

The effect of house design and environment on fungal movement in homes of bronchial asthma patients *

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Abstract

The effect of house building design and environment on the fungal movement in the houses of 41 bronchial asthma (BA) patients has been investigated by examining house dust. The presence and composition of fungi were determined and compared in relation to building structure, house age, size of living room, main flooring material, presence of a living-room rug or air purifier, and frequency of vacuum cleaning. Among these elements, fungal CFU apparently varied only between building structure: wooden-board houses had significantly higher numbers of fungi than reinforced concrete houses ($p < 0.01$), and wooden mortar or iron-framed prefabricated houses had significantly higher numbers of fungi than reinforced concrete houses ($p < 0.05$). Classification of the types of fungi present in the house dust of BA patients showed that, regardless of the building designs, there were high levels of osmophilic fungi (group A) and fungi that survive at relatively dry conditions (group B), whereas fungi that survive in very wet conditions (group D) were present at low frequency.

Key words: allergy, bronchial asthma, fungi, house design, house dust

Introduction

It is well known that bronchial asthma (BA) is caused by fungi as well as mites [1–3]. In a housing environment, fungi can be as important as mites as potential allergens [4–7]. Previously, we have researched the types of fungi, mainly air-born fungi, that we encounter in our living surroundings and have reported the fungal composition in wholehouse environments as fungal presence in house dust is a good indicator of fungal movement within the house environment [8, 9]. Research on the movement of fungi observed in the housing environment has included measuring monthly changes in fungal content; however, studies of differences in fungal numbers and composition arising from differences in house design have not been reported for the homes of BA patients.

In particular, modern house environments are not necessarily beneficial to our health because recent house designs have a tendency to favor comfort above

anything else. For example, house environments are becoming more draught-free or airtight and include various functions to utilize narrow space effectively. In terms of our health, neither of these features can be said to create a desirable environment [10].

The presence of fungi in houses is influenced by structural features and the age of the house, the floor materials, the inhabitants, the direction in terms of the sun and the degree to which the house is exposed to sunlight. In this study, we have examined to what extent the frequency of fungal outbreak may depend on house design and environment in the homes of BA patients, and also what improvements are required to make the housing environment more beneficial to health.

Materials and methods

The subject of the research

The study targeted 41 outpatients with bronchial

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asthma (BA) who attend the National Sagamihara Hospital, Kanagawa prefecture, Japan.

House design

The amounts and distributions of fungi were compared among the houses of the 41 BA patients for each of the following design elements.

- (1) Composition of building structure: reinforced concrete, iron-framed prefab, wooden mortar or wooden plate attachment.
- (2) House age: less than 3 yrs, 3–10 yrs or more than 10 yrs.
- (3) Size of living room: less than 10 m² or more than 12 m².
- (4) Main flooring material: TATAMI or wooden board.
- (5) Living-room rug: presence or absence.
- (6) Air purifier: presence or absence.
- (7) Frequency of vacuum cleaning: daily, once every 2–3 d or less than once a week.

Test sample for fungal detection

House dust from the homes of the BA patients collected from the vacuum cleaner over 10 days was tested for fungi.

Methods for fungal detection

A test sample was taken from the gathered house dust and incubated at 25 °C for 1 week by a dilution plate method using potato dextrose agar for general fungi and M4OY agar supplemented with an antimicrobial agent, such as chloramphenicol, for xerophilic fungi. After incubation, determination of fungal numbers and identification were carried out according to conventional methods.

Fungal evaluation

Fungi were classified as follows.

Group A: Osmophilic or xerophilic fungi, mostly *Aspergillus restrictus*, *Eurotium* and *Wallemia*.

Group B: Fungi surviving at relatively dry conditions for a long time, mostly *Aspergillus* (except *A. restrictus*) and *Penicillium*.

Group C: Fungi surviving at relatively wet conditions, and vulnerable to dry. Many fungi corresponding to this group: *Acremonium*, *Alternaria*, *Arthrinium*, *Aureobasidium*, *Cladosporium*, *Fusarium*, *Phoma*, etc.

Group D: Fungi surviving at highly wet conditions only, but markedly vulnerable to dry: *Absidia*, *Mucor*, *Rhizopus*, *Trichoderma*, and yeasts.

Fungi were classified into groups A–D and compared against the design elements listed above.

Results and discussions

Questionnaire for a style of building

The 41 BA patients filled in a questionnaire for the building designs of their houses. The results are listed in Table 1.

The building structure of the BA patients' homes was classified into 4 main types: 21 houses were made of wooden mortar; 11 reinforced concrete, 4 iron-framed prefabricated and 5 wooden board. Draught exclusion has been of great importance in modern housing design, and many of the houses had a high level of airtightness [11].

In terms of house age, houses were classified into three groups: 6 houses were comparatively new (less than 3 years after building); 6 houses were comparatively old (less than 10 years); and 29 houses were quite old (more than 10 years). Newly built houses (under 1-yr-old) were classified into the 'comparatively new' group because they were too few in number to be classified separately. It would be worth examining more specifically the relationship between house age and fungal content because the older houses showed a characteristic distribution of fungi.

The size of the living room was classified into areas that were less than 10 m² in 17 patient houses and more than 12 m² in 24 patient houses. The relationship of the house living area and fungi was investigated because of the length of time spent in the living space.

For the main flooring material, 17 houses had TATAMI flooring and 24 houses had wooden board flooring. The relationship of floor materials and fungi was investigated because of the variation in the quantity or quality of dust generated by the two flooring materials. In addition, 22 patient houses had a living-room rug (or carpet), and 19 houses had no rug. The amounts and distributions of fungi were compared between houses that had rugs and those that did not. Generally, the use of rugs gives rise to an increase in mite allergens [12–14]. Considering the symbiosis between fungi and mites, we thought that the use of rugs might also increase the presence and composition of fungi in the housing environment.

Table 1. Detail contents of house design in BA patients pattern

House no.	Structural features	House age (years)	Living space (m ²)	Flooring type	Living rug	Air purifier	Vacuum cleaner
1	Iron-framed prefabricated	10+	20	Flooring	No use	No use	Daily
2	Wooden mortar	—1	10	Flooring	Use	No use	Daily
3	Reinforced concrete	—1	10	Tatami	No use	No use	Once every 2–3 days
4	Wooden mortar	1–3	20	Flooring	Use	No use	Once every 2–3 days
5	Reinforced concrete	10+	20	Flooring	No use	Use	Daily
6	Wooden board	5–10	10	Tatami	Use	No use	Daily
7	Wooden mortar	—1	20	Flooring	No use	No use	Once every 2–3 days
8	Wooden board	3–5	20	Tatami	Use	No use	Daily
9	Iron-framed prefabricated	10+	10	Tatami	No use	No use	Less than once a week
10	Reinforced concrete	10	25	Other	No use	No use	Daily
11	Wooden mortar	10	?	Tatami	Use	No use	Less than once a week
12	Iron-framed prefabricated	10	20	Flooring	No use	No use	Less than once a week
13	Wooden mortar	10+	20	Tatami	No use	No use	Less than once a week
14	Reinforced concrete	10+	10	Flooring	Use	No use	Less than once a week
15	Iron-framed prefabricated	10+	15	Flooring	Use	No use	Once every 2–3 days
16	Wooden mortar	10+	15	Flooring	Use	No use	Once every 2–3 days
17	Wooden mortar	10+	20	Flooring	Use	No use	Once every 2–3 days
18	Wooden mortar	10+	10	Tatami	Use	No use	Once every 2–3 days
19	Wooden mortar	10+	10	Tatami	No use	No use	Once every 2–3 days
20	Wooden mortar	10+	15	Flooring	Use	No use	Less than once a week
21	Reinforced concrete	5–10	10	Tatami	No use	No use	Once every 2–3 days
22	Wooden mortar	10+	30	Flooring	Use	No use	Once every 2–3 days
23	Wooden mortar	5–10	10	Flooring	No use	No use	Daily
24	Reinforced concrete	10+	10	Tatami	Use	No use	Daily
25	Reinforced concrete	10+	10	Tatami	No use	No use	Daily
26	Reinforced concrete	10+	20	Flooring	Use	No use	Once every 2–3 days
27	Reinforced concrete	10+	15	Flooring	Use	No use	Once every 2–3 days
28	Wooden mortar	10+	15	Flooring	Use	No use	Once every 2–3 days
29	Wooden mortar	10+	15	Flooring	Use	Use	Once every 2–3 days
30	Reinforced concrete	1–3	20	Flooring	No use	No use	Once every 2–3 days
31	Wooden mortar	10+	20	Tatami	No use	No use	Once every 2–3 days
32	Wooden board	10+	15	Other	Use	No use	Less than once a week
33	Wooden mortar	10+	10	Tatami	No use	No use	Once every 2–3 days
34	Wooden board	10+	10	Tatami	No use	No use	Once every 2–3 days
35	Wooden mortar	5–10	15	Tatami	No use	Use	Daily
36	Wooden mortar	1–3	25	Flooring	Use	No use	Once every 2–3 days
37	Reinforced concrete	10+	15	Other	Use	No use	Daily
38	Wooden mortar	5–10	10	Flooring	No use	Use	Once every 2–3 days
39	Wooden board	10+	10	Tatami	Use	No use	Once every 2–3 days
40	Wooden mortar	10+	20	Flooring	Use	Use	Once every 2–3 days
41	Wooden mortar	10+	10	Tatami	No use	No use	Once every 2–3 days

The removal of air-borne particles by using an air purifier was regarded as an effective countermeasure. Five patient houses used an air purifier, whereas 36 patient houses did not use one, and the relationship between these two groups and fungal reproduction was examined.

Finally, the physical removal of house dust by using a vacuum cleaner is an effective countermeasure, and we examined to what extent the frequency of vacuum cleaning affected fungal reproduction. Vacuum cleaning was classified into three types: 11 patient houses used a vacuum cleaner daily, 7 patients used one less than once a week and 23 patients used 2–3 times every week.

Fungal group frequency and CFU in the house environment of 41 BA patients

Fungal group frequency from house dust

The fungal group frequency of house dust from 41 BA patients is summarized in Table 2. For each group (A–D), fungal evaluation was divided into two values, $>10^6$ CFU/g and 10^5 – 10^6 CFU/g (house dust) and the main fungal group frequency ($>10^6$ CFU/g) was expressed numerically. Thus, the higher the frequency number, the higher priority of that particular group. Only where a fungus was detected at more than 10^5 CFU/g were the isolates categorized as A to D. Among the house dust of the 41 BA patients, fungal groups A and B were highly detected, whereas group D was detected with a low frequency.

Building structure

In relation to the building structure (reinforced concrete, iron-framed prefabricated, wooden mortar, wooden board), the number of fungi was higher in wooden-board structures than in the other structures. Figure 1 shows both CFU (upper) and main fungal group frequency (lower). Out of the 4 groups, the mean CFU of fungus detected decreased in the order of wooden board $>$ iron-framed prefabricated $>$ wooden mortar $>$ reinforced concrete. The number of each fungus was significantly different higher in wooden board than in reinforced concrete ($p < 0.01$), and was also significantly different higher in wooden mortar or iron-framed prefabricated than in reinforced concrete ($p < 0.05$). This difference in fungal number was regarded as a characteristic of recent house-building design; that is, it seems that the airtightness of structure increases the number of fungi [8, 9].

Table 2. Fungal group frequency of house dust from BA patients

House no.	Fungal group detected	
	More than 10^6 /g	10^5 – 10^6 /g
1	A*, A, B, C	C, C
2	A, A	C
3		A, B, C, D
4		A, C, C, C
5	D	C
6	A, B, B	A, C
7		A
8	A	A, C
9	B	B
10		
11	A, A, B, D	A, C, C, C
12	A, A, C, C	C, D
13	A, A, C	A, B, B, C, C
14		B, C
15	A, A, B, C, C	
16	A, A, A, C, D	C
17	A, B, B	A, A, C, D, D
18	A	B, B, C
19	A, A, B, C	B, C
20	A, A	B, B
21	C	
22	B	A, B, C
23		C, D
24	A, A, B, C	
25	A, A	C, C
26		B, B
27		
28	A	A, C, D
29	A, B, C	A
30		
31		A, C
32	A	A, A, B, B, C, C
33	A, A	C, C
34	A, A	
35		
36	A, A, B, C	B, B, C
37	A, A, B, B, C, D	B, B, B
38	A, C	C
39	A, A, B	A, B, C, C
40	C	B
41	A, A, A	B

* Indication for fungal group isolated from each house dust.

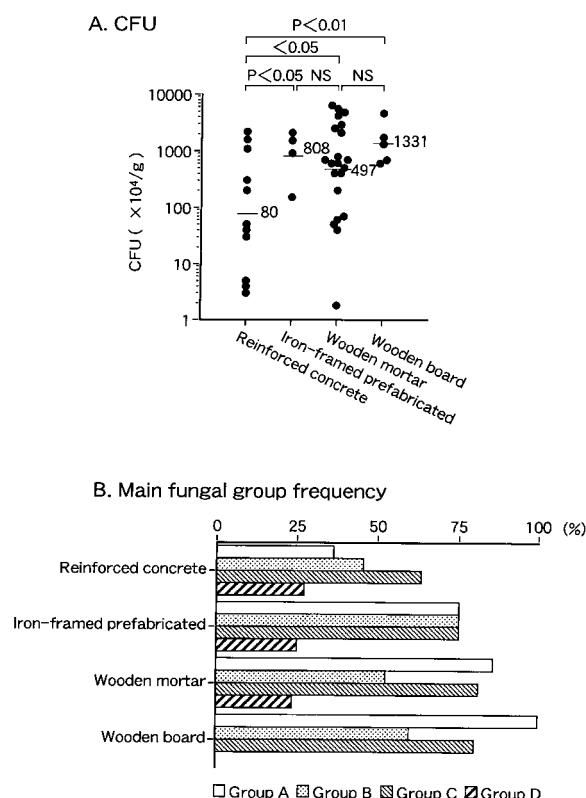


Figure 1. Comparison of CFU and main fungal group frequency in building structure.

House age

In relation to the age of the house, there was no significant difference in the number of fungi between houses of less than 3 years, houses of 3–10 years, and houses of more than 10 years (Figure 2). Although it seems that the number of fungi does not depend on house age, we should point out that in newly built houses the number of fungi was high with characteristic strains of fungi present.

Size of living room

For living-room size, the number of fungi was compared between areas of less than 10 m^2 and areas of more than 12 m^2 . The number of molds was high for living spaces of less than 10 m^2 in living rooms of all structural types (Figure 3). Furthermore, the mean number of fungi was higher in small areas than in areas of more than 12 m^2 , although the difference did not reach statistical significance.

Among the 4 fungal groups, groups A, B and C were present in both classes of room size with no significant differences. It might be expected that a narrow

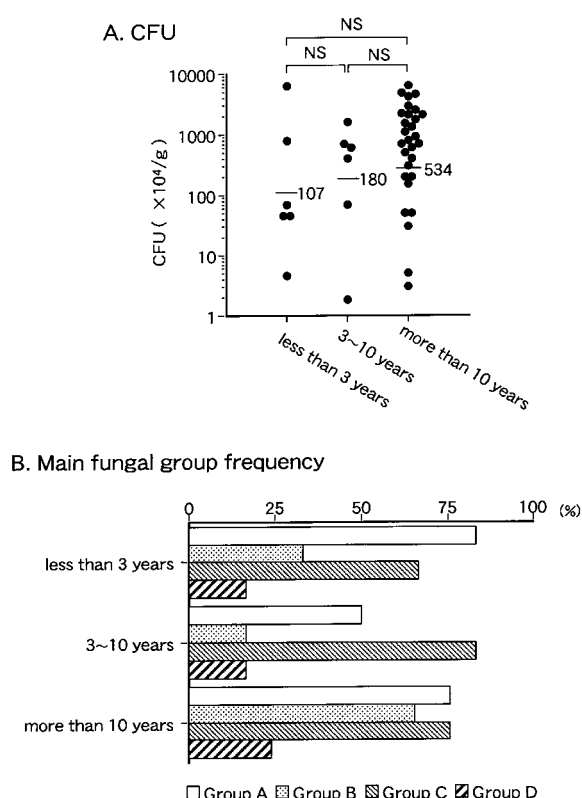


Figure 2. Comparison of CFU and main fungal group frequency in house age.

space would have higher humidity and provide a better environment for growth of microorganisms [15]. However, our result indicates that the fungal number was not affected greatly by room size.

Floor materials

The number of fungi was compared between TATAMI and wooden board flooring materials because TATAMI forms a network in which dust is likely to accumulate, whereas a wooden board is flat and less likely to accumulate dust. Figure 4 shows that the number of fungi tended to be higher for TATAMI, but the difference was not statistically significant. In addition, there was no definite difference in the composition of the fungi present. Namely, A, B, and C groups were dominant in both TATAMI and wooden floors, and D group was not.

Thus, there seems to be no difference in the fungal numbers between TATAMI and wooden board.

Living-room rug

The number of fungi was compared between the use of a rug and the use of other flooring materials, because

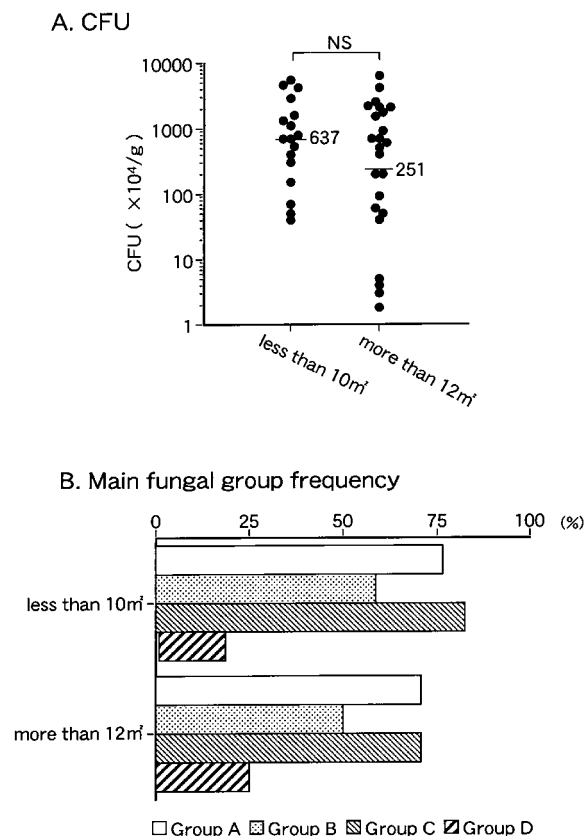


Figure 3. Comparison of CFU and main fungal group frequency in living room.

a carpet is usually synthesized out of fiber, which is likely to accumulate dust. Carpets are also likely to increase the numbers of mites [2, 7], and so would not be recommended for the environment of a patient suffering from allergies. Although no statistically significant difference in the number of fungi were found, there were clearly high numbers of fungi in houses that used rugs (Figure 5). Thus, rugs or carpet constitute a good environment for molds.

In addition, among the main fungal groups, groups A–C were distributed at high frequency. The relationship between rugs and fungi would benefit from further investigation.

Air purifier

The amount of indoor fungi clearly decreased by an air purifier use (Figure 6). Therefore, we examined whether there was a difference in the number of fungi in house dust from houses with and without an air purifier. Although the comparison might not be completely accurate because air purifier use was as little as

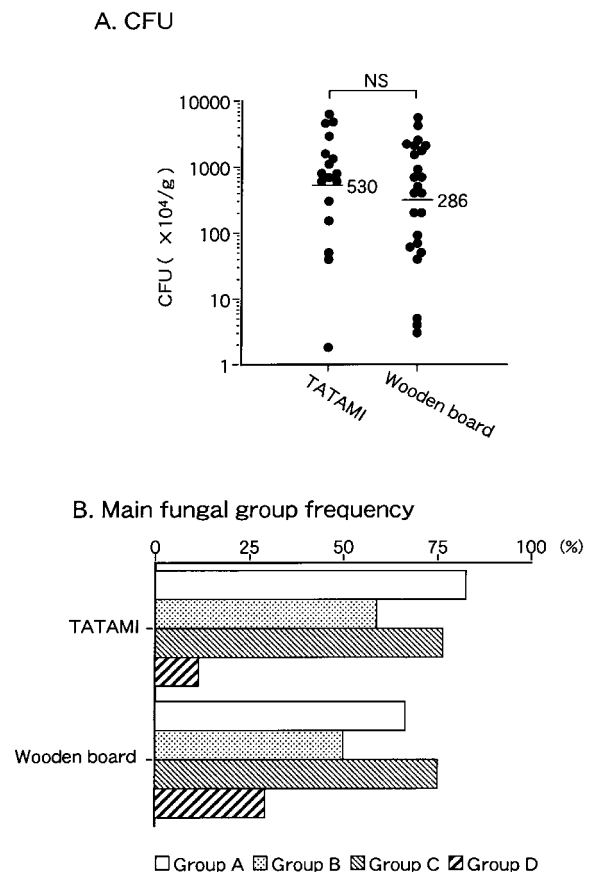


Figure 4. Comparison of CFU and main fungal group frequency in floor materials.

5 times in some cases, the fungal number was slightly higher in dust from houses where an air purifier was not used. However, this difference was not statistically significant.

For the composition of the fungi, the frequency of groups A, B and C was sometimes higher in dust where a purifier was not used, but it was difficult to say that there was a definite difference. This comparison should be repeated with increased use of the air purifier. While the air purifier purifies indoor air, it also changes the amount of dust per fixed area of floor; therefore, a difference in the fungal number may not have been observed because the amount of test sample was kept constant in this study and a reduction in the total dust collected was not taken into consideration. More definite environmental differences created by the presence or absence of an air purifier might be shown for comparisons made from dust collected over a fixed area.

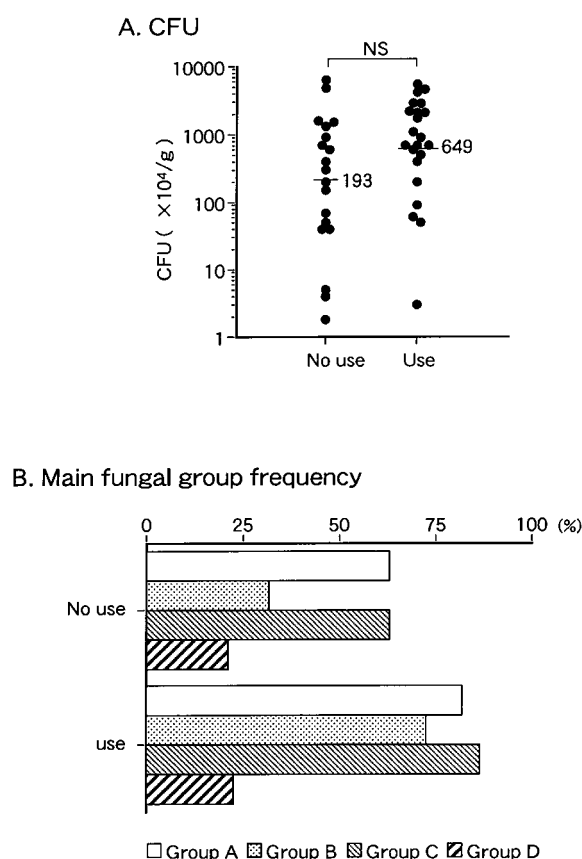


Figure 5. Comparison of CFU and main fungal group frequency in living-room rug.

Frequency of vacuum cleaner use

The effect of the frequency of vacuum cleaner use on the fungal number was examined. There was no significant difference between daily use, use once every 2–3 days, and use once a week, although the number of fungi was higher in dust from houses where use was once a week (Figure 7). There was no difference between daily use and use once every 2–3 days, nor in the fungal distributions.

We thought that with a decrease in frequency of vacuum cleaner use, the amount of dust would increase proportionally, the amount of fungi would increase, and changes in fungal distribution according to environmental conditions would become more apparent. However, such a result was not determined by this study.

It should be noted that the numbers shown in Figures 1–7 have been determined for a constant weight of dust, and there may be differences in the fungal number that are not observed by this method. Moreover, a comparison of the fungal number meas-

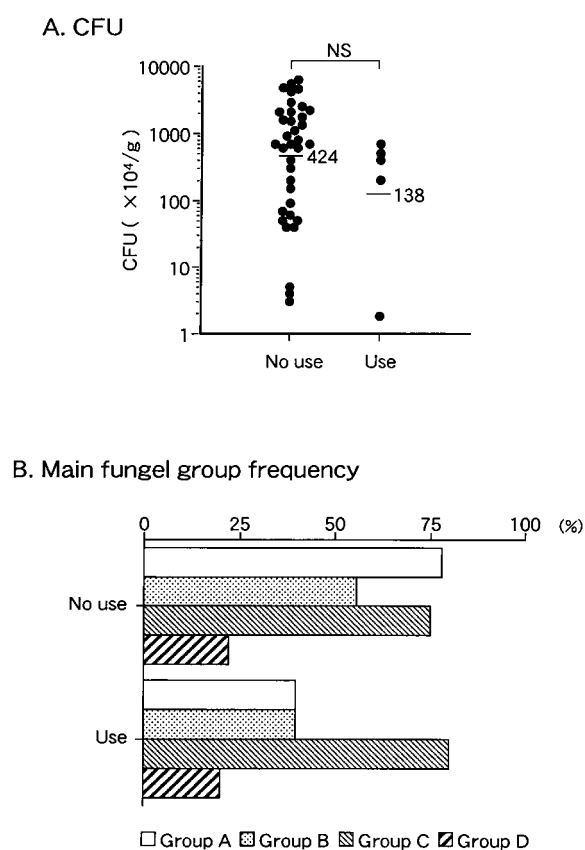


Figure 6. Comparison of CFU and main fungal group frequency between air purifier use and no use.

ured over a constant area might have more effect on these factors. For example, the results of the comparison for air purifiers and frequency of cleaning clearly indicated that a comparison across fixed areas was required.

Comparison of the conditions of house environment giving rise to high and low numbers of fungi

Our results have shown that different elements of house design and environment give rise to variations in the numbers of fungi in house dust. Overall, the number of fungi was high in houses of wooden-board structure, of more than 10 years in age, with living-rooms less than 10 m², with TATAMI floors and rugs or carpets, without an air purifier, and that were vacuum-cleaned less than once a week. By contrast, the fungal number was low in houses of reinforced concrete, of less than 3 years in age, with living rooms more than 12 m², with wooden floors and no rugs,

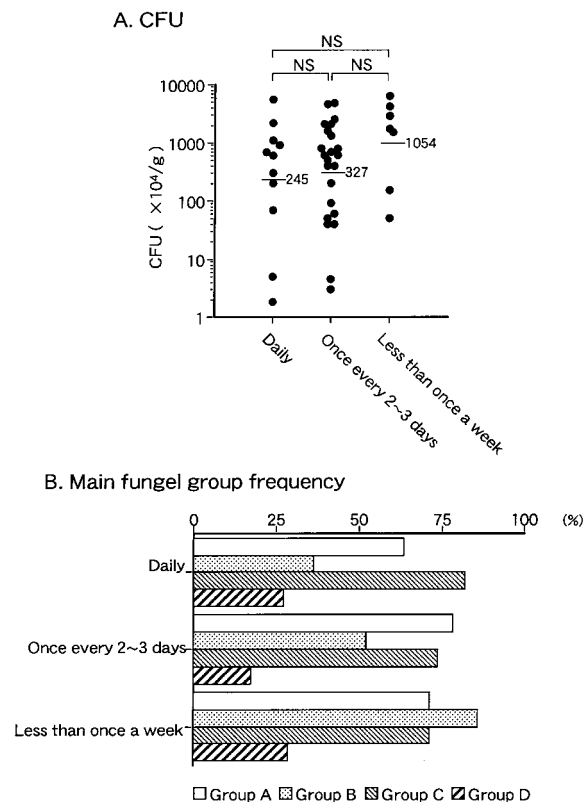


Figure 7. Comparison of CFU and main fungal group frequency under the condition of vacuum cleaner use.

without an air purifier, and that were vacuum-cleaned daily.

We randomly selected and compared BA patients' homes that met the conditions of high and low numbers of fungi. Six high fungal homes and six low fungal homes were selected, and the relationship between the high and low numbers of fungi and the design elements was examined. The building structure of the patients' homes with the high fungal number was wooden (Tables 1-2). Moreover, the high fungal houses were older than 10 years, with living rooms of less than 10 m². Floor materials, the fungal number was high where rugs and TATAMI were used, whereas it tended to be low with a wooden floor. These results may not be an accurate reflection because the number of fungi was expressed as the weight of dust [8]; however, TATAMI and carpet seem likely to be related to the high fungal number. It was thought that room size and presence or absence of an air purifier did not greatly affect the fungal number. Otherwise houses older than 10 years with small rooms had a high fungal number. In addition to the above compar-

isons, TATAMI and wooden floors were compared for only the living room. Although dust was not necessarily obtained within the limits of the living room, and so not an accurate comparison, the number of fungi was low as the number of mites found in dust from wood floors.

For the composition of fungi present in the house environments of BA patients, osmophilic and dry-resistant fungal groups were mainly detected, occurring at levels of over 10⁶ CFU/g of dust. Fungi that survive under wet conditions were not detected in high abundance; however, fungi that survive in absolute wet conditions were observed in 3 out of the 41 homes tested. The fungal number may have been high because the humidity in the indoor environment was high. In addition, the numbers of fungi surviving under wet conditions may have been high, not because the fungi has triggered contamination indoors, but because it has survived within indoor dust for a long period.

This study has examined whole-house dust for the presence and composition of fungi. Although many of the house design elements were not necessarily related to the numbers of fungi, the results have revealed high and low patterns of fungi that can be used to improve the environment for BA patients and other allergy sufferers.

Future studies will include a more detailed examination of fungal content in fixed areas and of the number of air-borne fungi as well as the dust ones, continuing the search for an improved patient environment.

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