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Long-range destruction of Der p 1 using experimental and commercially available ionizers

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Summary

Background To reduce the risk of sensitization and the elicitation of allergy symptoms, it is important to reduce the level of allergens in the home. It has previously been demonstrated that corona discharge, the process by which ionizers produce ions, can destroy the major house dust mite allergen Der p 1.

Objective In this paper the denaturing efficacy of an experimental ionizer and two commercially available products are evaluated.

Methods The first test was conducted in an electrically grounded chamber with samples of Der p 1 placed in various positions for 1, 2 and 3 weeks. The second test was conducted *in situ* in an unoccupied, furnished office room for 1 week. Der p 1 concentration was quantified by two-site monoclonal antibody enzyme-linked immunosorbent assay (ELISA).

Results All ionizers in both tests caused significant reductions in allergen concentration ($P < 0.05$), reaching a maximum of 92% with the experimental ionizer in the chamber after 3 weeks. The percentage reductions observed *in situ* with the experimental and the larger commercial ionizer were similar, reaching a maximum of 32% at a distance of 4 m away from the experimental ionizer after 1 week of exposure.

Conclusion With a revised protocol for use, air ionizers may offer a simple, efficient and inexpensive way to reduce allergen levels in the domestic environment.

Keywords asthma, corona discharge, Der p 1, house dust mites, ionizers

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Introduction

Due to the possible relationship between domestic exposure to house dust mites (HDMs) and the subsequent risk of sensitization to HDMs or actual development of current mite asthma [1], methods of reducing exposure to HDM allergens are important in the avoidance and control of these diseases. There have been many different attempts to eradicate HDMs from the typical domestic environment, with varying levels of success.

Previous research into the use of air ionizers for asthma sufferers has focussed on their ability to electrostatically precipitate airborne dust and allergens. However, this research has shown little or no evidence of any clinical benefit [2]. The direct actions of negative and positive ions on the respiratory system have also been investigated with inconclusive and often contradictory results [3, 4]. In this paper we present a possible new application for ionizers in asthma prevention.

It has previously been reported that the products of corona discharge, the process by which ionizers produce ions, can destroy the major HDM (*Dermatophagoides pteronyssinus*) allergen, Der p 1 [5]. This was shown using a simple pin-to-plane electrode arrangement to create a corona discharge within a small interelectrode gap. Corona discharge occurs when a high voltage is applied between electrodes in a non-uniform geometry, e.g. when one electrode has a small radius of curvature (i.e. a point or a wire) and the other is a plane [6]. This non-uniform electrode geometry leads to electric field intensification such that the local breakdown potential of the surrounding atmosphere is exceeded and monovalent ions of the same polarity as the point electrode are produced. These ions are then attracted to the opposite polarity and drift towards the other electrode colliding with the gaseous molecules of the surrounding atmosphere and so producing an ion wind which transmits up to 50% of the discharge power to the plane in the form of heat and chemically potent atomic and molecular radicals known as neutral metastable species [7].

Here we report the continuous use of an experimental ionizer, and two commercially available ionizers, for the purpose of reducing the Der p 1 concentration in the surrounding environment. The first series of tests were conducted in an electrically grounded chamber which served as a simple model of a natural small room or closet. An ionizer that was designed for use in closets as a deodorizing device, and used two wire-to-electrode configurations (electrode length: 101 mm) to produce the corona was used for these tests. An experimental ion wind generator was also tested separately in the chamber for different exposure times and the concentration of Der p 1 in the allergen

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samples were analysed. Evaporated allergen samples were used as these have good concentration homogeneity and could also be placed vertically onto the walls of the chamber [8]. The second test again used the experimental ionizer and also a larger ionizing air purifier with three wire-to-electrode configurations (electrode length: 478 mm) in an unoccupied, furnished room. This was performed in order to test the denaturing ability of the ionizers *in situ*, in a more natural domestic environment.

Materials and methods

Preparation of the evaporated aqueous Der p 1 samples

Cultures of HDMs were established using material obtained from domestic vacuum cleaner bags that tested positive for Der p 1. Cultures were maintained on a substrate of crushed dog biscuit and dried yeast mixed in a ratio of approximately 30 : 1 [9]. The established HDM culture was sieved to below 63 μm. An aqueous solution of this HDM culture was prepared by adding 15 g to 1.5 L of distilled water. This mixture was stirred well to allow the Der p 1 to dissolve. The mixture was then passed through filter paper (Whatman, qualitative, grade 4) to remove solid material. Thimerosal (sodium ethylmercurithiosalicylate) was added at a concentration of 0.001% as a preservative.

Samples were prepared by pippetting six 100-μL aliquots of the Der p 1 solution onto 80 × 60 mm rectangles of aluminium foil. The group of six Der p 1 samples were prepared adjacently to their paired controls. These were then all dried at 37 °C.

Exposure of samples to the nine-pin ion wind generator and the Ionic Closet Dry Cleaner™

The experimental ion wind generator was constructed by soldering nine pins to a vertical grille with 10 mm^2 mesh connected to a negative d.c. 15 kV power supply. A similar grille was placed 30 mm away from the pins, earthed and fixed into a plastic body. The velocity of the ion wind was measured at the front aperture using an AV2 Air Velocity and flow meter (Airflow Developments Ltd, Buckinghamshire, UK).

The ion wind generator was placed at one end of the chamber 70 cm high (see Fig. 1 for a diagram of the chamber with dimensions and positions of the samples). The chamber was made of Perspex mounted onto a metal frame. The inside surfaces of the chamber were covered with aluminium foil and tested to ensure that the entire chamber was electrically continuous and grounded.

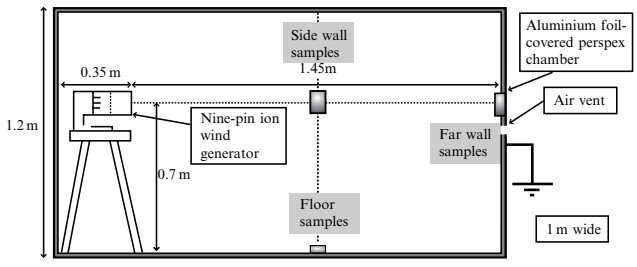

Fig. 1. Test chamber showing the relative positions of the Der p 1 samples. The experimental nine-pin ion wind generator is shown in position. The Ionic Closet Dry Cleaner was located in the same position facing the far wall for each test.

The foil with the six samples was then fixed at various positions in the test chamber, as indicated in Fig. 1. Six samples were placed on the far wall of the chamber, 1.45 m away and directly in front of the ion wind generator; six were placed 0.7 m below the generator and 0.725 m away on the floor, and six were placed on the sidewall 50 cm to the left and 0.725 m away from the generator.

The foil-lined chamber was then connected to ground and the ion wind generator connected to an applied voltage of 15 kV using a high voltage generator (Brandenberg Ltd). The experiments were allowed to run continuously for 1, 2 or 3 weeks. Controls were kept in an identical chamber for the equivalent duration. Ozone readings were taken once a week through a 20 × 100 mm air vent in the far wall of the chamber using short-term ozone detecting tubes (Drager, Sicherheitstechnik GmbH, Lübeck, Germany). At the completion of exposure, the samples and controls were removed and added to 1% bovine serum albumin (BSA)–phosphate-buffered saline (PBS)–Tris in a 1 : 6 dilution in preparation for Der p 1 concentration analysis by a two-site monoclonal antibody enzyme-linked immunosorbant assay (ELISA; Indoor Biotechnologies Ltd, Cardiff, UK).

The above protocol was also followed using the commercially available small Ionic Closet Dry Cleaner (Model S1630, Smarter Image Design, San Francisco, CA, USA) designed for use in closets. The Ionic Closet Dry Cleaner was placed in the same position as the nine-pin ion wind generator facing the far wall and connected to a 12-V mains transformer for the desired exposures times. The samples and controls were then removed and prepared for ELISA.

Room-scale exposure of Der p 1 samples to the nine-pin ion wind generator and the Ionic Breeze Silent Air Purifier

Samples of evaporated Der p 1 solution were prepared according to the protocol outlined above. Twelve groups of six Der p 1 samples were placed in an unoccupied, furnished, office room measuring 2.9 × 6.0 × 2.9 m (see Fig. 2 for a map of the samples in the room). The majority of samples were fixed horizontally and at the same height as the nine-pin ion wind generator that was placed on the table at one end of the room. The samples were positioned in radial sectors equidistant from the ionizer at 0.3, 1.2, 2.4 and 4 m for Sectors 1, 2, 3 and 4, respectively. Samples 2.2 and 4.2 were placed on the floor 1.05 m below the centre of the ion wind generator and samples 3.1 and 3.3 were fixed vertically against the walls.

The windows and door of the office were closed and the ion wind generator connected to a negative 15 kV power supply for two weeks. Sixteen control samples were kept in identical conditions without the ion wind generator present. The door was briefly opened every 2 days to measure the ozone concentration in the room. At the completion of exposure, the samples were removed and prepared for ELISA.

The above protocol was also followed using the commercially available Ionic Breeze Silent Air Purifier (Model S1624, Smarter Image Design), which was designed for use in rooms. The Ionic Breeze ionizer was placed in the same position as the smaller nine-pin ion wind generator and connected to a 110-V mains transformer for 2 weeks. Der p 1 samples were placed in identical positions to those used in the ion wind generator exposures. This was at a height of 150 mm from the bottom of the ionizer. The door was briefly opened every two days to

measure the ozone concentration and to clean the planar electrodes of the ionizer with a dry cloth in accordance with the manufacturer's instructions. After the duration of exposure the samples and controls were prepared for ELISA.

Measurement of the rate of ion production from the ionizers

The rate of ion production was measured by placing the ionizer onto a 1-m^2 sheet of Perspex and connecting it to its power supply. An aluminium foil-covered frame of $770 \times 440 \times 340$ mm dimensions was then placed over the ionizer to act as the ion collector and then connected to an electrometer (Model 610C Solid state electrometer, Keithley Instruments, Cleveland, OH, USA). The apparatus was all placed within an electrically grounded chamber to screen from background interference.

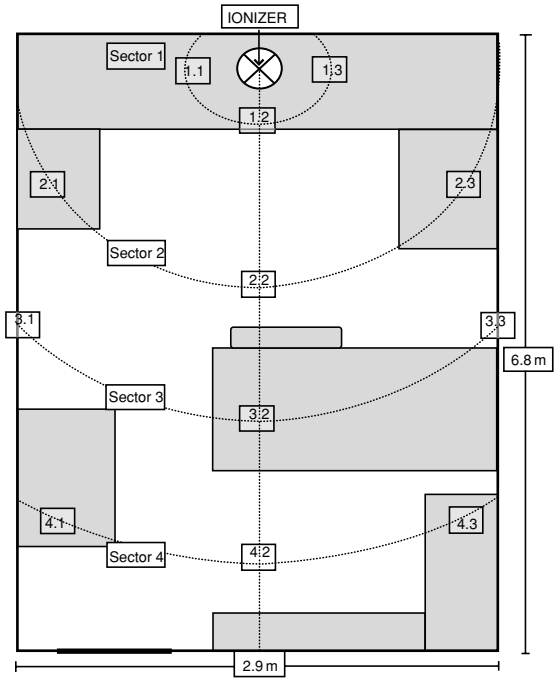

Fig. 2. Map of sample positions in unoccupied office room for *in situ* tests of the nine-pin ion wind generator and the Ionic Breeze Silent Air Purifier. Three sets of six samples were arranged in radial sectors equidistant from the ionizer. The tables and chair are shown and are of approximately the same height in line with the ion wind generator. Samples 2.2 and 4.2 are placed on the floor 1.05 m below the ionizer level.

The ionizer was then switched on and the resultant current flowing through the frame was measured. The rate of monovalent ion production could then be calculated.

Data analysis

For each duration of exposure, the Der p 1 concentrations of the six exposed samples were compared to their paired controls by the *F*-test. The concentration data for each time period was then analysed using the paired *t*-test for means, or the Mann–Whitney *U*-test where appropriate. These data were then presented as mean percentage reductions in Der p 1 concentration calculated by comparing the Der p 1 sample to its equivalent control for the same time period. Spearman rank correlations were performed on the percentage reductions of the chamber-exposed samples to determine whether the reductions were exposure time-dependent. Statistical significance was defined as $P < 0.05$.

Results

Exposure of samples in the chamber to the nine-pin ion wind generator

Table 1 shows the mean concentrations of the samples exposed to the nine-pin ion wind generator, or the Ionic Closet Dry Cleaner, in the chamber for 1, 2 or 3 weeks. All of the samples, except those located on the floor and side wall and exposed for 1 week, were statistically lower in Der p 1 concentration than their paired controls ($P < 0.05$). The concentration of the controls was relatively constant over the 3 weeks with a mean concentration of 227.22 ± 3.89 ng/mL ($n = 54$).

Significant positive correlations between the percentage reduction in Der p 1 and the period of exposure were observed for all sample positions in the chamber ($P < 0.01$). The greatest reduction was seen in the samples directly opposite the ion wind generator on the far wall (see Fig. 3). The percentage reduction rose from 18% after 1 week to 26% after 2 weeks and 92% after 3 weeks (Spearman's rho = 0.826). The second greatest reductions were seen in the samples situated on the sidewall, which rose from 3 to 14% and finally 83% after 3 weeks (rho = 0.787). The samples on the floor showed the lowest concentration reduction, with no mean percentage

Table 1. Mean concentrations of the samples and controls exposed to the nine-pin ion wind generator or the Ionic Closet Dry Cleaner in the chamber ($n = 6$)

Exposure time (weeks)	Position	Experimental ionizer				Commercial ionizer			
		Mean [Control]/ng/mL	SD	Mean [Sample]/ng/mL	SD	Mean [Control]/ng/mL	SD	Mean [Sample]/ng/mL	SD
1	Floor	240.02	31.20	240.28	30.42	223.08	27.07	189.64	8.31
	Side wall	229.92	39.84	218.92	29.98	238.68	15.53	220.37	13.64
	Far wall	235.81	25.12	193.78	28.91	222.98	11.18	186.84	17.16
2	Floor	219.58	15.69	197.21	15.61	233.16	5.91	205.80	10.61
	Side wall	221.59	40.12	187.44	27.31	226.52	7.34	188.84	10.97
	Far wall	220.24	10.56	163.14	14.72	227.72	6.55	190.55	6.17
3	Floor	221.97	14.99	138.62	16.62	223.80	17.34	185.59	6.86
	Side wall	226.01	17.01	38.30	13.16	227.78	18.69	185.07	19.54
	Far wall	229.88	49.94	18.75	13.19	218.70	25.00	184.59	14.82

reductions after 1 week and only 10 and 37% reductions after 2 and 3 weeks, respectively (rho = 0.787).

The velocity of the ion wind was 0.23 m/s immediately in front of the ionizer, which produced 2.417×10^{13} ions/s. The ozone concentration inside the booth remained at a constant 2.40 ppm throughout the experiment.

Exposure of samples in the chamber to the Ionic Closet Dry Cleaner

Significant reductions in Der p 1 concentration were measured at all positions of the chamber (see Fig. 4). The concentrations of the controls were relatively constant with a mean concentration of 226.94 $\pm$ 2.23 ng/mL ($n = 54$). The values of mean percentage reduction in Der p 1 concentration of most samples were all relatively constant irrespective of the length of exposure. Only the samples placed on the sidewall of the chamber had successive reductions in concentration. The sidewall sample concentration reductions ranged from 7% reduction after 1 week, 17% after 2 weeks and 19% after 3 weeks (rho = 0.669, $P < 0.01$). The values for the reduction in concentration of samples in the other positions ranged from 12 to 17% and showed no correlation between length of exposure and percentage reduction.

The ion wind velocity was negligible as it left the ionizer, which produced 2.185×10^{14} ions/s. The ozone concentration inside the booth remained a constant 0.05 ppm.

Room-scale exposure of samples to the nine-pin ion wind generator

The results of these tests show that highly significant reductions in the Der p1 concentration of samples were recorded after exposure to the experimental ion wind generator for 2 weeks in the unoccupied, furnished office room. Table 2 shows the mean Der p 1 concentrations of the controls and samples in their various positions in the furnished office room after exposure to either the nine-pin ion wind generator or the Ionic Breeze Silent Air Purifier. The control concentration was 225.268 $\pm$ 4.24 ng/mL. All samples were statistically lower than their controls ($P < 0.01$).

Reductions in allergen concentration were recorded in all positions around the room (see Fig. 5). There appears to be no decrease in denaturing efficacy as distance from the ion wind generator is increased. Reductions of 26%, 17% and 26% were observed in Sector 1, 0.3 m away; and 27%, 15% and 32% reductions in Sector 4, 4 m away from the ionizer. The lowest

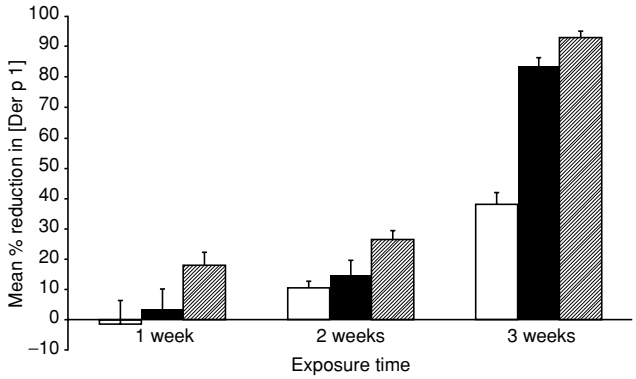

Fig. 3. The percentage reductions in Der p 1 concentration of samples in different positions in the chamber over time, with the negative ion wind generator. Samples were positioned on the floor of the chamber, the side wall and the far wall in front of the ionizer. SEM shown, $n = 6$.

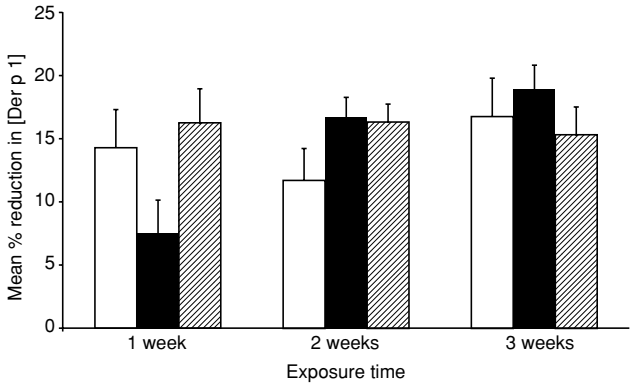

Fig. 4. The percentage reductions in Der p 1 concentration of samples in different positions in the chamber over time, with the Ionic Closet Dry Cleaner. Samples were positioned on the floor of the chamber, the side wall and the far wall in front of the ionizer. SEM shown, $n = 6$.

Table 2. Mean concentrations of the samples and controls exposed to the nine-pin ion wind generator or the Ionic Closet Dry Cleaner in the office room ($n = 6$)

Sample position (weeks)	Experimental ionizer				Commercial ionizer			
	Mean [Control]/ng/mL	SD	Mean [Sample]/ng/mL	SD	Mean [Control]/ng/mL	SD	Mean [Sample]/ng/mL	SD
1.1	225.278	16.99	166.63	8.72	223.35	13.66	176.11	4.60
1.2			186.23	12.64			203.15	8.88
1.3			166.96	6.66			185.18	10.51
2.1			156.17	6.51			183.40	13.19
2.2			198.12	6.79			190.52	7.25
2.3			169.55	4.38			204.04	9.28
3.1			196.88	2.84			211.69	7.56
3.2			207.90	1.42			179.31	23.77
3.3			203.85	5.79			207.78	12.60
4.1			163.37	2.32			200.48	16.35
4.2			192.54	8.23			215.60	13.29
4.3			153.47	4.14			216.85	4.55

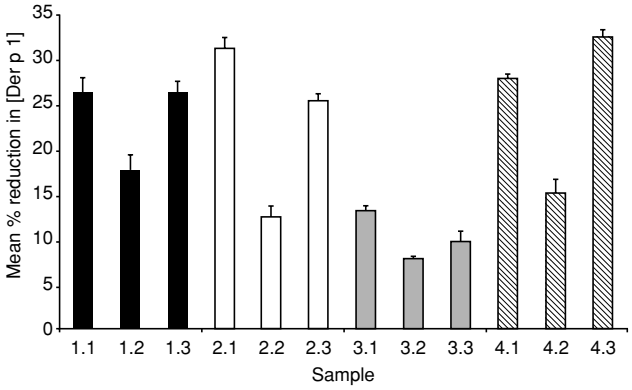

Fig. 5. The mean percentage reduction in Der p 1 concentration of samples in various positions around the unoccupied office room during *in situ* tests of the experimental nine-pin ion wind generator and the Ionic Breeze Silent Air Purifier. The sample numbers refer to the position in each sector as shown in Figure 4. all values are statistically significant. SEM shown, $n = 6$.

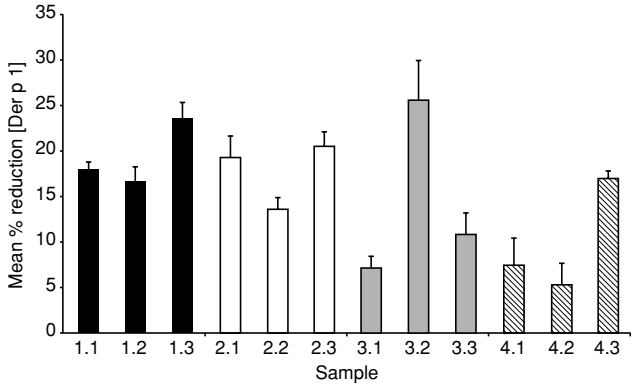

Fig. 6. The mean percentage reduction in Der p 1 concentration of samples in various positions around the unoccupied office room during *in situ* tests of the commercially available Ionic Breeze Silent Air Purifier. The sample numbers refere to the position in each sector as shown in Figure 4. all values are statistically significant. SEM shown, $n = 6$.

reductions observed were in Sector 3, which were 13%, 8% and 9%.

A pattern can be seen in the percentage reductions observed within each sector; the reductions in samples placed directly in line with the ionizer (i.e. Samples 1.2, 2.2 and 3.2) were always lower than those placed on either side. This suggests that the ion wind forms a divergent plume or bifurcates upon exiting the ionizer thus leaving a lower concentration of corona products in the middle. This effect was not observed in the chamber test, possibly due to the different positions of the samples and the smaller distances involved.

Another explanation for the lower reductions in the samples positioned in line with the ionizer could be due to their relative positions in the room: sample 1.2 was placed 0.3 m in front of the ionizer but below the flow of the ion wind; sample 2.2 was placed on the floor 1.05 m below the centre of the ion wind generator; sample 4.2 was also placed on the floor but with the desk and chair in line with the ionizer. These sample positions, particularly those fixed to the floor, could receive less exposure to the corona products than those 0.9 m above the floor and fixed horizontally (i.e. samples 1.1, 1.3, 2.1, 2.3, 4.1 and 4.3).

The lowest reductions were observed in Sector 3. Samples 3.1 and 3.3 were fixed vertically to the walls 0.9 m above the floor and 2.4 m away from the ionizer. These lower reductions might indicate less capture of the corona products because of their vertical position. It is likely that the other samples, which were fixed horizontally, had more exposure to the active corona product(s) due to precipitation directly onto the foil with the samples. Sample 3.2, although placed 0.9 m above the floor on the desk, was positioned with a soft-furnished office chair, with a height of 1 m, in between the desk and the ionizer. The chair might have shielded the samples from the corona products.

The ozone concentration in the room, measured at a distance of 6 m from the ion wind generator, was a constant 0.05 ppm.

Room-scale exposure of samples to the Ionic Breeze Silent Air Purifier

Statistically significant reductions ($P < 0.05$) in Der p 1 concentration of all samples were observed using the Ionic Breeze ionizer (see Fig. 6). The reductions were similar in magnitude to those of the experimental ionizer: 19%, 17% and 23% in Sector 1, and 19%, 14% and 21% in Sector 2 from a starting concentration of 223.35 ± 3.56 ng/mL. Sector 4 had comparably lower reductions in concentration. The pattern of reductions observed in the experiment with the nine-pin ion wind generator was not evident with the Ionic Breeze ionizer. This is possibly due to the difference in design and release pattern of the ion wind. Like the Ionic Closet Dry Cleaner used in the chamber tests, this ionizer used a long wire-to-electrode arrangement to generate the corona and so the ion wind left the ionizer in a diffuse manner from the front and behind, instead of directly ahead as with the experimental ionizer.

Whereas the experimental ionizer caused less reduction in the Der p 1 concentration of samples in Sector 3, the highest reduction of 26% was observed in sample 3.2 with the commercial ionizer. An explanation for this may reside in the height of the Ionic Breeze ionizer, which was 338 mm (electrode length) taller than the experimental ionizer. This would have enabled the corona products to overcome the shielding effect of the soft-furnished chair in line with the ionizer and sample 3.2 and so destroy more Der p 1 than the corona produced with the nine-pin experimental ionizer.

The ion wind velocity differed depending upon which side of the ionizer it was measured: from the front it was 0.69 m/s, from the back it was 0.29 m/s and from the side the velocity was negligible. The total ion production rate was 1.904×10^{15} ions/s. The ozone concentration inside the room was negligible, although a concentration of 0.025 ppm was recorded immediately in front of the ionizer.

Discussion

Significant reductions in allergen concentration were achieved with all ionizers in both the chamber and the room-scale tests. The experimental and commercial ionizers differed, however, in their pattern of allergen destruction. The reason for the difference in reductions observed with the experimental and commercially available ionizer in the chamber tests seems to be the direction of the ion wind. The experimental ion wind generator creates an ion wind with a velocity of 0.23 m/s and this was directed towards the far wall samples. Unlike the release of the

ion wind from the Ionic Closet Dry Cleaner ionizer, there appears to be little diffusion of the active corona products, especially to the floor of the chamber. As the chamber is connected to ground, the far wall could capture the active species allowing little lateral diffusion to destroy Der p 1 in the surrounding samples. This would suggest that the active species in the corona products are ionic, although it is also possible that the electrically neutral, but chemically reactive, radicals could be neutralized after contact with the far wall.

Although the Ionic Closet Dry Cleaner caused significant reductions in allergen concentration in each of the time exposures, the reductions in all positions were relatively constant. It is not clear, however, why the reductions observed were also constant for the different exposure times; the concentration of Der p 1 would be expected to decrease with an increase in exposure time. The reductions observed in this experiment were very different from those observed with the nine-pin ion wind generator. In the latter test, a clear relationship with both time of exposure and position of sample could be seen; the samples continued to decrease in concentration after each week of exposure, and the samples on the far wall in front of the ion generator were reduced the most. A possible explanation for this resides in the fact that the Ionic Closet Dry Cleaner released the ionized air in a diffuse manner in all directions with a negligible velocity, whereas the nine-pin ion generator carried its corona products on the ion wind directly onto the samples on the far wall. Thus it would appear that the denaturant is a corona product that is carried on the ion wind.

Another indication that the difference in concentration reductions between the ionizers tested is due to the pattern of ion wind release is the fact that both the Ionic Closet Dry Cleaner and Ionic Breeze have a faster ion production rate than the experimental ionizer (2.185×10^{14} and 1.904×10^{15} ions/s for the two commercially available ionizers, respectively, compared with 2.497×10^{13} ions/s for the experimental ionizer). Although the commercial, wire-to-electrode ionizers produced more ions than the nine-pin, experimental ionizer, in both tests greater reductions were observed after exposure to the experimental ionizer. However, due to the diffuse release of the ion wind, the long wire-to-electrode configuration used by the commercial ionizers might be better suited to overcoming the shielding effects of furniture and thereby distributing the corona products in a domestic environment. This design would lead to a more uniform distribution of the ion wind and so destroy allergens from a wider range of sources.

The chamber tests showed that allergen placed beneath the flow of the ion wind, from the experimental ionizer, were denatured the least. This has implications for considering a strategy to utilize corona discharge *in situ* in the domestic environment due to the habitat of dust mites in the matrix of carpets. However, the long-wire-to-electrode design, or focusing the direction of the ion wind from pin-to-grid ionizers would also enable the ion wind to reach this source of allergen.

Previous investigations into the effect of corona discharge on Der p 1 used a pin-to-plane configuration where the allergen samples were fixed to a planar electrode [5]. With the small interelectrode distance of 15 mm, heat would have been transmitted to the sample, which could have contributed to the destruction of the Der p 1 protein. However, in the present experiments there is a large distance between the corona source and the Der p 1 samples (up to 4 m in the case of the room-scale tests). This would indicate that heat is not a contributing factor to the mechanism of corona denaturing. The number of neutral metastable species would also be decreased with increasing distance due to their short half-life (milliseconds to seconds) [10].

The significance of the results presented here is that reductions in allergen content can be achieved using ionizers that utilize corona discharge. There is also evidence to suggest that corona products may be acaricidal (unpublished data). This is not surprising because ozone, a product of corona discharge in air, has been reported to kill a number of organisms including insects [11].

With a revised protocol for use, ionizers could be safely used to denature allergens and also kill house dust mites in the domestic environment thus keeping the allergen levels below the minimum needed to elicit sensitization and symptoms, i.e. below 2 μg/g of dust [12]. HDMs in laboratory cultures produce a mean of 20 fecal pellets per day, each pellet containing 10 ng/mL of Der p1 (or 100 pg/pellet) [13]. This research has demonstrated a maximum reduction of 211.13 ng/mL in samples on the far wall in the chamber test and 71.80 ng/mL in sample 4.3 in the room-scale tests both with the experimental ionizer.

Direct comparisons between the amounts of Der p1 destroyed by ionizers and the corresponding number of fecal pellets or mites cannot be made based on the research presented here alone due to the evaporated Der p 1 solution on aluminium foil method of preparing the samples. Although this method allows detailed investigation into the effect of electrostatic techniques on allergens, it does not mimic natural conditions [8]. Further research is necessary to determine the benefits of ionizer-denaturation under natural conditions in the domestic environment, especially any clinical benefits.

The allergen used in this investigation was present on the surface of aluminium foil. However, the majority of the allergenic reservoir in the domestic environment is found inside mattresses and soft furnishings [14]. Preliminary experiments have shown that the corona products responsible for the denaturing effect do not penetrate far: only 10 mm into open cell foam used in cushions [15]. However, this could be improved by artificially increasing the velocity of the ion wind, or by other methods, to force the corona products deep into furnishings.

It has previously been shown that molecular ozone is not responsible for the denaturing effect of corona discharge [5]. Modifying ionizers by reducing the deleterious ozone production would be extremely beneficial. By increasing the production of active corona products, whilst reducing ozone, for example by heating the corona electrode and modifying the electrode configuration [16], the allergen content of the room could be reduced more efficiently and safely.

It would be unwise to recommend continuous use of present-day commercially available ionizer products to reduce the allergen load in a house, due to the fact that exposure to ozone is harmful, especially to atopic individuals [17]. It may be acceptable to operate the ionizers while rooms are unoccupied. The development of intensive treatments using corona discharge and carried out by specialists, similar to steam cleaning or treatment by liquid nitrogen, could be envisaged. In this way, carpets, soft furnishings and mattresses could be cleaned of allergens and HDMs without exposure to patients or pets. Research will have to be directed at improving indoor ionizers in such a way that ozone production is minimized and maintained below legal limits. The Food and Drug Administration

of the United States regulation stipulates this as 50 ppb for an Indoor Air Cleaner [16].

Although the research reported here focussed on the Der p 1 allergen, the destruction of Der f 1, Der p 2 and Fel d 1 by corona discharge in a pin-to-plane electrode arrangement has also been observed [18]. Thus, ionizers may be used to reduce the allergenic load from a number of sources in the domestic environment.

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