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Mold allergen sensitization in adult asthma according to *ITGB3* polymorphisms and *TLR2/+596* genotype

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ABSTRACT

Background: Integrin $\beta 3$ (*ITGB3*) and Toll-like receptor 2 (*TLR2*) are candidate genes for asthma and sensitization to mold allergens. Integrin $\beta 3$ forms a complex with *TLR2*, and this biological interaction is required for the response of monocytes to *TLR2* agonists such as fungal glucan. **Objective:** To study whether genetic interaction between single nucleotide polymorphisms (SNPs) in genes encoding the *TLR2-ITGB3* complex enhances susceptibility to mold sensitization. **Methods:** Association analysis was conducted in 1243 adults (524 with asthma) who participated in the follow-up of the Epidemiological Study on the Genetics and Environment of Asthma (EGEA). Allergic sensitization to mold allergens was determined by skin prick testing (SPT). Association of mold sensitization with 14 *ITGB3* SNPs was tested under an additive genetic model. Interaction between *ITGB3* SNPs and *TLR2/+596*, which was previously shown to be associated with asthma, was studied. **Results:** Positive SPT to mold was found in 115 subjects with asthma (22.0%), and in 61 subjects without asthma (8.5%). The *ITGB3* rs2056131 A allele was associated with mold sensitization in subjects with asthma with an odds ratio and 95% confidence interval of 0.60 (0.43-0.83), $P=0.001$. Ten other *ITGB3* SNPs were significantly associated with mold sensitization in *TLR2/+596TT* subjects with asthma ($P=0.03$ to 0.002), whereas much weaker associations were found in carriers of the *TLR2/+596 C* allele ($P=0.60$ to 0.04). Interaction between *TLR2/+596* and these *ITGB3* SNPs was statistically significant (P interaction=0.05 to 0.001).

Conclusion: *TLR2/+596* genotype may influence the association between *ITGB3* SNPs and mold sensitization in adults with asthma.

Key Messages

- *TLR2*/+596 genotype may influence the association between *ITGB3* SNPs and mold sensitization in adults with asthma.
- Findings in this population study are consistent with a biological interaction between integrin β 3 and TLR2 in the innate immune response to fungal agents.

Capsule summary

This study sheds more light on the role of genetic variants in mold sensitization. Our results suggest that polymorphisms in *ITGB3* and *TLR2* interact to increase susceptibility to mold sensitization among subjects with asthma.

Key words

Alternaria; *Aspergillus*; allergy; asthma; *Cladosporium*; epidemiology; epistasis; genetics; innate immunity

Abbreviations

CI: Confidence interval

EGEA: Epidemiological study on the Genetics and Environment of Asthma

FDR: False discovery rate

GEE: Generalized estimating equations

ICS: Inhaled corticosteroids

ITGB3: Integrin β 3

LD: Linkage disequilibrium

OR: Odds ratio

SNP: Single nucleotide polymorphism

SPT: Skin prick test

TLR2: Toll-like receptor 2

INTRODUCTION

Allergic sensitization to molds such as *Alternaria* and *Cladosporium* is a risk factor for asthma, asthma severity, and allergic rhinitis.⁽¹⁻³⁾ The prevalence of mold sensitization depends strongly on geographic and climatic conditions,^(3, 4) and exposure to indoor mold allergens has been associated with mold allergy and asthma symptoms in children and adults.⁽⁵⁻⁸⁾ Besides the influence of the environment, heritable factors were shown to contribute to mold sensitization as well. Concordance for skin prick testing to a mixture of *Alternaria* allergens was significantly greater among identical twins than for non-identical twins,⁽⁹⁾ and maternal sensitization to *Alternaria alternata* significantly increased the risk of matched sensitization in their children.⁽¹⁰⁾ Only a small number of candidate gene studies investigated the role of specific genetic variants in mold sensitization.⁽¹¹⁻¹⁴⁾ Weiss et al.⁽¹²⁾ found that single nucleotide polymorphisms (SNPs) in the integrin β 3 gene (*ITGB3*), which is located on chromosome 17q21.32, were associated with asthma and sensitization to mold allergens in Hutterites, a founder population, and in three outbred replication populations, whereas other allergens showed no association. A candidate gene study and a study that used genome-wide genotyping to assess the reproducibility of previously published asthma genes also found associations between *ITGB3* SNPs and asthma, but these studies did not investigate mold sensitization as an outcome.^(15, 16)

ITGB3 encodes the beta chain of the receptor for a wide array of ligands including vitronectin and fibrinogen. Integrin β 3 and its ligands play a key role in cell adhesion, cell proliferation and differentiation, platelet activation, and various other biological processes.⁽¹⁷⁾ Vitronectin may participate in the remodelling process during lung development or response to injury by downregulating the expression of α -smooth muscle actin and reducing the contractile ability of human lung fibroblasts.⁽¹⁸⁾

Integrin β 3 forms a complex with Toll-like receptor 2 (TLR2), and vitronectin and integrin β 3 are required for the response of monocytes to bacterial lipopeptide and other TLR2 agonists such as fungal glucan.⁽¹⁹⁾ We therefore hypothesized that variants in genes encoding the TLR2-*ITGB3* complex may play a role in susceptibility to asthma and mold sensitization.

The present study is the first epidemiological study to address a gene-gene interaction between *ITGB3* and *TLR2*. In adults from the French Epidemiological study on the Genetics and Environment of Asthma (EGEA), the *TLR2*/+596 (rs3804099) C allele was associated with asthma in both case-control and family-based analyses.⁽²⁰⁾ We aimed to study whether *TLR2*/+596 genotype modified associations between *ITGB3* SNPs and asthma and sensitization to mold allergens. In addition, we aimed to confirm associations between *ITGB3* SNPs and asthma and mold sensitization.

METHODS

Population

The present analysis uses data from the 12-year follow-up of the EGEEA survey. The design and protocol of EGEEA, a family study and a case-control study of asthma, have been reported in detail elsewhere.^(21, 22) Briefly, 2047 subjects were enrolled at baseline (1991-1995): 388 asthma patients (aged 7 to 70 years) from six chest clinics in five French cities, their 1244 first degree relatives, and 415 population-based controls. At follow-up (2003-2007), 92.2% of the alive cohort returned a self-completed questionnaire, and 77.1% completed a detailed questionnaire.⁽²³⁾ At the follow-up survey, all subjects were adults. For the present cross-sectional analysis, we used 1243 subjects (62.8% of the alive cohort) with complete data on asthma, mold sensitization, and genotyping (Figure E1 in the online supplement shows a flowchart). The 1243 subjects with complete data were slightly older, had more often studied at university level, and reported rhinitis more often than the 300 subjects who were excluded due to missing genotype or phenotype (mold sensitization) data (Supplementary Table E1). All participants gave written informed consent.

Health outcomes and exposure variables

Inclusion criteria used to define asthma in probands were based on self-reported answers to the four questions “Have you ever had attacks of breathlessness at rest with wheezing?”, “Have you ever had asthma attacks?”, “Was this diagnosis confirmed by a physician?”, and “Have you had an asthma attack in the last 12 months?”, or a positive response to at least two questions and a positive review of their medical record.⁽²¹⁾ Asthma in relatives of probands was defined as a positive answer to at least one of the first two questions.⁽²¹⁾

Atopy was defined by the presence of a positive skin prick test (SPT) (mean wheal diameter ≥ 3 mm) to at least one of 11 aeroallergens (*Aspergillus*, *Cladosporium herbarum*, *Alternaria tenuis* (=alternata), cat, *Dermatophagoides pteronyssinus*, *Blattella germanica*, olive, birch, *Parietaria judaica*, timothy grass, and ragweed pollen) using extracts made by Stallergènes (Antony, France). Mold sensitization was defined as a positive SPT to at least one of the 3 mold allergens. Mold species tested in EGEEA were the same as in the study by Weiss et al.⁽¹²⁾

Environmental exposure to molds was assessed by questionnaire using items from the European Community Respiratory Health Survey.⁽⁶⁾ A small lake near Montpellier was assumed to be a source of molds,⁽²⁴⁾ we therefore investigated recruitment in Montpellier as an environmental determinant of mold sensitization.

Genotyping

Fourteen SNPs in *ITGB3* (located at chromosome 17q21.32) with a minor allele frequency $>5\%$ were selected using a tagging approach. All SNPs were in Hardy-Weinberg equilibrium ($P>0.01$). Online Figure E2 shows linkage disequilibrium (LD) between SNPs. Genotyping was performed using Taqman Probes (Applied Biosystems, Foster City, CA) on an ABI7900HT Sequence Detection System at the Centre National de Génotypage (CNG, Evry, France).

Data analysis

Analyses using mold sensitization as an outcome were conducted in subjects with and without asthma separately, because mold sensitization is strongly associated with asthma, and subjects were recruited through patients with asthma. Determinants of mold sensitization were first explored by using univariate analyses (Chi-square test or t-test). All further analyses were done by generalized estimating equations (GEE model) to account for dependence among subjects sharing the same household. Odds ratios (ORs) and 95% confidence intervals (CIs) were adjusted for age and sex, unless stated otherwise. In the lack of evidence for a recessive or dominant genetic model, the effect of *ITGB3* SNPs on health outcomes was tested under an additive genetic model with the minor allele as risk allele.^(12,15,16) To test whether association between *ITGB3* SNPs and health outcomes were modified by *TLR2/+596* (rs3804099) genotype (TT or CC+CT) we introduced a multiplicative gene-gene interaction term in the GEE model and used a generalized score test which follows a chi-square distribution with 1 degree of freedom. False Discovery Rate (FDR) adjusted *P*-values were calculated to take multiple comparisons ($n=14$ SNPs) into account.⁽²⁵⁾

RESULTS

Association of mold sensitization and asthma

The present study comprised 524 subjects with asthma and 719 subjects without asthma. Mold sensitization was significantly more prevalent among subjects with asthma ($n=115$, 22.0%) than in subjects without asthma ($n=61$, 8.5%), with an adjusted OR (95%CI) of 2.80 (2.03-3.87). Exclusive mold sensitization was rare: only 13 (2.5%) subjects with asthma and 16 (2.2%) subjects without asthma were sensitized to mold without being sensitized to any of the other common allergens. *Alternaria*, *Cladosporium*, and *Aspergillus* sensitization were present in 71 (13.5%), 39 (7.4%), and 29 (5.5%) subjects with asthma and 27 (3.8%), 25 (3.5%), and 22 (3.1%) subjects without asthma, respectively. Atopy (sensitization to any of the 11 allergens tested) was found in 414

(79.0%) subjects with asthma, and in 277 (38.5%) subjects without asthma. Subjects with asthma who were sensitized to mold had more often used corticosteroids in the past year, and tended to have a lower age at the onset of asthma than those who were not sensitized to mold (52.6% vs. 40.1% and 13.1 y vs. 16.1 y, respectively; Table 1).

Determinants of mold sensitization

Table 1 shows determinants of mold sensitization in subjects with and without asthma (univariate analysis). Subjects with asthma who were sensitized to mold were younger, and more likely to be recruited in Montpellier than in the other centers. Among subjects without asthma, those sensitized to mold allergen were more often female, and recruited in Montpellier than those who were not sensitized to mold. Smoking habits and the presence of molds or water damage in the home were not associated with mold sensitization. Multiple regression models that included age, sex, and recruitment in Montpellier showed similar results as the univariate analyses. Recruitment in Montpellier was more strongly associated with sensitization to *Alternaria alternata* than to other mold allergens (OR 7.99 (3.24-19.66) and OR 4.18 (1.81-9.69), respectively).

Association of *ITGB3* SNPs, mold sensitization, asthma and atopy

The *ITGB3* rs2056131 A allele was associated with a lower prevalence of mold sensitization in subjects with asthma, with a frequency of 26% in mold sensitized subjects and 37% in subjects not sensitized to mold (OR 0.60 (0.43-0.83); Table 2). The P-value (0.001) was still statistically significant after correction for multiple testing. The same direction of association was shown for subjects without asthma, but the association was not significant (P=0.16). Among subjects with asthma, similar associations with *ITGB3* rs2056131 were found for each of the mold allergens: *Cladosporium* OR 0.49 (0.27-0.89), *Aspergillus* OR 0.47 (0.25-0.86), and *Alternaria* OR 0.70 (0.49-1.01). Excluding subjects from Montpellier, or adjusting for recruitment in Montpellier did not change results (OR 0.56 (0.39-0.81) and OR 0.57 (0.41-0.81), respectively). Correction for other potential confounders (educational level, use of corticosteroids, and smoking habits) did also not change results (OR 0.58 (0.37-0.90)). Analysis restricted to 414 atopic subjects also resulted in a similar OR (0.62 (0.45-0.86)). *ITGB3* SNPs were not associated with asthma or atopy (P>0.05; Supplementary Table E2 and E3).

Gene-gene interaction between *ITGB3* and *TLR2*

TLR2+596 CC+CT was associated with asthma at the follow-up survey (OR 1.75 (1.36-2.26); P<0.0001), confirming the earlier reported association among adults at baseline.⁽²⁰⁾ *TLR2*+596 CC+CT was not associated with mold sensitization in subjects with asthma (OR 1.13 (0.70-1.83) or subjects without asthma (OR 1.25 (0.70-2.24)). Among subjects with asthma, the associations between *ITGB3* SNPs and mold sensitization analyzed according to *TLR2*+596 genotype showed statistically significant associations between 11 *ITGB3* SNPs and mold sensitization in *TLR2*+596TT subjects (P=0.03 to 0.002), whereas much weaker or no associations were found in carriers of the *TLR2*+596 C allele (P=0.60 to 0.04). Gene-gene interaction was statistically significant for 10 *ITGB3* SNPs (P interaction=0.05 to 0.001), and remained significant for 7 SNPs after adjusting for multiple comparisons (Table 3). Excluding subjects from Montpellier or adjusting for recruitment did not change these findings. The LD pattern (online Figure E2) shows that the SNPs involved in the interaction belong to different haplotype blocks. When a forward stepwise regression was applied in *TLR2*+596TT subjects, two *ITGB3* SNPs that were not in LD ($r^2=0.00$) entered the model with P<0.05, suggesting that they were both independently associated with mold sensitization (rs15908 (V381V) and rs11079772 (3'UTR)). Both gene-gene interaction terms were statistically significant in a multiple regression model (rs15908 x *TLR2*+596, p=0.02; rs11079772 x *TLR2*+596, p=0.006; Figure 1). Among subjects without asthma, association between *ITGB3* SNPs and mold sensitization was not modified by *TLR2*+596 (P interaction>0.05; Supplementary Table E4). Furthermore, *TLR2*+596 did also not modify associations between *ITGB3* SNPs and asthma (P interaction>0.05; Supplementary Table E5) or atopy (P interaction>0.05; data not shown).

DISCUSSION

In the present study, we found significant associations between *ITGB3* SNPs and mold sensitization among adults with asthma, which were confined to carriers of the *TLR2*+596TT genotype. Our findings suggest a gene-gene interaction between *ITGB3* and *TLR2*+596 in mold allergen sensitization. These results are consistent with the biological interaction between integrin $\beta 3$ and TLR2 that was recently demonstrated, suggesting an important role of the integrin $\beta 3$ -TLR2 complex in the innate immune response to fungal agents.⁽¹⁹⁾

Testing associations of multiple *ITGB3* SNPs and three phenotypes may have resulted in chance findings, which is a limitation of our study. However, our finding of epistasis between *ITGB3* and *TLR2* was still significant for seven *ITGB3* SNPs after correction for multiple testing. Another limitation is that skin tests were performed

with mold extracts which were not fully standardized and some subjects with mold allergy may have been missed. The allergen extracts were however of similar quality as those tested by Weiss et al.⁽¹²⁾ The biochemistry of mold allergens is still poorly understood, and the concordance between skin prick test (SPT) and specific serum IgE results for individual molds is much lower than for non-fungal allergens.⁽²⁶⁾ Interestingly, *TLR2*/+596 T/C did not modify associations between *ITGB3* SNPs and asthma or atopy, suggesting that the gene-gene interaction between *TLR2* and *ITGB3* may be specific for the response to molds. Weiss et al. also found associations between *ITGB3* SNPs and allergic sensitization to molds, but not to other common allergens.⁽¹²⁾ It is not clear whether our results concern one or more specific mold species, or rather mold allergens in general. We found similar risk estimates for the association between *ITGB3* rs2056131 and each of the three molds studied, but there was insufficient statistical power to study the interaction between *TLR2* and *ITGB3* for allergic sensitization to each of the three individual mold species. Multiple regression analysis showed that at least two *ITGB3* SNPs, rs15908 (V381V) and rs11079772, were independently involved in the interaction with *TLR2*. Rs2015729, a noncoding *ITGB3* SNP in high LD with rs15908, was previously associated with decreased *ITGB3* expression levels, which may provide a potential mechanism by which noncoding *ITGB3* variants have a functional effect.⁽²⁷⁾ Another functional *ITGB3* SNP (rs5918, Leu33Pro) has been associated with various effects, including enhanced thrombin formation,⁽²⁸⁾ coronary heart disease,⁽²⁹⁾ and cancer susceptibility.⁽³⁰⁾ *ITGB3* Leu33Pro was not genotyped in the present study, but it was in LD ($r^2=0.76$) with rs10514919, a SNP that showed a significant interaction with *TLR2* ($P=0.05$). Besides main effects of *ITGB3* variants on various clinical outcomes, three studies have presented evidence for epistasis between *ITGB3* and the serotonin transporter gene *SLC6A4* in autism susceptibility^(27, 31, 32) and in serotonin levels.⁽³¹⁾ Altogether, these findings suggest that multiple functional *ITGB3* SNPs may have different pleiotropic effects, possibly in interaction with other genes. We can only speculate on the mechanism by which the effect of *ITGB3* SNPs on mold sensitization is modified by *TLR2*/+596. A recent study has shown that peripheral blood leukocytes of *TLR2*/+596 TT subjects produce significantly less cytokines in response to bacterial lipoprotein stimulation than those of *TLR2*/+596 CT and CC subjects.⁽³³⁾ Moreover, *TLR2*/+596 TT was the only *TLR2* variant associated with a lower sepsis morbidity rate.⁽³³⁾ The *TLR2*/+596 C allele was associated with asthma in both case-control and family-based analyses among EGEA adults, which is consistent with a functional role of *TLR2*/+596.⁽²⁰⁾ However, the exact functional significance of *TLR2*/+596 is so far unknown. A possible explanation could be a different expression of TLR2 on the surface of innate immune cells among subjects carrying the TT genotype compared with subjects carrying the C allele. In subjects with certain functional *ITGB3* SNPs, a modified TLR2 expression may potentially result in a decreased function of the *ITGB3*-TLR2 complex. Finally, it can be hypothesized that this altered function could lead to a less effective response to fungal agents resulting in an increased risk of mold sensitization. We did not replicate associations between *ITGB3* variants and asthma.^(12, 15) In a recent study that used genome-wide genotyping to assess reproducibility of SNPs in 39 previously reported asthma genes, only 10 SNPs in 6 genes were significantly associated with childhood asthma, including one SNP in *ITGB3*, which was not included in the present study.⁽¹⁵⁾ Our study had sufficient statistical power (80%) to detect a relative risk (RR) between 1.32 and 1.40 for the association between *ITGB3* SNPs and asthma, and a RR between 1.66 and 1.82 for the association between *ITGB3* SNPs and mold sensitization in asthmatics, depending on disease allele frequency (varying between 0.19 and 0.40), and using the conservative Bonferroni correction for multiple comparisons. These RR seem reasonable and suggest that the lack of association cannot be attributed to a lack of power in our study. Replicating asthma susceptibility genes is a major challenge, and failure to replicate may be caused by heterogeneity between studies. Replicating interactions appears even more complicated.^(34,35) Findings of our epidemiological study were analogous to a previously reported biological interaction between integrin $\beta 3$ and TLR2.⁽¹⁹⁾ In addition, we have attempted to replicate our findings in the population of adult Hutterites.⁽¹²⁾ However, in that population only 93 subjects carried *TLR2*/+596 TT, and only 42 subjects were sensitized to mold (Dr. C. Ober, personal communication). Thus, there was no sufficient power to study interactions in this population. Moreover, Hutterites in general have a mild form of asthma, with corticosteroid use being quite rare. Other populations that were considered had not assessed sensitization to (the same) mold allergens. Variation between studies in asthma definition, age at onset, ethnicity, and other characteristics of the study population may reduce reproducibility. Furthermore, the influence of environmental exposures may also obscure genetic associations. For example, consistent associations between *CD14*/-260 and asthma or allergic sensitization were observed only after taking environmental endotoxin levels into account.⁽³⁶⁾ The present study would have benefited from measured fungal allergen and/or glucan levels in settled house dust. Due to the lack of objectively assessed environmental exposure, we cannot exclude the possibility that gene-environment interactions play an additional role in association of *ITGB3* and asthma or mold sensitization. In the present study we found an expected higher prevalence of mold sensitization in subjects recruited in Montpellier, where environmental exposure to mold was elevated.⁽²⁴⁾ However, excluding subjects from Montpellier, or adjusting for recruitment did not affect the results. In US homes, *Alternaria* antigen concentrations were higher in homes where either residents or field workers observed signs of mold or dampness,⁽³⁷⁾ and exposure to *Alternaria* was

associated with asthma symptoms.⁽⁸⁾ We also investigated water damage and visible mold in the home as self-reported mold exposures, but these were not associated with mold sensitization.

We did not study severity of asthma as another phenotype, although mold sensitization is known to be associated with a more severe asthma phenotype.⁽¹⁾ In adult asthma patients from EGEA who did not use inhaled corticosteroids (ICS), mold sensitization was significantly associated with an increased risk for uncontrolled asthma (OR, 95% CI of 3.15, 1.02-9.78), but not for partly controlled asthma.⁽²³⁾ However, mold sensitization was not associated with an increased risk for uncontrolled asthma in ICS users.⁽²³⁾ The number of subjects did not allow further stratification for ICS use, or stratification for multiple levels of asthma control or asthma severity, and therefore we decided not to study associations between uncontrolled asthma or asthma severity and *ITGB3* genotype in the present study.

In conclusion, our epidemiological study suggests that genetic variants in *ITGB3* and *TLR2* interact to increase susceptibility to mold sensitization among subjects with asthma. Following an experimental study that demonstrated the essential role of integrin $\beta 3$ in TLR2 signaling,⁽¹⁹⁾ our population study was the first to show this specific gene-gene interaction, which may influence the demonstrated biological interactions. Future studies need to replicate these findings, and functional experiments are needed to assess the mechanism by which *ITGB3* and *TLR2* SNPs influence susceptibility to mold sensitization.

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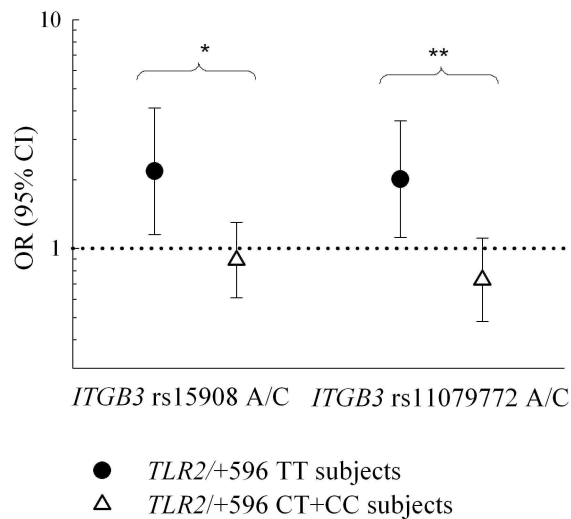


Figure 1. Association of two *ITGB3* SNPs (rs15908 A/C and rs11079772 A/C) with mold sensitization in a multiple regression analysis, stratified by *TLR2*/+596 genotype. *ITGB3* SNPs were tested under an additive model among subjects with asthma. *P value for interaction <0.05; **P value for interaction <0.01.

Table 1. Asthma characteristics and determinants of mold sensitization in 524 adults with asthma and 719 adults without asthma.

| | Subjects with asthma | | | | Subjects without asthma | | | |
|--|-------------------------------|-------------|-------------|----------|-------------------------------|-------------|-------------|----------|
| | Data available for n subjects | Mold SPT- | Mold SPT+ | <i>P</i> | Data available for n subjects | Mold SPT- | Mold SPT+ | <i>P</i> |
| N | 524 | 409 | 115 | | 719 | 658 | 61 | |
| Sex, n (%) men | 524 | 212 (51.8) | 65 (56.5) | 0.37 | 719 | 312 (47.4) | 20 (32.8) | 0.03 |
| Age (y), mean ± sd | 524 | 39.9 ± 16.8 | 36.3 ± 16.5 | 0.04 | 719 | 46.5 ± 16.3 | 43.4 ± 16.2 | 0.16 |
| Status at inclusion | 524 | | | 0.06 | 719 | | | 0.57 |
| Probands, n (%) | | 188 (46.0) | 68 (59.1) | | | 0 (0) | 0 (0) | |
| Relatives, n (%) | | 182 (44.5) | 39 (33.9) | | | 383 (58.2) | 39 (63.9) | |
| Spouses, n (%) | | 4 (1.0) | 2 (1.7) | | | 67 (10.2) | 4 (6.6) | |
| Controls, n (%) | | 35 (8.6) | 6 (5.2) | | | 208 (31.6) | 18 (29.5) | |
| Recruited in Montpellier, n (%) | 524 | 19 (4.7) | 18 (15.7) | <0.0001 | 719 | 33 (5.0) | 10 (16.4) | 0.0003 |
| Smoking habits | 519 | | | 0.70 | 711 | | | 0.45 |
| Never, n (%) | | 204 (50.4) | 58 (50.9) | | | 339 (52.1) | 32 (52.5) | |
| Former, n (%) | | 106 (26.2) | 26 (22.8) | | | 166 (25.5) | 19 (31.2) | |
| Current, n (%) | | 95 (23.5) | 30 (26.3) | | | 146 (22.4) | 10 (16.4) | |
| Education at university level, n (%) | 518 | 197 (48.8) | 63 (55.3) | 0.22 | 710 | 304 (46.7) | 39 (66.1) | 0.004 |
| Living in a rural commune before 16y, n (%) | 511 | 156 (39.0) | 39 (35.1) | 0.46 | 696 | 238 (37.3) | 15 (26.3) | 0.10 |
| Water damage last year, n (%) | 429 | 38 (11.3) | 12 (12.9) | 0.67 | 590 | 59 (11.0) | 9 (17.7) | 0.15 |
| Mold in any surface inside the home last year, n (%) | 457 | 72 (20.1) | 17 (17.4) | 0.55 | 619 | 100 (17.6) | 9 (17.3) | 0.95 |
| Asthma onset (y), mean ± sd | 492 | 16.1 ± 15.7 | 13.1 ± 14.2 | 0.07 | -- | -- | -- | -- |
| FEV1 % predicted, mean ± sd | 523 | 92.5 ± 17.4 | 91.5 ± 18.8 | 0.60 | -- | -- | -- | -- |
| Inhaled corticosteroids in the past 12 months, n (%) | 520 | 163 (40.1) | 60 (52.6) | 0.02 | -- | -- | -- | -- |
| Active asthma*, n (%) | 522 | 275 (67.6) | 87 (75.6) | 0.10 | | | | |

* Active asthma: asthma attack or asthma treatment in the past 12 months

-- Data only shown for subjects with asthma

Table 2. Association of *ITGB3* SNPs with mold sensitization under an additive model in 524 adults with asthma and 719 adults without asthma.

| <i>ITGB3</i> SNP | Position | Region | Alleles [†] | MAF | Subjects with asthma | Subjects without asthma |
|------------------|----------|--------------|----------------------|------|----------------------|-------------------------|
| | | | | | OR (95% CI) | OR (95% CI) |
| rs2317385 | 42684681 | 5'UTR | G/A | 0.19 | 1.21 (0.83-1.77) | 1.14 (0.74-1.76) |
| rs2056131 | 42688742 | intron 1 | G/A | 0.33 | 0.60 (0.43-0.83)* | 0.75 (0.51-1.12) |
| rs4525555 | 42692948 | intron 1 | C/T | 0.33 | 1.09 (0.80-1.48) | 1.05 (0.72-1.53) |
| rs3892084 | 42695420 | intron 1 | G/A | 0.19 | 1.04 (0.72-1.49) | 0.91 (0.57-1.46) |
| rs10514919 | 42697128 | intron 1 | G/T | 0.26 | 1.07 (0.76-1.51) | 1.12 (0.73-1.72) |
| rs8074094 | 42703020 | intron 1 | T/C | 0.28 | 1.10 (0.79-1.53) | 1.16 (0.77-1.73) |
| rs3851806 | 42705918 | intron 1 | G/C | 0.18 | 1.05 (0.72-1.53) | 0.92 (0.56-1.50) |
| rs2015729 | 42709492 | intron 2 | G/A | 0.40 | 1.17 (0.87-1.58) | 1.04 (0.73-1.48) |
| rs2292699 | 42717294 | intron 4 | C/T | 0.38 | 1.13 (0.83-1.53) | 1.02 (0.71-1.47) |
| rs15908 | 42723336 | exon 9 V381V | A/C | 0.38 | 1.12 (0.83-1.52) | 1.03 (0.71-1.50) |
| rs2292863 | 42724129 | intron 9 | C/G | 0.30 | 1.07 (0.77-1.49) | 1.10 (0.74-1.62) |
| rs3809863 | 42740011 | intron 14 | C/T | 0.47 | 1.03 (0.77-1.39) | 1.16 (0.85-1.59) |
| rs11650072 | 42748664 | 3'UTR | C/T | 0.33 | 0.91 (0.66-1.25) | 0.95 (0.67-1.35) |
| rs11079772 | 42748738 | 3'UTR | A/C | 0.29 | 0.93 (0.67-1.29) | 1.01 (0.69-1.47) |

*FDR-corrected P<0.05; [†]Major/Minor allele; MAF, minor allele frequency.

Table 3. Association of *ITGB3* SNPs with mold sensitization under an additive model in adults with asthma, according to *TLR2*/+596 genotype.

| <i>ITGB3</i> SNP | Alleles [†] | Carriers of <i>TLR2</i> /+596 TT (n=126) | | | Carriers of <i>TLR2</i> /+596 CT or CC (n=362) | | | P interaction |
|------------------|----------------------|---|---|------------------|---|---|------------------|---------------|
| | | Minor allele in mold SPT- subjects, n (%) | Minor allele in mold SPT+ subjects, n (%) | OR (95% CI) | Minor allele in mold SPT- subjects, n (%) | Minor allele in mold SPT+ subjects, n (%) | OR (95% CI) | |
| rs2317385 | G/A | 37 (19) | 11 (21) | 1.19 (0.58-2.43) | 101 (18) | 34 (21) | 1.24 (0.79-1.97) | 0.91 |
| rs2056131 | G/A | 82 (41) | 10 (19) | 0.36 (0.18-0.72) | 202 (36) | 46 (29) | 0.70 (0.47-1.03) | 0.09 |
| rs4525555 | C/T | 54 (27) | 23 (44) | 1.94 (1.04-3.63) | 185 (33) | 47 (30) | 0.89 (0.61-1.30) | 0.04 |
| rs3892084 | G/A | 32 (16) | 10 (19) | 1.17 (0.54-2.55) | 111 (20) | 31 (19) | 1.01 (0.65-1.55) | 0.75 |
| rs10514919 | G/T | 44 (22) | 19 (37) | 1.89 (1.05-3.40) | 145 (26) | 36 (23) | 0.83 (0.52-1.33) | 0.05 |
| rs8074094 | T/C | 47 (24) | 21 (40) | 2.08 (1.16-3.73) | 158 (28) | 40 (25) | 0.85 (0.55-1.32) | 0.02* |
| rs3851806 | G/C | 33 (17) | 11 (21) | 1.29 (0.63-2.62) | 105 (19) | 30 (19) | 0.99 (0.63-1.56) | 0.55 |
| rs2015729 | G/A | 66 (33) | 30 (58) | 2.79 (1.46-5.33) | 231 (41) | 61 (38) | 0.91 (0.63-1.31) | 0.003* |
| rs2292699 | C/T | 62 (31) | 28 (54) | 2.43 (1.28-4.62) | 218 (39) | 57 (36) | 0.90 (0.62-1.31) | 0.009* |
| rs15908 | A/C | 62 (31) | 26 (54) | 2.42 (1.24-4.70) | 219 (39) | 57 (36) | 0.89 (0.61-1.29) | 0.01* |
| rs2292863 | C/G | 53 (27) | 22 (42) | 1.85 (1.03-3.33) | 175 (31) | 44 (28) | 0.83 (0.54-1.27) | 0.04 |
| rs3809863 | C/T | 103 (52) | 15 (29) | 0.37 (0.18-0.77) | 252 (45) | 86 (54) | 1.38 (0.96-1.99) | 0.001* |
| rs11650072 | C/T | 61 (31) | 27 (52) | 2.38 (1.29-4.38) | 201 (36) | 42 (27) | 0.65 (0.43-0.99) | 0.001* |
| rs11079772 | A/C | 53 (27) | 22 (42) | 1.89 (1.06-3.34) | 174 (31) | 39 (24) | 0.72 (0.47-1.11) | 0.01* |

*FDR-corrected P<0.05. †Major/Minor allele