

# SENSITISATION TO THREE COCKROACH SPECIES IN SOUTHERN AFRICA

**AL Lopata,<sup>1</sup>** MSc, PhD (Med Science)

**MF Jeebhay,<sup>2</sup>** MB ChB, DOH, MPhil (Epi), MPH (Occ Med), PhD

**M Groenewald,<sup>3</sup>** MB ChB(Paed), DCH(SA), PGDiplntResEthics(UCT)

**A Manjra,<sup>4</sup>** MB ChB, FCPaed(SA), Dip Allergy (SA)

**G du Toit,<sup>5</sup>** MB ChB, DCH, FCP(SA), MMed, FRCP, Dip Allergy (SA)

**EN Sibanda,<sup>6</sup>** MB ChB, MSc, MD (Clinical Immunology)

**J Calvert,<sup>7</sup>** MRCP, MPH, PhD

**S Lee,<sup>5</sup>** BSc Hons

**M Schinkel,<sup>8</sup>** Med Tech

**B Fenemore,<sup>8</sup>** Med Tech

**C Motala,<sup>5</sup>** MD, DCH(SA), FCPaed(SA), FAAAAI, FAAAAI

**PC Potter,<sup>8</sup>** BSc Hons (Immunol), MD, FCP(SA), DCH(SA), FAAAAI, FAAAAI

<sup>1</sup> Division of Immunology, IIDMM/Allergy Section, Faculty of Health Sciences (NHLS), University of Cape Town, South Africa

<sup>2</sup> Occupational and Environmental Health Research Unit, School of Public Health and Family Medicine, University of Cape Town, South Africa

<sup>3</sup> Allergy Clinic, 1 Military Hospital, Pretoria, South Africa

<sup>4</sup> Westville Hospital, Durban, South Africa

<sup>5</sup> Department of Paediatrics, Allergy Clinic, Red Cross War Memorial Children's Hospital, Cape Town, South Africa

<sup>6</sup> Clinical Immunology and Allergy Clinic, Department of Immunology, University of Zimbabwe, Harare, Zimbabwe

<sup>7</sup> King's College Medical School, UK

<sup>8</sup> Allergology Unit, Groote Schuur Hospital, Cape Town, South Africa

## ABSTRACT

Cockroaches are important allergen sources in many countries, especially in the tropics. Cockroaches produce several allergens that are major risk factors for rhinitis and asthma. Worldwide, the prevalence of cockroach sensitivity varies between 30% and 70%. Geographical differences exist with regard to cockroach allergen exposure and sensitivity within countries and between countries. No data are available for Africa in this regard. Currently the diagnosis of cockroach sensitivity in southern Africa relies mainly on the detection of specific IgE to *Blattella germanica* (German cockroach), while a number of other species are found close to human dwellings. The aim of this study was to investigate the prevalence and distribution of sensitisation to three different cockroach species among subjects residing in four different geographical regions in southern Africa.

Strong IgE reactivity particular to *B. germanica* was found among subjects residing in Pretoria and Harare. By contrast strong IgE responses to other cockroach species, *Periplaneta americana* and *Blatta*

*orientalis*, were observed in subjects living in Cape Town and Durban. The levels of specific IgE antibodies to all three cockroach species appeared to be higher in Cape Town than those from the other three cities investigated. Monosensitivity to all three cockroach species was observed and minimal cross-reactivity to house-dust mite. These data show that allergy to *P. americana* and *B. orientalis* are an important diagnostic consideration in temperate and coastal regions of southern Africa, whereas sensitisation to *B. germanica* appears to predominate in regions of higher altitude such as Pretoria and Harare.

## INTRODUCTION

Cockroaches are important allergen sources in many countries, especially in the tropics. Cockroaches produce several allergens that cause sensitisation, and exposure to high levels of allergen is a major risk factor for asthma and allergic rhinitis. The clinical presentation of the asthmatic patients with cockroach allergy tends to be more severe in inner cities than in rural areas. Some patients test positive to cockroach without clear history of exposure to cockroaches. Most patients present with multiple indoor and outdoor allergies and patients are usually unaware of being allergic to cockroaches. Kang and co-workers<sup>1</sup> established the relationship between cockroach allergy and asthma by showing early-phase, late-phase and dual bronchoconstriction after inhalation of cockroach extract by sensitised asthmatic patients. These early studies have been confirmed by other groups establishing that asthma caused by cockroaches is antigen specific.<sup>2,4</sup>

Worldwide, the prevalence of cockroach sensitivity varies between 30% and 70%. Geographical differences exist with regard to cockroach allergen exposure and sensitivity within countries<sup>5</sup> (e.g. Northeast USA and northern or southern USA) and between countries (e.g. USA and Europe).<sup>6</sup> No data are available for Africa in this regard. In general, cockroach sensitivity is more prevalent in urban areas,<sup>7</sup> particularly in low socio-economic populations, e.g. inner-city African-American and Hispanic-American children in the USA.<sup>8-10</sup> Little is known about cockroach sensitisation in Africa. Previous studies from Morocco, the Ivory Coast and Nigeria reported prevalences of cockroach sensitivities of 25%,<sup>11</sup> 30.7%<sup>12</sup> and 44.6%<sup>13</sup> respectively (see Table I). In the light of the often discussed 'hygiene hypothesis', it is interesting to note that the prevalence of sensitivity to cockroach in Africa and particularly in South Africa is not any lower than studies from western countries. Two previous South African studies demonstrated cockroach sensitivity in 40% of allergic children (See Table II).<sup>14, 15</sup> A more recent study found sensitisation rates of 16% and 17% respectively in urban and rural children.<sup>16</sup> The prevalence rate in adult South Africans is similar, between 12% and 22%.<sup>17-20</sup>

The aim of this study was to investigate the prevalence and distribution of sensitisation to three different cockroach species among subjects residing in four different geographical regions in southern Africa.

Correspondence: Dr AL Lopata, Division of Immunology, IIDMM/Allergy Section, Faculty of Health Sciences (NHLS), University of Cape Town. Tel 021-406-6033, fax 021-406 6029, e-mail: alopat@uctgsh1.uct.ac.za

**Table I. Worldwide prevalence of cockroach sensitisation<sup>5,6, 11-13</sup>**

Country	Prevalence (%)	Patient selection	Allergy test
<b>America</b>			
USA, 8 inner city areas	37	Asthma, child	SPT
USA, New York	68	Asthma	ImmunoCAP
USA, Virginia	6	Epidemiological study	SPT
Brazil	31	Atopic	SPT
<b>Europe</b>			
Spain	26	Asthma/rhinitis	SPT
France	24	Respiratory sympt.	ImmunoCAP
Switzerland	6	Asthma/rhinitis	ImmunoCAP
Germany	4	General, child	ImmunoCAP
<b>Asia</b>			
Thailand	44	Asthma, child	SPT
Taiwan	36	Asthma	ImmunoCAP
Japan	16	Asthma	ImmunoCAP
<b>Africa</b>			
Morocco	25	Allergy	SPT
Ivory Coast	31	Allergy	SPT
Nigeria	45	Allergy	SPT

**Table II. Prevalence of cockroach sensitisation in South Africa**

Study	Prevalence [%]	Patient selection	Allergy test
Potter <i>et al.</i> <sup>14</sup>	40	Allergic children (n=260), Western Cape	ImmunoCAP ( <i>B. germanica</i> )
Manjra <i>et al.</i> <sup>15</sup>	41	Asthma (children) (n=40) Kwazulu-Natal	SPT (Species mixed)
Calvert <i>et al.</i> <sup>16</sup>		Epidemiological study of children	SPT ( <i>B. germanica</i> )
	16	- Inland rural (n=436) Eastern Cape	
	17	- Coastal urban (n=337) Western Cape	
Jeebhay <i>et al.</i> <sup>17-20</sup>		Epidemiological study of adult workforce Western Cape	SPT ( <i>B. germanica</i> )
	12	- Inland rural (n=190)	SPT
	11	- Inland urban (n=507)	SPT
	15	- Coastal rural (n=578)	SPT
	22	- Coastal urban (n=106)	ImmunoCAP ( <i>B. germanica</i> )
	15	- Coastal urban (n=106)	( <i>P. americana</i> )
	14	- Coastal urban (n=106)	( <i>B. orientalis</i> )

**MATERIAL AND METHODS**

The patient cohort was selected from allergic children (2-17 years of age) who had tested skin-prick-test-positive to *Blattella germanica*. Twenty children each from Cape Town (Red Cross Hospital), Durban (Durbanville Hospital) and Pretoria (Military Hospital) were analysed for specific IgE antibodies to three different cockroach species. The specific IgE response in serum samples was quantified by using the UniCAP System (Pharmacia Diagnostics AB, Uppsala, Sweden) for *Blattella germanica* (i6), *Periplaneta americana* (Ri206) and *Blatta orientalis* (Ri207), the three species shown in Figure 1. In addition 40 adult allergic patients from Harare (Zimbabwe) were analysed for cockroach-specific IgE antibodies. Cross-reactivity studies on selected subjects were performed by cockroach-ImmunoCAP (*B. germanica*)-inhibition assay with house-dust mite (HDM) extract, as previously described.<sup>21</sup>

Cape Town and Durban are located at the South African coast with moderate and warm humid climates respec-

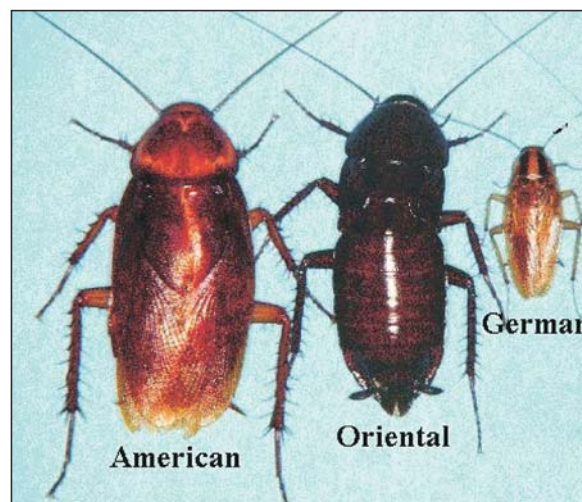


Fig. 1. Three different cockroach species, *Periplaneta americana* (American), *Blatta orientalis* (Oriental) and *Blattella germanica* (German).



Fig. 2. Map of southern Africa indicating the regions of patient recruitment.

tively. Cape Town is located in the winter-rainfall area whereas Durban has predominantly seasonal rainfalls (November to March). Pretoria and Harare are situated in the highveld at an altitude over 1 500 m above sea level. The cities can be described as dry with seasonal (November to March) rainfalls (see Figure 2 for geographical details).

**RESULTS**

In total 60 children and 40 adults were analysed for the distribution of cockroach species-specific IgE antibodies. Clinical data on the allergic diseases and severity could not be obtained from all patients analysed and were therefore omitted from this study.

Comparison of the IgE responses of patients to the three cockroach species highlighted the heterogenous responses observed in the various regions in southern Africa. In the Cape Town group the levels of specific IgE responses using the ImmunoCAP to the three species were very similar with mean values of 4.3, 3.9 and 4.1 kU/l (Fig. 3). In contrast the strongest IgE responses among Durban subjects were seen against *P. americana* and for subjects in Pretoria and Harare against *B. germanica*.

This differential IgE response is elaborated further when the strength of IgE response (quantified by ImmunoCAP) in patients with multiple cockroach sensitivity is compared. Among Cape Town subjects almost half of the patients (45%) had the strongest IgE response to *B. germanica* (Fig. 4), followed by *P. americana* (33%) and *B. orientalis* (22%). However, among subjects residing in Durban, *B. orientalis* attained the strongest IgE response in 41% of the patients, closely followed by *P. americana*. In contrast, the cockroach species *B. germanica* attained much stronger responses with 76% of subjects in Pretoria and 100% in Harare.

When the number of negative IgE responses to any of the three cockroach species was analysed, the data showed that none of the patients in Pretoria and Harare had a negative response to *B. germanica*, in contrast to 20% in Durban (data not shown). Not all patients demonstrated elevated IgE levels to all three species simultaneously. Monosensitivity among the analysed cockroach species to *B. germanica* (5/38) and *B. orientalis* (1/17) was observed in Pretoria/Harare/Cape Town and Durban (data not shown). ImmunoCAP inhibition (*B. germanica*) studies with selected patient sera demonstrated no significant cross-reactivity with HDM extract. In addition, all subjects from Cape Town, Durban and Pretoria were positive in the Phadiatop ImmunoCAP assay, indicating that they were atopic.

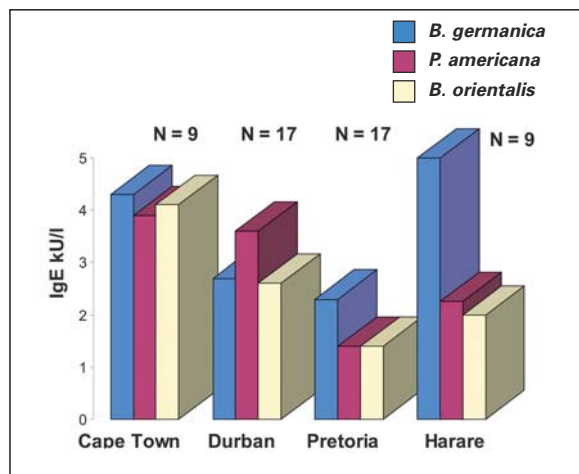


Fig. 3. Prevalence of specific IgE responses to three cockroach species in sensitised patients from four major cities in southern Africa analysed by ImmunoCAP.

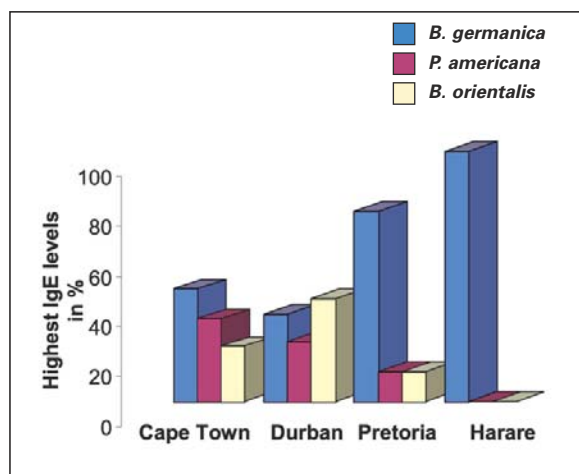


Fig. 4. Highest level of specific IgE response to a particular cockroach species among patients with multiple sensitivity in four major cities in southern Africa analysed by ImmunoCAP

**DISCUSSION**

In this study we demonstrated that IgE reactivity to *B. germanica* is common in all patients analysed from four different cities. However, it seems that the strongest response to this cockroach species was observed in cities at higher altitudes such as Pretoria and Harare. A high prevalence of sensitisation to *B. germanica* is not only seen in allergic children. A recent epidemiological study by Calvert *et al.*<sup>16</sup> on over 600 children from rural and urban areas in the Eastern and Western Cape provinces of South Africa demonstrated sensitisation prevalence of 16% and 17% respectively. This is even more evident in large-scale epidemiological studies among adult South African workers in the baking, grape farming, fishing and grain-milling industries, who demonstrated a prevalence of between 11% and 22%.<sup>17-20</sup> Interestingly the level of sensitisation to the other two cockroach species was less common in Pretoria and Harare and usually showed a much lower IgE response. This observation is most probably explained by cooler and drier winter seasons which prevent the growth of larger populations of *P. americana* and *B. orientalis*. Therefore, a much higher prevalence of sensitisation to these cockroach species was observed in areas with temperate climates, such as

**Table III. List of allergens identified to date in three well-known cockroach species of diagnostic importance**

Cockroaches	Allergen	Prevalence of IgE binding (%)	MW (kDa)	Protein function
<i>Blattella germanica</i>	Bla g 1	30-50	20-25	Unknown
	Bla g 1 (Bd90K)	77	90	Unknown
	Bla g 2	60	36	Aspartic protease
	Bla g 4	40-60	18	Lipocalin (Calycin)
	Bla g 5	70	23	Glutathione-S- transferase
	Bla g 6	~50	18	Troponin C
<i>Periplaneta americana</i>	Per a 1	50	20-25	Unknown/ in gut lumen
	Per a 3	>80	72-78	Arylphorin/ hemocyanin
	Per a 7	50	33	Tropomyosin
<i>Blatta orientalis</i>	Unknown	Unknown	14-263	Unknown

Modified from Arruda *et al.*<sup>35</sup>

Cape Town and Durban. This occurs in the context of multiple sensitivity to different cockroach species which is accompanied by a stronger IgE response.

A range of species-specific allergens have been described which probably result in these strong IgE responses observed. Sensitisation to the American cockroach (*P. americana*) has also been reported from warm and temperate regions such as New Orleans (USA)<sup>22</sup> and Taiwan.<sup>23</sup> Sensitisation rates of this species have been reported from Brazil in over 50% of asthmatic children.<sup>24</sup> A recent study from Italy comparing the IgE reactivity to three different cockroach species showed that only a few subjects demonstrated monosensitivity to one or other species.<sup>25</sup> In contrast, a study from New Orleans demonstrated monosensitivity to *P. americana* or *B. germanica* in 17 out of 38 subjects (40%).<sup>22</sup> Furthermore, in Taiwan 6 of 44 cockroach-positive subjects had specific IgE only to *P. americana*.<sup>23</sup>

A recent epidemiological study among adults in a grain mill by Jeebhay *et al.*<sup>20</sup> confirmed sensitisation to all three cockroach species in Cape Town. Sensitivity to the cockroach *P. americana* was 15% among the 106 workers, followed by 14% for *B. orientalis*.

Cockroach sensitivity is increasingly, but not exclusively, found in patients positive to other indoor allergens such as HDM in South Africa. There is an increasing body of evidence that cross-reactivity occurs among members of the class Arthropoda (see article by Auerwald and Lopata<sup>26</sup> in this issue), particularly insects, crustaceans and arachnids (such as HDM).<sup>21,27,28</sup> However, ImmunoCAP inhibition studies conducted on selected patients in our study demonstrated that minimal cross-reactivity was observed to HDM allergens. Furthermore, in our study the existence of monosensitised subjects to *B. germanica* and *B. orientalis* supports the view that the IgE response is species-specific and not based on cross-reactivity to cockroach or HDM allergens. Monosensitivity has previously been shown by Lehrer *et al.*<sup>29</sup> in 40% of the subjects in his study.

Of the over 3 500 known species of cockroaches, only a few commonly inhabit homes. Predominant species are the German (*B. germanica*), American (*P. americana*) and Oriental cockroach (*B. orientalis*), investigated in our study. They are quite similar in appearance, but can readily be distinguished by size and colour (Fig. 1).

Cockroach allergens are derived from several sources, such as saliva, faecal material, secretions, cast skins, debris and dead bodies.<sup>30,31</sup> Several allergens from two common cockroach species, *B. germanica* and *P. americana* have been purified and sequenced (see Table III)

and a few have even been produced as recombinant proteins.<sup>32-35</sup> Most cockroach allergens appear to be species-specific. The only cross-reactive allergens sequenced to date from both species are the Group 1 allergens Bla g1 and Per a1.<sup>32-34</sup> Bla g1 has an unusual structure, consisting of a series of up to 14 tandem repeats, each approximately 100 amino acids in length. Therefore Bla g1 shows up to 70% sequence identity to Per a1. Bla g4 belongs to the protein super family of ligand-binding proteins, also called lipocalins.<sup>35,36</sup> This family includes other important vertebrate allergens, such as mouse/rat, dog, cow and horse allergens and even  $\beta$ -lactoglobulin from cow's milk. Per a7 has only recently been identified and shows a high degree of sequence identity to tropomyosin from other invertebrates, particularly mites and shrimps. Therefore it is possible that this allergen might be the basis for cross-reactivity observed among various insects and crustaceans and therefore of clinical importance.

Sensitisation to cockroach is dependent on the exposure to cockroach allergens. Even without visible cockroach infestation, allergens can be found in a large proportion (50%) of homes, schools and workplaces.<sup>37</sup> A clear demonstration of high levels of cockroach allergen exposure as a risk factor for asthma provided the basis for exposure threshold limit values of 2 U/g dust and 8 U/g. These levels have recently been questioned. A large epidemiological study in Boston demonstrated sensitivity to cockroach in subjects as young as 3 months old and monosensitivity to cockroaches was found in 14% of children under the age of 4 years.<sup>38</sup> Furthermore, there was a striking correlation between very low levels of cockroach allergens of 0.05 U/g and repeated wheezing. Strategies for decreasing environmental exposure to cockroach allergen have recently been investigated. The results suggest that a sustained decrease in cockroach allergen levels is difficult to accomplish, even after successful extermination of cockroach populations.<sup>37</sup> Allergen exposure is frequently ignored or underestimated. Cockroach allergens are not only found in the dust. Up to 80% of aeroallergens are associated with particles larger than 10 nm, in the same category as HDM allergens and pollen grains. These large particles usually settle soon after disturbance. However, a study by Tovy *et al.*<sup>39</sup> in Australia demonstrated clearly that Bla g1 carrying particles could be detected during quiet domestic activity or even during the night. The researchers developed a novel technology by using intranasal air samplers, which demonstrated large amounts of allergens on amorphous and irregular particles.

Enzyme-linked immuno-assays (ELISA) have been developed for assessing allergen exposure by quantifying the levels of Bla g 1, Bla g 2, Per a 1 and Per a 3. The primary site of allergen accumulation is the kitchen; however, somewhat lower levels can also be found in dust samples from sofas and even bedding. Studies showed that approximately 20-50% of homes, without visible cockroaches, contained detectable allergen levels. But high allergen levels have been detected not only in homes, but also in schools, nurseries and at the workplace.<sup>40</sup>

In conclusion, cockroach sensitivity in southern Africa is as prevalent as reported in studies from Europe, USA and Asia. Our data show that allergy to *P. americana* and *B. orientalis* are an important diagnostic consideration in temperate and coastal regions of southern Africa, whereas sensitisation to *B. germanica* appears to predominate in regions at higher altitudes like Pretoria and Harare. Cockroach-induced asthma is an important public health problem. Patient education, improvements in living and working conditions, diagnosis and reduction in environmental exposure are important approaches to reduce the prevalence of cockroach sensitisation.

## ACKNOWLEDGMENTS

The authors wish to thank the Medical Research Council (MRC) of South Africa and the Allergy Society of South Africa (ALLSA-UCB Research Fund) for financial support.

## REFERENCES

- Kang BC, Wu CW, Johnson J. Characteristics and diagnoses of cockroach-sensitive bronchial asthma. *Ann Allergy* 1992; **68**: 237-244.
- Platts-Mills TA, Rakes G, Heymann PW. The relevance of allergen exposure to the development of asthma in childhood. *J Allergy Clin Immunol* 2000; **105**: S503-508.
- El-Sharif N, Abdeen Z, Barghuthy F, Nemery B. Familial and environmental determinants for wheezing and asthma in a case-control study of school children in Palestine. *Clin Exp Allergy* 2003; **33**: 176-186.
- Contreras JP, Ly NR, Gold DR, et al. Allergen-induced cytokine production, atopic disease, IgE, and wheeze in children. *J Allergy Clin Immunol* 2003; **112**: 1072-1077.
- Hirsch T. Indoor allergen exposure in west and East Germany: a cause for different prevalences of asthma and atopy? *Rev Environ Health* 1999; **14**: 159-68.
- Peruzzi M, de Luca M, Novembre E, de Martino M, Vierucci A. Incidence of cockroach allergy in atopic Italian children. *Ann Allergy Asthma Immunol* 1999; **83**: 167-171.
- Shapiro GG, Stout JW. Childhood asthma in the United States: urban issues. *Pediatr Pulmonol* 2002; **33**: 47-55.
- Kitch BT, Chew G, Burge HA, et al. Socioeconomic predictors of high allergen levels in homes in the greater Boston area. *Environ Health Perspect* 2000; **108**: 301-307.
- Stevenson LA, Gergen PJ, Hoover DR, Rosenstreich D, Mannino DM, Matte TD. Sociodemographic correlates of indoor allergen sensitivity among United States children. *J Allergy Clin Immunol* 2001; **108**: 747-752.
- Lester LA, Rich SS, Blumenthal MN, et al. Ethnic differences in asthma and associated phenotypes: Collaborative Study on the Genetics of Asthma. *J Allergy Clin Immunol* 2001; **108**: 357-362.
- Alaoui-Yazidi A, Bartal M, Fihry MTE, Laraqui C. Profile of respiratory and dermatologic allergies in health care personnel in Morocco. *Revue Francaise D Allergologie Et D Immunologie Clinique* 2003; **43**: 377-384.
- Ngom AS, Koffi N, Blessey M, Aka-Danguy E. Prevalence of allergy to cockroaches in the African intertropical zone. Review of the literature. *Allerg Immunol (Paris)* 1999; **31**: 351-356.
- Adanijo AO, Bandele EO. Cockroach hypersensitivity in asthmatics in Lagos, Nigeria. *East Afr Med J* 2000; **77**: 622-666.
- Potter PC, Lee S, Roodt L. Cockroach allergy in South Africa; Coastal versus inland. *Current Allergy & Clinical Immunology* 1998; **16**: 7.
- Manjra A, Prescott R, Potter PC. Cockroach allergy in Durban. *Current Allergy & Clinical Immunology* 1995; **8**: 3-7.
- Calvert JM. Asthma and atopy in urban and rural Xhosa school children. London: King's College School of Medicine & Dentistry, 2004.
- Jeebhay MF, Baatjies R, Lopata AL. Occupational allergy among table grape farm workers in South Africa. *Current Allergy & Clinical Immunology* 2002; **15**(4): 174-177.
- Jeebhay MF, Baatjies R, Lopata AL, Barnard V, Bateman E, Robins TG. Baker's asthma in small bakeries of a supermarket chainstore in the Western Cape (abstract). *SA Respiratory Journal* 2004; **10**(2).
- Jeebhay MF. Occupational allergy associated with saltwater bony fish processing in South Africa. In Dissertation Abstracts International (Publication no. 3106356), Proquest Information and Learning. Michigan: University of Michigan, 2003.
- Jeebhay MF, Baatjies R, Lopata AL. Work-related respiratory allergy associated with sensitisation to storage pests and mites among grain mill workers. *Current Allergy & Clinical Immunology* 2005; **18**: 72-76.
- Lopata AL, Fenemore B, Jeebhay MF, Gade G, Potter PC. Occupational allergy in laboratory workers caused by the African migratory grasshopper *Locusta migratoria*. *Allergy* 2005; **60**: 200-205.
- Lehrer SB, Horner WE, Menon PK, Oliver J, Hauck P. Cockroach allergenic activity: analysis of commercial cockroach and dust extracts. *J Allergy Clin Immunol* 1991; **88**: 895-901.
- Tsai JJ, Kao MH, Wu CH. Hypersensitivity of bronchial asthmatics to cockroach in Taiwan. comparative study between American and German cockroaches. *Int Arch Allergy Immunol* 1998; **117**: 180-186.
- Santos ABR, Chapman MD, Aalberse RC, et al. Cockroach allergens and asthma in Brazil: Identification of tropomyosin as a major allergen with potential cross-reactivity with mite and shrimp allergens. *J Allergy Clin Immunol* 1999; **104**: 329-337.
- Yman L, Holmquist I, Paganelli R. Cockroach-specific IgE antibodies in allergy. *Revue Francaise D Allergologie Et D Immunologie Clinique* 1998; **38**: 851-858.
- Auerswald L, Lopata AL. Insects – diversity and allergy. *Current Allergy & Clinical Immunology* 2005; **18**: 58-60.
- Leung PSC, Chow WK, Duffey S, Kwan HS, Gershwin ME, Chu KH. IgE reactivity against a cross-reactive allergen in crustacea and mollusca: Evidence for tropomyosin as the common allergen. *J Allergy Clin Immunol* 1996; **98**: 954-961.
- Witteaman AM, van den Oudenrijn S, van Leeuwen J, Akkerdaas J, van der Zee JS, Aalberse RC. IgE antibodies reactive with silverfish, cockroach and chironomid are frequently found in mite-positive allergic patients. *Int Arch Allergy Immunol* 1995; **108**: 165-169.
- Escobar MA, Lehrer SB, Mccants ML, Wolfe MA, Reyes M, Oneil CE. Comparison of prevalences of cockroach sensitivity in subjects from Cali, Columbia and New Orleans, La. *J Allergy Clin Immunol* 1992; **89**: 314.
- Menon P, Menon V, Hilman B, Stankus R, Lehrer SB. Skin-test reactivity to whole-body and fecal extracts of American (*Periplaneta americana*) and German (*Blattella-germanica*) cockroaches in atopic asthmatics. *Ann Allergy* 1991; **67**: 573-577.
- Arruda LK, Vailes LD, Ferriani VPL, Santos BR, Pomes A, Chapman MD. Cockroach allergens and asthma. *J Allergy Clinical Immunol* 2001; **107**: 419-428.
- Pomes A, Vailes LD, Helm RM, Chapman MD. IgE reactivity of tandem repeats derived from cockroach allergen, Bla g 1. *Eur J Biochem* 2002; **269**: 3086-3092.
- Wu CH, Lee MF, Yang JS, Tseng CY. IgE-binding epitopes of the American cockroach Per a 1 allergen. *Mol Immunol* 2002; **39**: 459-464.
- Jeong KY, Lee J, Lee IY, Ree HI, Hong CS, Yong TS. Allergenicity of recombinant Bla g 7, German cockroach tropomyosin. *Allergy* 2003; **58**: 1059-1063.
- Arruda LK, Ferriani VPL, Arruda JM, et al. Use of recombinant allergens to investigate cockroach allergy in patients with asthma and/or rhinitis. *J Allergy Clin Immunol* 1998; **101**: S29-S.
- Mantjarvi R, Rautiainen J, Virtanen T. Lipocalins as allergens. *Biochim Biophys Acta* 2000; **1482**: 308-317.
- Carter MC, Perzanowski MS, Raymond A, Platts-Mills TAE. Home intervention in the treatment of asthma among inner-city children. *J Allergy Clin Immunol* 2001; **108**: 732-737.
- Gold DR, Burge HA, Carey V, Milton DK, Platts-Mills T, Weiss ST. Predictors of repeated wheeze in the first year of life: the relative roles of cockroach, birth weight, acute lower respiratory illness, and maternal smoking. *Am J Respir Crit Care Med* 1999; **160**: 227-236.
- De Lucca SD, Taylor DJM, O'Meara TJ, Jones AS, Tovey ER. Measurement and characterization of cockroach allergens detected during normal domestic activity. *J Allergy Clin Immunol* 1999; **104**: 672-680.
- Sporik R, Squillace SP, Ingram JM, Rakes G, Honsinger RW, Platts-Mills TA. Mite, cat, and cockroach exposure, allergen sensitisation, and asthma in children: a case-control study of three schools. *Thorax* 1999; **54**: 675-680.