophagitis with 12 SQ house dust mite SLIT-tablet sublingual immunotherapy. J Allergy Clin Immunol Glob 2024;3:100250. PUBMED | CROSSREF
88. Lucendo AJ, Arias A, Tenias JM. Relation between eosinophilic esophagitis and oral immunotherapy for food allergy: a systematic review with meta-analysis. Ann Allergy Asthma Immunol 2014;113:624-9. PUBMED | CROSSREF
89. Gonsalves N, Yang GY, Doerfler B, Ritz S, Ditto AM, Hirano I. Elimination diet effectively treats eosinophilic esophagitis in adults; food reintroduction identifies causative factors. Gastroenterology 2012;142:1451-1459.e1. PUBMED | CROSSREF
90. Kagalwalla AF, Shah A, Li BU, Sentongo TA, Ritz S, Manuel-Rubio M, et al. Identification of specific foods responsible for inflammation in children with eosinophilic esophagitis successfully treated with empiric elimination diet. J Pediatr Gastroenterol Nutr 2011;53:145-9. PUBMED | CROSSREF
91. Pourpak Z, Mesdaghi M, Mansouri M, Kazemnejad A, Toosi SB, Farhoudi A. Which cereal is a suitable substitute for wheat in children with wheat allergy? Pediatr Allergy Immunol 2005;16:262-6. PUBMED | CROSSREF
92. Baur X, Degens PO, Sander I. Baker's asthma: still among the most frequent occupational respiratory disorders. J Allergy Clin Immunol 1998;102:984-97. PUBMED | CROSSREF
93. Ameille J, Pauli G, Calastreng-Crinquand A, Vervloët D, Iwatsubo Y, Popin E, et al. Reported incidence of occupational asthma in France, 1996–99: the ONAP programme. Occup Environ Med 2003;60:136-41. PUBMED | CROSSREF
94. Kwon SC, Song J, Kim YK, Calvert GM. Work-related asthma in Korea - findings from the Korea Work-Related Asthma Surveillance (KOWAS) program, 2004–2009. Allergy Asthma Immunol Res 2015;7:51-9. PUBMED | CROSSREF
95. Sander I, Rihs HP, Doekes G, Quirce S, Krop E, Rozynek P, et al. Component-resolved diagnosis of baker's allergy based on specific IgE to recombinant wheat flour proteins. J Allergy Clin Immunol 2015;135:1529-37. PUBMED | CROSSREF
96. Bittner C, Grassau B, Frenzel K, Baur X. Identification of wheat gliadins as an allergen family related to baker's asthma. J Allergy Clin Immunol 2008;121:744-9. PUBMED | CROSSREF
97. Takei M, Saito A, Yanagida N, Sato S, Ebisawa M. Cross-reactivity of each fraction among cereals in children with wheat allergy. Pediatr Allergy Immunol 2022;33:e13831. PUBMED | CROSSREF
98. Doyen V, Migueres N, Frère A, Walusiak-Skorupa J, Wiszniewska M, Suojalehto H, et al. Diagnostic accuracy of specific IgE against wheat and rye in flour-induced occupational asthma. J Allergy Clin Immunol Pract 2024;12:2017-2025.e5. PUBMED | CROSSREF
99. Baur X, Fruhmann G, Haug B, Rasche B, Reiher W, Weiss W. Role of aspergillus amylase in baker's asthma. Lancet 1986;1:43. PUBMED | CROSSREF
100. Matos ML, Cardoso RT. Evaluation of occupational exposure to flour dust and additives in a milling industry. Int J Occup Environ Saf 2024;8:18-27.

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