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Changes in airways conductance on smoking a cigarette

A study of repeatability and of the effect of particulate and vapour phase filters

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Measurements of airways conductance using a body plethysmograph were made on 25 men before and after smoking one cigarette on each of four days and before and after a control period without smoking on another day. The repeatability of these measurements and of the bronchoconstrictor effect of smoking was studied. The variance was as great as that observed in a previous field study in industry despite close supervision and a stable environment before the measurements. We think this variation is due to random fluctuation rather than to the lack of close supervision inevitable in a field survey.

A second study was made on 16 of the men in which the bronchoconstrictor effect of plain and filtered cigarettes was compared. Filters which removed either the particulate or the vapour phase of the smoke had a similar effect in reducing the bronchoconstrictor response of cigarette smoking.

Guyatt, Berry, Alpers, Bramley, and Fletcher (1970) reported a field study in which measurements of airways conductance were made with the body plethysmograph on a large number of working men before and after smoking a cigarette. They related these changes to smoking habits and symptoms of bronchitis. They found considerable variation in repeat measurements and suggested that this might have been due to the men having been studied during the course of their day's work which precluded careful control of their activities and environment immediately before the measurements were made. It was therefore decided that similar measurements should be made on a group of men who could be kept under close supervision in order to see whether this would improve the repeatability. A comparison was also made between the bronchoconstrictor response to smoking a plain cigarette and to smoking the same cigarette provided with filters designed to retain either the vapour or particulate phase of the smoke.

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METHODS

The subjects were men who were serving sentences in Her Majesty's Prison at Wormwood Scrubs and who volunteered for the study. Measurements were made of airways conductance on 80 men before and after smoking a plain cigarette. Twenty-five of the men who performed the test satisfactorily and who showed a significant bronchoconstrictor response to smoking were selected for further study. The questionnaire on respiratory symptoms (M.R.C., 1960) was used to ascertain the presence of cough, phlegm, and history of smoking. One-second forced expiratory volume (FEV_1) and forced vital capacity (FVC) were measured with an electrically-timed spirometer (McKerrow, McDermott, and Gilson, 1960) according to the technique described by Freedman and Prowse (1966).

Airways conductance (Gaw) and thoracic gas volume (Vtg) were measured by the method of DuBois, Botelho, and Comroe (1956) using a body plethysmograph housed in a caravan trailer (Guyatt, Alpers, and Davies, 1967). One observer (B.G.C.) made all the readings. The results were expressed as the natural logarithm of the specific conductance (SGaw/Vtg) and the change observed on smoking or control periods was expressed as the index log SGaw − log

SGaw' where the prime represents the second reading. This was done since we have found that the simple ratio Gaw/Vtg provides a satisfactory correction for the effect of changes in lung volume on conductance (Guyatt, Alpers, Hill, and Bramley, 1967). The logarithmic transformation is necessary since the distribution of specific conductance in man is log normal, and we have found that changes in specific conductance, either with or without smoking, are related to the initial value, but changes in the logarithm of specific conductance show no such relationship. The effect of using the change in log SGaw rather than SGaw itself is similar to the effect of using a percentage rather than an absolute change. No allowance was made for age and height since the smoking response was found to be independent of these factors (Guyatt *et al.*, 1970).

PROCEDURE

FIRST STUDY The 25 men were randomly divided into five groups of five and were studied on each of five days: Monday, Tuesday, Thursday, and Friday of one week and on the next Monday (a mechanical breakdown prevented measurements on Wednesday of the first week). The order in which measurements were made on the men within each group and the order in which the measurements were made on the groups each day was determined by a latin square plan. Each man had four smoking days and one non-smoking day. The choice of the day on which each man did not smoke was also fitted into this design. Only two subject-sessions were lost.

The men were assembled at 8 a.m. each day and kept under observation to ensure that they smoked only when indicated by the experimental design. Measurements were started at 9.30 a.m. and continued until 1.30 or 2.00 p.m. Supervision was continued throughout a luncheon interval from 11.30 a.m. to 12 noon. After the initial measurements there was an interval of 10 minutes before the second measurements. During this interval four men from each group smoked a plain, unfiltered, top-brand cigarette in his usual way while one, acting as control, spent a similar period without smoking. The observer who made the measurements did not know which men had smoked and which had not.

An analysis was made of the initial log SGaw values (similar to that described by Guyatt *et al.* (1967)) to see how much these measurements varied from day to day, during the day, from group to group or in the rank order (the order in which men within each group were examined).

Mean values and standard deviations were calculated for each man for the following groups of data: log SGaw values before tests (five values, including control test), log SGaw values before and after the smoking tests (four values, control tests excluded), and the difference in log SGaw on smoking (four values).

SECOND STUDY A similar procedure was followed in investigating the effect of cigarette filters. Sixteen of the men who had the largest smoking response were divided into four groups of four and measurements were made on four successive days. The effects of smoke from three types of cigarette made of the same tobacco were studied. First, smoke from the unfiltered cigarettes used in the first study, secondly from similar cigarettes fitted with a filter composed of 10 mm. of bonded carbon and a 5 mm. coarse acetate filter which removed about 15% of the particulate matter and some 85 to 90% of almost all volatile material, including acrolein and hydrocyanic acid, but not oxides of nitrogen or hydrocarbons with very low boiling point, such as methane, nor permanent gases, and thirdly smoke from a similar cigarette fitted with a Cambridge paper filter in a special holder which removed the particulate fraction of the smoke (Fig. 1). Between repeat measurements one man in each group of four smoked

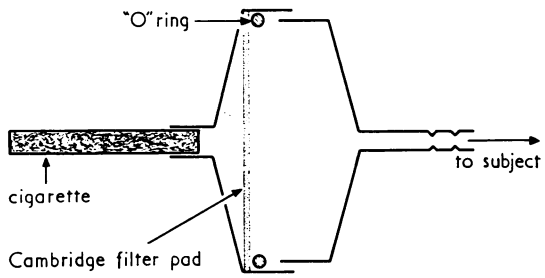

FIG. 1. *The filter pad (thick paper) is inserted into a polyethylene holder and fixed with a rubber ring* 'O'.

an unfiltered cigarette, another smoked a cigarette with the first type of filter, a third a cigarette with the second type of filter, while the fourth acted as control by not smoking. The allocation to the different smoking procedures on each day was determined by a latin square design.

RESULTS

The mean age of the subjects was 28 years (range 21 to 42). They were all cigarette smokers with a mean history of smoking of 11·5 'pack years' (range 0·5 to 25). None of them had spirometric evidence of airways obstruction. Eleven admitted to persistent cough or expectoration (Table I).

The study of repeatability showed that there was no significant variation between measurements at different times of day, between rank order or between groups. Nor were the initial values before smoking and before the rest period different (Table II). The mean initial value of log SGaw was −1·31 (range −0·94 to −1·93). All but one of the subjects showed bronchoconstriction after smoking a cigarette, the mean change

TABLE I

PHYSICAL CHARACTERISTICS OF THE MEN

Subject	Age (yr.)	Wt. (kg.)	FEV_1 (l.)	FVC (l.)	$\frac{FEV_1}{FVC}$ %	Pack Years[2]	Presence of Cough[3]	Presence of Phlegm[3]
1[1]	32	70	3·35	4·95	72	15	—	—
2	29	70	4·40	5·25	84	21	—	—
3	35	60	3·37	3·75	90	10	—	—
4[1]	21	70	4·80	5·68	84	6	—	—
5	36	75	3·40	4·65	73	25	—	—
6[1]	25	75	4·25	6·25	81	15	—	—
7[1]	32	70	4·33	5·70	83	21	+	+
8	22	75	4·00	5·40	74	6·5	+	—
9[1]	22	80	4·10	5·40	76	7·5	+	+
10[1]	22	75	4·98	6·35	78	6	—	—
11[1]	23	65	4·20	4·93	85	17	—	—
12[1]	37	75	3·25	5·60	58	25	+	+
13[1]	25	70	3·67	4·67	79	9	+	—
14[1]	24	70	4·42	5·30	83	9	+	+
15[1]	22	65	4·93	6·20	79	5	—	—
16[1]	43	80	3·53	4·53	78	5	—	—
17[1]	22	70	3·47	5·03	69	10	—	—
18	28	70	2·95	4·20	70	4	+	+
19	25	75	5·37	5·90	91	23	—	—
20	50	90	2·80	3·65	77	17	—	—
21	25	65	3·63	4·65	78	7·5	+	+
22	20	80	4·05	5·20	78	0·5	+	—
23[1]	25	70	3·83	4·80	80	15	+	—
24[1]	29	60	4·03	4·90	82	13	—	—
25[1]	32	65	4·20	5·20	81	5	+	—
Mean	28	71	3·97	5·13	78	11·5		

[1] These men took part in the filter study
[2] One pack year is equivalent to smoking 20 cigarettes or the equivalent amount of tobacco daily for one year
[3] 'Yes' to question: 'Do you usually cough first thing in the morning in the winter?', or to question: 'Do you cough up phlegm most days for as much as three months of the year?'.

TABLE II

LOG SGaw BEFORE AND AFTER SMOKING ONE PLAIN CIGARETTE

Subject	Initial Log SGaw		Log SGaw after Smoking		Change of Log SGaw	
	Mean before Smoking ± SD	Before Control	Mean ± SD	After Control	On Smoking ± SD	Non-smoking Control
1	−1·31 ± 0·15	−1·19	−1·49 ± 0·27	−1·21	+0·18 ± 0·24	+0·02
2	−1·93 ± 0·12	−1·74	−2·01 ± 0·13	−1·75	+0·07 ± 0·24	+0·01
3	−1·16 ± 0·03	−1·08	−1·25 ± 0·08	−1·14	+0·09 ± 0·06	+0·06
4	−1·48 ± 0·33	−1·24	−1·43 ± 0·32	−1·26	−0·04 ± 0·30	+0·02
5	−1·05 ± 0·04	−1·08	−1·20 ± 0·12	−1·20	+0·15 ± 0·08	+0·12
6	−0·94 ± 0·06	−0·97	−1·05 ± 0·07	−1·17	+0·11 ± 0·09	+0·19
7	−0·99 ± 0·04	−1·05	−1·11 ± 0·03	−1·14	+0·12 ± 0·07	+0·09
8	−1·51 ± 0·27	−1·50	−1·56 ± 0·28	−1·50	+0·05 ± 0·05	0·00
9	−1·20 ± 0·05	−1·15	−1·26 ± 0·04	−0·20	+0·06 ± 0·07	+0·05
10	−1·00 ± 0·11	−0·98	−1·06 ± 0·08	−0·78	+0·06 ± 0·08	−0·20
11	−1·74 ± 0·06	−1·19	−1·87 ± 0·05	−1·06	+0·13 ± 0·10	−0·13
12	−1·00 ± 0·11	−0·95	−1·22 ± 0·05	−1·05	+0·22 ± 0·15	+0·10
13	−1·78 ± 0·27	−1·88	−2·03 ± 0·03	−2·02	+0·26 ± 0·27	+0·14
14	−1·65 ± 0·31	−1·64	−1·87 ± 0·35	−1·68	+0·22 ± 0·28	+0·03
15	−0·94 ± 0·12	−1·05	−1·12 ± 0·11	−1·10	+0·18 ± 0·10	+0·05
16	−1·54 ± 0·11	Absent	−1·66 ± 0·13	Absent	+0·12 ± 0·04	Absent
17	−1·92 ± 0·09	−1·60	−2·22 ± 0·24	−1·57	+0·31 ± 0·24	−0·02
18	−1·21 ± 0·16	−1·42	−1·86 ± 0·07	−1·86	+0·65 ± 0·12	+0·44
19	−1·13 ± 0·08	−1·11	−1·26 ± 0·11	−1·18	+0·13 ± 0·10	+0·07
20	−1·17 ± 0·07	−1·29	−1·29 ± 0·11	−1·24	+0·12 ± 0·12	−0·05
21	−1·75 ± 0·58	−2·67	−2·56 ± 0·08	−2·53	+0·81 ± 0·50	−0·14
22	−1·17 ± 0·07	−1·23	−1·30 ± 0·10	−1·27	+0·12 ± 0·03	+0·05
23	−1·16 ± 0·10	−1·05	−1·29 ± 0·09	−0·87	+0·13 ± 0·02	−0·18
24	−1·10 ± 0·02	−1·21	−1·44 ± 0·24	−1·15	+0·34 ± 0·26	−0·07
25	−1·10 ± 0·22	−1·06	−1·19 ± 0·16	−1·43	+0·09 ± 0·10	+0·37
Mean	−1·31 ± 0·19	−1·31	−1·50 ± 0·16	−1·35	+0·19 ± 0·19	+0·04

N.B. It should be noticed that a *reduction* in airway conductance after smoking is shown as a + change (Change of Log SGaw).

being +0·19. The change after the non-smoking rest period was +0·04 (Table II). Analysis of variance showed that the differences between the change on smoking and the change on not smoking was highly significant (P<0·001).

The variance of four measurements on each of 25 men of the response to smoking a cigarette was 0·0345, which was closely similar to the value 0·0391 calculated from figures for two measurements made on each of 50 men by Guyatt *et al.* (1970). The variances of log SGaw before and after smoking were also very similar, 0·0368 and 0·0247 respectively, compared with 0·0323 and 0·0196 respectively in the study by Guyatt *et al.* (1970).

It will be noted in Table II that the mean standard deviations of the initial and final readings and of the difference on smoking were very similar, being 0·19, 0·16, and 0·19 respectively.

We wished to see if there was a relationship between the means and their standard deviations. The data are not even approximately normally distributed and so a non-parametric test was used to indicate the relationship between the individual means and their standard deviations. For this purpose 2×2 tables were constructed by finding the observed median of each variable, discarding any values which were equal to the median and assigning the values to four classes, according to whether they were greater or less than the two medians. The results of this analysis are presented in Table III. There is strong evidence for a relationship between the means and standard deviations for the five initial readings, good evidence for that between the means and standard deviations for the differences on smoking, fair evidence for that between the standard deviations of the initial readings and the differences on smoking, but no evidence of a relationship between the means of the initial values and the differences.

The effect of the filters on the change in log SGaw is shown in Figure 2. The average response to smoking a plain cigarette was +0·19 unit, as

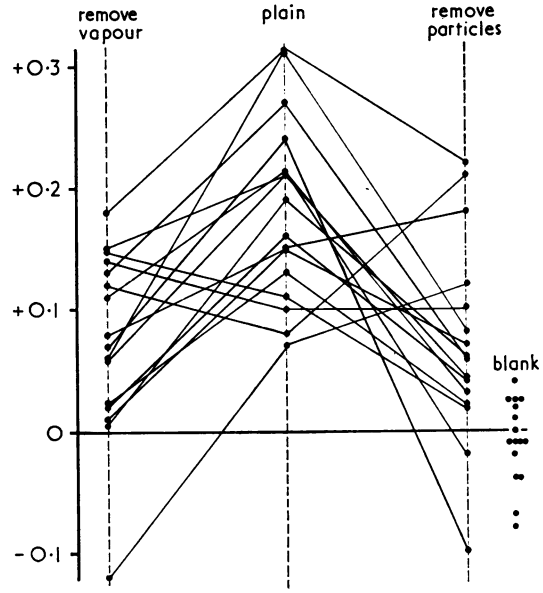

FIG. 2. *The change in log SGaw after smoking plain and filtered cigarettes. Blank refers to the difference between two measurements of SGaw when subjects did not smoke.*

opposed to +0·07 unit with the Cambridge filter and +0·08 unit with the carbon acetate filter. In this study the change on the control non-smoking period was again +0·04. The response to smoking a plain cigarette was greater than the response to a cigarette with the Cambridge filter in 12 out of the 16 cases and was greater than the response to a cigarette with the carbon acetate filter in 13 out of 16 cases. There was no significant difference between the response to the carbon acetate filter and the Cambridge filter, but both were significantly less than the response to the plain cigarette (P<0·01).

TABLE III

RELATIONSHIP BETWEEN INITIAL READINGS OF SGaw, THEIR STANDARD DEVIATIONS AND THE CHANGES ON SMOKING

		SD Initial Reading		
		+	−	
Mean of 5 initial readings	+	1	10	P=0·00012
	−	9	0	
		SD of Differences		
		+	−	
Mean of 4 differences on smoking	+	3	8	P=0·0098
	−	8	1	
		Mean of 4 changes on smoking		
		+	−	
Mean of 4 initial readings	+	4	6	P=0·62
	−	5	5	
		SD of 4 changes on smoking		
		+	−	
SD of 4 initial readings	+	3	7	P=0·025
	−	7	1	

P= exact 2-tail probability
+ =above median
− =below median
Numbers above and below the median are not exactly equal because of observations falling on the median line.

DISCUSSION

The study illustrates one of the problems of measuring the effects of cigarette smoking on airways conductance. Table II shows that the stan-

dard deviation of the change of log SGaw was in many cases greater than the mean change. The study of the individual responses shows that in many subjects a large degree of bronchoconstriction was found on only one out of the four occasions and very little response on the others. Only two subjects (Nos. 18 and 23) showed a consistently large response to smoking a plain cigarette.

The similarity of the variance of the smoking response found in this study carried out with close supervision of the subjects and that of the response observed in a field study without such supervision indicates that the absence of a stable environment before the test did not contribute to the poor reproducibility of the earlier study and that it is due to a combination of individual and instrumental variability. It is not surprising that the greater the variance of the initial reading on any individual the greater was the variance of the difference produced by smoking.

In this group of subjects there was a tendency for the readings to become more variable as log SGaw became more negative (higher airways resistance). This relative increase is not due to larger reading errors in men with a higher resistance, for the effect is removed by log transformation of the data (Guyatt *et al.*, 1970).

The filter experiment certainly suggests that the response to smoking can be reduced, though not abolished, by filtering out either the vapour or particulate phase of smoke. Nadel and Comroe (1961) suggested that the response was due to the submicronic particle in cigarette smoking because removal of volatile materials from smoke did not reduce the response. Our results suggest that the response to tobacco smoke is more generalized, due as much to the vapour as to the particulate phase. This conforms with the findings of Carson, Goldhamer, Mackars, and Silson (1965), who found that the increase of airways resistance in guinea-pigs exposed to cigarette smoke could be reduced by either carbon or cellulose acetate filters. Our findings of a reduction of response to smoking from a simple cellulose acetate filter have been confirmed by Robertson, Warrell, Newton-Howes, and Fletcher (1969), who also showed that a filter with higher retention efficiency reduced the response more than one with a lower efficiency.

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