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Abstract

Volume-time (V-T) and flow-volume (F-V) curves were measured in all the subjects of non-smoking young males (mean value 26.3 yrs. of age), healthy and asthmatics. Eleven parameters of pulmonary function tests composed of two V-T, six F-V, and three mean time constant (MTC) parameters, were calculated from the curves. These parameters were used in the two analyses through the all possible selection procedure (APSP) discriminating between healthy adults and mild asthmatics and also between healthy and moderate. Flow rate at 75% of FVC (V75) proved to be the most useful parameter and V50 the next best in both analyses. The probability of misclassification using all eleven parameters was 19.64% in the analysis of healthy adults and mild asthmatics, and 4.29% in the analysis of healthy adults and moderate asthmatics. There was a little difference in the parameters selected at every step. The discriminant analysis proved that the flow-volume patterns were different according to the severity of bronchial asthma. Thus flow-volume recognition was considered to be important in analyzing the severity of bronchial asthma.

KEYWORDS: discriminant analysis, the volume-time and flow-volume curve, the all possible selection procedure (APSP), asthmatic severity, and the probability of misclassification

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DISCRIMINANT ANALYSIS OF PULMONARY FUNCTION PARAMETERS
Healthy Adults versus Mild Asthmatics and Moderate Asthmatics

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Abstract. Volume-time (V-T) and flow-volume (F-V) curves were measured in all the subjects of nonsmoking young males (mean value 26.3 yrs. of age), healthy and asthmatics. Eleven parameters of pulmonary function tests composed of two V-T, six F-V, and three mean time constant (MTC) parameters, were calculated from the curves. These parameters were used in the two analyses through the all possible selection procedure (APSP) discriminating between healthy adults and mild asthmatics and also between healthy and moderate. Flow rate at 75 % of FVC ($\dot{V}_{75}$) proved to be the most useful parameter and $\dot{V}_{50}$ the next best in both analyses. The probability of misclassification using all eleven parameters was 19.64 % in the analysis of healthy adults and mild asthmatics, and 4.29 % in the analysis of healthy adults and moderate asthmatics. There was a little difference in the parameters selected at every step. The discriminant analysis proved that the flow-volume patterns were different according to the severity of bronchial asthma. Thus flow-volume recognition was considered to be important in analyzing the severity of bronchial asthma.

Key words : discriminant analysis, the volume-time and flow-volume curve, the all possible selection procedure (APSP), asthmatic severity, and the probability of misclassification.

It is generally said that the forced expiration curves of asthmatic patients in the asymptomatic stage are the same as those of healthy men. Takijima (1) reported that the flow-volume curves (F-V curves) (2, 3) of asthmatic patients were characteristic compared with those of other chronic obstructive lung disease (COLD), in that flow rates suddenly fell concavely at high lung volumes (70-80 % of FVC). He also reported that at the asthmatic stage, the flow rate of the flow-volume curve fell concavely all over the curve but that the sudden flow-fall just below the peak flow rate (PF) was not remarkable in the asymptomatic stage (1).

We (2-4) reported the discriminant analysis of healthy adults and asthmatic patients at the asymptomatic stage by using eight volume-time and flow-volume parameters. The analysis was performed through the forward selection procedure (FSP) (8). In the papers (5-7), we reported that the pulmonary function data of the patients at the asymptomatic stage were different from those of

healthy males, and computed the order of the selected parameters and the probabilities of misclassification and the discriminant function equations were computed. But since in FSP, independent parameters are ordered step by step, based on the multiple correlation coefficients effective to the dependent parameters, we did not compute the discrimination through the all possible selection procedure (APSP) (8). In the previous report (7), parameters selected at each step through FSP were not always the best.

In our previous paper (9) reporting the discriminant analysis through APSP of healthy adults and asthmatic patients, we showed the most useful parameters and the probabilities of misclassification for discriminating between the two groups of subjects.

In this study, we performed the two analyses through APSP. We wanted to investigate three points, the first point being to compare the most useful parameters selected in the two discriminant analyses, the second being to evaluate the discriminant ability of the F-V parameter group by comparing the final probabilities of misclassification obtained from the four parameter groups (the V-T, the F-V, the MTC, and the total parameter group), the third being to select the best parameters and to compute the probabilities of misclassification at each step by using the eleven parameters.

MATERIALS AND METHODS

The subjects were 32 nonsmoking healthy young males and 26 nonsmoking asthmatic young males (15 mild asthmatics and 11 moderate) (Table 1). A significant difference in age was found between healthy adults and the asthmatic patients, but not in height. Though the age difference was significant, the flow-volume patterns for asthmatic patients were characteristic (1) and were almost the same in each decade age group.

TABLE 1. ANTHROPOMETRIC DATA

Group	Number	Mean age (Yrs.)	Height (cm) (m ± U.S.D.)
Healthy adults	32	23.6	169.1 ± 5.6
Mild asthmatics	15	28.6	166.1 ± 4.5
Moderate asthmatics	11	31.3	167.1 ± 5.9

m : mean value, U.S.D. : unbiased standard deviation.

The patients were chosen while they were under medical control at the Allergy Outpatient Clinic of the Department of Internal Medicine of Okayama University Medical School. All the patients had been given bronchodilators under a doctor's control, but no patient had asthmatic attacks for at best two days including the tested day. The severity of bronchial asthma was classified according to Oshima's classification (2), which depends on the intensity of asthmatic attacks as shown by dyspnea and its effects on daily life and on the frequency of monthly attacks. The observation period of determing the severity of bronchial asthma was more than six months. The healthy males were medical students

and young doctors, and had no respiratory symptoms, no past history of respiratory diseases, or no physical abnormalities.

A flow-volume curve recorder (OST-70D, Chest Co. Ltd.) was used for the forced expiratory procedure, which consisted of the forced expiratory V-T and the forced expiratory F-V measurements. The forced expiratory V-T and F-V curves were measured in the sitting position several times and the chart obtained at the first measure was not used for calculation. Instead, one of the biggest F-V patterns with a sharp peak flow rate was selected out of those obtained at subsequent determinations. V-T parameters (%FVC and $FEV_{1.0\%}$), F-V parameters (peak flow rate (PF), $\dot{V}_{75}$, $\dot{V}_{50}$, $\dot{V}_{25}$, $\dot{V}_{10}$, and $\dot{V}_{50}/\dot{V}_{25}$), and MTC parameters ($MTC_{75-50}$, MTC_{50-25}, and MTC_{25-RV}) were calculated from the curves.

In this study, the eleven parameters were used for the discriminant analyses. In the discriminant analyses, the all possible selection procedure (APSP) was performed by using the electronic computer NEC ACOS 700-S in the Okayama University Computer Center.

RESULTS

Pulmonary Function Data

The results of the pulmonary function tests are shown in Table 2. The mean values of F-V parameters, for example, $\dot{V}_{75}$, $\dot{V}_{50}$, and $\dot{V}_{25}$, and those of MTC ones, MTC_{50-25} and MTC_{25-RV}, obtained from the asthmatic patients were lower than those from the healthy youths. Other parameters, for example, $FEV_{1.0\%}$, PF, $\dot{V}_{10}$, and MTC_{75-50} were also lower.

TABLE 2. RESULTS OF PULMONARY FUNCTION TESTS IN EACH GROUP

Parameters		Healthy adults		Mild asthmatics		Moderate asthmatics	
		Mean value	U.S.D.	Mean value	U.S.D.	Mean value	U.S.D.
1. %FVC	(%)	110.7	9.5	108.0	15.7	101.4	16.0
2. $FEV_{1.0\%}$	(%)	86.6	6.4	78.0	11.4	65.8	16.4
3. PF	(L/sec)	10.7	1.4	9.2	2.3	7.4	2.3
4. $\dot{V}_{75}$	(L/sec)	9.3	1.5	6.5	2.5	4.3	2.3
5. $\dot{V}_{50}$	(L/sec)	5.9	1.4	3.8	1.8	2.4	1.7
6. $\dot{V}_{25}$	(L/sec)	2.5	0.8	1.5	0.7	1.1	1.0
7. $\dot{V}_{10}$	(L/sec)	1.0	0.6	0.5	0.3	0.4	0.5
8. $\dot{V}_{50}/\dot{V}_{25}$		2.5	0.4	2.6	0.5	2.8	0.9
9. MTC_{75-50}	(1/sec)	2.85	0.89	2.48	0.81	1.80	0.63
10. MTC_{50-25}	(1/sec)	2.99	0.90	2.09	0.99	1.23	0.62
11. MTC_{25-RV}	(1/sec)	2.15	0.78	1.38	0.65	0.95	0.81

%FVC : per cent of forced vital capacity, $FEV_{1.0\%}$: per cent of first one second volume in forced expiration curve, PF : peak flow rate in maximal expiratory flow volume curve (MEFVC), $\dot{V}_{75}$: flow rate at 75% of FVC in MEFVC, $\dot{V}_{50}$: flow rate at 50% of FVC in MEFVC, $\dot{V}_{25}$: flow rate at 25% of FVC in MEFVC, $\dot{V}_{10}$: flow rate at 10% of FVC in MEFVC, $\dot{V}_{50}/\dot{V}_{25}$: ratio of $\dot{V}_{50}$ to $\dot{V}_{25}$, MTC_{75-50} : mean time constant (MTC) in the level of 75-50% of FVC, MTC_{50-25} : MTC in the level of 50-25% of FVC, MTC_{25-RV} : MTC in the level of 25-0% of FVC, U.S.D. : unbiased sample standard deviation.

The t-tests for differences between mean values. The differences in the mean values of the parameters other than %FVC and $\dot{V}_{50}/\dot{V}_{25}$ were statistically significant.

Discrimination with One Parameter

The order of the parameters. The order of the parameters from the lower in thh probability of misclassification to higher was as follows: Discrimination of healthy adults and mild asthmatics ($\dot{V}_{75}$, $\dot{V}_{50}$, $\dot{V}_{25}$, MTC_{25-RV}, $FEV_{1.0\%}$, MTC_{50-25}, PF, V_{10}, MTC_{75-50}, V_{50}/V_{25}, and %FVC) and Discrimination of healthy adults and moderate asthmatics ($\dot{V}_{75}$, $\dot{V}_{50}$, $FEV_{1.0\%}$, MTC_{50-25}, PF, $\dot{V}_{25}$, MTC_{25-RV}, MTC_{75-50}, $\dot{V}_{10}$, %FVC, and $\dot{V}_{50}/\dot{V}_{25}$).

The probability of misclassification. The results are shown in Table 3.

TABLE 3. THE PROBABILITIES OF MISCLASSIFICATION THROUGH THE ALL POSSIBLE SELECTION PROCEDURE

Parameter or parameter group	Probability of misclassification	
	Healthy adults vs. Mild asthmatics	Healthy adults vs. Moderate asthmatics
%FVC	45.34 %	34.11 %
$FEV_{1.0\%}$	30.29	14.53
PF	32.77	16.54
$\dot{V}_{75}$	23.35	7.29
$\dot{V}_{50}$	24.32	11.38
$\dot{V}_{25}$	25.76	19.23
$\dot{V}_{10}$	33.31	31.73
$\dot{V}_{50}/\dot{V}_{25}$	44.83	39.82
MTC_{75-50}	41.57	26.59
MTC_{50-25}	31.37	14.81
MTC_{25-RV}	30.05	22.18
Volume-time parameter group	27.97	13.80
Flow-volume parameter group	21.98	4.56
Mean time constant parameter group	28.17	9.28
Total parameter group	19.64	4.29

Discrimination of healthy adults and mild asthmatics. $\dot{V}_{75}$ showed the lowest probability of misclassification, 23.35%, $\dot{V}_{50}$ showed 24.32%, $\dot{V}_{25}$ 25.76%, and the results of the remaining parameters are shown in Table 3.

Discrimination of healthy adults and moderate asthmatics. $\dot{V}_{75}$ showed the lowest probability, 7.29%, $\dot{V}_{50}$ 11.38%, $FEV_{1.0\%}$ 14.53%, MTC_{50-25} 14.81%, PF 16.54%, and $\dot{V}_{25}$ 19.23%, and those of the remaining parameters are shown in Table 3.

Discrimination with the Four Parameter Groups (the V-T, the F-V, the MTC, and the Total

Parameter Group)

The probability of misclassification with the parameter group is shown in Table 3.

The probability of misclassification

Discrimination of healthy adults and mild asthmatics

The probability with the two V-T parameters: The probability was 27.97%.
The probability with the six F-V parameters: The probability was 21.98%.
The probability with the three MTC parameters: The probability was 28.17%.
The probability with the total parameter group: The probability was 19.64%.

Discrimination of healthy adults and moderate asthmatic

The probability with the two V-T parameters: The probability was 13.80%.
The probability with the six F-V parameters: The probability was 4.56%.
The probability with the three MTC parameters: The probability was 9.28%.
The probability with the total parameter group: The probability was 4.29%.

Discrimination with the Total Parameter Groups

The results are shown in Table 4 and Table 5.

TABLE 4. THE PARAMETERS OF THE BEST SELECTED GROUPS AND THE PROBABILITIES OF MISCLASSIFICATION THROUGH THE ALL POSSIBLE SELECTION PROCEDURE BETWEEN HEALTHY ADULTS AND MILD ASTHMATIC PATIENTS

Step	Parameters of the selected group	Probability of misclassification
1.	$\dot{V}_{75}$	23.35 %
2.	$\dot{V}_{75}$, MTC_{75-50}	22.12
3.	PF, $\dot{V}_{75}$, MTC_{75-50}	21.25
4.	$FEV_{1.0\%}$, PF, $\dot{V}_{75}$, MTC_{75-50}	20.42
5.	$FEV_{1.0\%}$, PF, $\dot{V}_{75}$, MTC_{75-50}, MTC_{50-25}	20.12
6.	$FEV_{1.0\%}$, PF, $\dot{V}_{75}$, $\dot{V}_{25}$, $\dot{V}_{50}/\dot{V}_{25}$, MTC_{25-RV}	19.92
7.	$FEV_{1.0\%}$, PF, $\dot{V}_{75}$, $\dot{V}_{50}$, $\dot{V}_{25}$, $\dot{V}_{50}/\dot{V}_{25}$, MTC_{75-50}	19.89
8.	%FVC, $FEV_{1.0\%}$, PF, $\dot{V}_{75}$, $\dot{V}_{50}$, $\dot{V}_{25}$, $\dot{V}_{50}/\dot{V}_{25}$, MTC_{75-50}	19.68
9.	%FVC, $FEV_{1.0\%}$, PF, $\dot{V}_{75}$, $\dot{V}_{50}$, $\dot{V}_{25}$, $\dot{V}_{50}/\dot{V}_{25}$, MTC_{75-50}, MTC_{25-RV}	19.66
10.	%FVC, $FEV_{1.0\%}$, PF, $\dot{V}_{75}$, $\dot{V}_{50}$, $\dot{V}_{25}$, $\dot{V}_{10}$, $\dot{V}_{50}/\dot{V}_{25}$, MTC_{75-50}, MTC_{25-RV}	19.64
11.	%FVC, $FEV_{1.0\%}$, PF, $\dot{V}_{75}$, $\dot{V}_{50}$, $\dot{V}_{25}$, $\dot{V}_{10}$, $\dot{V}_{50}/\dot{V}_{25}$, MTC_{75-50}, MTC_{50-25}, MTC_{25-RV}	19.64

The probability of misclassification at every step

Discrimination of healthy adults and mild asthmatics. The probability at the first step was 23.35%, the second 22.12%, the third 21.25%, the fourth 20.42%, and the fifth 20.12%. The decrease in the probability was slight from the fifth step to the final. The final probability was 19.64%.

Discrimination of healthy adults and moderate asthmatics. The probability at the first step was 7.29%, the second 5.72%, and the third 4.48%. The decrease in the probability was slight from the third step to the final step.

TABLE 5. THE PARAMETERS OF THE BEST SELECTED GROUPS AND THE PROBABILITIES OF MISCLASSIFICATION THROUGH THE ALL POSSIBLE SELECTION PROCEDURE BETWEEN HEALTHY ADULTS AND MODERATE ASTHMATICS

Step	Parameters of the selected group	Probability of misclassification
1.	$\dot{V}_{75}$	7.29 %
2.	$\dot{V}_{75}$, $\dot{V}_{10}$	5.72
3.	$\dot{V}_{75}$, $\dot{V}_{50}$, $\dot{V}_{25}$	4.48
4.	%FVC, $\dot{V}_{75}$, $\dot{V}_{25}$, MTC_{75-50}	4.46
5.	%FVC, $\dot{V}_{75}$, $\dot{V}_{25}$, $\dot{V}_{50}/\dot{V}_{25}$, MTC_{75-50}	4.44
6.	%FVC, $\dot{V}_{75}$, $\dot{V}_{25}$, $\dot{V}_{10}$, $\dot{V}_{50}/\dot{V}_{25}$, MTC_{75-50}	4.44
7.	%FVC, $\dot{V}_{75}$, $\dot{V}_{25}$, $\dot{V}_{10}$, MTC_{75-50}, MTC_{50-25}, MTC_{25-RV}	4.44
8.	%FVC, $FEV_{1.0\%}$, $\dot{V}_{75}$, $\dot{V}_{25}$, $\dot{V}_{10}$, $\dot{V}_{50}/\dot{V}_{25}$, MTC_{75-50}, MTC_{50-25}, MTC_{25-RV}	4.44
9.	%FVC, $\dot{V}_{75}$, $\dot{V}_{50}$, $\dot{V}_{25}$, $\dot{V}_{10}$, $\dot{V}_{50}/\dot{V}_{25}$, MTC_{75-50}, MTC_{50-25}, MTC_{25-RV}	4.43
10.	%FVC, $FEV_{1.0\%}$, $\dot{V}_{75}$, $\dot{V}_{50}$, $\dot{V}_{25}$, $\dot{V}_{10}$, $\dot{V}_{50}/\dot{V}_{25}$, MTC_{75-50}, MTC_{50-25}, MTC_{25-RV}	4.43
11.	%FVC, $FEV_{1.0\%}$, PF, $\dot{V}_{75}$, $\dot{V}_{50}$, $\dot{V}_{25}$, $\dot{V}_{10}$, $\dot{V}_{50}/\dot{V}_{25}$, MTC_{75-50}, MTC_{50-25}, MTC_{25-RV}	4.29

The final probability was 4.29%.

The Best Selection Parameters at Every Step

Discrimination of healthy adults and mild asthmatics. $\dot{V}_{75}$ was selected at the first step, and at all the steps. MTC_{75-50} was selected from the second step to the final. PF and $FEV_{1.0\%}$ were selected from the third and fourth step, and both to the final. The following selection parameter groups are shown in Table 4.

Discrimination of healthy adults and moderate asthmatics. $\dot{V}_{75}$ was selected at the first step, and was selected at all the steps. $\dot{V}_{10}$ was selected at the second step, but was not selected from the third to the fifth step. This parameter was selected again from the sixth step to the final. At the third step, $\dot{V}_{75}$, $\dot{V}_{50}$, and $\dot{V}_{25}$ were selected. The following selection parameter groups are shown in Table 5.

DISCUSSION

In controlling asthmatic patients, it is useful to perform the maximal expiratory volume-time and flow-volume tests and estimate the ventilatory abnormality. In the field of public health, it is difficult to perform further pulmonary function tests and allergic examinations, such as a bronchial hypersensitivity reaction tests, or a skin reaction test, or an IgE measurement.

The flow-volume curve is useful both because it easily indicates the severi-

ty of bronchial asthma and because it estimates the extent of bronchoconstriction. The sudden flow-fall near $\dot{V}_{75}$ and the changes in the flow rate from $\dot{V}_{75}$ to $\dot{V}_{50}$ were specific for the recognition of bronchial asthma. Its disadvantage is the subjective nature of the decision.

Therefore we attempted discriminant analysis using six pulmonary function parameters (the two V-T, and the four F-V parameters) (2) and using eight parameters (addition of $\dot{V}_{75}$ and $\dot{V}_{10}$) (4). Using six parameters (2), $\dot{V}_{50}$ showed the lowest probability. As $\dot{V}_{75}$ was considered to be more effective than $\dot{V}_{50}$ in flow-volume recognition, $\dot{V}_{75}$ was added to make eight parameters (4). $\dot{V}_{75}$ showed the lowest probability of misclassification. The probability of the healthy was 15.8% to total asthmatics at the fourth step. $\dot{V}_{75}$, $FEV_{1.0\%}$, PF, and $\dot{V}_{50}$, selected at the fourth step, were effective parameters for the discriminant analysis. The decrease in the probability was slight from the fifth step onward.

In the last paper (9), three MTC parameters of ventilatory mechanics were added to the eight parameters mentioned above because they were considered to be important and effective for the discriminant analysis. At the higher steps the MTC parameters were selected using the total parameter group, not in using any of the eleven parameters. At the three consecutive higher steps, the flow-volume parameters ($\dot{V}_{75}$, $\dot{V}_{50}$, and $\dot{V}_{25}$) were selected. The probabilities of misclassification in using the total parameter group was 15.46%. Therefore the discriminant analysis showed the importance of flow-volume recognition.

In this paper, we attempted two analyses discrimiinating between healthy adults and mild asthmatics and also between healthy and moderate on the basis of the sequential discrimination of bronchial asthma.

The view points we considered in the comparison were as follows: the first was the order of parameters using each of the eleven parameters, the second was the probabilities of misclassification, and the third was the best selection parameters. A slight difference was found in the order of the parameters selected at every step, but the probability of misclassification was markedly different in the two analyses.

Therefore sequential discrimination, the discriminant analysis of healthy adults and moderate asthmatics war not always necessary, because of the low probability of misclassification. However, discriminant analysis of bronchial asthma between healthy adults and mild asthmatics is necessary even when the subject is discriminated as healthy in the discriminant analysis of healthy adults and asthmatics.

Therefore, the sequential discrimination of mild asthmatics and moderate sthmatics will be discussed in the near future.

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