TITLE

Statistical Analysis of Mortality Rates of Cigarette, Pipe, and Cigar Smokers

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## ABSTRACT

Statistical analysis of recent data on the mortality rates of pipe, cigar and cigarette smokers showed that the mortality ratio of smokers could be best described in terms of the dose rate (volume of smoke per day), length of exposure and toxicity of the smoke. When the toxicity of cigarette smoke was defined as one, the toxicity of pipe smoke was found to be $0.07 \pm .11$ and of cigar smoke $0.28 \pm .13$. The hypothesis that the toxicity of the smoke is controlled by the combustion conditions during pyrolysis of the tobacco is shown, for the first time, to be the only reasonable explanation for this difference in toxicity.

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## Introduction

A proper correlation between the mortality rates of cigarette, pipe, and cigar smokers as a function of the three exposure variables, amount smoked, depth of inhalation, and age at which smoking started, has not been carried out. The purpose of this investigation is to develop the statistical "best fit" equations relating the mortality ratio and the exposure variables. Such an analysis permits a comparison between the toxicity of smoke from cigars, pipes, and cigarettes. In addition, the possibility of explaining the mortality ratios in terms of a more conventional dose rate and length of exposure concept is investigated. The development of these equations allows, for the first time, evaluation of hypotheses concerning the reason for the lower mortality ratios of pipe and cigar smokers compared to cigarette smokers.

## Calculations

For a proper investigation the mortality rate should be tabulated as a function of two of the exposure variables at every level of the third variable. For instance, the mortality rate of cigarette smokers as a function of the number of cigarettes smoked per day and the depth of inhalation should be shown for every age of started smoking for a given age group i.e. 40 to 69 years.

However, the mortality rates (1), (2), (3) and (4) have not been so tabulated. Table 3 reference (3) shows the mortality of cigarette smokers as a function of the depth of inhalation and the amount smoked at the average age of starting to smoke (19 years). From this table the best fit equation of the mortality ratio (easily calculated from the mortality rate) can be found by multinomial regression.

To convert the depth of inhalation which is expressed by (1), (2), (3) and (4) as none, slight, moderate, or deep, to a more mathematical form; the volume of air inhaled by smoking through a cigarette filter was measured when ten male subjects were requested to give the above depths of inhalation ten times. The rounded off ratios (compared to the average) were; none - 0.54, slight - 0.80, moderate - 1.00 (average smoker) and deep - 1.25. It should be noted that it is physically impossible to inhale more deeply without taking a larger volume of smoke into the body. While it can be argued that these values do not represent the population, they are almost certainly more representative than the subjective classification by smokers into one of four depth of inhalation groups. In addition the relationships derived below are valid for any reasonable assumption of the relative values. The standardized value used in all smoking machines is 35 cc which corresponds to the average cigarette smoker (2). The puff volume for any inhalation is calculated by multiplying the above ratio times 35 cc.

Thus the best fit multinomial equation relating the mortality ratio* (MR), to the number of cigarettes smoked per day (NC), and the depth of inhalation (DR) at the average age of starting to smoke for men aged 40 to 69 was found to be:

$$MR = 0.983 + 0.028(NC) + 0.0155(DR) - 0.00031(NC)^2 \pm 0.11 \quad (1)$$

where 0.11 is the standard error. Each of the above terms is significant at the 99% confidence level. The multiple correlation coefficient of this equation is 0.97 (a perfect correlation is 1.0) and the F value for analysis of variance is 86.

While equation (1) is the best fit equation for this data it does not have a physical interpretation. A more meaniful method of analyzing the results would be to postulate that the mortality rate was proportional to the "dose rate" of the smoke. Thus for cigarette smokers the daily dose rate would correspond to the number of cigarettes per day multiplied by the number of puffs per cigarette, multiplied by the volume inhaled per puff or; in other words, the volume of smoke inhaled per day. Analysis of the data in Table 3 reference (3) for male smokers aged 40 to 69 indicates the best fit equation is of the form:

$$MR = 1.01 + 0.95(\text{Dose Rate} \times 10^{-4})^{1/3} \pm 0.13$$

where Dose Rate = (NC) x 12 x (DR) = cc Smoke/Day. The multiple correlation coefficient for this relationship is 0.96, the

* mortality ratio is the ratio of death rates of smokers to non-smokers in the same age group.

dependence with (dose rate)$^{1/3}$ is significant at a confidence level of over 99.99%, and F value for analysis of variance is 105. Three extra data points for all the cigarette smoking relationships at MR = 1.0, DR = 0, NC = 0, were added as it is the best known point and represents the zero value for each variable. Thus expressing the mortality ratio as a function of the dose rate gives as good a fit to the data as the best fit multinomial equation.

As mentioned a proper multinomial regression on all three exposure variables is not possible because the information is not tabulated in a convenient form. However, the mortality rates are expressed as a function of the three variables when the other two are averaged (1), (2) and (3). A multinomial regression on this grouped data is thus possible. If a comparison between smokers of cigars, pipes, and cigarettes is to be made, it is necessary to consider the mortality of men over 45 years of age in order to have enough observations in each grouped data point. However, the mortality rates have not been summarized in this age group in any of the reference works. The mortality rates were thus calculated from tables presented in reference (2) in the age group 45 - 65 as this group contains a higher number of excess deaths from smoking than an older group.

The mortality rates were normalized on the standard population distribution (Table 1, Appendix of reference (2)) as was done in that work. The avarage values for amount smoked, age started smoking and depth of inhalation were averaged from the appropriate tables in (2) over the 45 to

65 age group. The mortality ratio as a function of the amount smoked, depth of inhalation, and age started smoking for cigarette, pipe and cigar smokers are shown in Table 1 for the age group 45 to 65.

The best fit equations were found to be:

Male Cigarette Smokers Only Aged (45 - 65)

$$MR = 3.18 + .0156(NC) - .134(AS) + .00017(AS)^2 + .00033(DR)^2 \pm .087 \quad (3)$$

multiple correlation coeff. = .99 F = 126.5

where AS = age started smoking.

Male Cigarette + Cigar + Pipe Smokers* Aged (45 - 65)

$$MR = 2.05 + .0101(NC) - .113(AS) + .027(DR) + .00023(NC)^2 + .00171(AS)^2 \pm .096 \quad (4)$$

multiple correlation coeff. = .98 F = 60.5

The corresponding best fit dose rate equations are:

Male Cigarette Smokers Only Aged (45 - 65)

$$MR = .93 + .031(NC \times 12 \times DR \times 10^{-4})^{1/3} \times (55 - AS) \pm .13 \quad (5)$$

where NC x 12 x DR = dose rate = volume smoke/day

multiple correlation coeff. = .97 F = 207.

Male Cigarette Plus Pipe and Cigar Smokers Aged (45 - 65)

$$MR = .92 + .026\ ((NC) \times 12 \times (DR) \times 10^{-4})^{1/3} \times (55 - AS) \pm .19 \quad (6)$$

multiple correlation coeff. = .91 F = 66.

For pipe and cigar smokers there are not enough data points to evaluate the best fit multinomial equations so only the mortality ratio as a function of the dose rate equations can be cal-

* classified by number of cigarettes smoked per day

culated. No data is available for the age started smoking for pipe and cigar smokers.

Male Pipe Smokers Only Aged (45 - 65)

$$MR = 1.02 \pm 0.16 \quad (7)$$

multiple correlation coeff. = .08 F = .01.

Cigar Smokers Only Aged (45 - 65)

$$MR = .82 + .208 (NCIG \times 60 \times DR \times 10^{-3})^{1/3} \pm .13 \quad (8)$$

where NCIG = number of cigars per day

multiple correlation coeff. = 0.7 F = 1.82.

The average number of puffs per cigar is 60 and for pipes 90.

Discussion

An excellent correlation (correlation coefficient = .99) relating the mortality ratio of cigarette smokers and the exposure variables of amount smoked, depth or volume of inhalation, and age started smoking, has been found by multinomial regression. The mortality ratio is linearly related to the dose rate (volume of smoke per day) to the one third power times the average length of exposure to the smoke.

If the mortality ratio of men who smoke cigars and pipes in addition to cigarettes is compared to that of men who smoke only cigarettes by utilization of the respective best fit equations (3) and (4), an important conclusion can be drawn. The best value of the mortality ratio for male cigarette smokers aged 45 to 65 at 24 cigarettes

per day, an inhalation volume of 35 cc, and an age of started smoking of 19, is 2.00 $\pm$ .087, while the corresponding value for cigarette plus cigar and pipe smokers is 1.80 $\pm$ .096. Thus one of the two following conclusions can be made depending whether the smokers smoked cigars and pipes concurrently with cigarettes or at some time switched mode of smoking:

(a) Cigar and pipe smoking in addition to cigarette smoking produces a significant lowering of the mortality ratio of the smoker; or:

(b) Cigar and pipe smoking did not induce mortality as readily as cigarette smoking over the period when those devices were smoked.

The most important conclusion is derived from the analysis of pipe smoking; namely, pipe smoking is not dangerous to health and there is no correlation between the dose rate or exposure and the mortality ratio. Cigar smoke is only slightly toxic and the relationship between the mortality ratio and the dose rate is not highly significant.

The lower mortality ratio of pipe and cigar smokers compared to cigarette smokers is often linked to a lower volume of inhalation. For example; 70% of pipe smokers (45 to 65 years) inhale only approximately 19 cc per puff, 80% of cigar smokers inhale only 19 cc per puff, while the average cigarette smoker inhales approximately 35 cc per puff (see

Table 1. When converted in terms of dose rates the average daily dose of these three modes of smoking are: cigarette - 12,000 cc/day, pipe - 15,000 cc/day, cigar - 4,000 cc/day. Calculation of the mortality ratio from equations (5, 7, 8) at equivalent dose rates clearly indicate, at a confidence level of better than 99.9%, that the lower mortality ratio of pipe and cigar smokers cannot primarily be caused by a smaller depth of inhalation or dose rate. No data is available for the age started smoking of pipe and cigar smokers so the effect of this variable cannot be checked. However, even if the average age of starting to smoke cigarettes was 24 years instead of 19 years the same conclusion would result.

A more fundamental way of expressing the data is to calculate the relative toxicity of pipe and cigar smoke compared to cigarette smoke. If the toxicity of the smoke is defined by the equation:

$$\text{MORTALITY RATIO (MR)} = a + b\ (\text{TOXICITY})\ (\text{DOSE RATE})^{1/3} \times (\text{LENGTH OF EXPOSURE})$$

then the relative toxicity of pipe and cigar smoke can be easily calculated from a comparison of the respective mortality ratio versus dose rate equation (5, 7, 8).

Let the toxicity of cigarette smoke be 1.0; then the mortality ratio for all male smokers aged 45 to 65 is expressed by the equation:

$$MR = 0.93 + 0.031(\text{TOXICITY})(\text{CC SMOKE/DAY} \times 10^{-4})^{1/3} \times (55 - AS) \quad (9)$$

where AS is the age started smoking.

Comparison of eqn. (9) with eqn. (7) and (8) yields the following toxicity values.

| DEVICE SMOKED | TOXICITY OF SMOKE |
|---|---|
| CIGARETTE | $1.0 \pm .07$ (Defined) |
| CIGAR | $.28 \pm .13$ |
| PIPE | $.07 \pm .11$ |

Placing the appropriate toxicity value in equation (9) allows the calculation of the mortality ratio of a male smoker ages 45 to 65 for any smoking device.

Conclusions

The mortality ratio of cigarette smokers is highly correlated (multiple correlation coefficient = .97) to the dose rate of the smoke (volume of smoke inhaled per day) and the length of exposure to the dose. The increase in mortality ratio with dose rate is large for cigarette smokers and represents a doubling of the death rate of male smokers from 45 to 65 at average dose rates.

The mortality ratio of pipe smokers is independent of the dose rate of the smoker.

The mortality ratio of cigar smokers is correlated to the dose rate of the smoke but the increase in mortality with dose rate is not large.

The mortality ratio of cigarette smokers who also smoke pipes and cigars is significantly lower than smokers who smoke only cigarettes at the same cigarette smoke dose rate and length of exposure.

The lower mortality ratio of pipe and cigar smokers compared to cigarette smokers cannot be explained by a difference in amount smoked, depth of inhalation, or age started smoking.

If the relative toxicity of smoke from a cigarette is defined as 1.0 then the toxicity of pipe smoke is $0.07 \pm .11$ and cigar smoke $.28 \pm .13$. No factors mentioned in current reports on smoking and health (1), (2), (3) and (4) can satisfactorily account for the lower toxicity of pipe and cigar smoke. The only hypothesis which might satisfactorily explain the smoke toxicity differences is a difference in smoke composition produced by different combustion conditions in the pipe, cigar and cigarette.

The combustion of tobacco is a complex process involving both destructive distillation and oxidation reactions. Two major phases are present in the smoke - a gaseous phase

and a liquid particulate phase. From thermodynamic and kinetic considerations it is well known that the time - temperature relationships which exist during the combustion are the important variables governing the composition of both the particulate and gaseous phases. Tests were undertaken to see if differences in the time - temperature relationship in the combustion of tobacco in a cigarette, pipe, and cigar did occur and if the smoke from these devices was different.

Results of preliminary tests indicate for instance that the velocities of the burning interfaces are for cigarettes, cigars and pipes 1.9, 1.1, and 0.25 in/min respectively, and the tar content on a relative per puff basis is 100, 45, and 8 respectively. These results indicate indisputably that there are differences in both the time - temperature relationship during combustion and in the products of the combustion. A detailed description of a more complete investigation will be the basis of a future communication.

The hypothesis that the differences in the combustion conditions of the pipe, cigar and cigarette are responsible for their different effect on mortality, has not received the widespresd attention it would appear to merit and this fact is somewhat disturbing.

## TABLE 1

Mortality Ratios For American Males Ages 45 to 65 As A Function Of Amount Smoked, Depth of Inhalation, Age Started Smoking And Smoking Device

| Mode of Smoking | Mortality Ratio | Average Number Of Cigarettes Per Day | Draw Volume | Age Of Starting To Smoke |
|---|---|---|---|---|
| Cigarettes Only | 1.64 | 5 | 35 | 19 |
| | 2.04 | 15 | 35 | 19 |
| | 2.18 | 30 | 35 | 19 |
| | 2.44 | 50 | 35 | 19 |
| | 1.74 | 28 | 19 | 19 |
| | 2.05 | 28 | 27 | 19 |
| | 2.14 | 28 | 35 | 19 |
| | 2.36 | 28 | 44 | 19 |
| | 1.35 | 28 | 35 | 33 |
| | 1.77 | 28 | 35 | 27 |
| | 1.86 | 28 | 35 | 22 |
| | 2.24 | 28 | 35 | 17 |
| | 2.56 | 28 | 35 | 13 |
| Cigarettes Plus Other | 1.50 | 5 | 34 | 19 |
| | 1.65 | 15 | 34 | 19 |
| | 1.86 | 30 | 34 | 19 |
| | 2.54 | 50 | 34 | 19 |
| | 1.43 | 24 | 19 | 19 |
| | 1.72 | 24 | 28 | 19 |
| | 1.81 | 24 | 35 | 19 |
| | 2.10 | 24 | 44 | 19 |
| | 1.66 | 24 | 34 | 33 |
| | 1.37 | 24 | 34 | 27 |
| | 1.62 | 24 | 34 | 22 |
| | 1.84 | 24 | 34 | 17 |
| | 2.24 | 24 | 34 | 13 |
| | | Number of Cigars Or Pipe Fulls Per Day | | |
| Cigar | 1.09 | 2 | 20 | 20 |
| | 1.03 | 7 | 20 | 20 |
| | 1.02 | 3 | 19 | 20 |
| | 1.28 | 3 | 28 | 20 |
| Pipe | 1.08 | 5 | 21.5 | 20 |
| | .92 | 13 | 21.5 | 20 |
| | .98 | 8 | 19 | 20 |
| | 1.21 | 8 | 28 | 20 |

References

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