



Prevalence of fish and shellfish allergy

A systematic review

Harriet Moonesinghe, BSc^{*}; Heather Mackenzie, PhD^{*}; Carina Venter, PhD^{*,†}; Sally Kilburn, PhD^{*}; Paul Turner, PhD[‡]; Kellyn Weir, MRes^{*}; Taraneh Dean, PhD^{*,†}

^{*} University of Portsmouth, Portsmouth, United Kingdom

[†] David Hide Asthma and Allergy Centre, Isle of Wight, United Kingdom

[‡] Imperial College London, London, United Kingdom

ARTICLE INFO

Article history:

Received for publication April 20, 2016.

Received in revised form June 9, 2016.

Accepted for publication July 11, 2016.

ABSTRACT

Background: Accurate information on the prevalence of food allergy facilitates a more evidence-based approach to planning of allergy services and can identify important geographic variations.

Objective: To conduct a systematic review to assess the age-specific prevalence of fish and shellfish allergy worldwide.

Methods: Searches were conducted using Web of Science and PubMed. Population-based cross-sectional studies and cohort studies that examined the prevalence of fish and shellfish allergy (IgE mediated and non-IgE mediated) at an identifiable point in time were eligible for inclusion in the study. Reviewers extracted general study information and study design, type of food allergy considered, food(s) assessed, method of diagnosis, sampling strategy, and sample characteristics. Raw data were extracted and percentage prevalence and 95% confidence intervals calculated.

Results: A total of 7,333 articles were identified of which 61 studies met the inclusion criteria and were included in this review. The prevalence of fish allergy ranged from 0% to 7% and the prevalence of shellfish allergy from 0% to 10.3%, depending on the method of diagnosis. Where food challenges were used, the prevalence for fish allergy was found to be 0% to 0.3% and for shellfish allergy was 0% to 0.9%.

Conclusion: Few studies have established the prevalence of fish or shellfish allergy using the gold standard double-blind, placebo-controlled challenge criteria, with most instead relying on self-reported questionnaire-based methods. The limited data available suggest that fish allergy prevalence is similar worldwide; however, shellfish allergy prevalence may be higher in the Southeast Asia region.

© 2016 American College of Allergy, Asthma & Immunology. Published by Elsevier Inc. All rights reserved.

Introduction

Fish and shellfish are major allergens as defined by the European Community and are a leading cause of anaphylaxis.¹ Allergic reactions to fish and shellfish are usually immediate (ie, related to an IgE response), although non-IgE-mediated reactions (including food protein-induced enterocolitis syndrome) can also be triggered.² Reactions can be triggered by direct ingestion or skin contact or (in some cases) through ingestion or contact with cooking vapors.³ In contrast to allergens such as egg and cow's milk, fish and shellfish allergy does not in general resolve with age; therefore,

lifelong dietary avoidance is necessary.⁴ Evidence suggests that there is an increased prevalence of fish and shellfish allergy in countries with high seafood consumption, such as Australia, Asia, and parts of Europe.⁵

Accurate information about the prevalence of allergies to specific foods facilitates an evidence-based approach to the planning and provision of allergy services both nationally and internationally.² Prevalence data can be used to identify which food allergens are the most common and their natural history within countries. At an international level, geographic variations can be explored and greater understanding of trends and mechanisms in the development of food allergy reached. Existing policy and legislation in the field of food allergy (eg, manufacturing and labeling practices, care guidelines, catering practices) are largely informed by self-reported prevalence, which is widely recognized to overestimate true prevalence.⁶ There are currently 3 existing systematic reviews on the

Reprints: Heather Mackenzie, PhD, University of Portsmouth, St Andrew's Court, St Michael's Road, Portsmouth PO1 2PR, United Kingdom; E-mail: Heather.mackenzie@port.ac.uk.

Disclosures: Authors have nothing to disclose.

Funding Sources: This study was supported by grant CFT/EFSA/NUTRI/2012/02 from the European Food Standards Agency.

<http://dx.doi.org/10.1016/j.anai.2016.07.015>

1081-1206/© 2016 American College of Allergy, Asthma & Immunology. Published by Elsevier Inc. All rights reserved.

prevalence of food allergy.^{7–9} However, there are no single systematic reviews that report on the prevalence of allergy to 13 of 14 food allergens as listed under European Union food-labeling legislation or any that examine prevalence worldwide. Therefore, we conducted a systematic review to assess the prevalence of fish and shellfish allergy and help identify any gaps in evidence.

Methods

This review is part of a larger systematic review that assessed the prevalence of 13 of the 14 main allergens (milk, egg, cereals, peanut, nuts, celery, fish, crustacean, mollusk, soy, lupin, mustard, and sesame).

Search Strategy and Reference Management

We searched Web of Science, PubMed, and the Conference Proceedings Citations Index. No language, date, or study type restrictions were used. Gray literature was sought via direct contact with a list of topic experts and relevant research funders. Search results were managed using EndNote and duplicates removed. English language versions of articles were obtained where necessary.

Screening

The titles and abstracts of all identified articles were screened by 1 review author (H.M.) and excluded if, for example, they were obviously unrelated to the topic of the review, the sample was inappropriate for the scope of the review, or they did not present primary research. If the review author was unsure about the eligibility of the article for inclusion in the review, the article was discussed with another author. Reasons for exclusion were recorded. The full-text of all potentially eligible studies was assessed against the following criteria.

Types of studies

Population-based cross-sectional studies and cohort studies that examined the prevalence of fish and shellfish allergy (IgE mediated and non-IgE mediated) at an identifiable point (or period) in time were eligible for inclusion in this review.

Types of participants

Participants of all age groups from any country were considered. Studies that did not present region- or country-specific data were excluded from the review. Studies must have been population based, using a fixed cohort or an appropriate sampling strategy. Studies conducted in a clinical setting or in selected patient groups were excluded.

Types of outcome measure

Prevalence of allergies (or sensitization) to 1 or more of the following food allergens (crustaceans, fish, mollusks) were eligible for inclusion as diagnosed by self-report, positive skin prick test (SPT) results (as reported in the articles), positive serum specific IgE test result (>0.35 kUA/L), clinical history of adverse reactions to foods, and positive SPT result (for IgE-mediated food allergy), positive serum specific IgE test result (for IgE-mediated food allergy), or positive food challenge result (open or double-blind, placebo-controlled: for IgE-mediated and non-IgE-mediated food allergy, allowing for delayed reactions in the case of non-IgE-mediated food allergy). Studies that did not present separate prevalence data for individual allergens were excluded from the review. In addition, studies that used atopy patch tests or other diagnostic tests (eg, IgG measures) were

excluded because these are not recommended for the routine diagnosis of food allergy.¹⁰

Data Extraction and Analysis

The following were extracted for all included studies (using EPPI-Reviewer software; EPPI Centre, 2011): general information (authors' contact details, research funder, year[s] study conducted, country or countries in which conducted), methods (study design, type of food allergy considered, food(s) assessed, method of diagnosis, including additional information with regard to the procedure, sampling strategy and sample characteristics, and outcomes (percentage prevalence, raw data and confidence intervals [CIs]). Where there was ambiguity in the reporting of results, all efforts were made to contact the study authors to provide additional information.

Assessing the Quality of Included Studies

Studies were assessed as being at low, medium, or high risk of bias on the basis of 2 quality criteria: risk of bias of the diagnostic method (in studies that used >1 method of diagnosis, the risk of bias of the highest quality method was judged) and method of sampling. Table 1 reports the outcome for each study.

Data Synthesis and Presentation

For each allergen, we present a forest plot that maps the data (percentage prevalence and 95% CIs, where possible) according to region and country and then by age. The prevalence data have been presented by method of diagnosis, and information has also been included on the year and age group for which data are being presented. Data have additionally been narratively reported for the prevalence of allergy to fish and shellfish both across Europe and for countries outside Europe. Meta-analysis was not conducted because of the high heterogeneity among studies, which would make a pooled estimate misleading.

Results

Results of the Search

Of the 7,333 articles identified by the search, 7,145 were excluded during the title and abstract screening. Hence, the full text was obtained for 216 articles, of which 116 were excluded after screening. There were 100 studies that were included in the systematic review, of which 61 presented data on the prevalence of fish and/or shellfish allergy.

Description of Included Studies

Forty-eight studies used a cross-sectional design, and 13 studies used a cohort design. Forty-one studies were based on a pediatric population (<18 years old), 11 on an adult population (≥ 18 years old), and 9 on all ages presented collectively. Questionnaire-based methods for assessing suspected fish and/or shellfish allergy were presented in 44 studies, 25 studies measured sensitization rates, and 10 studies performed food challenges to confirm fish and/or shellfish allergy.

Fish Allergy Prevalence

Assessed using questionnaire-based methods

In Europe, the highest reported prevalence in adults was found in Greece,⁵⁶ with 1.5% (95% CI, 1.0–2.2) of 20- to 54-year-olds reporting an adverse reaction to fish, and the lowest reported prevalence was in Denmark,⁴⁹ with only 0.2% (95% CI, 0.0–1.0) of 22-year-olds reporting an adverse reaction to fish (cod specifically). With regard to children, the prevalence ranged from 7.0% (95% CI, 5.4–9.0) in 1-year-olds in Finland³⁰ to 0.0% (95% CI,

Table 1
Quality Assessment of Included Studies^a

Study	Diagnostic methods: risk of bias	Sampling strategy method: risk of bias
Al-Hammadi et al, ¹¹ 2010	High	Medium
Arshad, ¹² 2001	High	Medium
Ben-Shoshan et al, ¹³ 2010	High	Medium
Branum et al, ¹⁴ 2009	High	Medium
Brugman, ¹⁵ 1998	High	High
Burney et al, ¹⁶ 2010	High	Medium
Chen et al, ¹⁷ 2011	High	Low
Connett et al, ¹⁸ 2012	High	Medium
Dalal et al, ¹⁹ 2002	Medium	High
Eggesbo, ²⁰ 1999	High	Low
Emmett, ²¹ 1999	High	Not reported
Falcao et al, ²² 2004	High	High
Gelincik et al, ²³ 2008	Low	Medium
Greenhawt et al, ²⁴ 2009	High	Medium
Gupta et al, ²⁵ 2011	High	Medium
Haahela et al, ²⁶ 1980	High	Low
Hu et al, ²⁷ 2010	High	Medium
Jansen, ²⁸ 1994	Low	Medium
Johansson et al, ²⁹ 2005	High	High
Kajosaari, ³⁰ 1982	Low	Medium
Kavaliunas et al, ³¹ 2012	High	Medium
Kim, ³² 2011	High	Not reported
Krause, ³³ 2002	High	Low
Kristjansson et al, ³⁴ 1999	Low	High
Lao-araya and Trakultivakorn, ³⁵ 2012	Low	Medium
Leung et al, ³⁶ 2009	High	Medium
Liu et al, ³⁷ 2010	High	Medium
Marklund, ³⁸ 2004	High	High
Marrugo, ³⁹ 2008	High	Medium
Martínez-Gimeno et al, ⁴⁰ 2000	High	Medium
Mustafayev et al, ⁴¹ 2012	High	Not reported
Obeng et al, ⁴² 2011	High	Not reported
Oh, ⁴³ 2004	High	Medium
Orhan et al, ⁴⁴ 2009	Low	Medium
Osborne, ⁴⁵ 2011	High	High
Ostblom, ⁴⁶ 2008	High	Not reported
Ostblom, ⁴⁷ 2008	High	Not reported
Osterballe et al, ⁴⁸ 2005	Low	Medium
Osterballe et al, ⁴⁹ 2009	Low	Medium
Penard-Morand, ⁵⁰ 2005	High	Medium
Pereira, ⁵¹ 2005	High	Low
Pyrhonen et al, ⁵² 2009	High	Low
Rance, ⁵³ 2005	High	Low
Ro et al, ⁵⁴ 2012	High	Not reported
Roberts et al, ⁵⁵ 2005	High	Low
Sakellariou et al, ⁵⁶ 2008	High	High
Santadusit et al, ⁵⁷ 2005	Low	Medium
Schafer et al, ⁵⁸ 2001	High	Low
Shek, ⁵⁹ 2010	High	Medium
Sicherer et al, ⁶⁰ 2004	High	Low
Touraine et al, ⁶¹ 2002	High	High
Van Bockel-Geelkerken, ⁶² 1992	High	Not reported
Venter et al, ⁶³ 2006	Low	Low
Venter, ⁶⁴ 2008	Low	Low
Vierk et al, ⁶⁵ 2007	High	Medium
Von Hertzen, ⁶⁶ 2006	High	Medium
Woods et al, ⁶⁷ 1998	High	Medium
Wu et al, ⁶⁸ 2012	High	Medium
Young et al, ⁶⁹ 1994	High	Medium
Zannikos, ⁷⁰ 2008	High	High
Zuberbier et al, ⁷¹ 2004	High	Medium

^aLow risk of bias indicates food challenges (open or double-blind) with or without clinical history; medium risk of bias, sensitization (skin prick test and/or serum specific IgE) with clinical history; and high risk of bias, sensitization (skin prick test and/or serum specific IgE) without clinical history on questionnaire-based methods (self-report, clinical history, or clinician diagnosed). Low risk of bias was measured in the whole population; medium risk of bias, random; and high risk of bias, nonrandom.

0.0–0.1) of 0- to 2-year-olds in Israel.¹⁹ In Africa, only 1 study could be identified that reported fish prevalence data in Ghana⁴² and found the reported prevalence of 5- to 16-year-old children to be 0.3% (95% CI not reported). In the Americas, the

highest reported fish allergy in adults was seen in the United States²⁴ (2.7%; 95% CI, 1.6%–4.7%), and the lowest was 0.12% (95% CI, 0.08%–0.16%) in Canada.¹³ The highest prevalence for children was 0.2% (95% CI, 0.1%–0.5%) in the United States,⁵⁰ and the lowest prevalence found was in Canada¹³ at 0% (95% CI not reported). One study identified from the Eastern Mediterranean¹¹ reported that the clinician-diagnosed prevalence of fish allergy in children (6–9 years old) was 2.8% (95% CI, 1.5%–5.1%). In Southeast Asia, the highest reported prevalence seen in Thailand³⁵ was 1.1% (95% CI, 0.4%–2.7%) for 3- to 7-year-olds compared with the lowest, which was 0.3% (95% CI, 0.1%–1.2%) of 6-month and 6-year-olds also in Thailand.⁵⁷ In the Western Pacific region of the world,⁶⁷ the reported prevalence of fish or shellfish allergy in 20- to 44-year-olds in Australia was 2.1% (95% CI, 1.2%–3.6%). In Taiwan, in those older than 19 years,⁶⁸ the prevalence was lower at 1.2% (95% CI, 1.0%–1.4%) when a clinician diagnosis of fish allergy was used. The reported prevalence of childhood fish allergy ranged from 4.3% (95% CI, 4.0%–4.7%) in 14- to 16-year-olds in the Philippines¹⁸ to 0.2% (95% CI, 0.1%–0.5%) of 2- to 7-year-olds in Hong Kong (eFig 1 and eFig 2).²⁶

Assessed using sensitization

In Europe, 1 study in Germany⁵⁸ used SPT in an adult population (25–74 year olds), revealing a 2.9% (95% CI, 2.2%–3.9%) sensitization to mackerel. In children the highest sensitization rate was found in Finland,²⁶ where 2.7% (95% CI, 1.7%–4.2%) of 15- to 17-year-olds were sensitized to fish, and the lowest sensitization rate was seen in the United Kingdom,⁵⁵ where 0% (95% CI, 0%–0.3%) of 7-year-olds were sensitized to fish (cod specifically). One study in the Americas region¹⁶ measured sensitization using serum specific IgE tests and found that 0% (95% CI, 0%–5.3%) of 20- to 44-year-olds were sensitized to fish. The same study¹⁶ found 0% (95% CI, 0%–2.1%) fish sensitization in 20- to 44-year-olds in Australia. For children, the sensitization rate ranged from 0.2% (95% CI, 0%–1.4%)¹⁷ to 0.8% (95% CI, 0.2%–2.5%)²⁷ in China (Fig 1).

Assessed using clinical history and sensitization

In Europe, the highest prevalence was seen in Norway,¹⁹ where 1.1% (95% CI, 0.4%–3.1%) of 2-year-olds were sensitized to fish, and the lowest was 0% (95% CI, 0%–0.1%) of 0- to 2-year-olds in Israel. Adult fish allergy prevalence ranged from 0.8% (95% CI, 0.2%–2.5%) in 20- to 44-year-olds in Germany¹⁶ to 0% in several other studies. In Southeast Asia, the prevalence was 0.2% (95% CI, 0%–1.0%) of 6-month to 6-year-olds in Thailand⁵⁷ (Fig 1).

Assessed using food challenges

In Europe, with regard to open food challenges, only 1 study in Denmark⁴⁹ reported data for adult fish (cod) allergy as 0.1% (95% CI, 0%–0.8%) of 22-year-olds. For children, the lowest confirmed prevalence was 0% (95% CI, 0%–4.2%) of those younger than 3 years old in Denmark,⁴⁸ and the highest was 0.1% (95% CI, 0%–0.8%) of 6-year-olds in Finland.³⁰ When a double-blind, placebo-controlled food challenge was used, the rate of confirmed prevalence ranged from 0.2% (95% CI, 0%–0.9%) in Denmark⁴⁸ to 0% (95% CI, 0%–0.1%) in Turkey in adults²³ and from 0.3% (95% CI, 0%–2.0%) in Iceland³⁴ to 0% in Denmark,⁴⁸ Turkey,⁴⁴ and the United Kingdom⁶³ in children. In Southeast Asia, a prevalence of 0.2% (95% CI, 0%–1.4%) was found for 3- to 7-year-olds based on an open food challenge³⁵ (Fig 2).

Shellfish Allergy Prevalence

Assessed using questionnaire-based methods

In Europe, with regard to adult crustacean allergy, 1 study was performed in Denmark,⁴⁹ which found 2.0% (95% CI, 1.2%–3.3%) self-reported allergy to shrimp. In children, the reported prevalence ranged from 5.5% (95% CI, 4.3%–7.1%) of 5- to 17-year-

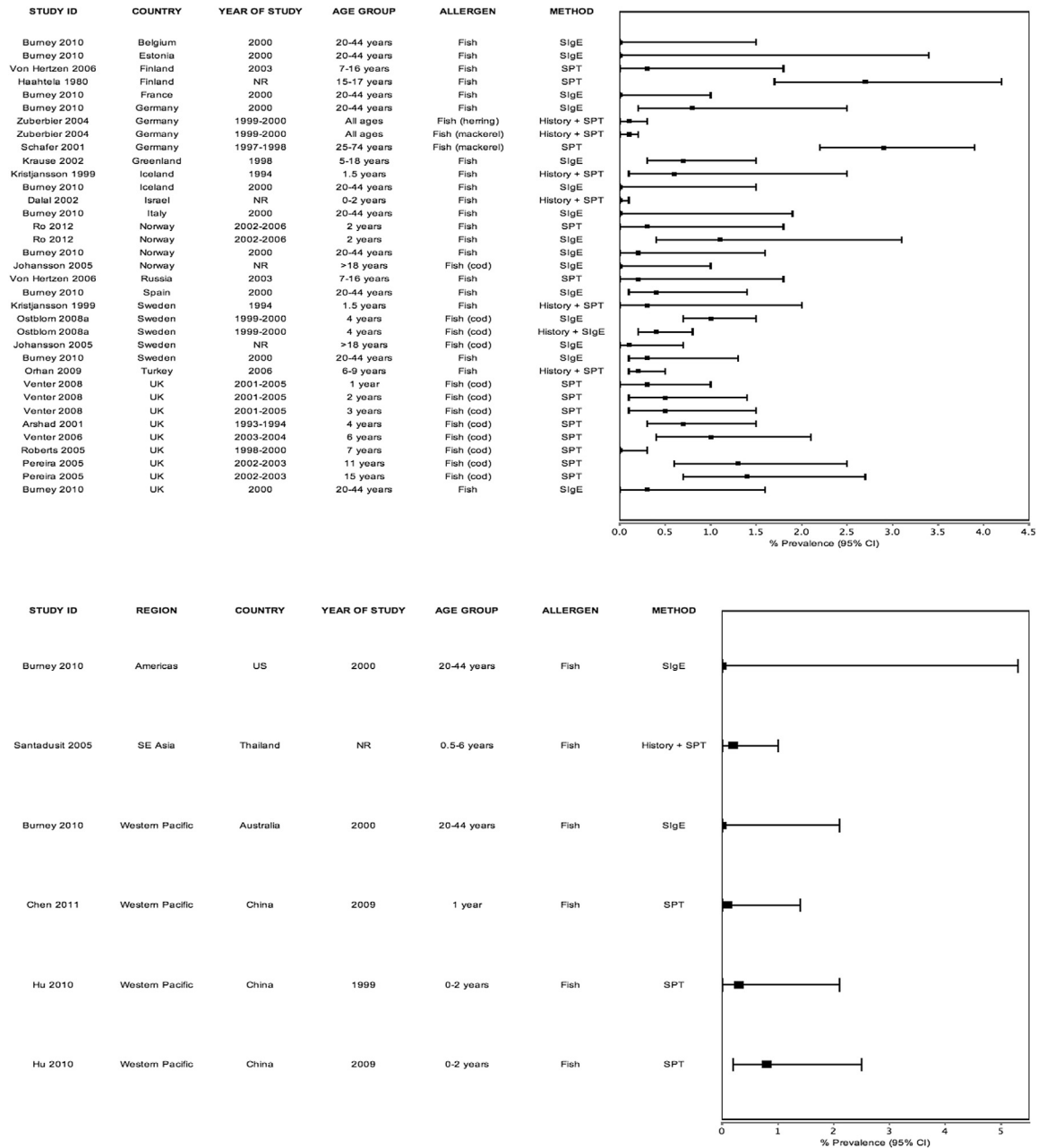


Figure 1. Fish allergy prevalence in Europe (top) and other regions of the world (bottom) diagnosed by sensitization methods.

olds in France⁶¹ to 0.1% (95% CI, 0%–0.5%) of 5- to 12-year-olds in Lithuania.³¹ The reported prevalence of mollusk (oyster) allergy was 1.5% (95% CI, 0.9%–2.4%) in 5- to 17-year-olds in France⁶¹; for octopus allergy, it was 0.4% (95% CI, 0.1%–1.1%) of 22-year-olds in Denmark⁴⁹; and for octopus and squid allergy combined, it was 0.5% (95% CI, 0.1%–1.5%) of those 39 years and older in Portugal.²² In Africa, the 1 study identified was from Ghana,⁴² which reported a shrimp allergy prevalence in 5- to 16-year-old children of 0.1% (95% CI not reported). In the Americas, 1 study,⁶⁵ performed in the United States, specifically asked about crustacean allergy, finding that for adults the reported prevalence was 0.7% (95% CI, 0.5%–1.0%). The remaining studies report on shellfish allergy collectively. The highest reported prevalence seen in adults was 9.0% (95% CI, 6.7%–11.9%),²⁴ and the lowest was 1.69% (95% CI, 1.39%–1.98%).¹³ The

highest reported shellfish allergy in children was 2.0% (95% CI, 1.7%–2.5%),²⁵ and the lowest was 0.06% (95% CI, 0.01%–0.10%).¹³ In Southeast Asia, the highest reported crustacean allergy was 3.1% (95% CI, 1.8%–5.3%) of 3- to 7-year-olds (shrimp),³⁵ and the lowest was 0.7% (95% CI, 0.2%–2.1%) of 3- to 7-year-olds (crab).³⁵ With regard to mollusk allergy, the reported prevalence was 0.2% (95% CI, 0%–1.4%) for 3- to 7-year-olds,³⁵ and for shellfish, it was 0.5% (95% CI, 0.1%–1.5%) of 6-month to 6-year-olds.⁵⁷ In the Western Pacific region, 1 study⁶⁸ reported clinician-diagnosed prevalence for adults in Taiwan, with shrimp allergy affecting 3.3% (95% CI, 3.0%–3.6%), crab allergy affecting 2.3% (95% CI, 2.0%–2.5%), and mollusk allergy affecting 1.5% (95% CI, 1.3%–1.7%). Crustacean allergy in children was reported as high as 4% (95% CI, 3.7%–4.4%) for shrimp allergy and low as 0.4% (95% CI, 0.1%–1.2%) for crab allergy.⁶⁸ Mollusk allergy in children was

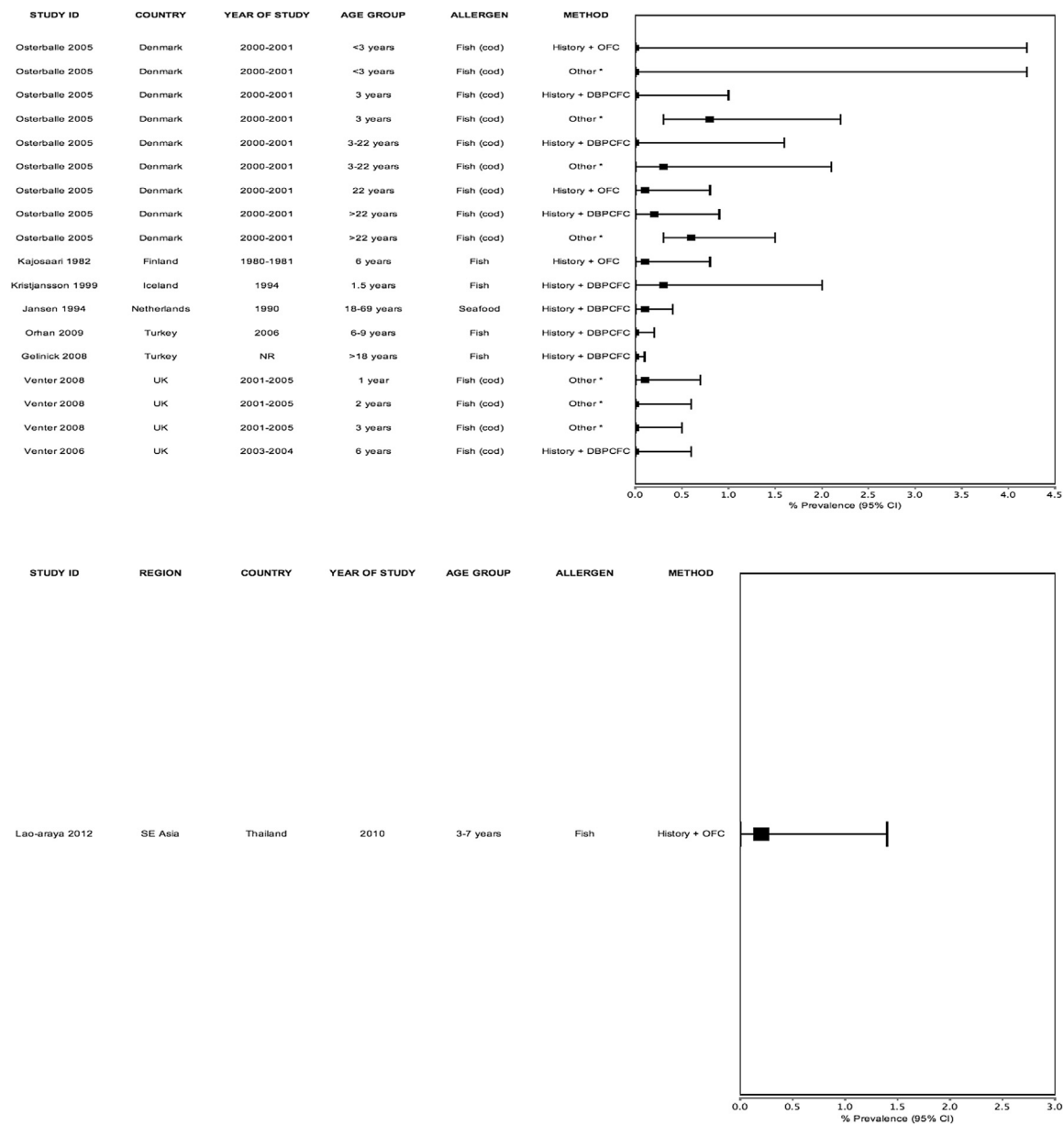


Figure 2. Fish allergy prevalence in Europe (top) and other regions of the world (bottom) diagnosed by food-challenge methods.

reported as high as 1.1% (95% CI, 1.0%–1.3%) in 4- to 18-year-olds and as low as 0.1% (95% CI, 0%–0.8%) in those younger than 3 years (eFig 3 and eFig 4).⁶⁸

Assessed using sensitization

In Europe, for crustacean allergy, the highest sensitization rate was reported in Italy in adults (10.3%; 95% CI, 7.0%–14.9%) and the lowest in Switzerland (0%; 95% CI, 0%–2.3%).¹⁶ In the Americas region, the highest sensitization rates were 6.1% (95% CI not reported) in 6- to 19-year-olds³⁷ and 6.7% (95% CI not reported) in 40- to 59-year-olds,³⁷ and the lowest were 5.2% (95% CI not reported) of those younger than 18 years¹⁴ and 0% (95% CI, 0%–5.3%) of those 20 to 44 year old.¹⁶ In the Western Pacific region, adult shrimp sensitization was reported to be 2.3% (95% CI, 0.8%–5.5%) in Australia,¹⁶ and in children, the latest data from China indicated a prevalence of 0.3% (95% CI, 0%–1.7%) (Fig 3).²⁷

Assessed using clinical history and sensitization

In Europe, when a clinical history was combined with a positive SPT result, a prevalence rate of 0.2% (95% CI, 0.1%–0.5%) was found for crab allergy and 0.0% (95% CI, 0%–0.2%) for mussel allergy in all ages in Germany.⁴⁵ In the Southeast Asia region, the sensitization rate (including a clinical history) for both shrimp and shellfish was 0.3% (Fig 3).⁵⁷

Assessed using food challenges

Two studies in Europe (Denmark) used food challenges to confirm the prevalence of shellfish allergy. Open food challenges were conducted by both studies and found a shrimp allergy confirmed prevalence rate of 0% (95% CI, 0%–4.2%) for those younger the 3 years and 0.2% (95% CI, 0%–1.0%) for 22-year-olds⁴⁸ and an octopus allergy confirmed prevalence rate of 0.1% (95% CI, 0%–0.8%) for 22-year-olds.⁴⁹ One study performed double-blind, placebo-controlled food challenges to shrimp, which revealed a confirmed prevalence of 0% (95% CI, 0%–1.0%) in 3-year-olds and

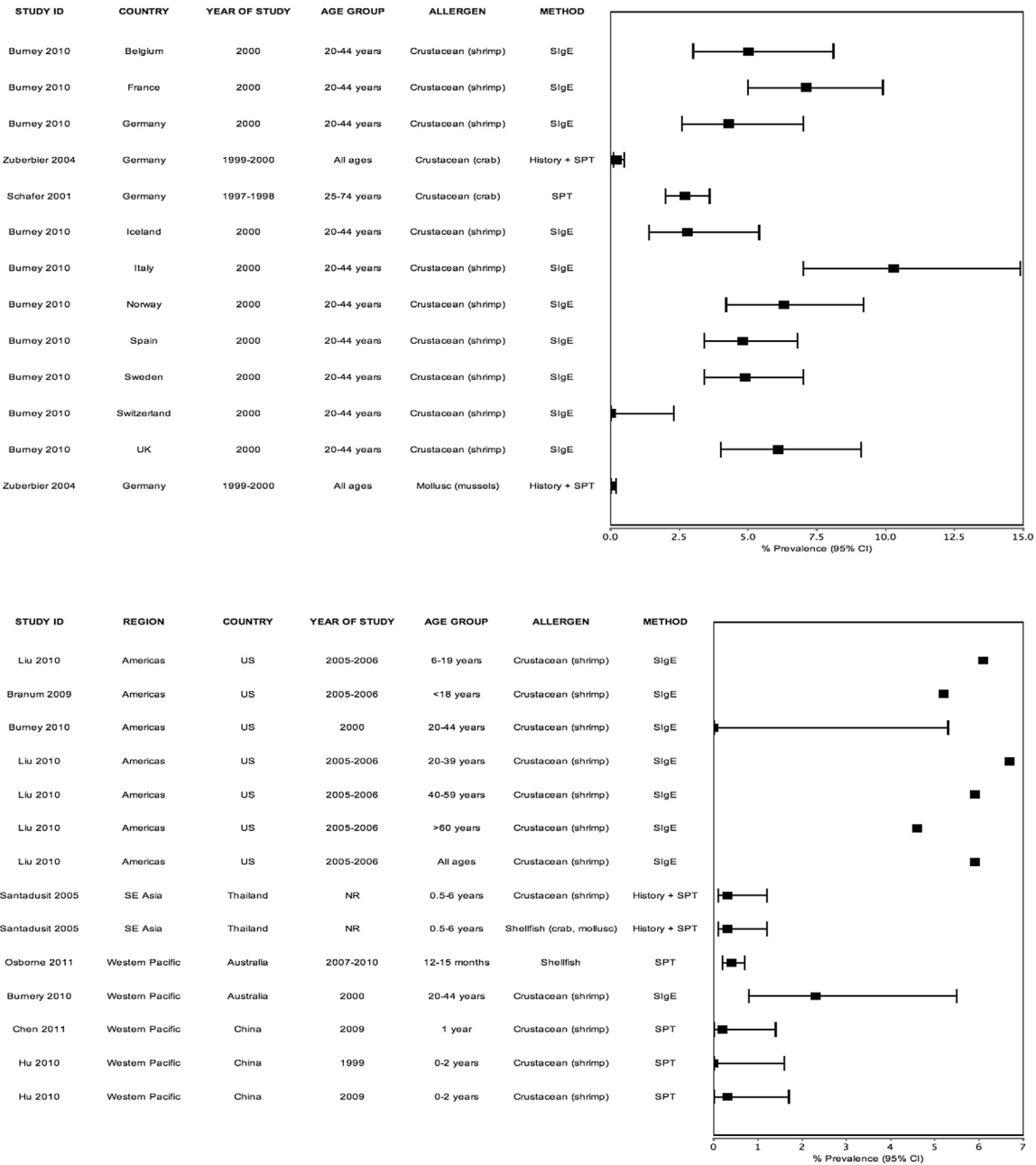


Figure 3. Shellfish allergy prevalence in Europe (top) and other regions of the world (bottom) diagnosed by sensitization methods.

0.3% (95% CI, 0.1%–1.0%) in adults.⁴⁸ In Southeast Asia, challenge-proven prevalence ranged from 0.3% (95% CI, 0.1%–1.2%)⁵⁷ to 0.9% (95% CI, 0.3%–2.4%)³⁵ for shrimp allergy and 0.2% (95% CI, 0%–1.4%)³⁵ for crab allergy (Fig 4).

Discussion

To summarize, in this article, we report that with regard to fish allergy the reported prevalence assessed by questionnaire-based methods ranged from 0.0% to 7.0%, sensitization rates identified in this review ranged from 0.0% to 2.9%, and food challenge-confirmed prevalence rates were 0.0% to 0.3%. For shellfish allergy, the reported prevalence assessed by questionnaire-based methods was 0.1% to 5.5% for crustacean allergy, 0.4% to 1.5% for mollusc, and 0.1% to 1.5% for shellfish allergy. Sensitization rates ranged from 0% to 10.3% for crustacean and 0% for mollusc, and

food challenges confirmed a 0% to 0.9% prevalence of crustacean allergy and 0.1% prevalence of mollusk allergy.

The current National Institute of Allergy and Infectious Diseases guidelines refer largely to a previous review by Rona and colleagues,⁸ which was based on studies from Europe. However, we found a higher range of reported fish allergy prevalence compared with this previous review,⁸ which found that the variation in reported prevalence of fish allergy ranged from 0% to 2%. This finding is attributable to our inclusion of more recent studies and those from outside Europe.^{30,34,40,41,52,61,69} In addition, Rona et al⁸ report a higher range of self-reported shellfish allergy (0%–10%) because of their inclusion of a study that did not meet the inclusion criteria for this review. The current European Academy of Allergy and Clinical Immunology guidelines refer to a review by Nwaru and colleagues,⁹ which reports the following positive findings based on a meta-analysis: 0.6% self-report, 0.6% SPT, 0.7% specific IgE, and

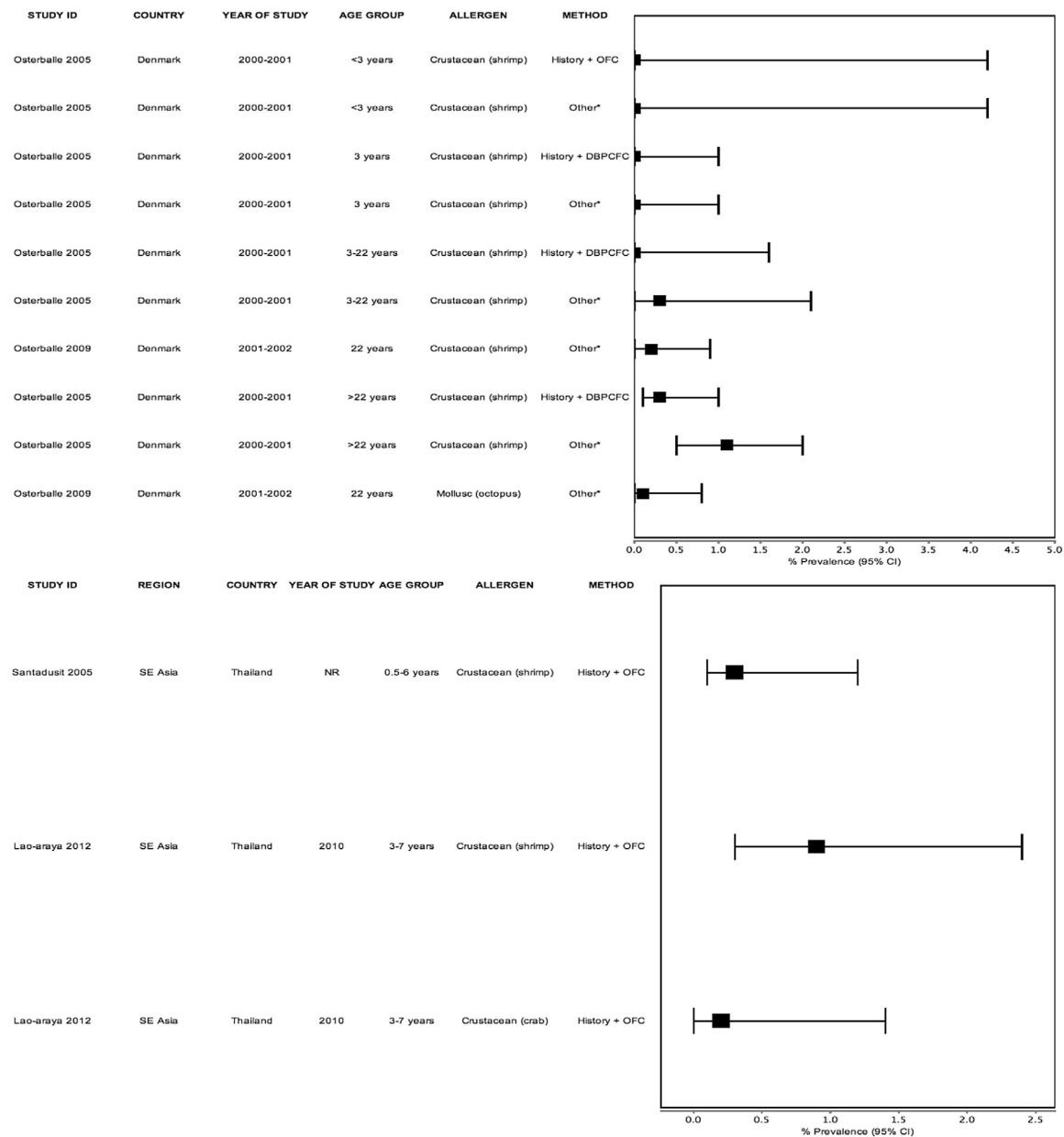


Figure 4. Shellfish allergy prevalence in Europe (top) and other regions of the world (bottom) diagnosed by food-challenge methods.

0.1% food challenge or history for fish allergy. Self-reported and SPT prevalence rates were higher in younger people, whereas for other methods of diagnosis the prevalence was higher in older people. In addition, the prevalence of shellfish allergy as reported by Nwaru et al was 0.7% for self-report data and 0.1% based on food challenges, and rates were found to be higher in older than younger people. It is difficult to compare the results because the current study did not perform meta-analysis because of the high heterogeneity. The current review is, however, more comprehensive because it includes studies from Europe and other regions of the world (including those from America).

There was a significant paucity in food challenge data worldwide, which makes comparisons between children and adults and different regions of the world challenging. The limited data available suggest that fish allergy prevalence is similar worldwide; however, shellfish allergy prevalence is higher in the Southeast Asia region, perhaps because of the high consumption of shellfish in the local diet. Few studies investigated mollusk allergy, with most

failing to distinguish between crustacean and mollusk allergy; further studies are needed to measure the prevalence of this allergy.

A strength of the current review is the rigorous search strategy used to identify potential studies for inclusion. In addition, experts within the field of food allergy epidemiology were contacted to ensure thoroughness of literature searches and in the extraction and interpretation of the data. In most cases, we were able to present the raw data from the studies and calculate the prevalence and 95% CIs to avoid misreporting. Nonetheless, there are some limitations to the current review. We are aware that some potentially eligible studies were excluded because of the lack of clarity of the results, and despite every effort being made to contact the study authors for clarity, not all authors responded to our request, and thus the studies had to be excluded from the review.

The current study provides comprehensive and up-to-date estimates of fish and shellfish allergy across age groups and regions of the world. There is some evidence to suggest that the

prevalence of fish and shellfish allergy varies according to age and region. The wide variation of prevalence found among studies and regions may be attributable to differing availability and dietary and cultural practices, and it is still unclear to what effect the age of introduction or the consumption of raw fish (ie, sushi) has on the development of clinical allergy. However, there is a marked scarcity of high-quality prevalence studies for fish and shellfish allergy; only 10 were included in the present review. Future research should use more rigorous diagnostic methods and be conducted across all regions of the world in both children and adults.

Acknowledgment

We thank Ruth Wills for her considerable assistance with many aspects of this study.

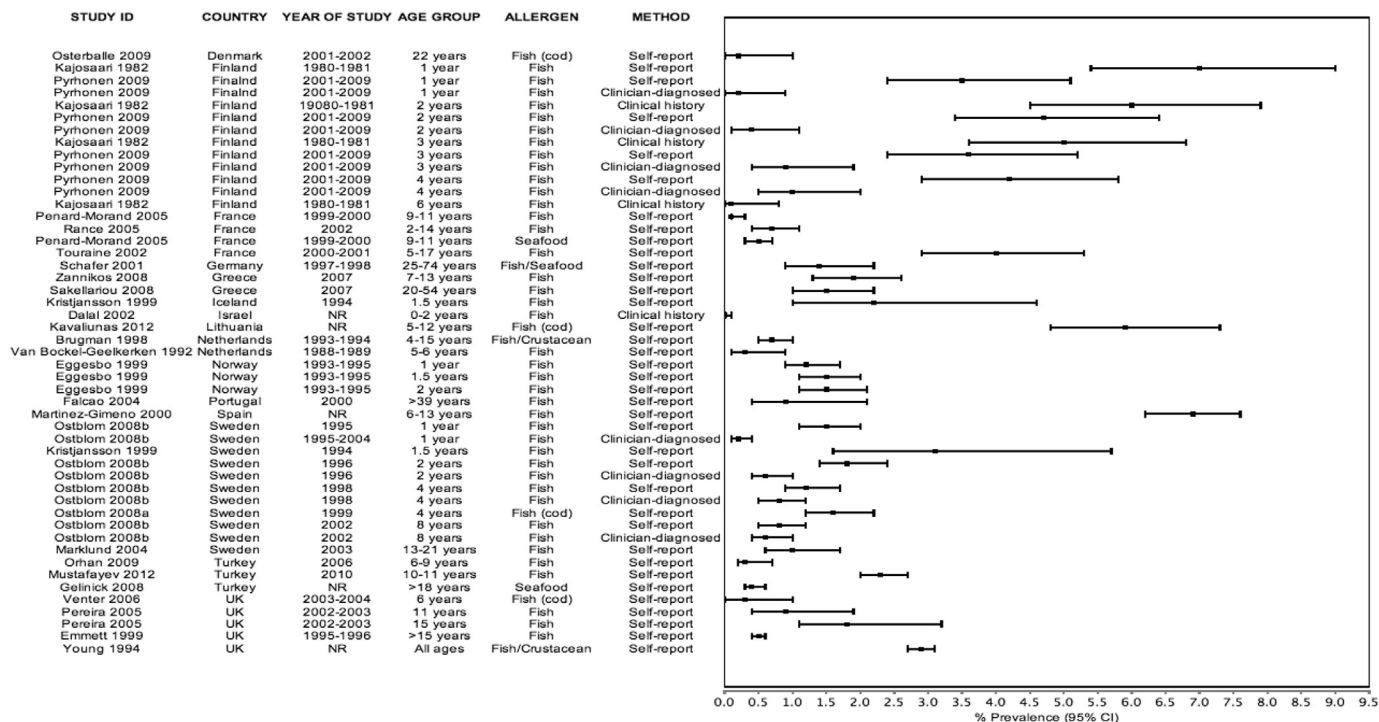
Supplementary Data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.anai.2016.07.015>.

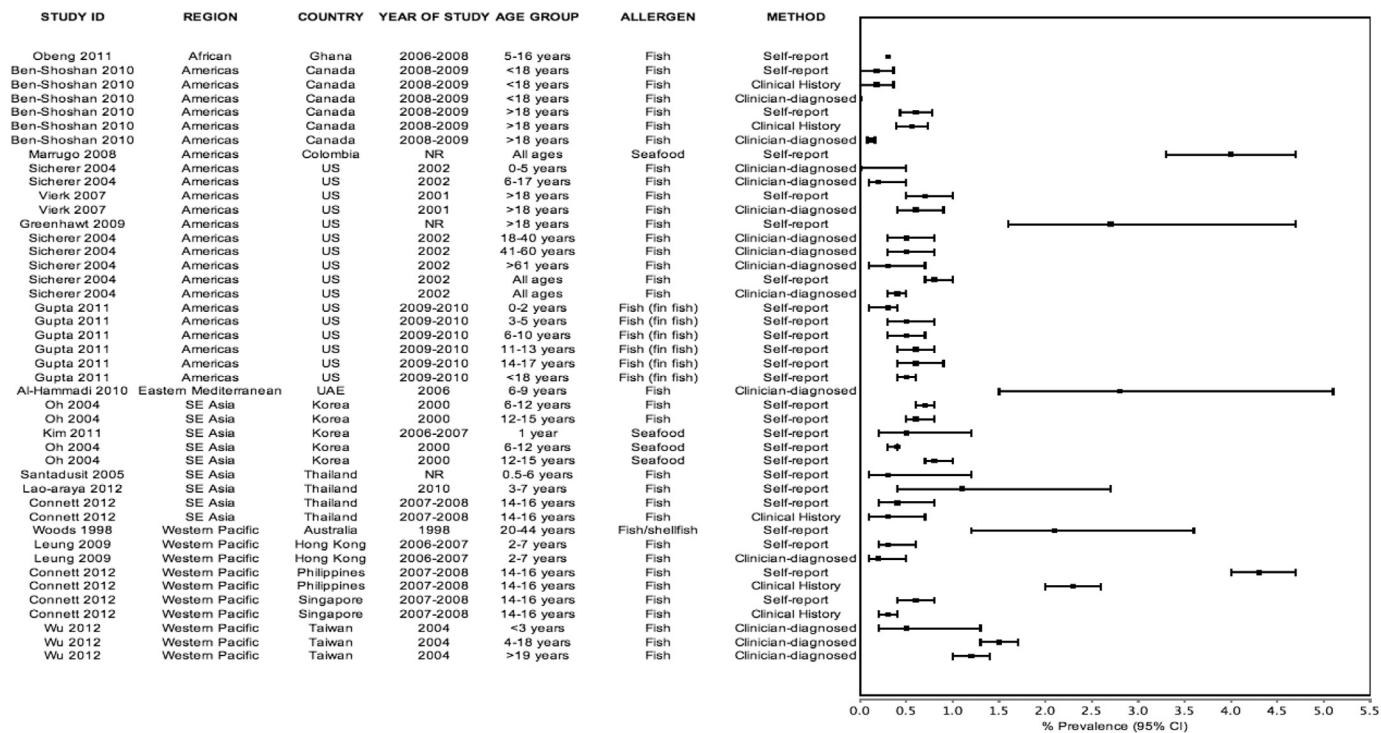
References

- [1] Sampson HA. Anaphylaxis and emergency treatment. *Pediatrics*. 2003;111:1601–1608.
- [2] Skypala I, Venter C. *Food Hypersensitivity: Diagnosing and Managing Food Allergies and Intolerance*. Hoboken, NJ: Wiley-Blackwell; 2009.
- [3] Lopata AL, Jeebhay MF. Airborne seafood allergens as a cause of occupational allergy and asthma. *Curr Allergy Asthma Rep*. 2013;13:288–297.
- [4] Lopata AL, Lehrer SB. New insights into seafood allergy. *Curr Opin Allergy Clin Immunol*. 2009;9:270–277.
- [5] Ng IE, Turner PJ, Kemp AS, Campbell DE. Parental perceptions and dietary adherence in children with seafood allergy. *Pediatr Allergy Immunol*. 2011;22:720–728.
- [6] Johansson SGO, Bieber T, Dahl R, et al. Revised nomenclature for allergy for global use: report of the Nomenclature Review Committee of the World Allergy Organization, October 2003. *J Allergy Clin Immunol*. 2004;113:832–836.
- [7] Zuidmeer L, Goldhahn K, Rona RJ, et al. The prevalence of plant food allergies: a systematic review. *J Allergy Clin Immunol*. 2008;121:1210–1218.e4.
- [8] Rona RJ, Keil T, Summers C, et al. The prevalence of food allergy: a meta-analysis. *J Allergy Clin Immunol*. 2007;120:638–646.
- [9] Nwaru BI, Hickstein L, Panesar SS, Roberts G, Muraro A, Sheikh A. Prevalence of common food allergies in Europe: a systematic review and meta-analysis. *Allergy*. 2014;69:992–1007.
- [10] Muraro A, Werfel T, Hoffmann-Sommergruber K, et al. EAACI Food Allergy and Anaphylaxis Guidelines: diagnosis and management of food allergy. *Allergy*. 2014;69:1008–1025.
- [11] Al-Hammadi S, Al-Maskari F, Bernsen R. Prevalence of food allergy among children in Al-Ain city, United Arab Emirates. *Int Arch Allergy Immunol*. 2010;151:336–342.
- [12] Arshad SH, Tariq SM, Matthews S, Hakim E. Sensitization to common allergens and its association with allergic disorders at age 4 years: a whole population birth cohort study. *Pediatrics*. 2001;108:E33.
- [13] Ben-Shoshan M, Harrington DW, Soller L, et al. A population-based study on peanut, tree nut, fish, shellfish, and sesame allergy prevalence in Canada. *J Allergy Clin Immunol*. 2010;125:1327–1335.
- [14] Branum AM, Lukacs SL. Food allergy among children in the United States. *Pediatrics*. 2009;124:1549–1555.
- [15] Brugman E, Meulmeester JF, Spee-van der W, Beuker RJ, Radder JJ, Verloove-Vanhorick S. Prevalence of self-reported food hypersensitivity among school children in The Netherlands. *Eur J Clin Nutr*. 1998;52:577–581.
- [16] Burney P, Summers C, Chinn S, Hooper R, van R, Lidholm J. Prevalence and distribution of sensitization to foods in the European Community Respiratory Health Survey: a EuroPrevall analysis. *Allergy*. 2010;65:1182–1188.
- [17] Chen J, Hu Y, Allen KJ, Ho MH, Li H. The prevalence of food allergy in infants in Chongqing, China. *Pediatr Allergy Immunol*. 2011;22:356–360.
- [18] Connert GJ, Gerez I, Cabrera-Morales EA, et al. A population-based study of fish allergy in the Philippines, Singapore and Thailand. *Int Arch Allergy Immunol*. 2012;159:384–390.
- [19] Dalal I, Binson I, Reifen R, et al. Food allergy is a matter of geography after all: sesame as a major cause of severe IgE-mediated food allergic reactions among infants and young children in Israel. *Allergy*. 2002;57:362–365.
- [20] Eggesbo M, Halvorsen R, Tamsb K, Botten G. Prevalence of parentally perceived adverse reactions to food in young children. *Pediatr Allergy Immunol*. 1999;10:122–132.
- [21] Emmett SE, Angus FJ, Fry JS, Lee PN. Perceived prevalence of peanut allergy in Great Britain and its association with other atopic conditions and with peanut allergy in other household members. *Allergy*. 1999;54:380–385.
- [22] Falcao H, Lunet N, Lopes C, Barros H. Food hypersensitivity in Portuguese adults. *Eur J Clin Nutr*. 2004;58:1621–1625.
- [23] Gelincik A, Buyukozturk S, Gul H, et al. Confirmed prevalence of food allergy and non-allergic food hypersensitivity in a Mediterranean population. *Clin Exp Allergy*. 2008;38:1333–1341.
- [24] Greenhawt MJ, Singer AM, Baptist AP. Food allergy and food allergy attitudes among college students. *J Allergy Clin Immunol*. 2009;124:323–327.
- [25] Gupta RS, Springston EE, Warrier MR, et al. The prevalence, severity, and distribution of childhood food allergy in the United States. *Pediatrics*. 2011;128:e9–e17.
- [26] Haahtela T, Bjorksten F, Heiskala M, Suoniemi I. Skin prick test reactivity to common allergens in Finnish adolescents. *Allergy*. 1980;35:425–431.
- [27] Hu Y, Chen J, Li H. Comparison of food allergy prevalence among Chinese infants in Chongqing, 2009 versus 1999. *Pediatr Int*. 2010;52:820–824.
- [28] Jansen JJ, Kardinaal AF, Huijbers G, Vlieg-Boerstra BJ, Martens BP, Ockhuizen T. Prevalence of food allergy and intolerance in the adult Dutch population. *J Allergy Clin Immunol*. 1994;93:446–456.
- [29] Johansson SG, Nopp A, Florvaag E, et al. High prevalence of IgE antibodies among blood donors in Sweden and Norway. *Allergy*. 2005;60:1312–1315.
- [30] Kajosaari M. Food allergy in Finnish children aged 1 to 6 years. *Acta Paediatr Scand*. 1982;71:815–819.
- [31] Kavaliunas A, Surkiene G, Dubakiene R, et al. EuroPrevall survey on prevalence and pattern of self-reported adverse reactions to food and food allergies among primary schoolchildren in Vilnius, Lithuania. *Medicina (Kaunas)*. 2012;48:265–271.
- [32] Kim J, Chang E, Han Y, Ahn K, Lee SI. The incidence and risk factors of immediate type food allergy during the first year of life in Korean infants: a birth cohort study. *Pediatr Allergy Immunol*. 2011;22:715–719.
- [33] Krause TG, Koch A, Poulsen LK, Kristensen B, Olsen OR, Melbye M. Atopic sensitization among children in an arctic environment. *Clin Exp Allergy*. 2002;32:367–372.
- [34] Kristjansson I, Ardal B, Jonsson JS, Sigurdsson JA, Foldevi M, Bjorksten B. Adverse reactions to food and food allergy in young children in Iceland and Sweden. *Scand J Prim Health Care*. 1999;17:30–34.
- [35] Lao-araya M, Trakultivakorn M. Prevalence of food allergy among preschool children in northern Thailand. *Pediatr Int*. 2012;54:238–243.
- [36] Leung TF, Yung E, Wong YS, Lam CW, Wong GW. Parent-reported adverse food reactions in Hong Kong Chinese pre-schoolers: epidemiology, clinical spectrum and risk factors. *Pediatr Allergy Immunol*. 2009;20:339–346.
- [37] Liu AH, Jaramillo R, Sicherer SH, et al. National prevalence and risk factors for food allergy and relationship to asthma: results from the National Health and Nutrition Examination Survey 2005–2006. *J Allergy Clin Immunol*. 2010;126:798–806.e13.
- [38] Marklund B, Ahlstedt S, Nordstrom G. Health-related quality of life among adolescents with allergy-like conditions - with emphasis on food hypersensitivity. *Health Qual Life Outcomes*. 2004;2:65.
- [39] Marrugo J, Hernandez L, Villalba V. Prevalence of self-reported food allergy in Cartagena (Colombia) population. *Allergol Immunopathol (Madr)*. 2008;36:320–324.
- [40] Martínez-Gimeno A, Del Castillo P, García-Hernández G, Luna-Paredes C, García-Sánchez JA, Nogales-Espert A. 388 Prevalence of food allergy/intolerance in children: Results from a population based survey. *J Allergy Clin Immunol*. 2000;105:S130.
- [41] Mustafayev R, Civelek E, Orhan F, Yuksel H, Boz AB, Sekerel BE. Similar prevalence, different spectrum: IgE-mediated food allergy among Turkish adolescents. *Allergol Immunopathol (Madr)*. 2013;41:387–396.
- [42] Obeng BB, Amoah AS, Larbi IA, et al. Food allergy in Ghanaian schoolchildren: data on sensitization and reported food allergy. *Int Arch Allergy Immunol*. 2011;155:63–73.
- [43] Oh JW, Pyun BY, Choung JT, et al. Epidemiological change of atopic dermatitis and food allergy in school-aged children in Korea between 1995 and 2000. *J Korean Med Sci*. 2004;19:716–723.
- [44] Orhan F, Karakas T, Cakir M, Aksoy A, Baki A, Gedik Y. Prevalence of immunoglobulin E-mediated food allergy in 6–9-year-old urban schoolchildren in the eastern Black Sea region of Turkey. *Clin Exp Allergy*. 2009;39:1027–1035.
- [45] Osborne NJ, Koplin JJ, Martin PE, et al. Prevalence of challenge-proven IgE-mediated food allergy using population-based sampling and predetermined challenge criteria in infants. *J Allergy Clin Immunol*. 2011;127:668–676.e661.
- [46] Ostblom E, Wickman M, van H, Lilja G. Reported symptoms of food hypersensitivity and sensitization to common foods in 4-year-old children. *Acta Paediatr*. 2008;97:85–90.
- [47] Ostblom E, Lilja G, Pershagen G, van H, Wickman M. Phenotypes of food hypersensitivity and development of allergic diseases during the first 8 years of life. *Clin Exp Allergy*. 2008;38:1325–1332.
- [48] Osterballe M, Hansen TK, Mortz CG, Host A, Bindslev-Jensen C. The prevalence of food hypersensitivity in an unselected population of children and adults. *Pediatr Allergy Immunol*. 2005;16:567–573.
- [49] Osterballe M, Mortz CG, Hansen TK, Andersen KE, Bindslev-Jensen C. The prevalence of food hypersensitivity in young adults. *Pediatr Allergy Immunol*. 2009;20:686–692.
- [50] Penard-Morand C, Raherison C, Kopferschmitt C, et al. Prevalence of food allergy and its relationship to asthma and allergic rhinitis in schoolchildren. *Allergy*. 2005;60:1165–1171.
- [51] Pereira B, Venter C, Grundy J, Clayton B, Arshad SH, Dean T. Prevalence of sensitization to food allergens, reported adverse reaction to foods, food

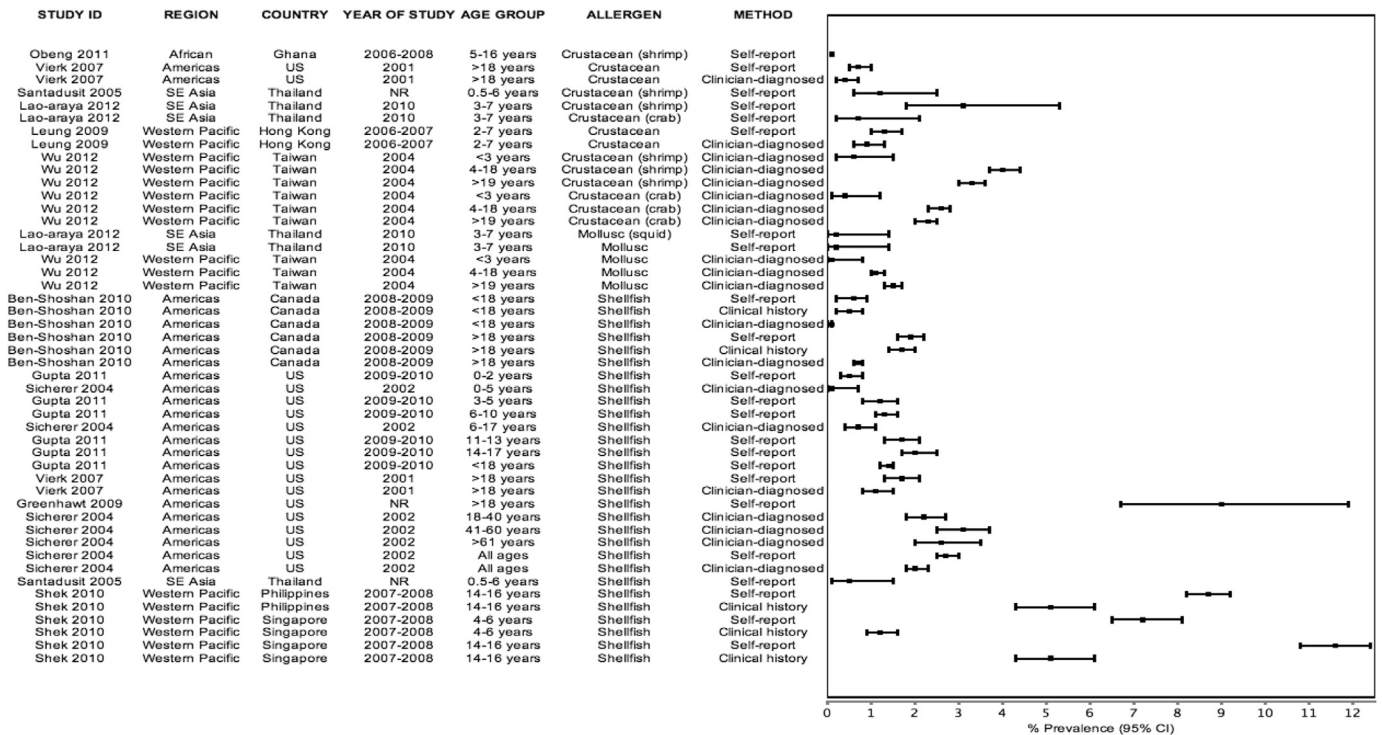
- avoidance, and food hypersensitivity among teenagers. *J Allergy Clin Immunol*. 2005;116:884–892.
- [52] Pyrhonen K, Nayha S, Kaila M, Hiltunen L, Laara E. Occurrence of parent-reported food hypersensitivities and food allergies among children aged 1–4 yr. *Pediatr Allergy Immunol*. 2009;20:328–338.
- [53] Rance F, Grandmottet X, Grandjean H. Prevalence and main characteristics of schoolchildren diagnosed with food allergies in France. *Clin Exp Allergy*. 2005;35:167–172.
- [54] Ro AD, Saunes M, Smidesang I, et al. Agreement of specific IgE and skin prick test in an unselected cohort of two-year-old children. *Eur J Pediatr*. 2012;171:479–484.
- [55] Roberts G, Peckitt C, Northstone K, et al. Relationship between aeroallergen and food allergen sensitization in childhood. *Clin Exp Allergy*. 2005;35:933–940.
- [56] Sakellariou A, Zannikos K, Tzannis K, et al. The prevalence of perceived food hypersensitivity in adults in the city of Athens. *Allergy*. 2008;63:583.
- [57] Santadusit S, Atthapaisalsarudee S, Vichyanond P. Prevalence of adverse food reactions and food allergy among Thai children. *J Med Assoc Thai*. 2005;88(suppl 8):S27–S32.
- [58] Schafer T, Bohler E, Ruhdorfer S, et al. Epidemiology of food allergy/food intolerance in adults: associations with other manifestations of atopy. *Allergy*. 2001;56:1172–1179.
- [59] Shek LP, Cabrera-Morales EA, Soh SE, et al. A population-based questionnaire survey on the prevalence of peanut, tree nut, and shellfish allergy in 2 Asian populations. *J Allergy Clin Immunol*. 2010;126:324–331e321.
- [60] Sicherer SH, Munoz-Furlong A, Sampson HA. Prevalence of seafood allergy in the United States determined by a random telephone survey. *J Allergy Clin Immunol*. 2004;114:159–165.
- [61] Touraine F, Ouzeau JF, Boullaud C, Dalmay F, Bonnaud F. Survey on the prevalence of food allergy in school children. *Rev Fr Allergol Immunol Clin*. 2002;42(8):763–768.
- [62] van BG, Meulmeester JF. [Prevalence of putative food hypersensitivity in young children]. *Ned Tijdschr Geneesk*. 1992;136:1351–1356.
- [63] Venter C, Pereira B, Grundy J, Clayton CB, Arshad SH, Dean T. Prevalence of sensitization reported and objectively assessed food hypersensitivity amongst six-year-old children: A population-based study. *Pediatr Allergy Immunol*. 2006;17:356–363.
- [64] Venter C, Pereira B, Voigt K, et al. Prevalence and cumulative incidence of food hypersensitivity in the first 3 years of life. *Allergy*. 2008;63:354–359.
- [65] Vierk KA, Koehler KM, Fein SB, Street DA. Prevalence of self-reported food allergy in American adults and use of food labels. *J Allergy Clin Immunol*. 2007;119:1504–1510.
- [66] von H, Makela MJ, Petays T, et al. Growing disparities in atopy between the Finns and the Russians: A comparison of 2 generations. *J Allergy Clin Immunol*. 2006;117:151–157.
- [67] Woods RK, Abramson M, Raven JM, Bailey M, Weiner JM, Walters EH. Reported food intolerance and respiratory symptoms in young adults. *Eur Respir J*. 1998;11:151–155.
- [68] Wu TC, Tsai TC, Huang CF, et al. Prevalence of food allergy in Taiwan: a questionnaire-based survey. *Intern Med J*. 2012;42:1310–1315.
- [69] Young E, Stoneham MD, Petrukevitch A, Barton J, Rona R. A population study of food intolerance. *Lancet*. 1994;343:1127–1130.
- [70] Zannikos K, Sakellariou A, Emmanouil E, et al. The prevalence of parentally perceived food hypersensitivity in Greek schoolchildren. *Allergy*. 2008;63:318–318.
- [71] Zuberbier T, Edenharter G, Worm M, et al. Prevalence of adverse reactions to food in Germany: a population study. *Allergy*. 2004;59:338–345.



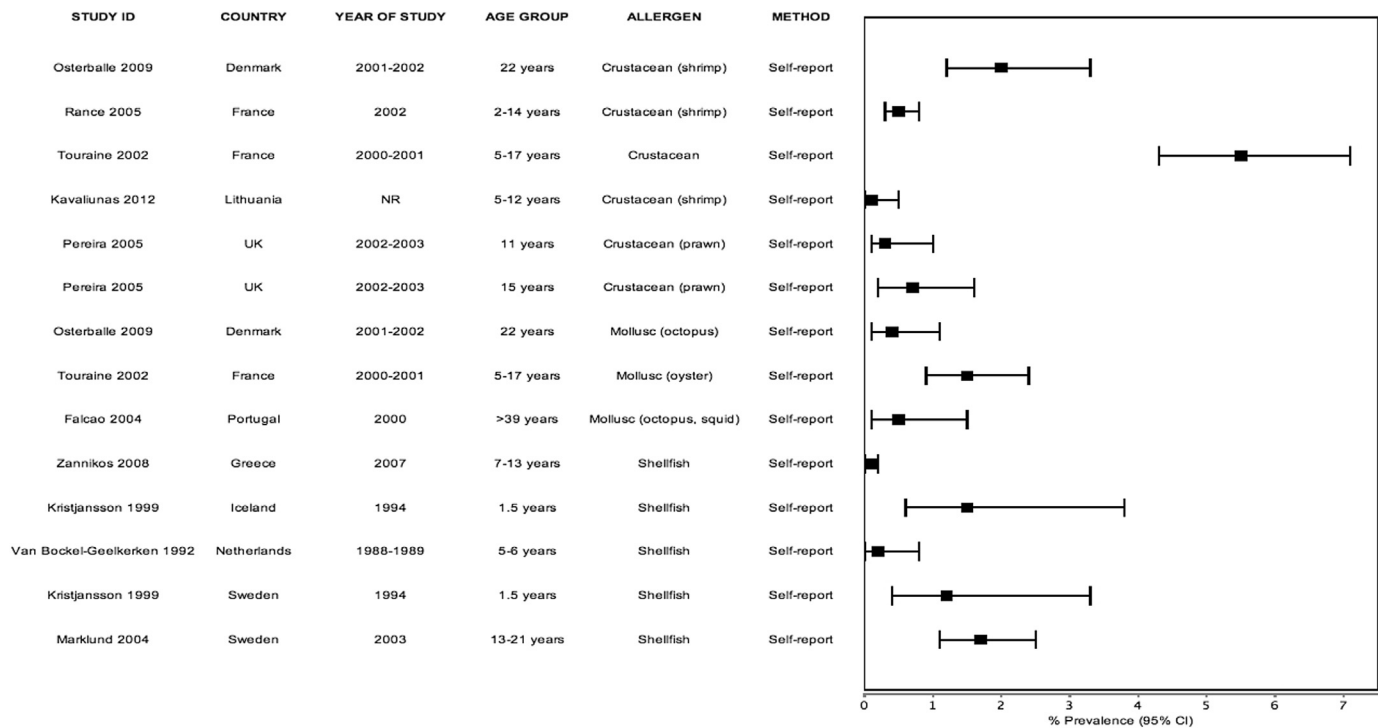
eFigure 1. Fish allergy prevalence in Europe diagnosed by questionnaire-based methods.



eFigure 2. Fish allergy prevalence in other regions of the world diagnosed by questionnaire-based methods.



eFigure 3. Shellfish allergy prevalence in other regions of the world diagnosed by questionnaire-based methods.



eFigure 4. Shellfish allergy prevalence in Europe diagnosed by questionnaire-based methods.