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A longitudinal study of environmental risk factors for subjective symptoms associated with sick building syndrome in new dwellings

Tomoko Takigawa [a,*], Bing-Ling Wang [a], Noriko Sakano [a], Da-Hong Wang [a], Keiki Ogino [a], Reiko Kishi [b]

[a] Department of Public Health, Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences, 2-5-1 Shikata-cho, Kita-ku, Okayama, 700-8558, Okayama, Japan
[b] Department of Public Health, Hokkaido University Graduate School of Medicine, Kita 15, Nishi 7, Kita-ku, Sapporo, 060-8638, Hokkaido, Japan

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ABSTRACT

This study was performed to explore possible environmental risk factors, including indoor chemicals, mold, and dust mite allergens, which could cause sick building syndrome (SBS)-type symptoms in new houses. The study was conducted in 2004 and 2005 and the final study population consisted of 86 men and 84 women residing in Okayama, Japan. The indoor concentrations of indoor aldehydes, volatile organic compounds, airborne fungi, and dust mite allergens in their living rooms were measured and the longitudinal changes in two consecutive years were calculated. A standardized questionnaire was used concomitantly to gather information on frequency of SBS-type symptoms and lifestyle habits. About 10% of the subjects suffered from SBS in the both years. Crude analyses indicated tendencies for aldehyde levels to increase frequently and markedly in the newly diseased and ongoing SBS groups. Among the chemical factors and molds examined, increases in benzene and in *Aspergillus* contributed to the occurrence of SBS in the logistic regression model. Indoor chemicals were the main contributors to subjective symptoms associated with SBS. A preventive strategy designed to lower exposure to indoor chemicals may be able to counter the occurrence of SBS.

1. Introduction

Sick building syndrome (SBS) is a constellation of health problems caused by indoor chemical and biological pollution, uncomfortable temperature and humidity, or other factors in office buildings, which has been acknowledged as a problem in Western countries since the 1970s (Godish, 1994; Skov et al., 1987; World Health Organization, 1983). Occupants suffer from a variety of nonspecific subjective symptoms, such as irritation of the eyes, nose, and throat, headache, and general fatigue (Burge et al., 1987; Finnegan et al., 1984; Lyles et al., 1991; Mendell and Smith, 1990). In Japan, some people living in newly-built or renovated residential buildings began to complain of various nonspecific subjective symptoms in the 1990s (Saijo et al., 2004). These symptoms are similar to SBS-related symptoms and have been called "sick house syndrome" (Ando, 2002; Seki et al., 2007; Torii, 2002). This concept has now been applied to similar situations in schools or cars (Schupp et al., 2005; Yoshino et al., 2004).

SBS is difficult to define and no single cause has been identified. Many epidemiological studies have been performed, and a number of possible contributing factors have been reported, including airborne chemicals, microorganisms, physical condition, and psychosocial status (Bornehag et al., 2004; Marmot et al., 2006; Nakayama and Morimoto, 2007; Skov et al., 1989; Sunesson et al., 2006; Teeuw et al., 1994; Wolkoff and Kjaergaard, 2007). However, most of these studies had a cross-sectional design and there were differences among participants. Norback et al. (Norback et al., 1990) carried out a longitudinal research in occupational settings, primary schools, but they performed chemical measurements only in the 4th year. To exclude the time-invariant unobserved differences in individual characteristics, the present longitudinal study was performed to explore indoor aldehydes, VOCs, airborne fungi, house dust mite allergens, and other possible contributing factors. To our knowledge, there have been no longitudinal studies including both wide-ranging environmental measurements and questionnaire survey in many dwellings.

2. Materials and methods

2.1. Study population and selection of houses

This study was conducted in Okayama Prefecture, located in the western part of Japan, between September and December in both 2004 and 2005. In 2003, a preliminary questionnaire survey was carried out on the indoor environment of newly built dwellings and SBS. Dwellings built within 5 years as of 2003 were chosen randomly from building plan approval applications, which are official data available for inspection. The occupants of 91 dwellings (247 residents) from among the respondents of 519 dwellings in the 2003 survey agreed to participate in the 2004 survey. Of the subjects in 2004, 185

* Corresponding author. Department of Public Health, Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences, Mailing address: 2-5-1 Shikata-cho, Okayama 700-8558, Japan. Tel.: +81 86 235 7184; fax: +81 86 226 0715.
E-mail address: ttomoko@md.okayama-u.ac.jp (T. Takigawa).

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residents in 49 dwellings participated in the investigation in 2005. A final total of 170 people from 48 dwellings without missing data were included in the analyses.

This epidemiological study was approved by the Ethics Committee of Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences. All subjects gave their written informed consent.

2.2. Environmental monitoring of chemical substances

Air samples were collected onto diffusive air samplers for aldehydes (DSD-DNPH; Sigma-Aldrich, Tokyo, Japan) and for VOCs (VOC-SD; Sigma-Aldrich) placed approximately 1.5 m above the floor for 24 h. To eliminate contamination effects, field blank samples were obtained simultaneously to subtract the blank results from the crude chemical concentrations. Temperature and relative humidity were also measured. Concentrations of 13 aldehydes (including one ketone, acetone) and 33 VOCs were quantified in the laboratory using the methods described in previously (Takigawa et al., 2004). Briefly, the derivatives in the DSD-DNPH samplers were eluted with acetonitrile before analysis by high-performance liquid chromatography equipped with a UV detector. The VOC-SD samplers were desorbed with carbon disulfide before analysis with a gas chromatograph/mass spectrometer. The analysis methods were standardized to make the results compatible between the two survey years. The list of chemicals included the major components of indoor chemicals detected in Japanese residences (Tanaka-Kagawa et al., 2005). Total VOC (TVOC) concentration was defined as the sum of concentrations of the target VOCs. If aldehydes and VOC concentrations were lower than the limits of quantification (1.0 μg/m^3 for each substance), they were considered half the limit of quantification.

2.3. Environmental monitoring of microorganisms

Airborne fungal spores were collected using an SAS air sampler (AINEX BIO-SAS, International PBI, Milano, Italy) for an air volume of for 0.1 m^3 with dichloran 18% glycerol agar (DG-18) as culture medium. Samples were taken at a height of 1.5 m above the floor in the living room. After incubation, fungal colonies were counted and species were identified morphologically (Wang et al., 2008). The fungal concentrations were expressed as colony forming units per cubic meter of air (cfu/m^3).

Living room floor dust was collected by vacuuming 2 m^2 of wooden floor or tatami (Japanese traditional rush mats), or 1 m^2 of carpet. Dust samples were collected into paper bags using a hand vacuum cleaner (HC-V15; National, Osaka, Japan). Dust mite allergens were measured by ELISA for Der p1 and Der f1 and expressed in micrograms

Table 1
Description of the subjects (n = 170).

	%
Age at the first study	
<10	26.5
10–20	7.1
20–30	9.4
30–40	25.9
40–50	11.8
50–60	12.9
≥60	6.5
Gender	
Male	50.6
Female	49.4
SBS	
Newly diseased	8.8
Ongoing	3.5
Recovered	7.6
Symptom-free	80.0

Table 2
Indoor chemical concentrations in living rooms (n = 48).

	2004			2005			P*
	Median	25%	75%	Median	25%	75%	
Formaldehyde	37.00	28.00	47.44	29.81	20.26	51.93	0.30
Acetaldehyde	15.25	10.60	21.24	7.88	4.61	16.52	<0.01
Acetone	27.81	21.68	35.85	17.83	11.50	26.13	<0.01
Acrolein	0.50	0.50	0.50	0.50	0.50	0.50	0.32
Propionaldehyde	6.60	4.13	11.90	0.50	0.50	0.50	<0.01
Crotonaldehyde	0.50	0.50	3.57	0.50	0.50	2.02	0.26
n-Butyraldehyde	1.40	0.50	2.10	0.50	0.50	0.50	0.01
Benzaldehyde	1.80	0.50	6.76	0.50	0.50	0.50	<0.01
iso-Valeraldehyde	0.50	0.50	4.94	0.50	0.50	0.50	<0.01
Valeraldehyde	1.35	0.50	2.52	0.50	0.50	0.50	<0.01
Tolualdehyde	1.00	1.00	9.17	1.00	1.00	1.00	<0.01
Hexaldehyde	6.00	3.33	19.63	0.50	0.50	1.48	<0.01
2,5-Dimethylaldehyde	0.50	0.50	0.50	0.50	0.50	0.50	0.03
Methylethylketone	0.50	0.50	2.78	2.21	0.50	3.22	0.29
Ethyl acetate	2.80	0.50	8.09	3.24	0.50	7.77	0.84
n-Hexane	0.50	0.50	2.38	0.50	0.50	1.58	0.48
Chloroform	0.50	0.50	0.50	0.50	0.50	1.05	0.59
1,2-Dichloroethane	0.50	0.50	0.50	0.50	0.50	0.50	0.05
2,4-Dimethylpentane	0.50	0.50	0.50	0.50	0.50	0.50	0.66
1,1,1-Trichloroethane	0.50	0.50	0.50	0.50	0.50	0.50	0.32
n-Butanol	0.50	0.50	1.43	0.50	0.50	0.90	0.90
Benzene	1.20	0.50	4.48	1.77	1.36	2.69	0.76
Carbon tetrachloride	0.50	0.50	0.50	0.50	0.50	0.50	1.00
1,2-Dichloropropane	0.50	0.50	0.50	0.50	0.50	0.50	1.00
Trichloroethylene	0.50	0.50	0.50	0.50	0.50	0.50	0.18
n-Heptane	0.50	0.50	1.98	0.50	0.50	1.34	0.63
Methylisobutylketone	0.50	0.50	0.50	0.50	0.50	0.89	0.42
Toluene	9.80	8.02	19.43	7.49	3.98	9.69	<0.01
Chlorodibromomethane	0.50	0.50	0.50	0.50	0.50	0.50	0.18
Butyl acetate	1.35	0.50	4.35	1.92	0.65	3.48	0.81
n-Octane	0.50	0.50	1.58	1.08	0.50	1.95	0.24
Tetrachloroethylene	0.50	0.50	0.50	0.50	0.50	0.50	0.66
Ethylbenzene	2.57	1.53	4.39	1.82	1.00	3.27	0.02
m, p-Xylene	3.52	1.13	5.76	2.55	1.32	3.44	0.03
Styrene	0.50	0.50	0.50	0.50	0.50	0.50	0.74
n-Nonane	0.80	0.50	5.46	0.78	0.50	4.02	0.39
o-Xylene	1.50	0.50	2.30	0.50	0.50	1.59	0.04
α-Pinene	7.35	2.23	21.93	4.88	1.60	13.43	0.02
1,3,5-Trimethylbenzene	0.50	0.50	1.23	0.50	0.50	0.50	0.04
n-Decane	0.50	0.50	7.25	0.50	0.50	3.15	0.08
1,2,4-Trimethylbenzene	2.26	1.29	6.66	1.39	0.50	2.34	<0.01
p-Dichlorobenzene	2.75	1.13	30.80	2.19	1.05	9.91	0.01
1,2,3-Trimethylbenzene	0.50	0.50	0.50	0.50	0.50	0.50	0.98
Limonene	10.00	4.46	30.05	5.63	2.38	10.56	0.01
n-Undecane	1.20	0.50	6.48	2.16	1.10	4.87	0.74
TVOC	101.50	63.10	190.83	69.00	50.00	123.34	0.01

Units: μg/m^3; TVOC = total volatile organic compounds. *Wilcoxon test.

Table 3
Concentrations of mold colonies and dust mite allergen levels in living rooms (n = 48).

	2004			2005			P*
	Median	25%	75%	Median	25%	75%	
Genus							
Alternaria	0	0	10	0	0	0	< 0.01
Aspergillus	10	0	27.5	10	0	20	0.65
Aureobasidium	0	0	0	0	0	0	0.16
Candida	0	0	0	0	0	0	0.50
Cladosporium	185	72.5	810	335	150	717.5	0.15
Cryptococcus	0	0	0	0	0	0	1.00
Eurotium	0	0	0	0	0	10	< 0.01
Rhodotorula	0	0	0	0	0	0	0.03
Strain							
Arthrinium sp.	0	0	0	0	0	0	0.09
Penicillium sp.	20	0	60	0	0	0	< 0.01
Fusarium sp.	0	0	10	0	0	0	0.01
Total colonies	325	187.5	995	565	255	957.5	0.22
Der p	0.3	0.1	1.3	0.1	0.1	2.8	0.96
Der f	1.0	0.4	4.1	2.2	0.7	5.2	0.05
Der 1	2.2	0.6	8.9	3.7	0.9	12.1	0.09

Units: cfu/m^3 for mold colonies and μg/g fine dust for dust mite allergen levels. *Wilcoxon test.