

Airborne Seafood Allergens as a Cause of Occupational Allergy and Asthma

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Abstract Occupational allergy and asthma is a serious adverse health outcome affecting seafood-processing workers. Allergic reactions are directed to two major seafood groups: fish and shellfish, with the latter group comprising crustaceans and molluscs. Several allergenic proteins have been identified in these different groups, but few have been characterised on a molecular level. Parvalbumin appears to be the major fish allergen, while tropomyosin the major crustacean allergen. Other IgE-binding proteins have also been identified in molluscs and other seafood-associated agents (e.g. *Anisakis sp*), although their molecular nature has not been characterised. Aerosolised allergens can be identified and quantified using immunological and chemical approaches, detecting levels as low as 10 ng/m³. This contemporary review discusses interesting and recent findings in the area of occupational seafood allergy including high-risk occupations, environmental risk factors for airborne exposures, major and minor allergens implicated and innovative approaches in diagnosing and managing occupational allergy and asthma associated with seafood processing.

Keywords Occupational · Occupational allergy · Asthma · Allergens · Seafood · Airborne seafood allergens · IgE antibody

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Introduction

According to the Food and Agriculture Organisation (FAO) over 45 million people are directly involved in fishery and aquaculture production, producing 142 million tonnes of seafood worldwide (Food and Agriculture Organisation, 2010). The increase in harvesting and processing activities in the last 3 decades has been associated with exposure to seafood allergens in various forms that can cause allergic disease and asthma. Occupational sensitisation to fish was first reported in 1937 by De Besche in a fisherman who developed allergic symptoms when handling codfish [1]. Since then, various other seafood groups have been reported to cause occupational allergy and asthma (Table 1) [2, 3]. Most of the current studies focus on a variety of processed crustacean species and bony fish, while other groups and associated agents are less well characterised. This review provides an overview of current knowledge in the area of occupational sensitisation to seafood and discusses novel approaches in assessing and quantifying exposure to airborne seafood allergens.

Clinical Presentation and Epidemiology

Occupational seafood allergy can manifest as both upper and lower respiratory symptoms, as well as urticaria and protein contact dermatitis. Rhinitis, conjunctivitis and less frequently urticaria are often associated and may precede the development of chest symptoms. Systemic anaphylactic reactions have also been reported but are rare [3].

Rhinitis

Ocular-nasal symptoms and allergic rhinitis are commonly encountered in seafood-exposed workers. Rhino-conjunctivitis may therefore precede or coincide with the onset of occupational asthma. This is often the first indicator of underlying

Table 1 Seafood species causing allergic sensitisation and allergens identified

Phylum	Class	Family species (common name)	Allergen name (source)	Molecular weight
Arthropoda	Crustacea	Crab	Tropomyosin (meat)	33 kDa
			Arginine kinase (meat)	40 kDa
			Unidentified (meat, crab water)	4.4, 18.5, 25 kDa
		Scampi, lobster	Unidentified (meat, waste water)	30.2, 97 kDa
		Shrimp, shrimp meal	Unidentified (dried whole body)	80 kDa
			Unidentified (raw, shrimp water)	35–39 kDa
			Unidentified (cysts)	97 kDa
Mollusca	Gastropoda	Prawn	—	—
		Abalone	—	—
	Bivalvia	Scallop	Unidentified (meat, viscera)	19–42 kDa
		Clam, oyster, mussel	—	—
	Cephalopoda	Octopus, squid	Unidentified (meat)	32.43 kDa
Pisces (sub-phylum Chordata)	Osteichthyes (bony fish)	Cuttlefish (and bone)	—	—
		Pilchard, anchovy	Parvalbumin (whole body)	36,48,60 kDa (oligomers)
			Glyceraldehyde-phosphate-dehydrogenase (whole body)	36 kDa
	Chondrichthyes (cartilaginous fish)	Salmon, plaice, tuna, hake, cod, herring, trout, swordfish, sole, pomfret, yellowfin, turbot, fishmeal (flour)	—	—
		Shark (cartilage)	—	—
Other agents		Hoya (Sea-squirt), Anisakis, Red soft coral, Daphnia, Marine sponge, Algae	—	—

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allergic disease and a large proportion of individuals with occupational asthma also report co-existing occupational rhinitis [4]. The prevalence of occupational rhinitis associated with fish and seafood proteins is between 5 and 24 %, although this is likely to be an underestimate [5].

Asthma

The prevalence of occupational asthma in seafood workers is between 2 and 36 % [2, 3, 6•]. The differences in prevalence are partly due to varying definitions of occupational asthma. Furthermore, the allergenic potential of the specific seafood proteins as well as the type of work process, such as steam, organic dust, air blowing and water jets causing excessive exposure, also plays a role. It is well known that occupational asthma is more commonly associated with shellfish (4–36 %) [7–9] than with bony fish (2–8 %) [10•, 11, 12]. About 7 % of workers with ingestion-related seafood allergy are estimated to also have asthma symptoms associated with inhalational seafood exposure [11]. Conversely, there are also isolated case reports of workers (fishmongers handling shrimp and lobster, fish smoking factory workers handling trout, anchovy, salmon and sardines) with occupational asthma

who subsequently developed ingestion-related allergic symptoms to the same seafood species [3].

Pathophysiological Mechanisms

In seafood-exposed individuals, both allergic and irritant reactions have been observed. The allergy is commonly mediated by specific IgE antibodies in response to a seafood allergen or associated agent present in the seafood matrix. These antibodies bind to specific receptors, mainly located on tissue-bound mast cells and circulating basophils, and cause activation of cells upon interaction with the allergen.

There is also strong evidence from in-vitro models that seafood digestive enzymes such as trypsin from salmon, pilchard and king crab can activate specific receptors on cells central in the inflammatory response. These so-called protease activation receptors-2 (PAR-2) on epithelial cells of the airways, once stimulated, can cause airway inflammation through the expression of various cytokines including IL-8 [13]. This cellular activation capacity has recently been demonstrated in vitro for salmon trypsin

[13] and also for trypsin from Rock lobster and Tiger prawn [14]. Four different trypsin and trypsin-like proteases demonstrated strong activity in raw and to some degree in heated crustacean protein extracts and were able to activate respiratory epithelial cells in vitro. From the current literature available on the role of proteases in inflammatory reactions, it is clear that these proteins, commonly found in inhaled allergen sources, are of significant importance. However, very little is currently known about the impact of inhaled proteases on activating PAR-2 in enhancing the allergic and inflammatory response in seafood-processing workers.

The Seafood Matrix, Allergen Sources and Characterisation of Allergens

The three most important seafood groupings include the arthropods, molluscs and fish. The two invertebrate phyla of crustaceans and molluscs are generally referred to as 'shellfish' in the context of seafood consumption. Fish are generally subdivided into bony fish, which are most commonly involved in allergic reactions, and cartilaginous fish, which include sharks and rays. In addition, many other aquatic organisms are processed for domestic consumption including algae, marine sponges, red soft coral and fish-contaminating parasites. All have been associated with occupational allergy and asthma in high-risk populations (Table 1).

Components of Seafood

Exposures generated from processing seafood are complex. For example, studies of aerosols generated in crab-processing plants demonstrate mainly crab exoskeleton containing chitin, meat, primarily muscle protein, gills and kanimiso/internal organs [3]. Fish juice produced in fish filleting and canning plants contains various biogenic amines, degradation compounds associated with postmortem changes, digestive enzymes, skin, slime/mucin, collagen and fish muscle proteins.

Aside from the actual seafood, various contaminants have also been detected in the seafood matrix and may trigger allergic and respiratory symptoms. These include protochordates (*Hoya* or *sea-squirt*), red soft coral and algae (dinoflagellates - *Hematodinium*), and algae-derived marine toxins (e.g. saxitoxins). In addition, contaminants such as the parasite *Anisakis* sp, often found in a range of fish species, can cause allergic sensitisation (see below) [15, 16].

Non-seafood derived agents, added during seafood processing, include additives such as chemicals (sulphites) and spices (paprika, garlic), can also cause allergic sensitisation and must be taken into account [3].

Occupational Seafood Allergens

Molecular characterisation studies show that aerosolised seafood allergens are primarily high molecular weight proteins and many are muscle components [2, 3, 17, 18] (Table 1). Interestingly, seafood allergens causing respiratory disease in workers are often, but not always, similar to those causing seafood allergies through ingestion.

In recent years, our knowledge about the structure of food-derived allergens has increased tremendously as a result of the application of sophisticated molecular biological techniques and the production of recombinant allergens. Since the cloning of the first allergenic food protein from codfish in the late 1980s, hundreds of food allergens have been identified and their sequences and structures determined. The generation of large volumes of information led to the development of a number of databases, which provide molecular, biochemical and clinical data of allergenic proteins: e.g. the International Union of Immunological Societies Allergen Nomenclature Subcommittee (<http://www.allergen.org>), the Allergome (<http://www.allergome.org>), the InFormAll database (<http://foodallergens.ifr.ac.uk>) and AllFam (<http://www.meduniwien.ac.at/allergens/allfam>).

Shellfish

Crustaceans

Sensitisation to crustaceans in the seafood-processing industry usually occurs via inhalation. A recent study by Gill et al. [19•] among snow crab-processing workers identified several IgE antibody-binding proteins ranging from 14.4 to 50 kDa. While these proteins were not characterised on a molecular level, a potential association between protein reactivity and allergic disease was suggested for a 34-kDa protein. Anas et al. [20] subsequently quantified aerosolised snow crab tropomyosin using mass spectroscopy and demonstrated that this allergen is most likely the same allergen identified by Gill et al. Furthermore, arginine kinase was identified in this study as an important aerosolised allergen. Airborne snow crab tropomyosin and arginine kinase allergens have been shown to be elevated in certain work stations of processing plants such as in butchering and cooking activities as compared to cleaning, packing and storage activities [21•]. Furthermore, in the aquaculture industry frequent sensitisation to farmed organisms has been reported, such as brine shrimp, which are used as feed (*Artemia*) for aquarium fish throughout the world [8].

Some of the identified allergens, such as tropomyosin and arginine kinase, are highly conserved proteins among crustacean species. Hence, individuals allergic to one type

of seafood, such as crab, may also develop allergic symptoms to the same allergen found in other processed crustacean species including Rock lobster, shrimp and scampi. Interestingly, the fish parasite *Anisakis sp.*, often found in contaminated fish, also possesses immunologically related tropomyosin with crustaceans [2, 18], suggesting a potential for cross-reactivity reactions among workers processing crustaceans as well as fish in the workplace. While no other aerosolised allergenic proteins have been characterised on a molecular level to date, other potential allergens could include myosin light chain [22, 23] and sarcoplasmic calcium-binding protein [24].

Molluscs

There have been few studies investigating mollusc-derived occupational allergic sensitisation when compared to crustaceans. However, allergenic proteins that have been detected range in molecular weight between 19 kDa and 43 kDa, suggesting that tropomyosin and arginine kinase could also be implicated in sensitisation to molluscs [3, 25]. Although IgE cross-reactivity between different crustacean tropomyosins is commonly reported, the amino acid sequence identity of mollusc tropomyosin compared to crustacean is very low being less than 60 % [18, 26]. It is therefore unlikely that workers sensitised to crustacean tropomyosin cross-react with molluscs, but instead develop co-sensitisation to mollusc-derived tropomyosin and other yet unidentified allergens.

Fish

Fish are probably the largest proportional seafood group processed and can be divided into two main groups, viz. bony fish and cartilaginous fish. Most edible fish are bony fish (Osteichthyes), whereas sharks and rays being cartilaginous belong to a different class, the Chondrichthyes. The majority of studies on fish allergens have focussed on cod, carp and salmon. Although there are more than 32,400 different species of fish described, the consumption and related processing depend to a great extent on regional availability.

Bony Fish

The major allergens in bony fish are very different from shellfish, with the muscle protein parvalbumin being the most commonly implicated in ingestion-related sensitisation [17]. However, this allergen also seems to be involved in aerosolised sensitisation to fish. A highly cross-reactive allergenic isoform of pilchard parvalbumin was demonstrated to be one of the airborne allergens responsible for allergic respiratory disease in fish-processing workers [27]. In contrast to food

allergic patients, who recognise mainly the monomeric form of parvalbumin (12 kDa), occupationally sensitised workers appear to recognise higher molecular weight isoforms, including dimers and oligomers of parvalbumin. Furthermore, fish-derived glyceraldehyde-3-phosphate dehydrogenase (36 kDa) has also been characterised in an inhalant murine model of occupational fish sensitisation [28]. A recent study of occupational asthma among fish farmers demonstrated parvalbumin in addition to higher molecular weight allergens of 38 kDa and 50 kDa in turbot [29], while no other aerosolised allergenic fish proteins have been characterised on a molecular level, other potential allergens could include skin collagen [30, 31] and vitellogenin found in fish roe (caviar) [32].

Cartilaginous Fish

There are very few reports on allergic sensitisation to cartilaginous fish in the seafood-processing industry [33, 34]. While sharks and rays are often consumed and processed, only reports identifying cartilage as being a possible sensitising agent appear in the literature. Cartilage consists mainly of collagen and a few proteins. It is worth noting that the muscle protein parvalbumin from cartilaginous fish is very different in its amino acid structure from bony fish and shares only about 60 % homology [17]. It is very unlikely that workers sensitised to bony fish parvalbumin would clinically cross-react to shark parvalbumin and other as yet unidentified cartilaginous fish allergens that may be involved.

Environmental Risk Factors for Occupational Allergy and Asthma

The aetiology and development of allergic disease are due to an interaction between genetic, environmental and host factors giving rise to different allergic disease phenotypes. Studies on occupational allergy and asthma associated with seafood have shown that while host factors such as atopy, upper airways disease and smoking have enjoyed considerable attention in the past, the evidence for environmental factors is gaining momentum [3, 6].

High-Risk Occupations

Workers that are involved in either manual or automated processing of crabs, prawns, mussels, fish and fishmeal in factories are exposed to high levels of aerosolised seafood. Processing techniques are quite variable, depending on the size of the plants with smaller workplaces mainly using manual methods whereas larger factories are highly automated. Aside from food-processing workplaces, there are other work activities that involve contact with seafood in

different forms such as those involved with harvesting-related activities (e.g. fishermen, aquaculture, oyster shuckers, fishmongers, truck drivers, maintenance), food preparation activities (e.g. restaurant chefs and waiters), laboratory and pharmaceutical activities, pet food production activities and value-added work activities (e.g. shell grinders, jewellery polishers) [3, 6•, 10•, 35].

High-Risk Work Processes

Processing and preservation procedures can vary from filleting, freezing, drying, cooking, smoking to high-pressure techniques [3, 6•, 36]. Work processes that have been identified to generate excessive bioaerosols include butchering or grinding; degilling, "cracking" and boiling of crabs; cleaning and brushing of crabs; "tailing" of lobsters; "blowing" of prawn meat through shells; washing or scrubbing of shellfish; degutting, heading and cooking/boiling of fish; mincing of seafood; and cleaning of the processing line or storage tanks with high-pressured water hoses [35]. It would appear that processes that generate dry aerosol particulates through using compressed air as in prawn-blowing operations and fishmeal loading/bagging generate higher levels of particulate than wet processes (e.g. prawn-blowing using water jets). It is these wet or dry aerosolised particles produced from seafood during processing operations that are inhaled by workers.

Impact of Storage and Processing on Seafood Allergenicity

The aerosolised particles produced in the seafood processing industry are rarely inert but instead contain biologically active natural allergens. There is increasing evidence that food-processing techniques such as heating, freezing and high pressures have the ability to change the nature, dose and allergenicity of food [36]. These processes produce seafood products or by-products that are concentrated into major allergen source compartments such as muscle, visceral contents, skin slime/mucin and collagen. The allergenic potential of these proteins is dependent on the seafood grouping, with crustaceans being more allergenic than fish. Furthermore, other by-products, such as protease enzymes from the gut, chitin from shellfish and endotoxin from gram negative bacteria, are also known to promote airway inflammation. Storage conditions may also affect the allergenicity of seafood by influencing the relative distribution of various IgE reactive proteins [37]. It has been demonstrated that fish kept on ice for several days has additional high molecular weight allergens and higher IgE-binding capacity than fresh fish. Furthermore, codfish stored for several days (at 4 °C) displays a much higher IgE reactivity than very fresh fish. It has been postulated that these changes may be due to the natural production of formaldehyde in fish tissue, which may affect the

allergenicity of some proteins [37]. Recent studies suggest that exposure to raw seafood may be less sensitising to individuals than cooked seafood during processing activities [38].

Exposure Assessment Studies of Seafood-Processing Workers

Various environmental exposure assessments in seafood processing plants have shown that the aerosol concentrations can vary considerably and can reach high levels of up to 11 mg/m³ for total inhalable particulates, 6 mg/m³ for protein and 75 µg/m³ for allergen levels [6•, 12, 21•, 35, 39, 40] (Table 2). The highest particulate and allergen concentrations have been demonstrated during fishmeal operations as well as aboard crab-processing vessels at sea, since seafood processing in the latter instance occurs in confined spaces with poor ventilation. More recent studies also show that concentrations are higher in factories with old seafood-processing machines. Air sampling in crab processing environments have shown that at least 30 % of airborne particulates are <5 µm, whereas in herring fish filleting environments almost 100 % are <1 µm in size [3, 41, 42]. This suggests that most of these particles are capable of being inhaled and reach the small airways. Aside from allergen exposures, relatively low levels of endotoxin have been demonstrated in crab and shrimp processing plants. However, much higher levels (103.7–136 EU/m³) were found in fish gutting and fishmeal operations relative to filleting and canning activities [35, 43, 44].

Exposure-Response Relationships

The evidence for an increased risk of sensitisation and occupational asthma with elevated exposures to seafood aerosols has been accumulating since the first studies documented a while ago. In these earlier studies, a substantial proportion of prawn processors using compressed air jets for prawn meat extrusion activities experienced relief of allergic symptoms, including asthma, when these were replaced with cold-water jets resulting in a major reduction in particulate concentrations from 1.8–3.3 mg/m³ to 0.1–0.3 mg/m³ [45]. In another study of salmon processors, the introduction of exhaust ventilation over gutting machines also resulted in inhalable aerosol levels decreasing from a mean of 3.14 mg/m³ to <0.01 mg/m³ [46]. This was accompanied by a conspicuous absence of new cases of occupational asthma over 24 months post intervention when compared to an initial prevalence of 8 % (24/291) in the 18 months prior to this period. More recent studies of crab processors have shown that cumulative exposure to snow crab allergens is associated with an increased risk of occupational allergy and asthma in a dose-response manner [47]. Among pilchard and anchovy fish processors, the odds for work-related asthma symptoms were three times greater (OR=3.53, CI=1.56–

Table 2 Exposure assessment of seafood handling workers on land and aboard vessels

Seafood category	Particle fraction measured	Particulate conc. (mg/m ³) range	Protein conc. (mg/m ³) range	Allergen (ng/m ³) range	Endotoxin (EU/m ³) range
Crustaceans					
Crab (snow, Tanner, common, King)	Total inhalable	0.001–0.680	0.001–6.400	1 – 5,061	32.6 (inhalable) 15.6 (respirable)
Crab (snow)*	Total inhalable	ND	ND	79 – 21,093	ND
Prawn	Total inhalable	0.100–3.300	ND	ND	ND
Shrimp	Total inhalable	ND	ND	1,500–6,260	5.8 – 29.9 (inhalable)
Rock lobster	Thoracic	LOD–0.661	LOD–0.002	ND	ND
Scampi	Total inhalable	ND	ND	47–1,042	ND
Finfish					
Whiff megrim/hake	Total inhalable	ND	ND	2–25	ND
Salmon	Respirable	0.040–3.570	ND	100–1,000	ND
	Total inhalable	ND	ND	LOD–1,600	6.8–7.9
Pollock	Total inhalable	0.004	ND	ND	ND
Cod	Total inhalable	ND	ND	3,800–5,100	8.6–23.9
Pilchard	Thoracic	LOD–2.954	LOD–0.006	10–898	49
Herring	Total inhalable	ND	ND	300–1,900	103.7
Fishmeal (anchovy)	Thoracic	LOD–11.293	LOD–0.004	69–75,748	136
Shark cartilage**	Respirable	0.920–5.140	ND	ND	ND
	Total inhalable	26.400–44.700	ND	ND	ND

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7.96) for workers exposed to fish antigen levels >90 ng/m³ compared to those exposed to <30 ng/m³ [42]. Non-parametric statistical approaches show that higher current and cumulative fish antigen exposures (thoracic fraction) are associated with increasing prevalence of work-related asthma symptoms and NSBH, whereas sensitisation to fish is associated with cumulative exposures [48]. In these studies, the prevalence of work-related asthma symptoms rose with increasing fish antigen levels up to 100 ng/m³ for pilchard antigens and 150 ng/m³ for anchovy antigens, and then they levelled off and declined with higher exposure concentrations. The relationship between fish antigen exposure and work-related asthma symptoms was more bell-shaped with cumulative rather than current exposures. Both atopy and, to a lesser extent, smoking status increased the effect. Although a portion of these findings probably represents a healthy worker effect, it has been suggested that a component may be due to the development of tolerance in some of the workers.

General Workplace Organisational Factors Mediating Exposure to Seafood

Many environmental and organisational factors mediate hazardous exposures and worker vulnerability in the seafood industry. Some of the factors are global, including ecological

degradation and environmental and global shifts in seafood production. Some of the factors are local and specific to the nature of work and the workers, including rural location, a migrant and seasonal workforce, divisions of labour along gender and racial lines, as well as shortcomings in occupational health and safety laws and interventions [49].

Immunological Diagnostic Approaches

Clinical

Most affected workers are commonly sensitised to more than one allergen, which may trigger clinical symptoms, and it is often difficult to distinguish the major offender. Therefore, in-vitro and in-vivo assays are employed to determine the immunological mechanisms behind the clinical symptoms. Skin prick testing is frequently used to demonstrate the presence of cell bound specific IgE antibody to allergens including fish [11], artemia [8] and snow crab [9]. In crab-processing workers, the positive predictive value of a positive skin prick test to crab extracts or positive specific IgE for occupational asthma confirmed by specific bronchial inhalation challenge was 76 % and 89 %, respectively. A negative skin test therefore does not exclude the diagnosis of occupational asthma whereas a positive test supports the diagnosis but is not definitive in and

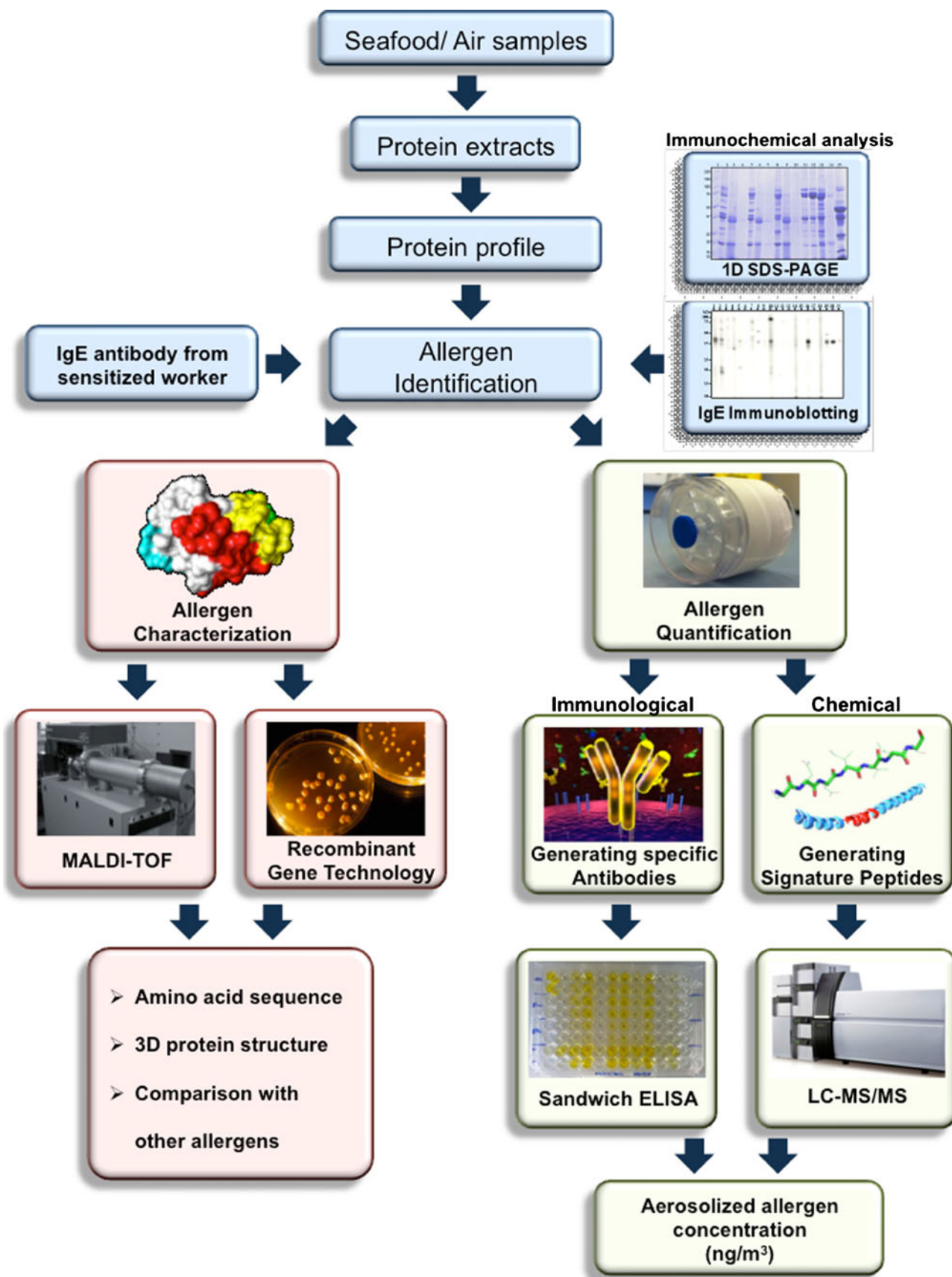


Fig. 1 Allergenomic approach in characterizing and quantifying occupational seafood allergens

of itself [6•]. In the absence of reliable SPT solutions, in-vitro diagnostics are preferred, which rely on the detection and/or quantification of seafood-specific IgE antibodies using assays such as the commercial ImmunoCAP (Phadia) [2, 3, 50] or in-house ELISA tests [32, 38, 51] and immunoblotting [27] using the patient's sera, and more recently allergen microarray techniques. For ingestion-related crustacean allergy, it has recently been suggested that the quantification of tropomyosin-specific IgE is superior to skin prick testing [52], and this may also be of importance in the occupational setting. Since all these techniques rely on the availability of clinically relevant allergen components, the purification and characterisation of specific allergens are crucial.

The best detection of seafood-specific IgE antibody in sensitised workers currently still depends on the use of well-characterised in-house generated allergen preparations. The use of heat-treated allergen preparations may improve diagnostics, as has recently been demonstrated for shrimp and should be considered in the occupational setting [38].

Aside for these immunodiagnostic tests, specific bronchial inhalation challenge with the implicated seafood still remains the gold standard in diagnosing occupational asthma associated with airborne exposure to seafood [6•].

Work Environment

Almost all studies evaluating total protein exposure and quantifying specific allergenic proteins have until recently relied on immunological reactivity techniques (Fig. 1). These include the generation of allergen-specific antibodies in ELISA (enzyme-linked immune-sorbent assay), RAST (radio allergosorbent test) and immunoblotting. A comprehensive and well-illustrated example of the development of a specific ELISA-based test system is the quantification of pilchard allergens in air samples using in-house generated rabbit antibody [12]. This system demonstrated relatively good sensitivity, having a detection limit of 105 ng/m³. A more recent study on Atlantic salmon exposure by ELISA detected salmon parvalbumin as low as 10 ng/m³ [53]. Using this type of assay has potential limitations in that ELISA-based techniques measure the allergenic protein based on the recognition by specific antibodies, which in turn are labelled and react with colorimetric substrates, enabling the indirect quantification of these proteins. Consequently, the sensitivity, specificity and selectivity of these indirect techniques are limited by the recognition of the proteins in air samples by these allergen-specific antibodies. Modifications of allergenic proteins during processing could therefore result in an underestimation of actual allergen concentrations in air samples. More recent studies have investigated alternative techniques in quantifying the exact amount of allergen present as

demonstrated for snow crab tropomyosin and arginine kinase [20, 21•, 22]. The allergenomic strategy includes the chemical characterisation of seafood allergens, applying mass spectrometry to sequence novel allergens de-novo and the use of signature peptides to quantify aerosolised allergens, as demonstrated for tropomyosin and arginine kinase (Fig. 1). The lower limit of detection for sampling airborne tropomyosin in a simulated processing plant using this approach is 33 ng/m³, which is more sensitive compared to conventional immunoassays. Furthermore, the determination has the added advantage in that it could be achieved in a very short sampling time of less than 1 h. Recently, parvalbumin, the major allergen present in hake tissue, could also be detected using a mass spectrometric approach [54].

Conclusions

This review has highlighted the importance of evaluating, identifying and characterising the allergens responsible for occupational seafood allergy and asthma. The insights that have been developed have the potential for promoting its application and use in various settings in the home and work environment. For seafood-processing workers, these include evaluation of the work environment, in-vitro evaluation of suspected materials, product labelling, monitoring of allergen exposure during specific inhalation allergen challenge, development of exposure standards, evaluating the impact of allergen avoidance, medical surveillance of exposed workers in relation to observed sensitisation patterns and symptoms, and exploring the possibility of developing immunotherapy options. Future research needs to focus on [35]:

- Better characterisation of the spectrum of allergens involved, both major and minor, with the development of standardised approaches to identify and measure them
- Measurement of single and mixed exposures over time, and as related to specific tasks.
- Identification of the interaction between immunological and irritant co-exposures such as proteases, sulphites, toxins, bacteria and bacterial products that may potentiate asthma and allergic disease
- Further characterisation of relevant allergen dose-response relationships
- Improvement of medical surveillance programmes using immunological approaches that can detect early sensitisation and allergic respiratory disease

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Conflict of Interest Andreas L. Lopata declares that he has no conflict of interest.

Mohamed F. Jeebhay declares that he has no conflict of interest.

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