ABSTRACT Two methods of interpreting histamine inhalation dose-response curves were compared in 27 normal and 41 asthmatic subjects. The histamine provocation concentration producing a 20% fall (PC_{20}) in forced expiratory volume in one second (FEV_{1}) was calculated on the basis of the lowest FEV_{1} after inhalation of saline and the lowest value after inhalation of histamine. The histamine threshold was determined as the first histamine concentration causing the FEV_{1} to fall more than 2 SD below the mean of five pre-histamine (three pre-saline, two post-saline) FEV_{1} determinations. The PC_{20} was on average one doubling concentration larger than the threshold. The PC_{20} provided better discrimination between asthmatic and normal subjects than did the histamine threshold and was significantly more reproducible. These findings suggest that the histamine threshold may prove useful for studies on populations, particularly those with a low degree of responsiveness to histamine, because of the possibility of measuring a response at a lower histamine concentration. On the other hand, the PC_{20} is preferable for clinical use in individuals because of its better discriminating power and better reproducibility.

Bronchial provocation tests with chemical mediators such as histamine and methacholine are being used increasingly frequently in the assessment of patients with respiratory disorders.\(^1\)\(^2\) The need to standardise methods has been emphasised recently.\(^3\)\(^4\) One factor requiring standardisation is the method of measurement of the response. The one-second forced expiratory volume (FEV_{1}) is commonly used. Most often the concentration (or dose) of the bronchoconstricting agent producing a predetermined response—for example, a 20% reduction in FEV_{1},—is calculated and called PC_{20} or PD_{20}.\(^3\)

Recently Habib et al have suggested the use of histamine threshold as a method of expressing the results of histamine bronchial provocation.\(^6\) The histamine threshold was defined as the concentration of histamine producing a fall in FEV_{1} of more than 2 SD below the mean of four pre-histamine (three pre-saline and one post-saline) determinations.

In this study we have compared the histamine PC_{20} with the histamine threshold in 41 asthmatic and 27 normal subjects. Reproducibility of both determinations was assessed in 20 of the asthmatic subjects.

Methods

Subjects

Forty-one subjects with definite bronchial asthma\(^7\) were selected from the respiratory clinic at the University Hospital in Saskatoon. Twenty-seven normal non-smoking subjects with no chest disease or symptoms, no asthma, no rhinitis, and no recent respiratory infection (that is, in the last four weeks) were also studied. The study was approved by the University of Saskatchewan ethics committee and signed informed consent was obtained.

Histamine inhalation

Histamine inhalation tests were performed as previously described.\(^8\) Aerosols were generated with a Wright’s nebuliser calibrated to deliver an output of 0.130–0.135 ml/min; this required an air flow of 7.5 l/min. Aerosols were inhaled for two minutes of tidal breathing through the mouth at five-minute intervals. Isotonic 0.9% saline was inhaled first, followed by doubling concentrations of histamine from 0.03 mg/ml to 8.0 mg/ml. The FEV_{1} was measured three times before any inhalation, and 30 and 90 seconds after each inhalation. The test was continued until the FEV_{1} had fallen by 20% or until the top concentration had been administered.
The histamine PC_{20} and the histamine threshold were determined from all curves. The percentage fall in FEV_{1} was determined from the lowest FEV_{1} after saline inhalation and the lowest FEV_{1} after histamine inhalation. Histamine PC_{20} was calculated by linear interpolation between the last two data points on the dose-response curve, or was expressed as ">8 mg/ml" if there had been no response.\(^9\) The histamine threshold was determined by the method of Habib \textit{et al}.\(^6\) The mean and SD of the five pre-histamine (three before saline and two after saline) FEV_{1} measurements were determined. The threshold was defined as the lowest concentration first causing the FEV_{1} to fall more than 2 SD below the mean pre-histamine FEV_{1}.

**Study design**

All 68 subjects attended the laboratory when symptoms (if any) were well controlled. Inhaled sympathomimetic agents were withheld for six hours, and oral theophylline products for 12 hours, while corticosteroids were continued in the same dosage. None of the subjects was using sodium cromoglycate or antihistamines. In all subjects a single histamine inhalation test was carried out and both PC_{20} and the threshold were determined.

Reproducibility was assessed in 20 asthmatic subjects. Duplicate histamine inhalation tests were performed at the same time of day within five days. Tests were done at a time when symptoms were stable, when there had been no respiratory infection or allergen exposure for at least four weeks, and when baseline FEV_{1} was reproducible to within 10%.

**Analysis**

Standard statistical tests were used.\(^9\) Histamine PC_{20} and histamine threshold were compared in the 41 asthmatic patients by the method of least-squares regression. Reproducibility of the two determinations was assessed by examining the correlation obtained by least-squares linear regression of the first and second determination, and by comparing the percentage difference (100 \times \text{difference between 2 tests/mean of 2 tests}) for PC_{20} and threshold by the paired \(t\) test. Since PC_{20} is a continuous variable and threshold a discontinuous variable, reproducibility was also assessed with "clinical PC_{20}" defined as the first concentration to produce a 20% fall in FEV_{1}. The reproducibility of the clinical PC_{20} was compared with the reproducibility of threshold by the paired \(t\) test.

**Results**

Anthropometric data are shown in the table. The asthmatic subjects were older and had lower FEV_{1} values than the normal subjects.

The distribution of histamine PC_{20} and histamine threshold values is shown in figure 1. All asthmatic subjects but only one normal subject had a histamine PC_{20} below 8 mg/ml. All asthmatic subjects and eight normal subjects (30%) had a histamine threshold of 8 mg/ml or below. The threshold occurred after a fall in FEV_{1} of 6-6\% \pm 4-6\% in the asthmatic subjects compared with a 3-4\% \pm 1-9\% fall in normal subjects (\(t = 3-96, p < 0-001\)). PC_{20} and threshold values are compared in figure 2. The results of the linear regression were as follows: log threshold = 0-86 \times \log PC_{20} - 0-03 (r = 0-89). On average the threshold was one concentration lower than the PC_{20}.

The reproducibility of the PC_{20} and threshold in 20 asthmatic subjects is shown in figure 3. The PC_{20}...
was more reproducible, all repeat tests being within one doubling concentration. The correlation for repeat PC$_{20}$ determinations was 0·98 and for repeat threshold determinations 0·91. The mean percentage difference between two tests was 20% ± 18% for PC$_{20}$ and 43% ± 38% for the threshold (paired $t = 2·52, p < 0·05$). The clinical PC$_{20}$ was identical on repeat testing in 15 of the 20 tests, and differed by one concentration in the other five. The clinical PC$_{20}$ was more reproducible than the threshold ($t = 2·1, p < 0·05$).

**Fig 2** Comparison of histamine PC$_{20}$ and histamine threshold in 41 asthmatic subjects.

**Discussion**

The results show that the histamine PC$_{20}$ provides better discrimination between asthmatic and normal subjects than does the histamine threshold, and that it is also more reproducible. The threshold is on average one concentration less than the PC$_{20}$ and thus, unlike the PC$_{20}$, can be determined in many normal subjects.

Since the PC$_{20}$ and the threshold were calculated from the same curves, the greater degree of overlap between asthmatic and normal subjects for the threshold was initially surprising. The explanation is that the threshold in normal subjects occurs at a lower percentage fall in FEV$_1$ than in the asthmatic subject, 3-4% compared with 6-6%. There are three possible reasons for this. Firstly, asthmatic patients are known to have a greater variability in flow rates than normal subjects. Secondly, a response to diluent that may be seen in asthma$^{11}$ would be reflected by increased variability of the baseline FEV$_1$ by the technique used to calculate the histamine threshold. Thirdly, since asthmatic subjects had lower baseline FEV$_1$ values a similar absolute value for the standard deviation would represent a larger percentage of the mean FEV$_1$. All three factors were probably relevant in this study and explain why the histamine threshold often reflects a smaller change in FEV$_1$ in normal subjects than in asthmatic subjects, leading to the observed greater overlap.

Reproducibility of results is important in standardisation of inhalation provocation tests. The histamine PC$_{20}$ calculated by this method has been shown to be reproducible to within one doubling

**Fig 3** Reproducibility of histamine PC$_{20}$ (left) and histamine threshold (right) in 20 asthmatic subjects. The first determination is plotted against the second determination. The solid lines are the lines of identity and the dotted lines represent ± 1 doubling dilution difference.
concentration. This was confirmed in the present study. The reproducibility of PC_{20} was better than that of the threshold. Statistical comparison of the PC_{20} and threshold values may not be entirely valid because PC_{20} is a continuous variable and threshold is a stepwise non-continuous doubling variable (that is, 1-2-4-8). From a practical point of view, the histamine PC_{20} is reported clinically as a non-continuous variable. Thus the reproducibility data were reanalysed with the “clinical PC_{20}” defined as the histamine concentration producing a fall in FEV\textsubscript{1} of 20% or more. This comparison also showed PC_{20} to be more reproducible than threshold values. Nevertheless, the threshold was fairly reproducible, showing a difference of one concentration or less in 19 of 20 asthmatics.

There are at least two theoretical reasons for discouraging the use of the histamine threshold, as calculated by this method, in individual subjects. The standard deviation obtained from only five measurements may not be an accurate enough assessment of the true standard deviation, in which case a change of more than 2 SD below the mean would be required to represent a significant change in FEV\textsubscript{1}. In our normal subjects 2 SD represented a 3-3% fall in FEV\textsubscript{1}; thus the threshold, on average, was equivalent to a “PC_{3-3}” only. More than 2 SD might be more appropriate when only five pre-histamine measurements are used. Furthermore, deriving the threshold in this manner excluded consideration of response to diluent, a feature considered important in analysing response to bronchoconstricting agents. On these two theoretical grounds histamine threshold probably has little clinical application to individual subjects performing inhalation provocation tests.

Methods used to perform and interpret the results of bronchial provocation tests may vary, depending on the purpose of the test. The data presented here show that histamine PC_{20} is preferable to histamine threshold for clinical use because of better discrimination and better reproducibility. Histamine threshold, however, might be useful for research studies applied to populations. It has been particularly valuable in studying groups of subjects who are normal or near normal, where the increased sensitivity can be put to advantage and histamine responses can be measured in many normal subjects.

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