Evaluation of materials used for bedding encasement: Effect of pore size in blocking cat and dust mite allergen

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Background: Mattress and pillow encasings are recommended for patients allergic to dust mites. Many encasements block allergen and are vapor permeable but do not allow free passage of air through the material. Recently, breathable fabrics made from tightly woven synthetic fibers or nonwoven synthetics have been recommend as encasements.

Objective: The purpose of this study was to develop a method for testing encasement materials made of breathable fabrics.

Methods: Dust samples containing a known quantity of allergen (Der f 1, Der p 1, and Fel d 1) were pulled across a variety of fabrics using a modified dust trap. Airflow through the dust trap was controlled with a vacuum pump. Five minutes after dust was introduced, the pump was shut off. A filter located downstream of the fabric collected allergen passing through the fabric during the test and was assayed with ELISA for the relevant allergen. Fabrics to be tested were obtained from manufacturers and specialty catalogs.

Results: As the average pore size decreases, the airflow through a fabric becomes restricted, and the pressure differential created by the vacuum pump increases. Dust mite allergens (Der f 1 and Der p 1) were blocked below detectable limits by fabrics of less than 10 μm in pore size. Fabrics with an average pore size of 6 μm or less blocked cat allergen (Fel d 1).

Conclusion: The method we developed provided a rigorous and reliable test for leakage of common indoor allergens through breathable barrier fabrics. Our results show that tightly woven fabrics and nonwoven synthetic fabrics can block common indoor allergens but still allow airflow. (J Allergy Clin Immunol 1999;103:227-31.)

Key words: *Mite avoidance, encasements, breathable fabrics, allergen avoidance*

Reducing exposure to allergens found in the home is recognized as an integral part of the management of asthma, perennial rhinitis, and atopic dermatitis.[1-3] For patients who are allergic to dust mites, the use of impermeable covers for mattresses and pillows is a major part of the protocol recommended to decrease exposure.[2-4] Many of the encasings on the market today are comprised of either a thick vinyl cover or a woven material bound to a membrane. Some of these materials are vapor permeable; however, they do not allow for the free flow of air, and their comfort is variable. In an effort to better replicate the feel and breathability of a cotton sheet or pillowcase, several manufacturers have begun to develop tightly woven fabrics with pore sizes small enough to block allergen, thus eliminating the need for a membrane. We report here the development of a technique for testing materials recommended for use in encasing pillows and mattresses. This method provided accurate measurement of the pressure gradient across the fabric, the airflow rate through the fabric, and the amount of allergen allowed to pass through each material.

The initial studies tested the passage of Der p 1 and Der f 1, the allergens found in fecal particles of *Dermatophagoides pteronyssinus* and *D farinae*.[5] The test was repeated on the same fabrics with the cat allergen Fel d 1. Although mite fecal particles are 10 to 40 μm in diameter, a significant proportion of cat allergen is associated with particles less than 10 μm in diameter.[6,7] Because of the size of particles carrying Fel d 1 and the quantity of this allergen in dust samples, cat allergen was used to provide a more rigorous test of the fabric's ability to block passage of allergens.

METHODS

Preparation

House dust obtained from vacuum cleaner bags that contained a known amount of Der p 1, Der f 1, or Fel d 1 was sieved through a 300-μm screen and weighed out into 0.1 and 1.0 g aliquots. In addition, a more concentrated form of dust containing Der p 1 was prepared by combining 0.1 g of spent *D pteronyssinus* culture with 0.9 g of house dust.

Fabrics were obtained from a variety of specialty catalogs and manufacturers, including 3M, Goretex, GSI (Brooklyn, NY), and Precision Fabrics Group Inc (PFG, Greensboro, NC). Each fabric was cut into 7-inch squares and stored in protective bags. The controls included the cotton sheeting that is routinely used for collecting dust samples (laboratory control), a commercially available pillowcase, and a commercially available cotton sheet. Testing involved the use of a modified dust trap (Fussnecker, Springfield, Ohio) that enabled the aerosolized house dust to be pulled onto and through the fabric being tested (Fig 1). A 1.1 horsepower vacuum cleaner (Model no S1211, Hoover Sprint 100; The Hoover Co, North Canton, Ohio) was used as the vacuum pump for all fabrics studied.

Testing

Before testing a group of materials, airflow readings through the laboratory control were set to within 0.5 L/min of the average airflow reading. Pressure readings were also taken and set to within 25

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TABLE I. Measurement of airflow and pressure differential for selected fabrics

Fabric tested	Fiber blend	Yarns per inch*	Filament denier*†	Airflow through fabric (L/min)	Pressure differential across fabric (Pa)
Controls					
Laboratory control (n = 5)	Cotton/polyester	—	—	21.9 (21.6-22.7)	12.0 (9.96-14.9)
Retail control (n = 5)	Cotton/polyester	90/90	~1.5/~1.5	21.6 (21.3-22.2)	44.8 (42.4-47.3)
Polycotton placebo (n = 5)	Cotton/polyester	—	—	21.4 (20.3-21.9)	11.0 (7.47-12.5)
Fine woven fabrics‡					
50 µm (n = 5)	Polyester	109/85	2.1/2.1	21.9 (21.4-22.8)	52.3 (49.8-54.8)
20 µm (n = 5)	Nylon	171/134	1.2/1.2	20.6 (20.2-21.4)	257 (252-262)
10 µm (n = 5)	Polyester	144/89	2.1/2.1	21.1 (20.8-22.0)	282 (269-286)
6 µm (n = 5)	Polyester	144/89	2.1/2.1	11.3 (10.8-11.7)	2476 (2411-2546)
2 µm (n = 5)	Polyester	173/89	2.1/2.1	6.5 (5.98-8.03)	3450 (3383-3550)
Microdenier fabrics‡					
9.9 µm (n = 5)	Polyester	142/84	2.1/0.7	19.1 (18.6-19.4)	297 (272-341)
8.4 µm (n = 5)	Polyester	164/84	2.1/0.7	18.3 (17.7-18.6)	436 (374-481)
6.6 µm (n = 5)	Polyester	164/84	2.1/0.7	16.3 (15.6-16.8)	882 (546-1026)
Commercially available fabrics					
Wondertex (GSI; n = 2)	Nonwoven synthetic	—	—	17.8 (17.7-17.8)	82 (79.7-84.7)
Microfiber (Priorities; n = 7)	Polyester/nylon	—	—	14.8 (14.2-15.5)	1679 (1495-1769)
3M Propore (n = 5)	Nonwoven synthetic	—	—	1.3 (1.3)	4319 (4185-4434)
Clean living vinyl (Sears; n = 2)	Vinyl	—	—	<0.1 (<0.1, <0.1)	4384 (4384, 4384)

*Machine direction of the fabric/cross machine direction of the fabric.
†1 denier = 1 g/9000 m of yarn.
‡Average pore size reported by Precision Fabrics Group.

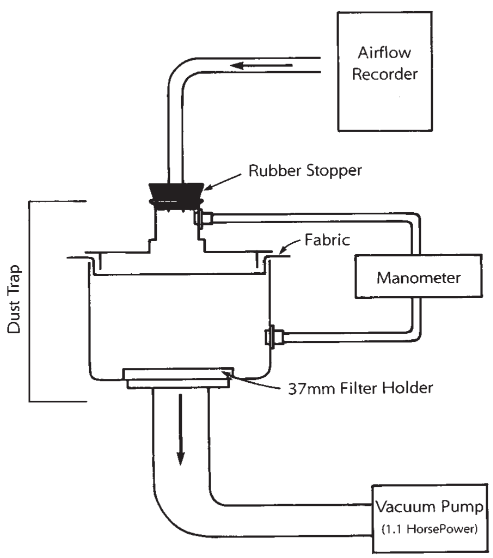

FIG 1. Diagrammatic representation of a modified Fussnecker dust trap showing placement of fabric, location of flow meter and pressure gauges, and direction of airflow.

Pa. An even spreading of dust across the fabric was achieved by pulling the dust into the trap through a 14-inch section of Fisherbrand tubing (5/16 ID × 1/16-inch wall) (Fisher Scientific, Pittsburgh, Pa). A hole was cut into a number 7 rubber stopper, tubing was inserted and sealed with silicone adhesive, and the rubber stopper was pressed firmly into the entrance of the dust trap before testing. Airflow readings were taken through the tubing by using a mini-Buck calibrator (A.P. Buck, Inc, Orlando, Fla) 1 minute after the vacuum cleaner was turned on. Pressure readings were also taken at this time through holes in the top and bottom portions of the dust trap by using a pocket manometer (APM 5000; Davis Instruments, Baltimore, Md). Fabrics with known airflow and pressure characteristics were used to calibrate the airflow through the dust trap before each group of fabrics was tested. After the dust sample was introduced, the vacuum pump was allowed to run for 5 minutes. Airflow and pressure readings were repeated before the vacuum pump was shut off. Four seams commonly used by manufacturers were also tested with the dust trap. They were the standard seam with no overlap (8 stitches/inch), the overlapped and double stitched seam (8 stitches/inch), the standard over-edge pillow seam with no overlap (8 stitches/inch), and the single stitched overlap seam (8 stitches/inch).

Analysis

A 37-mm filter holder (Catalog no B7632/Z-11; Casella Ltd, Bedford, England) was mounted downstream of the fabric and sealed over the exit. Particles passing through the fabric were collected on a Millipore prefilter (Catalog no AP20 035 00; Millipore Corp, Bedford, Mass) while the vacuum pump was running. The filter was removed, folded, and placed into a 3-mL syringe. One milliliter of 1% BSA in PBS-Tween 20 was added to the syringe, and the sample was spun overnight at 4°C. The extract was recovered by squeezing the syringe into a 2.0-mL vial and assayed by using 2-site mAb ELISA techniques.[7,8]

RESULTS

The initial group of experiments tested woven fabrics with a range of pore sizes. As expected, our results show that a smaller than average pore size decreases the airflow through fabrics and increases the pressure differential created by the vacuum pump (Table I). Scanning electron micrographs of the fabrics illustrate the tightness of the weave that can be achieved by using modern manufacturing techniques (Fig 2). The 20-µm and 10-µm fabrics performed similarly in airflow and pressure read-

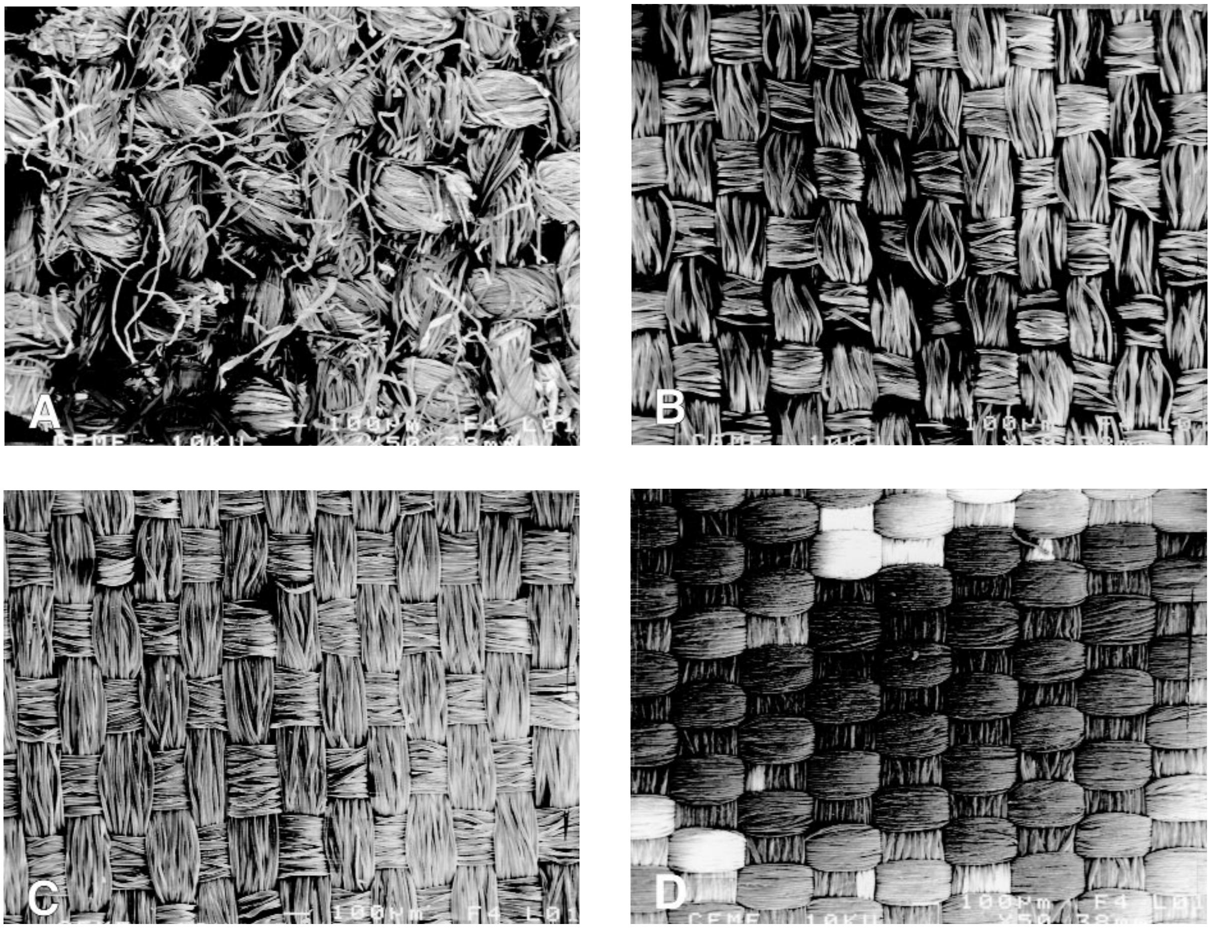

FIG 2. Scanning electron microscope pictures of 4 woven fabrics: laboratory control **(A)**, 50-μm fabric **(B)**, 10-μm fabric **(C)**, and 2-μm fabric **(D)** (see Table I for details).

ings, and both blocked approximately 95% of concentrated Der p 1 compared with a used cotton sheet (laboratory control). However, allergen blockage below detectable limits only occurred at the 6- and 2-μm level (Fig 3).

Twenty-one further fabrics were tested, which are marketed for encasement and available through local stores or catalogs (Table II). Fifteen of these fabrics, including all of those described as vapor permeable, restricted airflow to less than 0.1 L/min. Tests of these fabrics in which 1.0 g of dust with a high concentration of Der p 1 was placed directly onto the fabric demonstrated no detectable passage of allergens. Three of these restricting fabrics were also tested with Fel d 1, and once again results indicated no detectable passage of allergen. Of the 6 fabrics allowing airflow to pass through them, 4 were nonwoven synthetic fabrics, and 2 were tightly woven. All 6 of these fabrics blocked the majority of allergen presented during testing. Three microdenier fabrics were also tested, with average pore sizes reported at 9.9, 8.4, and 6.6 μm. The term "microdenier" typically describes a yarn that is comprised of filaments that have a linear density of less than 1.0 denier (1 denier = 1 g/9000 m of yarn) (Montgomery TG. Personal communication, 1998). Although the microdenier fabrics had

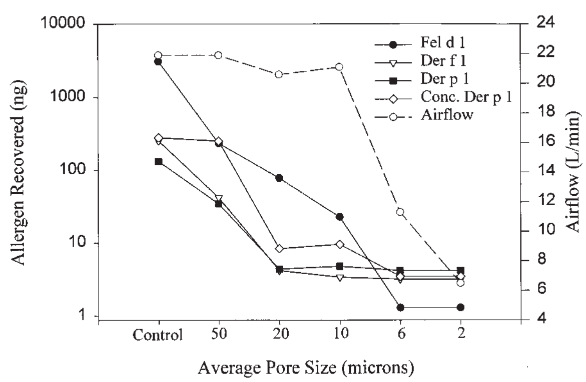

FIG 3. Allergen recovered from filter after testing fine woven fabrics with 1.0 g of dust containing 510 μg/g Fel d 1, 5.5 μg/g Der f 1, 3.7 μg/g Der p, 1 or 26.9 μg/g concentrated Der p 1. The amounts of allergen recovered from the 6-μm and 2-μm fabrics reflect the lower limit of the assay. The control was a used cotton sheet (laboratory control).

slightly different airflow and pressure characteristics than previously tested fabrics, the most effective allergen barrier was once again the fabric with a pore size closest to 6 μm. Further tests were carried out on 10-μm woven

TABLE II. Allergen levels recovered from fabrics recommended as encasements

Manufacturers/ suppliers	Fabric tested	Airflow (L/min)	Fel d 1 * (ng)	Concentrated Der p 1 (ng)*
Fabrics provided by manufacturer				
Nonwoven synthetic fabrics	Goretex (n = 2)†	<0.1	<0.6	<1.2
	3M Propore (n = 5)†	1.3	2.3	<2.4
	Wondertex (GSI; n = 2)†	17.8	1.1	<2.0
Microdenier fabrics from PFG‡	9.9 µm (n = 5)	19.1	78.0	<2.5
	8.4 µm (n = 5)	18.3	14.9	<2.5
	6.6 µm (n = 5)	16.3	5.7	<2.5
	Used fabric (~4.0 µm; n = 2)§	8.2	1.9	<1.2
Fabrics manufactured for allergen avoidance				
Allergy control products	Polycotton placebo (n = 5)	21.4	599	133
	ACb Elite Cotton/Polyester (n = 3)	<0.1	<1.8	<3.6
	ACb Stretch (n = 2)	<0.1	NT	<3.6
	Pristine (n = 3)	18.4	7.4	<2.0
	Pristine, Washed-1	17.5	3.4	<1.2
	Pristine, Washed-2	17.9	3.5	<1.2
Allergy-free environment	Ultra (n = 2)	<0.1	NT	<3.6
	Terry cloth (n = 2)	<0.1	NT	<3.6
Aller/Guard	Standard polyester/cotton (n = 2)	<0.1	NT	<3.6
	Premium polyester/blend (n = 2)	<0.1	NT	<3.6
	Terry cloth (n = 2)	<0.1	NT	<3.6
Comtrad Industries	Medibed (n = 2)†	21.9	2.65	<1.2
National Allergy Supply	Satin Soft (n = 3)	<0.1	<1.8	<3.6
	Cotton Guard (n = 2)	<0.1	NT	<3.6
	Softek (n = 2)†	22.3	4.7	<1.2
Priorities	Microfiber (n = 7)	14.8	2.0	<3.1
	Stretch knit (n = 2)	<0.1	NT	<3.6
	Polyester/cotton (n = 2)	<0.1	NT	<3.6
	Cotton terry (n = 2)	<0.1	NT	<3.6
Sears	Clean Air (n = 2)	< 0.1	NT	<3.6
	Clean Living Vinyl (n = 2)	<0.1	NT	<3.6

NT, Not tested.
*1.0 g of dust added.
†Synthetic fabrics recommended for allergen avoidance.
‡Average pore size reported by manufacturer.
§Fine woven fabric originally averaging 2 µm in pore size.
Commercially available.

fabric with seams used by pillow manufacturers. In each case the seam was placed across the dust trap. None of the seams leaked more than 5 ng of allergen, and there was no significant difference between the seams tested.

DISCUSSION

The method described here makes use of a commercially available vacuum pump to create a pressure gradient across the material being tested. The primary allergen for which these fabrics are designed is dust mite because pillows, mattresses, and box springs are important sites for dust mite growth. The results show that all fabrics rated as less than 10 µm in pore size excluded mite allergen below detectable limits, even when allowing up to 20 L/min airflow. In addition, we tested 3 nonwoven synthetic fabrics that had similar characteristics (Table II). Under most circumstances, controlling passage of cat allergen is not the purpose of these fabrics. However, the use of Fel d 1 as a second allergen allowed us to confirm and substantiate the findings. The leakage of Fel d 1 was consistently greater than that of Group 1 mite allergen. The leakage of Fel d 1 is in keeping with previous data showing that cat allergen becomes airborne on particles smaller than 10 µm.[7] However, that evidence is related to aerodynamic size. The results shown here provide supporting evidence that cat allergen is carried on particles that are physically smaller than mite allergen.

The current technique is robust and provides consistent measurements in regard to airflow, pressure, and leakage of both Der p 1 and Fel d 1. For materials that are impervious or vapor permeable, no airflow was measurable, and the validity of the test may be in doubt. However, as expected, no allergen was detected passing through any of these fabrics. The results indicate that both finely woven fabrics and nonwoven synthetic fabrics can be permeable to air and provide efficient barriers to cat and dust mite allergen. Three nonwoven synthetics allowed airflow of 15 L/min or greater but restricted Fel d 1 to less than 5 ng, making them comparable with fine woven fabrics with pore sizes of approximately 6 µm. A further nonwoven synthetic fabric that was tested (3M Propore) only allowed limited airflow (ie, 1.3 L/min) and would better be described as permeable rather than breathable. Although we have not systematically tested all the fabrics with repeated washing, 2 pillow cases made of 6-μm microdenier fabric were washed 22 times and retested. The results show very little change in performance, with a slightly improved blockage of Fel d 1 (Table II).

For woven fabrics, the key factor in blocking allergens is pore size. Our results show that a woven fabric with an average pore size of 6 μm or less will block common indoor allergens below detectable limits. We would caution against the use of fabrics with larger than average pore sizes (eg, 10 μm or higher) as allergen barriers for a variety of reasons. First, a fabric with an average pore size of 10 μm will, by definition, have pores both larger and smaller than 10 μm, potentially allowing the passage of fecal particles through the material. Second, it is possible that the average pore size of these fabrics may increase during normal wear and tear. For example, the used fabric listed in Table II originally averaged a pore size of 2 μm; however, after repeated laundering, the manufacturer now estimates the fabric to have an average pore size of 4 μm.

Our current judgement is that fabrics of 2 μm to less than 10 μm in pore size will effectively block passage of all dust mite allergen and would be suitable for use on pillow cases and mattresses. Recent results from Japan suggest that fabric of this kind used in a home can decrease exposure of infants to dust mite allergens.[9] It remains to be established how these materials should be maintained or for how long they will last. However, the experience with tightly woven fabrics used in hospital gowns and our own analysis is that they are robust and will withstand repeated washing. The results establish that there are several methods of producing a material of this kind, and that woven fabrics with pore sizes of approximately 6 μm will allow airflow but completely prevent the passage of allergen.

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