Moisture Damage and Asthma: A Birth Cohort Study

Anne M. Karvonen, PhD[a], Anne Hyvärinen, PhD[a], Matti Korppi, MD[b], Ulla Haverinen-Shaughnessy, PhD[a], Harald Renz, MD[c], Petra I. Pfefferle, PhD[c], Sami Remes, MD, MPH[d], Jon Genuneit, MD[e], Juha Pekkanen, MD[a,f]

abstract

BACKGROUND: Excess moisture and visible mold are associated with increased risk of asthma. Only a few studies have performed detailed home visits to characterize the extent and location of moisture damage and mold growth.

METHODS: Structured home inspections were performed in a birth cohort study when the children were 5 months old (on average). Children (N = 398) were followed up to the age of 6 years. Specific immunoglobulin E concentrations were determined at 6 years.

RESULTS: Moisture damage and mold at an early age in the child's main living areas (but not in bathrooms or other interior spaces) were associated with the risk of developing physician-diagnosed asthma ever, persistent asthma, and respiratory symptoms during the first 6 years. Associations with asthma ever were strongest for moisture damage with visible mold in the child's bedroom (adjusted odds ratio: 4.82 [95% confidence interval: 1.29–18.02]) and in the living room (adjusted odds ratio: 7.51 [95% confidence interval: 1.49–37.83]). Associations with asthma ever were stronger in the earlier part of the follow-up and among atopic children. No consistent associations were found between moisture damage with or without visible mold and atopic sensitization.

CONCLUSIONS: Moisture damage and mold in early infancy in the child's main living areas were associated with asthma development. Atopic children may be more susceptible to the effects of moisture damage and mold.

WHAT'S KNOWN ON THIS SUBJECT: Moisture damage and mold increase the risk of asthma and asthmatic symptoms. However, the location of the damage, or the specific group of children who are at greater risk of asthma, is rarely taken into account.

WHAT THIS STUDY ADDS: Inspector-observed moisture damage or mold in the child's bedroom, living room, or kitchen increased the risk of asthma and persistent asthma during a 6-year follow-up. Atopic children may be more susceptible to the effects of moisture damage and mold.

[a]*Department of Environmental Health, National Institute for Health and Welfare, Kuopio, Finland;* [b]*Pediatric Research Center, Tampere University and University Hospital, University of Tampere, Tampere, Finland;* [c]*Institute for Laboratory Medicine and Pathobiochemistry, Molecular Diagnostics, Philipps-University Marburg, Marburg, Germany;* [d]*Department of Pediatrics, Kuopio University Hospital, Kuopio, Finland;* [e]*Institute of Epidemiology and Medical Biometry, Ulm University, Ulm, Germany; and* [f]*Department of Public Health, University of Helsinki, Helsinki, Finland*

Dr Karvonen performed the statistical data analyses, coordinated the data collection, and drafted and prepared the initial manuscript; Drs Hyvärinen and Haverinen-Shaughnessy designed the moisture damage assessment and reviewed and revised the manuscript; Drs Korppi and Remes reviewed and revised the manuscript; Drs Renz and Pfefferle performed the immunoglobulin E measurements and reviewed and revised the manuscript; Dr Genuneit coordinated data management and reviewed and revised the manuscript; Dr Pekkanen designed the study, supervised the data collection and data analyses, and reviewed and revised the manuscript; and all authors approved the final manuscript as submitted.

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Address correspondence to Anne M. Karvonen, PhD, Department of Environmental Health, National Institute for Health and Welfare, PO Box 95, FIN-70701 Kuopio, Finland. E-mail: anne.karvonen@thl.fi

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Moisture damage and mold growth in buildings have been associated with asthma exacerbation.[1–4] In addition, recent reviews[3,4] offer sufficient evidence that moisture damage or mold is associated with the development of asthma. In contrast, there are few data on the association with atopic sensitization.[3] Although a substantial number of epidemiologic and other studies have been performed thus far, the causal agents are still unknown.[4]

Previously, knowledge regarding the association between moisture damage and mold and asthma was based on cross-sectional studies or studies with short follow-up periods (≤2 years) and occupants' self-report of dampness, moisture damage, or mold.[4] However, more studies with longer follow-up times have recently been able to analyze the emergence of asthma.[5] Occupants' reports on dampness or mold growth are more subjective and therefore more inaccurate than home inspections performed by trained civil engineers,[6,7] and these reports may thus lead to artificial associations between home dampness and adverse health effects, especially in cross-sectional studies.[8,9]

We recently reported from this same cohort[10] that inspector-observed moisture damage with or without visible mold in the kitchen and in the main living area (including bedrooms, living rooms, and main hallways connecting these rooms), especially in the children's bedrooms, were associated with respiratory and asthmatic symptoms during the first 18 months of life. Because early wheezing is often transient, asthma cannot be assessed at that early age. The aim of the present study was to prospectively evaluate whether inspector-observed moisture damage with or without visible mold in the home in infancy is associated with the development of new physician-diagnosed asthma and with respiratory tract symptoms and atopic sensitization up to the age of 6 years.

METHODS

Study Population

The study population consisted of a birth cohort that has been prospectively followed up from the third trimester of pregnancy.[10] A total of 442 children were born between September 2002 and May 2005. The first half of the study population, Finnish PASTURE (n = 214), belongs to a European birth cohort (PASTURE [Protection against Allergy Study in Rural Environments])[11] from rural areas. The second half of the cohort comes mainly from suburban areas (n = 228)[10] (Supplemental Information). The study protocol was approved by the research ethics committee of the Hospital District of Northern Savo, Kuopio, Finland. Written informed consent was obtained from the parents of participating children.

Follow-up

Questionnaires were used at the age of 12, 18, and 24 months, and thereafter annually[10]; they inquired about respiratory symptoms and physician-diagnosed asthma or bronchitis for the time period after the preceding questionnaire. The response rates for each follow-up ranged from 80% to 95%. Information about housing characteristics and parent-reported moisture damage was collected by the use of a questionnaire during the home inspection.

Home Inspection

The methods of home inspection have been described previously[10,12,13] and are discussed in the Supplemental Information. Briefly, the homes were inspected by a trained civil engineer for moisture damage (ie, assessment of signs of excess moisture on the surfaces and building structures by using a predesigned checklist). Children were 5 months old (on average) during the home inspection. Results of the home inspection were reported to the parents.

Classification of Moisture Damage

Each sign of excess moisture was graded by using a 6-point "need for repair" estimation scale[12] and the area of the damage was measured[13] (discussed further in the Supplemental Information). "No damage" was defined as need for repair class 0 or 1. "Major damage" was defined as: (1) a need for repair class 2 with the area of damage ≥1 m^2; (2) a need for repair class 3 with the area of damage ≥0.1 m^2; or (3) a need for repair class 4 or 5. Damage other than these instances was classified as "minor damage." If there were several moisture-damaged locations in a given room or area, the areas of damage with the same need for repair estimation were totaled. Presence of mold odor or visible mold was recorded for each damage observation. Mold growth only on silicone sealants in the kitchen or in the bathroom was classified as no mold. A combined variable ("moisture damage or mold in the child's main living areas") was created by using information regarding signs of moisture damage and visible mold in the child's bedroom, the living room, or kitchen (Supplemental Information).

Immunoglobulin E Determinations

Venous blood samples collected from children at the ages of 1 and 6 years, and from mothers and fathers, were analyzed for allergen-specific immunoglobulin E (IgE) to 19 common allergens (Mediwiss Analytic, Moers, Germany)[14]; 13 inhalant and 6 food allergens were included.[10] The cutoff level to define atopic sensitization to inhalant allergens was 0.70 kU/L at the age of 6 years, and this factor was analyzed in 310 children with data on home inspection in infancy.

Statistical Analysis

Survival analysis (discrete-time hazard models) was used to analyze

"asthma ever," which was defined as positive at the time of the first parent-reported, physician-diagnosed asthma and/or second diagnoses of asthmatic (or obstructive) bronchitis. "Persistent asthma" was analyzed in the same way, but the child with asthma ever also had to have parent-reported wheezing and/or use of asthma medication in the past 12 months at age 6 years.

Logistic regression with generalized estimating equations (with an exchangeable correlation structure to account for correlation between repeated measures within subjects) were used to determine associations between moisture damage and presence of mold and repeated reported wheezing or cough at ages 1, 1.5, 2, 3, 4, 5, and 6 years. Logistic regression was used for atopic sensitization to inhalant allergen at the age of 6 years.

In stratified analyses, asthma ever cases were divided into 2 equal groups based on age of onset, and respiratory symptoms were divided into 2 time periods ($<$3 years and $\geq$3 years of age). For stratified analyses, atopy was defined as atopic sensitization to any of the tested allergens ($\geq$0.35 kU/L) at the age of 1 year and parental atopy as maternal and/or paternal atopic sensitization to any of the tested allergens ($\geq$3.50 kU/L). Age and atopic status interactions were studied, adding an interaction term into the model, and the *P* values for the overall effect of the multiplicative interactions between moisture damage and age group or atopic status were reported.

All models were adjusted for the following a priori–selected covariates: study cohort, maternal history of allergic diseases (asthma, atopic dermatitis, or allergic rhinitis), gender, number of older siblings ($\geq$2 or 1 vs no siblings), smoking during pregnancy, and farming status. The models of asthma ever and moisture damage in the kitchen and in the main living area were also tested for 16 additional confounding factors (Supplemental Information). None of these potential confounders changed any of the tested estimates of exposure by $>$10% and thus were not included in any of the analyses. Adjustments for amount of house dust from the living room floor at the age of 2 months did not change the results (data not shown).

The data were analyzed by using SAS version 9.2 for Windows (SAS Institute, Inc, Cary, NC).

RESULTS

Most of the families lived in detached single-family or semidetached houses (80.9%) with relatively large living spaces ($\geq$100 m^2 in 71.1% of the houses) (Supplemental Table 5). Only 8.3% of the houses had no signs of moisture damage or mold (ie, without any need for repair). Approximately 36% of families moved to a different house during the first 6 years of the child's life.

Parents reported fewer signs of moisture damage than the inspector. Parents reported major damage in only 5.3% and inspectors observed damage in 11.9% of the child's main living areas. The proportion of the inspector-observed major damage that was also reported by the parents was 34%; for minor damage, the amount noted was 11.8%.

During the 6-year follow-up, 65 children developed asthma ever; among them, 35 children had persistent asthma at 6 years of age (Supplemental Table 6). Eighteen persistent asthma cases (51%) were diagnosed during the first 2 years of life. Prevalence data regarding respiratory symptoms and inhalation atopy are provided in Supplemental Table 7.

Several signs of moisture damage with or without mold were associated with asthma ever, persistent asthma, and respiratory symptoms (Tables 1 and 2). The strongest associations with mostly dose-related responses were found between moisture damage with visible mold in the child's bedroom and living room and asthma and persistent asthma (Table 1). Moisture damage or mold in the child's main living areas was associated with asthma ever and respiratory symptoms.

Weak and mostly nonsignificant associations were observed between moisture damage classifications of the whole house and asthma ever, persistent asthma, and respiratory symptoms (Supplemental Table 8). Mold odor was seldom detected in the whole house (Supplemental Table 5) and never in the kitchens, and no consistent associations between moisture damage with mold odor and health outcomes were found (Tables 1 and 2, Supplemental Table 8). No consistent associations were observed between health and moisture damage with or without visible mold in the bathrooms or in the other interior spaces.

The associations between moisture damage or mold in the child's main living areas and asthma ever (Table 3) or persistent asthma changed during the follow-up (*P* values for interaction, .001 and .02, respectively); it was stronger if asthma ever or persistent asthma was diagnosed during the first 2 years of life rather than after 2 years of age. Interaction with follow-up period was also seen for wheezing apart from cold (*P* value for interaction, .08) (Table 4), mainly due to the stronger association related to moisture damage with or without visible mold in the kitchen in the early part of the follow-up compared with the latter part of the follow-up (data not shown). No time interaction ($P > .2$) was seen with nocturnal cough.

Moisture damage or mold in the child's main living areas was associated with asthma ever (*P* value for interaction, .04) (Table 3) especially in atopic children at the age of 1 year compared with nonatopic

TABLE 1 Adjusted Associations Between Characteristics of Moisture Damage or Mold and Incidence of Asthma Ever and Persistent Asthma

Characteristic	Asthma Ever				Persistent Asthma			
	N	*n*	*N*[a] (%)	aOR[b] (95% CI)	*N*	*n*	*N*[a] (%)	aOR[b] (95% CI)
Kitchen								
Moisture damage, no (ref)	298	48	1689 (2.8)	1	270	25	1670 (1.5)	1
Minor	75	11	402 (2.7)	0.99 (0.50–1.97)	69	7	391 (1.8)	1.17 (0.49–2.79)
Major	21	5	92 (5.4)	2.50 (0.93–6.72)	19	3	98 (3.1)	2.32 (0.66–8.18)
Moisture damage with mold, no (ref)	379	61	2112 (2.9)	1	345	33	2089 (1.6)	1
Spots	5	2	22 (9.1)	2.81 (0.60–13.15)	5	2	22 (9.1)	5.07 (1.03–24.93)*
Visible mold	10	1	49 (2.0)	0.55 (0.07–4.14)	8	0	48 (0)	–[c]
Living room								
Moisture damage, no (ref)	326	49	1826 (2.7)	1	294	26	1797 (1.5)	1
Minor	48	12	247 (4.9)	2.11 (1.07–4.18)*	44	7	246 (2.9)	2.32 (0.95–5.66)
Major	20	3	110 (2.7)	1.55 (0.45–5.27)	20	2	116 (1.7)	1.82 (0.40–8.25)
Maximum severity,[d] class 0 (ref)	285	46	1591 (2.9)	1	259	25	1576 (1.6)	1
Class 1	41	3	235 (1.3)	0.46 (0.14–1.52)	35	1	221 (0.5)	0.29 (0.04–2.19)
Class 2	39	10	204 (4.9)	2.07 (0.98–4.38)	35	5	203 (2.5)	1.94 (0.69–5.46)
Class 3	27	4	149 (2.7)	1.17 (0.40–4.38)	27	3	155 (1.9)	1.61 (0.45–5.73)
Class 4	2	1	4 (25.0)	40.47 (3.28–499.59)**	2	1	4 (25.0)	67.45 (4.48–1016)**
Moisture damage with mold, no (ref)	383	60	2141 (2.8)	1	347	32	2111 (1.5)	1
Spots	6	2	24 (8.3)	3.42 (0.75–15.63)	6	2	24 (8.3)	6.72 (1.35–33.29)*
Visible mold	5	2	18 (11.1)	7.51 (1.49–37.83)*	5	1	24 (4.2)	5.85 (0.66–52.05)
Moisture damage with mold odor, no (ref)	391	64	2167 (3.0)	1	355	35	2143 (1.6)	1
Yes	3	0	16 (0)	–[c]	3	0	16 (0)	–[c]
Child's bedroom								
Moisture damage, no (ref)	338	55	1869 (2.9)	1	307	30	1843 (1.6)	1
Minor	47	6	270 (2.2)	0.81 (0.34–1.93)	43	3	271 (1.1)	0.76 (0.23–2.55)
Major	9	3	44 (6.8)	3.25 (0.91–11.66)	8	2	45 (4.4)	2.84 (0.60–13.39)
Maximum severity,[d] class 0 (ref)	299	49	1651 (3.0)	1	271	27	1629 (1.7)	1
Class 1	39	6	218 (2.8)	0.89 (0.36–2.17)	36	3	214 (1.4)	0.80 (0.23–2.82)
Class 2	30	2	187 (1.1)	0.38 (0.09–1.59)	27	0	185 (0)	–[c]
Class 3	26	7	127 (5.5)	2.17 (0.93–5.05)	24	5	131 (3.8)	2.39 (0.87–6.61)
Moisture damage with mold, no (ref)	378	58	2114 (2.7)	1	343	31	2084 (1.5)	1
Spots	8	3	36 (8.3)	3.13 (0.89–11.02)	7	2	36 (5.6)	3.35 (0.70–16.14)
Visible mold	8	3	33 (9.1)	4.82 (1.29–18.02)*	8	2	39 (5.1)	5.53 (1.11–27.48)*
Moisture damage with mold odor, no (ref)	391	63	2170 (2.9)	1	356	35	2145 (1.6)	1
Yes	3	1	13 (7.7)	1.82 (0.22–15.19)	2	0	14 (0)	–[c]
Other main living areas								
Moisture damage, no (ref)	302	48	1690 (2.8)	1	276	25	1681 (1.5)	1
Minor	53	10	285 (3.5)	1.40 (0.68–2.90)	46	7	265 (2.6)	2.20 (0.89–5.45)
Major	39	6	208 (2.9)	1.15 (0.47–2.83)	36	3	213 (1.4)	1.02 (0.30–3.54)
Moisture damage with mold, no (ref)	366	59	2030 (2.9)	1	330	32	1998 (1.6)	1
Spots	10	2	61 (3.3)	1.41 (0.33–6.15)	10	2	61 (3.3)	2.80 (0.62–12.76)
Visible mold	18	3	92 (3.3)	1.06 (0.31–3.62)	18	1	100 (1.0)	0.65 (0.08–5.01)
Moisture damage with mold odor, no (ref)	390	63	2159 (2.9)	1	354	34	2135 (1.6)	1
Yes	4	1	24 (4.2)	1.66 (0.21–13.13)	4	1	24 (4.2)	3.06 (0.35–26.48)
Child's main living areas								
Moisture damage or mold (combined)								
No moisture damage and no mold (ref)	254	39	1437 (2.7)	1	230	22	1410 (1.6)	1
Minor damage with or without mold spots	90	17	485 (3.5)	1.31 (0.72–2.36)	81	9	475 (1.9)	1.25 (0.56–2.79)
Major moisture damage or any moisture damage with visible mold	50	8	261 (3.1)	1.33 (0.60–2.98)	47	4	274 (1.5)	0.98 (0.32–2.95)

*$P < .05$; ** $P < .01$. aOR, adjusted odds ratio; CI, confidence interval; *N*, total number of children in the beginning of the follow-up; *n*, the number of cases in each category.

[a] Subjects contributed up to 7 repeated observations to this survival analysis that used discrete-time hazard models.

[b] Models were adjusted for study cohort, farming status, gender, maternal history of allergic diseases (hay fever, atopic dermatitis, and/or asthma), smoking during pregnancy, and number of siblings.

[c] Cannot be estimated.

[d] Defined as the highest "need for repair" class of the damage in a given area (discussed in the Supplemental Information).

children. No such effect modification (*P* value for interaction, >.2) was observed for parental history of atopy, for living on a farm, or for cohort (data not shown). No consistent associations were found between moisture damage with or without mold and sensitization to inhalant allergens at the age of 6 years (Table 2) or between moisture damage or mold in the child's main living areas and sensitization to dust

TABLE 2 Adjusted Associations Between Characteristics of Moisture Damage and Mold and Presence of Respiratory Symptoms at Each Questionnaire Survey and Sensitization to Inhalant Allergens at the Age of 6 Years

Characteristic	Wheezing Apart From Cold		Nocturnal Cough Apart From Cold		Sensitization to Inhalant Allergens[a]	
	N[b] (%)	aOR[c] (95% CI)	*N*[b] (%)	aOR[c] (95% CI)	*N* (%)	aOR[c] (95% CI)
Kitchen						
Moisture damage, no (ref)	1913 (6.9)	1	1908 (16.5)	1	232 (38.8)	1
Minor	501 (7.8)	1.10 (0.63–1.90)	501 (16.0)	1.01 (0.65–1.57)	62 (33.9)	0.89 (0.48–1.64)
Major	133 (14.3)	2.20 (1.08–4.49)*	134 (17.2)	1.05 (0.52–2.12)	16 (37.5)	1.16 (0.39–3.43)
Moisture damage with mold, no (ref)	2448 (7.2)	1	2444 (16.4)	1	297 (38.4)	1
Spots	34 (14.7)	1.35 (0.40–4.58)	34 (14.7)	0.66 (0.18–2.36)	5 (20.0)	0.41 (0.04–3.77)
Visible mold	65 (10.8)	1.21 (0.39–3.75)	65 (18.5)	0.97 (0.37–2.51)	8 (25.0)	0.59 (0.11–3.10)
Living room						
Moisture damage, no (ref)	2098 (6.7)	1	2093 (15.4)	1	255 (39.6)	1
Minor	313 (10.5)	1.35 (0.73–2.50)	313 (21.4)	1.51 (0.93–2.47)	39 (30.8)	0.73 (0.35–1.53)
Major	136 (11.0)	2.07 (0.70–6.18)	137 (19.7)	1.71 (0.83–3.55)	16 (25.0)	0.55 (0.17–1.80)
Moisture damage with mold, no (ref)	2474 (7.1)	1	2469 (16.1)	1	301 (38.2)	1
Spots	40 (10.0)	1.18 (0.36–3.83)	40 (17.5)	0.83 (0.29–2.42)	5 (20.0)	0.41 (0.04–3.95)
Visible mold	33 (27.3)	5.77 (1.16–28.72)*	34 (35.3)	3.56 (0.98–13.01)	4 (25.0)	0.64 (0.06–6.41)
Moisture damage with mold odor, no (ref)	2527 (7.4)	1	2523 (16.3)	1	308 (37.7)	1
Yes	20 (5.0)	0.85 (0.17–4.12)	20 (30.0)	1.64 (0.59–4.56)	2 (50.0)	1.07 (0.06–18.11)
Child's bedroom						
Moisture damage, no (ref)	2173 (7.5)	1	2169 (16.2)	1	264 (27.9)	1
Minor	316 (5.4)	0.72 (0.33–1.60)	315 (14.3)	0.93 (0.54–1.59)	38 (39.5)	1.12 (0.55–2.29)
Major	58 (17.2)	2.21 (0.76–6.41)	59 (33.9)	2.66 (1.00–7.09)*	8 (25.0)	0.66 (0.13–3.41)
Moisture damage with mold, no (ref)	2443 (7.0)	1	2439 (15.9)	1	298 (37.9)	1
Spots	51 (17.7)	2.58 (0.67–9.96)	50 (30.0)	1.69 (0.69–4.16)	6 (33.3)	0.71 (0.12–4.24)
Visible mold	53 (15.1)	2.05 (0.51–8.21)	54 (25.9)	1.88 (0.51–6.89)	6 (33.3)	1.10 (0.19–6.29)
Moisture damage with mold odor, no (ref)	2530 (7.4)	1	2526 (16.3)	1	308 (37.7)	1
Yes	17 (11.8)	0.83 (0.25–2.81)	17 (35.3)	1.55 (0.26–9.32)	2 (50.0)	1.52 (0.09–25.44)
Other main living areas						
Moisture damage, no (ref)	1946 (6.8)	1	1940 (16.7)	1	233 (38.6)	1
Minor	350 (7.7)	0.97 (0.49–1.91)	349 (17.5)	1.04 (0.65–1.67)	45 (33.3)	0.92 (0.46–1.85)
Major	251 (11.6)	1.65 (0.81–3.35)	254 (13.0)	0.79 (0.43–1.43)	32 (37.5)	1.10 (0.49–2.48)
Moisture damage with mold, no (ref)	2361 (7.1)	1	2356 (16.6)	1	284 (38.7)	1
Spots	70 (12.9)	1.90 (0.51–7.19)	70 (15.7)	0.97 (0.43–2.21)	9 (33.3)	0.83 (0.20–3.49)
Visible mold	116 (10.3)	1.26 (0.42–3.76)	117 (13.7)	0.79 (0.30–2.07)	17 (23.5)	0.59 (0.18–1.89)
Moisture damage with mold odor, no (ref)	2519 (7.4)	1	2515 (16.5)	1	307 (37.5)	1
Yes	28 (10.7)	1.75 (0.62–4.94)	28 (7.1)	0.40 (0.07–2.41)	3 (66.7)	2.11 (0.18–24.54)
Child's main living areas						
Moisture damage or mold (combined)						
No moisture damage and no mold	1627 (6.6)	1	1623 (15.9)	1	197 (39.1)	1
Minor moisture damage with or without mold spots	587 (7.5)	1.16 (0.69–1.94)	586 (16.2)	1.07 (0.71–1.59)	72 (36.1)	0.94 (0.53–1.66)
Major moisture damage or any moisture damage with visible mold	333 (11.4)	1.69 (0.88–3.24)	334 (19.2)	1.27 (0.77–2.09)	41 (34.2)	0.96 (0.46–2.00)

*$P < .05$. aOR, adjusted odds ratio; CI, confidence interval.

[a] Atopic sensitization to any tested inhalant allergen (≥0.70 kU/L) at the age of 6 years.

[b] Subjects contributed up to 7 repeated observations to this analysis by using logistic regression with generalized estimating equations.

[c] Models were adjusted for study cohort, farming status, gender, maternal history of allergic diseases (hay fever, atopic dermatitis, and/or asthma), smoking during pregnancy, and number of siblings.

mites or to the outdoor mold *Alternaria alternata* (data not shown).

DISCUSSION

In the present study, observations of moisture damage in the living rooms, child's bedrooms, and kitchens (but not in the bathrooms or other interior spaces) were associated with the risk of physician-diagnosed asthma ever, persistent asthma, and respiratory symptoms. Associations with asthma ever were strongest for moisture damage with visible mold in the child's bedroom and in the living room. The observed associations with asthma ever were stronger among atopic children and during the first 2 years of follow-up. No consistent associations were found between moisture damage with or without mold and atopic sensitization.

Moisture damage with or without mold in the child's bedroom or living room was associated with asthma ever or persistent asthma, that were rather diagnosed during the first 2 years of life but not later. These effects were weaker in the latter part

TABLE 3 Adjusted Associations Between Moisture Damage or Mold in the Child's Main Living Areas (combined) and Incidence of Asthma Stratified by Age When Asthma Was Physician-Diagnosed at First Time and by Atopy at the Age of 1 Year

	Asthma Ever					Asthma Ever				
	Diagnosed First Time at Age ≤2 Years (n = 30)		Diagnosed First Time at Age >2 Years (n = 34)		P[d]	Children Without Atopy[e]		Children With Atopy[f]		P[h]
	N[a] (%)	aOR[b] (95% CI)	N[c] (%)	aOR[b] (95%CI)		N[g] (%)	aOR[b] (95% CI)	N[g] (%)	aOR[b] (95% CI)	
No moisture damage and no mold (ref)	710 (1.8)	1	727 (3.6)	1		967 (2.6)	1	383 (3.4)	1	
Minor moisture damage with or without mold spots	246 (3.7)	2.05 (0.84–5.00)	239 (3.4)	0.96 (0.42–2.18)		295 (3.4)	1.24 (0.57–2.71)	182 (3.3)	0.95 (0.34–2.63)	
Major moisture damage or any moisture damage with visible mold	135 (5.9)	3.81 (1.45–10.01)**	126 (0)	–[i]	.001	216 (1.9)	0.82 (0.27–2.45)	36 (11.1)	9.08 (1.95–42.23)**	.04

**$P < .01$. aOR, adjusted odds ratio; CI, confidence interval.

[a] Subjects contributed up to 3 repeated observations to this survival analysis that used the discrete-time hazard model.

[b] Models were adjusted for study cohort, farming status, gender, maternal history of allergic diseases (hay fever, atopic dermatitis, and/or asthma), smoking during pregnancy, and number of siblings.

[c] Subjects contributed up to 4 repeated observations to this survival analysis that used the discrete-time hazard model.

[d] P value for interaction term between 2 age groups.

[e] Nonatopic children were defined as every tested specific IgE <0.35 kU/L at the age of 1 year.

[f] Atopic children were defined as any specific IgE ≥0.35 kU/L at the age of 1 year.

[g] Subjects contributed up to 7 repeated observations to this survival analysis that used the discrete-time hazard model.

[h] P value for interaction term between atopic and nonatopic children.

[i] Cannot be estimated.

of the follow-up period. In line with our findings, a meta-analysis of European birth cohorts showed that the strongest effect on asthma was found among children aged ≤2 years.[15] In addition, in a birth cohort from Cincinnati, Ohio, inspector-observed moisture damage or visible mold in the home at an early age was associated with recurrent wheezing at the age of 1 year,[16] but no association was found with asthma at 7 years of age.[17] Our results indicate that exposure to moisture damage with or without mold at an early age is not only associated with asthma ever started at early age but also with persistent asthma, which is likely to remain symptomatic until adulthood.[18]

The results of this study from the current 6-year follow-up and from the previous 18-month follow-up[10] demonstrated that the location of the moisture damage in the home is important, which we also suggested previously.[13] Significant associations with asthma and wheezing were mainly noted for moisture damage with or without mold in the main living area, child's bedroom,[10,13] and kitchen.[10] No consistent associations were found for damage in bathrooms or when the classification of the whole house was used,[10,13] which could be due to the fact that bathrooms in Finland usually include a mechanical exhaust, resulting in negative air pressure and increased ventilation. The aforementioned rooms are obviously the rooms in which the children spend most of their time. The presence of moisture damage with or without mold in the kitchen may be important for children during the first year of life,[10] because at that age, children (at least Finnish) are mainly taken care of at home and they spend a lot of time in the kitchen with their parents. However, in the present study, the damage located in the kitchen

TABLE 4 Adjusted Associations Between Moisture Damage in the Child's Main Living Areas (combined) and Presence of Respiratory Symptoms Stratified According to Age

	Wheezing Apart From Cold			Nocturnal Cough Apart From Cold		
	Aged <3 y aOR[a] (95%CI)	Aged 3–6 Years aOR[a] (95%CI)	P[b]	Aged <3 y aOR[a] (95%CI)	Aged 3–6 Years aOR[a] (95%CI)	P[b]
No moisture damage and no mold (ref)	1	1		1	1	
Minor moisture damage with or without mold spots	1.38 (0.80–2.39)	0.84 (0.37–1.92)		1.09 (0.68–1.73)	1.05 (0.63–1.74)	
Major moisture damage or any moisture damage with visible mold	2.44 (1.25–4.75)**	1.01 (0.36–2.86)	.08	1.62 (0.93–2.81)	1.01 (0.51–1.98)	.54

**$P < .01$. aOR, adjusted odds ratio; CI, confidence interval.

[a] Models were adjusted for study cohort, farming status, gender, maternal history of allergic diseases (hay fever, atopic dermatitis and/or asthma), smoking during pregnancy, and number of siblings.

[b] P value for interaction term between 2 age groups.

appeared less important than in the earlier follow-up period.

If the house is large, as in the present study, the main living area may include rooms in which the children do not spend much time. Thus, we found weaker respiratory health effects for moisture damage with or without mold in the other main living areas than in the child's main living area. However, it can be argued that moisture damage in different rooms may have similar effects on health (ie, if the child spends time in rooms or if the air is effectively mixed in the whole living space). When assessing exposure to moisture damage and mold, taking into account the size of the home, air exchange and/or ventilation within and between the rooms, as well as occupants' time spent in these rooms, should be investigated in more detail in future studies.

In the present study, moisture damage with or without mold was associated with asthma ever, especially in children with atopy. The results from earlier studies are contradictory. Earlier findings from prospective or case-control studies[13,15]support our findings, but the results from a few cross-sectional studies do not.[19] Most of the other studies[20–23] compared atopic asthma or atopic wheeze with all nonasthmatic or nonwheezing children, which leads to biased estimates[24]; thus, the results are not comparable. Atopic children seem to be more sensitive to environmental exposures such as mold, and they therefore comprise a particular group who should avoid exposure to mold and moisture damage in buildings.

We found no associations between moisture damage with or without mold in the home in infancy and atopic sensitization at the age of 6 years. This outcome is in line with a recent meta-analysis[15] and with the report of the World Health Organization,[4] which categorized the evidence of an association between moisture damage and atopy as insufficient. The present cohort study found a tendency for a positive association between mold exposure and atopy when the children were 1 year of age.[10] This association was possibly transient and related to the natural maturation of the immune system at an early age. The mechanisms behind the adverse health effects of moisture damage and mold may not be IgE mediated. Only a small proportion of exposed people are sensitized to molds.[25] Exposure to moisture damage or mold may cause allergy-like symptoms due to histamine release[4] without measured IgE levels. Repeated irritation in the respiratory tract might lead to long-lasting inflammation and inflammation-related diseases (eg, asthma).

Our exposure assessment was based on a home investigation by a trained engineer, similar to some other studies on asthma incidence.[5] Self-reporting can cause biased results, especially in cross-sectional studies in which the parents of symptomatic children may overreport the damage or parents in damaged homes may overreport the symptoms of the child[8] due to awareness of potential adverse health effects. These biases could have occurred in cross-sectional studies, which have reported strong associations between moisture damage or mold in the whole house and health outcomes in children.[4] This type of bias was also suggested by a case-control study, in which self-reported house dampness was associated with symptoms, but no associations were found with inspector-observed dampness.[26]

The main strengths of our study are its prospective study design with high participation rate and the use of a trained engineer to observe and characterize in detail each observation of moisture damage or mold throughout the house. Relaying the results of the moisture damage investigation to the parents may have affected their reporting of respiratory symptoms, but this action probably had less effect on parent-reported physician-diagnosed asthma and no effect on atopic sensitization. A weakness of the study is that exposure assessment only covers early infancy; we were therefore unable to estimate the effect of lifetime exposure or length of exposure to moisture damage or mold on the development of asthma. Because the home inspection was based only on observation and nondestructive measurements, the sensitivity to detect all (especially hidden) moisture damage is limited.

Our estimates, especially regarding the associations between asthma ever or persistent asthma and moisture damage with or without visible mold in the living room and in the child's bedroom, are unstable due to low numbers. Given the estimates from earlier studies[5] and the low number of children in our study, the true associations are likely to be smaller than estimates presented in this study. This outcome is also reflected in the lower estimates for the combined variable for child's main living areas, which are close to the estimates obtained from recent meta-analyses.[5] Larger prospective studies are needed, with objective and detailed assessment of moisture damage and mold, to obtain new and more accurate methods of assessing asthma risk in moisture-damaged buildings.

CONCLUSIONS

Moisture damage and mold in early infancy in the child's bedroom, living room, or kitchen were associated with asthma development. Atopic children may be more susceptible than nonatopic children to the harmful effects of moisture damage and mold growth.

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REFERENCES

1. Institute of Medicine. *Damp Indoor Spaces and Health*. Washington, DC: National Academies Press; 2004
2. Bornehag CG, Blomquist G, Gyntelberg F, et al. Dampness in buildings and health. Nordic interdisciplinary review of the scientific evidence on associations between exposure to "dampness" in buildings and health effects (NORDDAMP). *Indoor Air*. 2001;11(2):72–86
3. Mendell MJ, Mirer AG, Cheung K, Tong M, Douwes J. Respiratory and allergic health effects of dampness, mold, and dampness-related agents: a review of the epidemiologic evidence. *Environ Health Perspect*. 2011;119(6):748–756
4. World Health Organization. World Health Organization. WHO Guidelines for Indoor Air Quality: Dampness and Mold. 2009. Available at: www.euro.who.int/__data/assets/pdf_file/0017/43325/E92645.pdf. Accessed January 7, 2015
5. Quansah R, Jaakkola MS, Hugg TT, Heikkinen SA, Jaakkola JJ. Residential dampness and molds and the risk of developing asthma: a systematic review and meta-analysis. *PLoS One*. 2012;7(11):e47526
6. Engman LH, Bornehag CG, Sundell J. How valid are parents' questionnaire responses regarding building characteristics, mouldy odour, and signs of moisture problems in Swedish homes? *Scand J Public Health*. 2007;35(2):125–132
7. Haverinen-Shaughnessy U, Hyvärinen A, Pekkanen J, et al. Occurrence and characteristics of moisture damage in residential buildings as a function of occupant and engineer observations. *Indoor Built Environ*. 2005;14(2):133–140
8. Strachan DP, Elton RA. Relationship between respiratory morbidity in children and the home environment. *Fam Pract*. 1986;3(3):137–142
9. Sun Y, Sundell J, Zhang Y. Validity of building characteristics and dorm dampness obtained in a self-administrated questionnaire. *Sci Total Environ*. 2007;387(1–3):276–282
10. Karvonen AM, Hyvärinen A, Roponen M, et al. Confirmed moisture damage at home, respiratory symptoms and atopy in early life: a birth-cohort study. *Pediatrics*. 2009;124(2). Available at: www.pediatrics.org/cgi/content/full/124/2/e329
11. von Mutius E, Schmid S; PASTURE Study Group. The PASTURE project: EU support for the improvement of knowledge about risk factors and preventive factors for atopy in Europe. *Allergy*. 2006;61(4):407–413
12. Nevalainen A, Partanen P, Jääskeläinen E, et al. Prevalence of moisture problems in Finnish houses. *Indoor Air*. 1998;7(suppl 4):45–49
13. Pekkanen J, Hyvärinen A, Haverinen-Shaughnessy U, Korppi M, Putus T, Nevalainen A. Moisture damage and childhood asthma: a population-based incident case-control study. *Eur Respir J*. 2007;29(3):509–515
14. Herzum I, Blümer N, Kersten W, Renz H. Diagnostic and analytical performance of a screening panel for allergy. *Clin Chem Lab Med*. 2005;43(9):963–966
15. Tischer CG, Hohmann C, Thiering E, et al; ENRIECO consortium. Meta-analysis of mould and dampness exposure on asthma and allergy in eight European birth cohorts: an ENRIECO initiative. *Allergy*. 2011;66(12):1570–1579
16. Cho SH, Reponen T, LeMasters G, et al. Mold damage in homes and wheezing in infants. *Ann Allergy Asthma Immunol*. 2006;97(4):539–545
17. Reponen T, Singh U, Schaffer C, et al. Visually observed mold and moldy odor versus quantitatively measured microbial exposure in homes. *Sci Total Environ*. 2010;408(22):5565–5574
18. Grad R, Morgan WJ. Long-term outcomes of early-onset wheeze and asthma. *J Allergy Clin Immunol*. 2012;130(2):299–307
19. Weinmayr G, Gehring U, Genuneit J, et al; ISAAC Phase Two Study Group. Dampness and moulds in relation to respiratory and allergic symptoms in children: results from Phase Two of the International Study of Asthma and Allergies in Childhood (ISAAC Phase Two). *Clin Exp Allergy*. 2013;43(7):762–774
20. Iossifova YY, Reponen T, Ryan PH, et al. Mold exposure during infancy as a predictor of potential asthma development. *Ann Allergy Asthma Immunol*. 2009;102(2):131–137
21. Jaakkola JJ, Hwang BF, Jaakkola N. Home dampness and molds, parental atopy, and asthma in childhood: a six-year population-based cohort study. *Environ Health Perspect*. 2005;113(3):357–361
22. Rydjord B, Marton JH, Strømsnes H, et al. Mould-specific immunoglobulin antibodies quantified by flow cytometry reflect mould exposure in Norwegian children. *Clin Exp Allergy*. 2008;38(3):430–437
23. Rönmark E, Jönsson E, Platts-Mills T, Lundbäck B. Different pattern of risk

factors for atopic and nonatopic asthma among children—report from the Obstructive Lung Disease in Northern Sweden Study. *Allergy*. 1999;54(9):926–935

24. Pekkanen J, Lampi J, Genuneit J, Hartikainen AL, Järvelin MR. Analyzing atopic and non-atopic asthma. *Eur J Epidemiol*. 2012;27(4):281–286
25. Immonen J, Meklin T, Taskinen T, Nevalainen A, Korppi M. Skin-prick test findings in students from moisture- and mould-damaged schools: a 3-year follow-up study. *Pediatr Allergy Immunol*. 2001;12(2):87–94
26. Naydenov K, Melikov A, Markov D, Stankov P, Bornehag CG, Sundell J. A comparison between occupants' and inspectors' reports on home dampness and their association with the health of children: The ALLHOME study. *Build Environ*. 2008;43(11):1840–1849

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