THE USE OF CYLINDER MODEL VACUUM CLEANERS

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With a Statistical Analysis

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(With 4 Figures in the Text)

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INTRODUCTION

Investigations into the spread of gastro-enteritis in the Parsons block at the Birmingham Children's Hospital, have been in progress for more than 18 months, during which period there has been no evidence of cross-infection between the different floors of the Parsons block although many cross-infections have occurred within the wards themselves. This observation seemed to justify concentrating the investigation on the articles used in common for all the cubicles in a ward, because of the possibility that it was contamination of these that was spreading infection. The Parsons block is made up of three floors; on each floor is one ward made up of ten cubicles with two cots in each cubicle.

It was found that brooms, from a ward in which there were cases of enteritis, were contaminated with the type strain of *Bacterium coli* associated with the cases of enteritis in that ward, even after the brooms had been thoroughly washed in 5 % carbolic acid and then left to dry in the sun.

The M.R.C. Special Report Series, no. 262, mentions the need to avoid sweeping with dry brooms, and states that the 'ordinary sweeper dust bag is said to allow the passage of many bacteria through its walls. In new institutions a built-in vacuum pipe-line is worth considering for this and other reasons.' As it would have been impossible to introduce such a pipe-line system in the Parsons block it was decided to investigate the efficiency of cylinder-type vacuum cleaners. This paper records the results of these investigations.

EXPERIMENTAL INVESTIGATIONS

The experiments were carried out as follows:

(1) *Artificially contaminated dust*

Dust from vacuum cleaners was collected, passed through a 28-mesh sieve to remove the large particles, and sterilized in the hot-air oven. A broth culture, or emulsion of the organism to be examined, was mixed into the fine dust, and the mud-like mixture was dried over phosphorous pentoxide in a vacuum. When dry the dust was finely powdered in a sterile pestle and mortar. A weighed sample of the dust was emulsified in sterile saline, and a pour-plate count was made to estimate the number of viable bacteria present.

Samples of the artificially contaminated dust were sucked into the vacuum cleaner. After each sample had been sucked up the air entry to the cleaner was intermittently obstructed in an attempt to produce a reduced pressure within the machine. When the obstruction was suddenly removed it was hoped that any flaws in the bag would be demonstrated by organisms escaping through the cleaner on to the plates which were exposed at the blower end of the machine whence the cleaned air was expelled.

It was found that *Bact. coli* (500,000 per gram of dust), *Chromobacterium prodigiosum* (100,000 per gram), *Staphylococcus aureus* (10 million per gram) and the dust failed to pass through the bag. Most of the experiments were made with a cleaner that had been used by the makers for demonstrations over a period of 18 months without the bag being changed. The makers supplied new bags, and it was then found that an absolutely new bag allowed a few staphylococci to escape, but that by the time 70 g. of dust had been sucked up the bag was a nearly perfect bacterial filter. A further experiment showed that when talcum powder was sucked into an absolutely new bag, which was then emptied of the talc, on further testing with artificial contaminated dust no organisms escaped. The results are shown in Table 1.

Table 1. *The effect of impregnation on the efficiency of the bag in a cylinder model vacuum cleaner. Dust artificially infected with* Staphylococcus aureus

(Plates exposed for 1 min. at blower end of vacuum cleaner)

Time in min.	Contaminated dust sucked up (g.)	Obstruction to air inlet	Colonies of staphylococci grown: Absolutely new bag	Colonies of staphylococci grown: Talc impregnated new bag
0–1	35	None	33	0
1–2	None	Intermittent	2	0
2–3	70	None	11	0
3–4	None	Intermittent	1	0
4–5	10	Control (no bag in the cleaner)	Uncountable	Uncountable

Experiments with several different makes of cylinder-type vacuum cleaners showed that all but one suffered from the serious drawback that the outer surface of the bags became contaminated when removed for emptying, so that the next time the machine was used organisms were expelled with the cleaned air. The exception is the Hoover model 402 from which the bag is never removed, as the machine is fitted with a mechanical foot-operated bag shaker (see Figure 1).

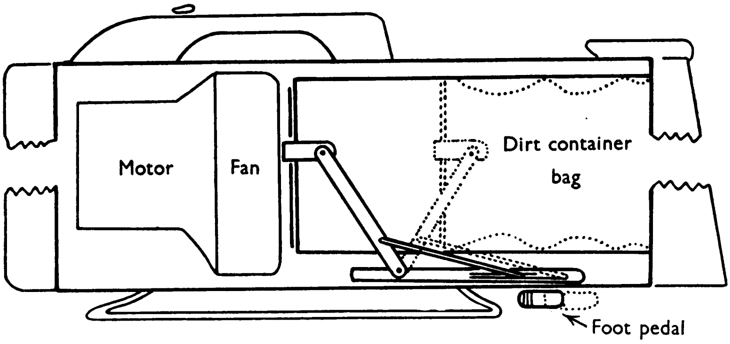

Fig. 1. Hoover 402. Diagram of emptying mechanism.

(2) *Field experiment in a ward with an epidemic of gastro-enteritis*

A ward, in which there was an epidemic of infantile gastro-enteritis, was swept with a cylinder-type vacuum cleaner. MacConkey plates were exposed over the aperture from which the air was expelled at the back of the machine. Before the sweeping swabs of dust were taken from the parts of the ward which were to be swept with the vacuum cleaner, incubated in nutrient broth for 18 hr. and then subcultured on very dry MacConkey plates.

No growth was obtained on any of the plates exposed at the blower end of the vacuum cleaner, although the type strain of *Bact. coli* was isolated from the dust of the ward.

(3) *Experiment in a ward with an unoiled floor*

Experiments were made to compare the efficiency of the cylinder-type vacuum cleaner with that of a broom when used in the empty cubicles of a premature baby ward in which the floors were unoiled. The cubicles were paired, one of each pair being swept with a broom, the other with the Hoover (see Fig. 2). The findings given in Fig. 3 are the average results of the three experiments using either the broom or the Hoover and were obtained by spraying with an atomizer 2 ml. of a heavy suspension of *Chr. prodigiosum* in each cubicle. The cubicles were left undisturbed until they were swept 48 hr. later. Bacterial counts were made using the improved M.R.C. slit sampling machine (Bourdillon *et al.* 1948), and phosphate agar plates on which the bright red colonies of the *Chr. prodigiosum* were easily counted.

(4) *Experiment in a ward with oiled floor*

The final experiment was made in a premature-baby ward, the floors of which were oiled once a week. On three successive mornings following the oiling slit sampling was carried out whilst the ward was swept with a broom. The next week the experiment was repeated using a Hoover instead of a broom. Fig. 4 shows a record of the average of the three separate observations of sweeping with either the broom or the Hoover, and in Tables 2–8 the individual results are given and

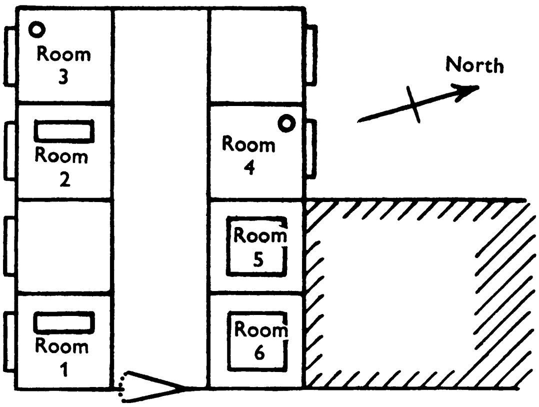

Fig. 2. Lay-out of premature-baby ward cubicles.

Pair	Rooms	Contents
A	1 and 2	Contained cots. Windows present
B	3 and 4	Contained chairs. Windows present
C	5 and 6	No furniture. No windows

Rooms, 1, 3 and 5 swept with broom.
Rooms 2, 4 and 6 swept with Hoover.

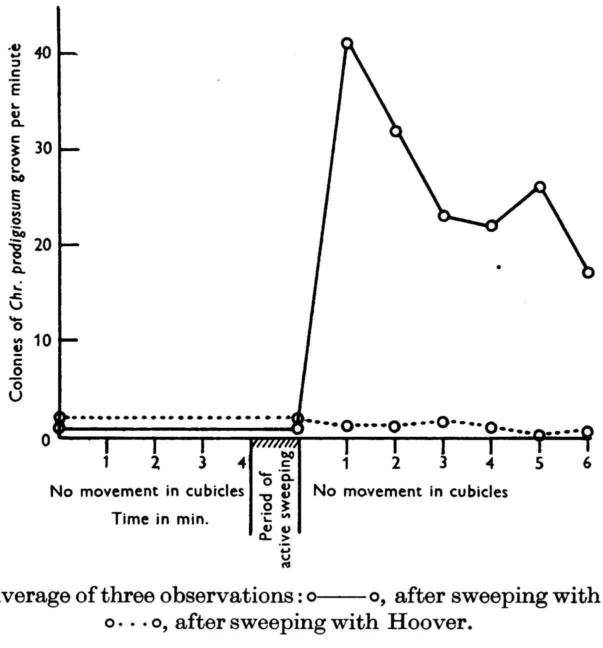

Fig. 3. Average of three observations: o——o, after sweeping with broom; o· · ·o, after sweeping with Hoover.

analysed. These are presented to show how, even when sweeping an oiled floor, a statistically significant improvement results from the use of a vacuum cleaner. These results do not show the great and added advantage of avoiding the deliberate transfer of a broom, laden with infected dust, from one part of a ward to another.

In Fig. 4 it is seen that there is a slow drop in the bacterial count during sweeping, but this appears to be a continuation of the fall which was observed as soon as the bed-making ceased, when slit sampling was carried out in the same ward on another occasion.

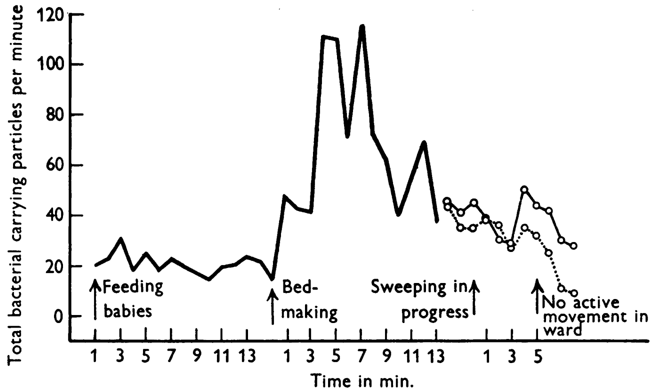

Fig. 4. Ward with oiled floor. Average of three observations: o——o, after sweeping with broom; o---o, after sweeping with Hoover.

STATISTICAL ANALYSIS

(1) *Comparison between sweeping unoiled floors with a broom and with Hoover model* 402 *in an empty premature-baby ward.*

In this experiment the six cubicles in the ward were treated in pairs, the two cubicles in each pair being as similar as possible. One cubicle of each pair was swept with a broom, the other with a Hoover (see Fig. 2). Table 2 shows that, before

Table 2. *Aerial slit sampling to show: Comparison of sweeping with broom and Hoover* (402). *Unoiled floor. Experimental ward*

Each cubicle sprayed with the same quantity of *Chr. prodigiosum* suspension. Cubicles swept in the following order; unit faces north and south:

South side cubicle: 1, broom; 2, Hoover; 3, broom.
North side cubicle: 4, Hoover; 5, broom; 6, Hoover.

Counts made of *Chr. prodigiosum* colonies only in minute periods

	South			North				
Cubicle ...	1	2	3	4	5	6	Average	
	Broom	Hoover	Broom	Hoover	Broom	Hoover	Broom	Hoover
5 min. period of no movement	0	0	0	1	2	5	1	2
Sweeping 1 min.	14	0	25	4	85	0	31	$1\frac{1}{3}$
No activity	23	0	34	2	39	3	32	$1\frac{2}{3}$
	9	0	30	1	30	4	23	$1\frac{2}{3}$
	5	0	29	2	31	1	22	1
	8	0	47	1	23	0	23	$\frac{1}{3}$
	5	0	27	1	18	1	17	$\frac{2}{3}$

sweeping began, the average count of *Chr. prodigiosum* colonies over a period of 5 min. differed little between the two cubicles of each pair. Where differences exist the count is higher in the cubicle which was to be swept with a Hoover.

We have therefore measured the magnitude of the differences between cubicles at minute intervals from the beginning of sweeping, without adjusting for differences in the initial counts. The paired differences are shown in Table 3; a positive difference indicates a higher count in the cubicle swept by a broom.

Table 3

Aerial slit sampling to show:

Comparison of sweeping with a broom or a Hoover (402). Unoiled floor. Premature-baby ward.

Differences in number of colonies of *Chr. prodigiosum* grown in the cubicles which were paired on the basis of their furniture and the presence or absence of windows.

	Min.	Pair A (rooms 1 and 2)	Pair B (rooms 3 and 4)	Pair C (rooms 5 and 6)
Sweeping	1	+14	+21	+85
No activity	2	+23	+32	+36
	3	+ 9	+29	+26
	4	+ 5	+27	+30
	5	+ 8	+46	+23
	6	+ 5	+26	+17
Mean difference		+10·67	+30·17	+36·17
Standard error of mean		2·8	3·5	10·1
t		3·81	8·62	3·58
		($0{\cdot}01 < P < 0{\cdot}02$)	($P < 0{\cdot}001$)	($0{\cdot}01 < P < 0{\cdot}02$)

If Student's t-test for paired differences is applied, each of the three cubicles swept with a broom shows a significantly higher count than the corresponding one swept with a Hoover. However, it may be that the three cubicles containing the most dust happened to be allotted to the broom purely by chance. The hypothesis that broom and Hoover would give on the average (over a large number of cubicles) equal counts may be tested from the three values of the mean difference, given in Table 3. These are 10·67, 30·17 and 36·17. A t-test on these three mean differences yields a value of t equal to 3·33 on 2 degrees of freedom, which is not quite significant at the 5% level ($0{\cdot}05 < P < 0{\cdot}10$).

(2) *The effect of sweeping an oiled floor with a broom or with a Hoover* (402) *in the premature-baby ward, Sorrento*

The observations in Table 4 are distinguishable in virtue of: (*a*) time in minute intervals, before, during and after sweeping; (*b*) the day of the week. If we consider primarily the trichotomy before, during and after sweeping regarding this as the only source of systematic variation, we obtain for the estimated residual variance by the procedure known as 'Analysis of Variance for testing the significance of mean differences' a value $S_e^2 = 236$ in the case of the Hoover and $S_e^2 = 200$ in the case of the broom. The observations with their means and standard errors computed on this basis are set out in Tables 5 and 6. The mean differences and the standard error of the difference for each pair of categories may be summarized:

	Broom	Hoover
Before sweeping − during sweeping	$+7{\cdot}22 \pm 6{\cdot}24$	$+4{\cdot}25 \pm 6{\cdot}48$
During sweeping − after sweeping	$+3{\cdot}56 \pm 6{\cdot}24$	$+18{\cdot}42 \pm 6{\cdot}48$
Before sweeping − after sweeping	$+10{\cdot}78 \pm 6{\cdot}67$	$+22{\cdot}67 \pm 7{\cdot}25$

Subject to the reservation that grouping the data in this way may well make the variances of the mean differences too high and hence their critical ratios too low, it is evident that no significant differences are manifest as a result of sweeping with a broom, but that there is a consistent difference between the conditions before and after sweeping with the Hoover. This conclusion is consistent with

Table 4

Aerial slit sampling to show:

Comparison of sweeping with a broom and a Hoover (402).
Oiled floor. Premature-baby ward, Sorrento.

Each figure gives total colony count per minute.

		Broom			
No. of babies in ward ...		5	3	3	
Day ...		Wed.	Thurs.	Fri.	
		(28. ix. 49–30. ix. 49)			Mean
Time in min.:					
Before sweeping	1	59	40	40	46
	2	50	37	35	41
	3	61	44	32	46
Sweeping	4	56	22	40	39
	5	50	21	20	30
	6	30	30	24	28
	7	62	66	23	50
After sweeping	8	63	40	22	42
	9	38	30	23	30
	10	32	30	23	28

		Hoover			
No. of babies in ward ...		3	3	2	
Day ...		Wed.	Thurs.	Fri.	
		(5. x. 49–7. x. 49)			Mean
Time in min.:					
Before sweeping	1	18	78	35	44
	2	25	53	26	35
	3	16	61	28	35
Sweeping	4	25	64	24	38
	5	25	54	28	36
	6	14	44	23	27
	7	23	45	38	35
	8	25	43	28	32
After sweeping	9	13	28	34	25
	10	6	11	17	11
	11	6	11	10	9

the inference that the Hoover procedure appreciably reduces the number of bacterial particles by suction, and that sweeping with a broom has little effect upon the number of such particles in the air when the floor is oiled. The effect of the Hoover in reducing the count after sweeping actually varied significantly from day to day. If the day-to-day variation is regarded as random, a test may be performed of the hypothesis that the reduction is *on the average* (i.e. over a large number of days) zero; the result is non-significant, i.e. this hypothesis is *not* contradicted by the data.

We may also lay our data in the customary form involving two criteria of classification if we break down the three major groups by 1 min. intervals and compute the residual variation on the assumption that the day of the week (*a*) constitutes and (*b*) does *not* constitute a systematic source. We then obtain

Table 5. *Total bacterial counts made at successive minutes on three different days with their means and standard errors before, during and after sweeping with a broom*

Day and min.		Before sweeping	During sweeping	After sweeping
Wed.	1	59	56	63
	2	50	50	38
	3	61	30	32
	4	—	62	—
Thurs.	1	40	22	40
	2	37	21	30
	3	44	30	30
	4	—	66	—
Fri.	1	40	40	22
	2	35	20	23
	3	32	24	23
	4	—	23	—
Means		44·22	37·00	33·44
Standard errors		4·72	4·09	4·72

S_e^2 using one criterion of classification 200·21

Table 6. *Total bacterial counts made at successive minutes on three different days with their means and standard errors before, during and after sweeping with a Hoover*

Day and min.		Before sweeping	During sweeping	After sweeping
Wed.	1	18	25	13
	2	25	25	6
	3	16	14	6
	4	—	23	—
	5	—	25	—
Thurs.	1	78	64	28
	2	53	54	11
	3	61	44	11
	4	—	45	—
	5	—	43	—
Fri.	1	35	24	34
	2	26	28	17
	3	28	23	10
	4	—	38	—
	5	—	28	—
Mean		37·78	33·53	15·11
Standard errors		5·12	3·97	5·12

S_e^2 using one criterion of classification 236·27

somewhat smaller values for our residual variation, viz. for the broom 92 and 156 and for the Hoover 106 and 209 (see Tables 7 and 8).

Though the effect of eliminating the diurnal source of variation is to increase the efficiency of our estimates of the column means, the picture disclosed does not substantially modify our previous conclusions. For the broom procedure none of the differences is as great as 3σ, where σ is the standard error of a difference, and the highest mean value (at the end of the period of sweeping) does not exceed by as much as $1\frac{1}{2}\sigma$ the mean of any of the counts before sweeping began. The difference between the last mean count and the mean count at the end of the period of sweeping is over $2\frac{1}{2}\sigma$, but the somewhat erratic trend of the figures during sweeping discounts great reliance on this feature. The figures are consistent with a small increase of bacterial particles in the atmosphere at the end of sweeping but do not disclose an effect of the magnitude of that produced by sweeping unoiled floors.

Table 7. *Total bacterial counts made on three different days with their means and standard errors for successive minutes before, during and after sweeping with a broom*

	Before sweeping			During sweeping				After sweeping			
Day	1	2	3	4	5	6	7	8	9	10	Day mean
Wed.	59	50	61	56	50	30	62	63	38	32	50·1
Thurs.	40	37	44	22	21	30	66	40	30	30	36·0
Fri.	40	35	32	40	20	24	23	22	23	23	28·2
Min. mean	46·33	40·67	45·67	39·33	30·33	28·00	50·33	41·67	30·33	28·33	

	One criterion of classification	Two criteria of classification
S_e^2	155·65	91·54
Standard error of minute mean	7·10	5·52
Standard error of difference between two minute means	10·19	7·81
Standard error of day mean	—	3·03
Standard error of difference between two day means	—	4·28

Table 8. *Total bacterial counts made on three different days with their means and standard errors for successive minutes before, during and after sweeping with a Hoover*

	Before sweeping			During sweeping					After sweeping			
Day	1	2	3	4	5	6	7	8	9	10	11	Day mean
Wed.	18	25	16	25	25	14	23	25	13	6	6	17·82
Thurs.	78	53	61	64	54	44	45	43	28	11	11	44·73
Fri.	35	26	28	24	28	23	38	28	34	17	10	26·45
Minute mean	43·67	34·67	35·00	37·67	35·67	27·00	35·33	32·00	25·00	11·33	9·00	

	One criterion of classification	Two criteria of classification
S_e^2	209·134	106·061
Standard error of minute mean	8·35	5·95
Standard error of difference between two minute means	11·80	8·31
Standard error of day mean	—	3·10
Standard error of difference between two day means	—	4·39

The results of Hoover sweeping shown by the mean figures in Table 8 reveal no significant differences before and during sweeping, but a highly significant drop in the last two mean counts in confirmation of the results already stated.

For both Hoover and broom mean daily counts differ significantly from one another, all but two of the differences being greater than 3σ. There is no apparent trend in this variation, however, either in relation to the number of babies in the ward or to the number of days since the floor was oiled and it is more likely to be caused by some extraneous circumstance.

DISCUSSION

The use of the ordinary broom to sweep wards carries the potential risk of the transfer of contaminated material from one part of a ward to another. This is one of the ways by which the protection provided by an otherwise efficient barrier nursing system can be destroyed.

Experiments showed that the cylinder-type vacuum cleaners acted as bacterial as well as dust filters. Artificially infected dust was sucked into the machines and none of the infecting organisms escaped from used bags or from new bags after they had been filled once. Under field conditions, when unoiled floors were swept with vacuum cleaners, there was no increase in the number of bacterial particles thrown into the air, whereas a domestic broom caused a marked rise in the total of bacterial particles in the air. Even on oiled floors there is a statistically significant improvement when a vacuum cleaner is used.

Several models were tested, all except one suffering from the drawback that the outside of the dust bags became contaminated when they were emptied. The exception was the machine fitted with a foot-operated device, which allowed the bag to be emptied without removing it from the cleaner.

SUMMARY

Cylinder-model vacuum cleaners cause no bacterial contamination of the air, whereas even on oiled floors domestic brooms caused statistically significant contamination of the air when compared with a vacuum cleaner.

The Hoover model 402 was the only machine tested whose bag is never removed, a theoretical as well as a practical advantage. Domestic brooms can destroy an otherwise efficient barrier nursing system and should be avoided in hospital wards.

I wish to thank the makers and agents of the many vacuum cleaners that have been examined in this work, and especially to Mr D. H. Lowrie of Hoover Ltd. Also Dr R. E. O. Williams for loaning the slit sampler, Dr V. Mary Crosse for allowing the experiments at Sorrento Premature Baby Unit and Dr Leonard Colebrook for his encouragement.

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(*MS. received for publication* 20.I.51)