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DYNAMIC SPIROMETRY STUDIES IN PATIENTS WITH LUNG DISEASE

VI. *Forced Inspirograms Compared to Expirograms in Evaluation of Airways Obstruction*

By

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Obstruction to air flow in the airways can be due to *local* or *generalized* mechanisms: 1) muscular constriction—"broncho-spasm"; 2) mucosal oedema, inflammation or scar tissue; 3) secretions in the lumina; 4) collapse of airways due to local lack of strength of the bronchial wall, or lack of elastic support around airways; 5) tumours. Combinations of the various factors often occur.

The current simple clinical method for evaluation of airways obstruction is dynamic spirometry. The usual obstructive pattern is a decrease below the predicted $FEV_{1.0}$ and $FEV\%$ ¹; VC is often diminished, too (7). Sometimes local obstruction gives a picture of purely "restrictive impairment"—i.e. there is an "amputation" of the last part of the VC.

In the present paper the forced expiratory one-second volume ($FEV_{1.0}$), forced expiratory vital capacity (FVC) and the ratio $FEV_{1.0}/FVC$, called $FEV\%$, were compared to corresponding forced inspiratory volumes— $FIV_{1.0}$, FIVC, and $FIV\%$ —in normal subjects and in patients with generalized airways obstruction or pulmonary sarcoidosis and/or fibrosis. The tumour group is excluded. Further, the effect of drug-

¹ Nomenclature according to *Gandevia-Hughes-Jones* (39).

For references see page 407.

induced bronchoconstriction and bronchodilation on expiratory and inspiratory volumes is compared to that on the maximal midexpiratory flow (MMF) (56) and peak expiratory flow (PEF) obtained with Wright's Peak Flow Meter (91).

MATERIAL

Normal subjects. Seventeen subjects with normal spirometry (7), 11 males (ages 23–34), and 6 females (ages 24–32) were studied. Most of them were laboratory assistants, doctors or students. Table 1.

Patients with generalized airways obstruction (GAO). In all these patients the FEV% was lower than or equal to the predicted—2 SD (7). Two groups were encountered: group A with normal FIV% ($\geq 85\%$), group B with an FIV% below 80%.

Group A comprised 15 males (ages 42–67 years) and 4 females (ages 42–69 years). Table 2A.—In group B the FIV% was low ($\leq 80\%$). This group included 13 males (ages 41–73 years) and 4 females (ages 36–64 years). Table 2B.

Patients with pulmonary sarcoidosis and/or fibrosis. Thirteen patients with pulmonary sarcoidosis or fibrosis were studied. There were 5 males (ages 28–64 years) and 8 females (ages 17–57 years). Table 3.

Subjects used for drug-induced bronchoconstriction. The group consisted of 15 subjects, 5 males (ages 52–65 years) and 10 females (ages 26–58 years). Average basic spirometric values are seen in Table 5. Two female subjects were without symptoms but had a tendency to react with bronchospasm (BJ, KG), another reacted against cold air (EB). The rest included 3 females and 1 male with bronchitis but normal FEV%, and 4 males and 4 females with bronchitis and airways obstruction. Subjects with obvious bad technique or co-operation were not included.

TABLE I
Seventeen normal subjects.

Subj.	Sex.	Age	Forced expirograms				Forced inspirograms				Ratios	
			FEV _{1.0}	%Pred.	FVC	%Pred.	FEV _{1.0}	FVC	FIV _{1.0}	FIV%	FEV/FIV	FVC/FIVC
UA	F	32	2.75	100	3.55	95	80	3.32	3.32	100	0.83	1.07
BJ	F	28	2.45	80	3.16	89	80	3.06	2.75	95	0.89	1.03
IE	F	24	2.65	86	3.26	91	81	3.18	3.18	100	0.83	1.02
AP	F	26	2.19	78	2.60	81	84	2.50	2.40	96	0.91	1.04
AGB	F	29	2.96	91	3.98	102	74	3.88	3.72	96	0.80	1.03
IE	F	24	3.83	123	4.02	106	96	3.83	3.83	100	1.00	1.05
ON	M	25	3.88	85	4.90	87	79	3.47	3.47	74	1.11	1.04
IE	M	23	3.83	91	4.69	91	82	4.59	4.59	100	0.83	1.03
HAH	M	23	4.69	105	5.76	108	81	5.41	5.41	100	0.87	1.06
RL	M	34	3.80	108	4.37	101	87	4.36	4.36	99	0.87	0.99
KM	M	32	3.30	87	4.74	99	70	4.00	4.00	90	0.82	1.07
HM	M	28	3.93	93	4.44	85	89	4.34	4.34	100	0.90	1.03
BS	M	34	4.49	111	5.71	112	79	5.56	5.56	100	0.81	1.03
JE	M	26	3.98	91	5.41	101	74	5.25	5.36	99	0.76	1.01
CJ	M	27	4.44	113	5.20	118	85	4.79	5.10	95	0.93	1.02
BA	M	30	4.05	93	4.56	(83)	90	4.54	4.54	100	0.89	1.01
RM	M	31	4.00	94	4.59	90	87	4.54	4.54	100	0.88	1.01
Mean values		28	3.60*	96	4.41	96	82§	4.12*	4.28	97§	0.88	1.03

* § Significant difference between pairs ($P < 0.001$). All volumes in litres ATPS.

METHOD AND PROCEDURE

The spirometry was performed on low resistance spirometers (9, 7). After maximal expiration, the patients inspired maximally as fast and as forcefully as possible. (See Introduction, page 329). Three to five spirograms were made. The volumes were calculated in accordance with Fig. 1 in General Introduction (page 331).

In 15 subjects, all known reactors to acetylcholine aerosol, a series of 3-5 spirograms was made before and after inhalation of acetylcholine (Ach) in increasing concentrations and further after isoprenaline. Maximal midexpiratory flow (MMF) according to *Leuallen* and *Fowler* (56) was also calculated from 12 of these spirograms. Furthermore, peak expiratory flow was measured between the spirograms with a Wright Peak Flow Meter (9).

RESULTS

I. *Normal subjects* (Tables 1 and 5). The average $FEV_{1.0}$ was 3.6 litres (96 % of predicted) as compared to 4.1 litres for $FIV_{1.0}$. The $FEV_{1.0}/FIV_{1.0}$ ratio was 0.88. There was a significant difference between pairs of $FEV_{1.0}$ and $FIV_{1.0}$ ($P < 0.001$), the FIV being larger.—The mean FVC was 4.4 litres (97 % of predicted), the FIVC was 4.3, the FVC/FIVC ratio thus being 1.03. The difference between pairs of FVC-FIVC was not significant.—The average FEV% was 82, while FIV% was 97; the difference was significant ($P < 0.001$).

Patients with generalized airways obstruction.

A) In Tables 2A and 5 are the results of spirometry in patients with low FEV% but high FIV% ($> 85\%$). The mean FEV% was 44, while the FIV% was as high as 95. The average $FEV_{1.0}$ was 1.1 litres, which is 39 % of predicted; the $FIV_{1.0}$ was 2.4 litres, the FEV/FIV ratio being 0.46.

The average FVC was 2.6 litres, 61 % of predicted normal. The FVC/FIVC ratio was 1.00.

TABLE
Patients with mainly

Subj. Sex. Age Diagnoses	Roentgenology			Bronchoscopy		Allergy history		Forced				
	Low diaphragm	Diminished vascularity	Bullae	Oedema	Bronchial collapse	Heredity	Spasmodic attacks	FEV _{1.0}				
								Litres	% pred.	Isopren. + %		
GROUP A: LOW												
BN F 42 PRGAO	+	+	—	+	++	—	—	0.80	31	16		
AA F 69 Br+PRGAO	+	—	—			?	—	0.97	54	13		
PS F 46 TBC+PRGAO	+	—	—		++	—	—	1.90	73	15		
SH F 62 RGAO	—	—	—		++	?	+	1.28	64			
MA M 65 BR+PRGAO	+	+	—	+	—	—	—	1.12	36	33		
EB M 58 BR+PRGAO	+	+	+	+	+	+	—	1.01	29	57		
AG M 63 PRGAO	+	+	(+)			?	—	0.61	21	21		
HJ M 56 Br+Bullae	—	+	++	—	+	—	—	0.97	33	18		
AL M 62 BR+PRGAO	—	—	—			—	—	1.35	53	15		
HL M 55 Br+PRGAO	+	+	—	+		+	—	0.80	25	12		
RL M 42 Br+PRGAO	+	+	(+)			?	—	0.98	25	4		
OO M 67 PRGAO	++	+	—			—	—	0.54	17	5		
AO M 63 Br+PRGAO	+	(+)	—	+		—	—	1.34	42	14		
KE M 57 Br+PRGAO	+	(+)	—			—	—	2.43	75	5		

2 A

expiratory obstruction.

expirograms				Forced inspirograms					Ratios	
FVC				FIV _{1.0}		FIVC			FEV/FIV	FVC/ FIVC
Litres	% pred.	Isopren. + %	FEV %	Litres	Isopren. + %	Litres	Isopren. + %	FIV %		
FEV%, NORMAL FIV%										
1.53	48	38	52	1.53		1.53		100	0.52	1.00
1.73	72	12	58	1.84	6	1.84	6	100	0.53	0.94
3.88	102	3	49	3.30	1	3.72	2	89	0.57	1.04
2.04	57		64	1.86		1.99		93	0.69	1.02
2.65	57	20	43	2.50	26	2.60	25	96	0.44	1.02
3.06	66	48	34	3.06		3.15		97	0.33	0.97
2.50	59	24	24	2.24		2.30		97	0.27	1.09
2.75	64	15	35	2.50		2.78		97	0.39	0.99
2.65	70	15	50	2.60	3	2.91	15	89	0.52	0.91
2.68	60	23	30	2.30		2.32		91	0.35	1.06
2.30	46	4	40	2.24	4	2.35	4	95	0.44	0.98
1.34	33	30	40	1.49		1.49		100	0.36	0.90
3.26	80	8	41	2.92		3.09		94	0.46	1.05
5.15	110	8	47	4.79	0	4.79	2	100	0.51	1.07

TABLE

Subj. Sex. Age Diagnoses			Roentgenology			Bronchoscopy		Allergy history		Forced		
										FEV _{1.0}		
			Low diaphragm	Diminished vasculatiry	Bullae	Oedema	Bronchial collapse	Heredity	Spasmocip attacks	Litres	% pred.	Isopren. + % ₀
ÅS	M	48	+	+	+	—	++	—	—	0.70	20	
TBC+PRGAO			+Vent. insuff.									
GL	M	52	+	+	+			?	—	1.20	34	35
TBC+Br+PRGAO												
BS	M	55	+	+	—			—	—	1.79	49	19
Br+PRGAO												
FS	M	64	+	+	+			—	—	0.90	32	15
Br+PRGAO												
EF	M	59	+	+	+			—	—	0.63	22	17
Br+PRGAO												
Mean values	F: 55 M: 58		16+	13+	6+	5+	6+	2+	1+	1.12	39	18
N:			19	19	19	7	7	19	19	19	19	17

TABLE
Patients with expiratory

GROUP B: LOW

HH	F	64	+	+	(+)			—	+	0.53	25	4
TBC+PRGAO			St.p.pnth.									
SG	F	54	+	+	+			+	—	0.82	32	21
Br+PRGAO												
EG	F	36	—	(+)	(+)			+	—	0.71	27	18
Br+PRGAO			+st.p.pnth.									
MM	F	50	—	—	—			—	—	1.84	71	14
TBC+PRGAO												
EA	M	63	+	—	+			?	—	0.56	21	
Br+IGAO+			Resp.insuff.									
BJ	M	41	+	+	(+)			?	—	2.60	80	
TBC+IGAO+			St.p.pleurit									

2 A (cont.)

expirograms				Forced inspirograms					Ratios	
FVC				FIV _{1.0}		FIVC			FEV/FIV	FVC/FIVC
Litres	% pred.	Isopren. + %	FEV %	Litres	Isopren. + %	Litres	Isopren. + %	FIV %		
1.60	34		44	1.40		1.45		97	0.50	1.10
2.50	52	20	55	2.18	10	2.40	17	91	0.55	1.04
3.21	62	34	56	3.26	30	3.26	20	100	0.55	0.99
2.53	61	1	36	2.30	7	2.45	5	94	0.39	0.97
1.45	35	12	44	1.48	20	1.53	22	97	0.43	0.93
2.57	61	18	44	2.41	11	2.53	12	95	0.46	1.00
19	19	17	19	19	10	19	10	19	19	19

2 B

and inspiratory obstruction.

FEV%, LOW FIV%

1.68	68	10	32	0.85	68	1.60	13	57	0.62	1.00
1.89	56	41	49	1.22	100	1.95	32	63	0.67	0.97
1.79	57	26	40	1.17	4	1.84	27	64	0.60	0.97
3.52	107	2	52	2.68	-7	3.55	1	78	0.69	1.01
1.79	45		31	0.92		1.84		50	0.61	0.97
4.73	88		55	3.25		4.80		74	0.80	0.99

TABLE

Subj. Sex. Age Diagnoses	Roentgenology			Bronchoscopy		Allergy history		Forced FEV _{1.0}		
	Low diaphragm	Diminished vascularity	Bullae	Oedema	Bronchial collapse	Heridity	Spasmodic attacks	Litres	o/pred.	Isopren. + o/o
JS M 73 Br+PRGAO St.p.pleurit	—	—	—	+	—	?	—	0.92	34	48
JL M 60 Br+PRGAO	—	—	—	+	+	?	+	1.38	43	29
FG M 56 Br+PRGAO	+	—	—			?	+	0.76	22	65
TJ M 63 Br+PRGAO+ Hypertension	+	(+)	—	+	+	+	—	1.12	41	21
ÅS M 61 Br+PRGAO+ Hypertension		(+)	—			—	?	0.75	28	8
GB M 60 Br.ect.+PRGAO	+	(+)	—			—	?	0.77	26	36
AK M 53 Br+PRGAO	—	—	—			—	—	0.87	28	34
GS M 56 Br+PRGAO	+	+	+			+	—	0.82	20	6
EB M 66 Br+PRGAO St.p.pleurit.	+	—	—			—	—	1.33	51	18
FB M 49 Br	—	—	—	++	+	—	—	2.50	78	-7
GA M 69 Br+PRGAO Br.ect.	+	—	—			+	?	1.45	85	22
Mean F: 51 values M: 59	10+	4+	3+	4+	3+	5+	3+	1.16	42	24
N:	17	17	17	4	4	17	17	17	17	15

2 B (cont.)

expirograms				Forced inspirograms					Ratios	
FVC				FIV _{1.0}		FIVC			FEV/FIV	FVC/FIVC
Litres	% pred.	Isopren. + %	FEV %	Litres	Isopren. + %	Litres	Isopren. + %	FIV %		
2.25	52	31	41	1.48	19	1.09	32	71	0.62	1.08
2.55	57	14	54	1.63	5	2.91	—	56	0.85	0.88
1.97	43	59	40	1.01	—	2.02	61	50	0.75	0.97
3.16	49	19	35	1.82		2.65		69	0.61	0.84
1.75	45	11	43	1.25	26	1.70	19	74	0.60	1.03
2.16	49	40	36	1.04	23	2.27	23	46	0.74	0.95
2.45	57	37	36	1.63	86	2.30	45	71	0.53	1.07
2.50	50	19	34	1.58	0	2.50	23	74	0.52	1.00
2.75	68	7	48	2.09	42	2.86	8	73	0.64	1.04
3.77	87	—7	66	2.65	8	3.57	3	75	0.94	1.06
2.60	95	2	56	1.95	17	2.45	17	80	0.74	1.06
2.55	65	21	44	1.66	28	2.52	22	66	0.68	1.00
17	17	15	17	17	14	17	14	17	17	17

TABLE 3
Thirteen patients with pulmonary sarcoidosis or fibrosis.

Subj.	Sex.	Age	Forced expiragrams						Forced inspiragrams			Ratios		Diagnoses (PAD)	Discovered year
			FEV _{1.0}	% pred.	FVC	% pred.	FEV % ₀	FEV ₀ pred.	FIV _{1.0}	FIVC	FIV % ₀	FEV/FIV	FVC/FIVC		
BO	F	53	1.58	75	1.82	70	88	78	1.52	1.83	94	1.03	1.00	Sarcoidosis	1951
SL	F	42	1.58	62	2.14	69	74	81	2.19	2.19	100	0.72	0.98	Sarcoidosis	1954
ES	F	37	2.19	74	2.70	75	81	82	2.70	2.70	100	0.81	1.00	Sarcoidosis	1962
TJ	F	52	1.22	52	1.62	53	73	81	1.94	1.96	99	0.63	0.86	Sarcoidosis	1962
GJ	F	57	1.63	76	2.14	79	76	77	0.97	1.99	49	0.77	1.08	St. p. sarc.	1952
BL	F	17	2.66	78	3.18	81	84	87	2.91	3.13	93	0.91	1.01	Sarcoidosis	1963
KO	F	56	1.43	70	1.94	73	74	77	1.81	2.06	88	0.79	0.94	Sarcoidosis	1947
BA	F	23	3.11	97	3.52	93	90	86	3.42	3.47	99	0.91	1.01	Sarcoidosis	1963
GE	M	59	2.13	65	2.59	59	82	76	2.64	2.64	100	0.80	0.98	Fibrosis	1954
POS	M	64	2.15	74	2.65	62	83	68	2.18	2.70	84	0.99	0.98	Fibrosis	1952
BW	M	29	2.14	50	2.30	43	93	81	2.55	2.55	100	0.84	0.90	Sarcoidosis	1958
AB	M	48	2.86	79	4.23	86	68	74	4.03	4.13	98	0.71	1.02	Sarcoidosis	1952
LA	M	28	4.23	96	5.05	90	84	81	5.05	5.05	100	0.91	1.00	Sarcoidosis	1963
Mean values		48	2.22	73	2.76	72	81	79	2.61	2.80	93	0.83	0.98		

Table 2A shows that 16/19 subjects had a low-standing diaphragm on roentgenograms, and 13/19 also had diminished vascular markings in the lungs. Bullous changes, usually on the bases, were encountered in 6/19 cases.—Bronchoscopy had been performed in 7 patients. In 5 of these there was mucosal oedema in the central airways, with expiratory collapse in 6/7 cases. Heredity for allergic diseases was recorded in only 2/19 cases. In one subject there was a record of attacks of wheezing and dyspnoea in the past.

B) In Tables 2B and 5 are listed the values in Group B. These patients had a low FEV% (44 %) and a FIV% ≤ 80 %, the mean being 66 %. The average FEV_{1.0} was 1.2 litres, which is 42 % of predicted normal, and the FIV_{1.0} was 1.7 litres. The FEV_{1.0}/FIV_{1.0} ratio was 0.68.

The FVC averaged 2.5 litres, i.e. 65 % of predicted. The ratio FVC/FIVC was 0.99.

In Table 2B can be seen that 10/17 subjects in group B had a low-standing diaphragm; in 4/17 vascular markings on the chest roentgenograms were diminished. Bullae were visible in 3/17 subjects. Bronchoscopy had been performed on 4 subjects; all had marked mucosal oedema and in 3/4 there were evidences of expiratory collapse. Heredity for allergic diseases was present in 5/17 and 3 had acute "asthmatic" attacks according to the records.

After inhalation of 2–3 breaths of isoprenaline, the FEV_{1.0} and FIV_{1.0} in group A increased with in average 18 % (17 subjects) and 11 % (10 subjects) respectively. The FVC increased with a mean of 18 % as compared to 12 % for FIVC.—For group B the average increase of FEV_{1.0} in 15 subjects was 24 % as compared to 28 % for FIV_{1.0} in 14 subjects tested. The increase of FIV_{1.0} (+ 28 %) in the group with low FIV% was almost significantly larger than corresponding bronchodilation in the group with high FIV% (+ 11 %) ($P < 0.2$).

The FVC was increased with 21 %, the FIVC with 22 %. There was no significant difference between the percentage

increase of $FEV_{1.0}$ after isoprenaline inhalation between Group A and Group B.

Patients with pulmonary sarcoidosis or fibrosis. The $FEV\%$ averaged 81 % (predicted value 79 %), the $FIV\%$ was 93. The mean $FEV_{1.0}$ was 73 % and the FVC 72 % of predicted normal. The $FEV_{1.0}/FIV_{1.0}$ ratio was 0.83, the $FVC/FIVC$ being 0.98. Tables 3 and 5.

II. Drug-induced bronchoconstriction and bronchodilation. (Table 4).

1) The mean basic $FEV_{1.0}$ and FVC were 72 % and 84 % of predicted, respectively. The average $FEV\%$ was 64, mean $FIV\%$ was 88, the ratio $FEV_{1.0}/FIV_{1.0}$ was 0.76 and the $FVC/FIVC$ was 1.04.

Inhalation of acetylcholine brought about a significant reduction in both maximal $FEV_{1.0}$ and $FIV_{1.0}$, comprising an average of 20 % ($P < 0.001$). FVC and $FIVC$ likewise decreased significantly ($P < 0.001$). The ratio FEV/FIV was 0.75, while $FVC/FIVC$ was 1.05. The $FEV\%$ and $FIV\%$ decreased in 9 and *increased* in 6 patients after bronchoconstriction.

Inhalation of isoprenaline reversed the constriction and brought the volumes back up approximately to the control values.

2) *Comparison of $FEV_{1.0}$ and $FIV_{1.0}$ with MMF and PEF* (Fig. 1). In 12 patients the spiograms could be used for calculating the MMF. (In the three remaining studies the kymograph speed was decreased after the first second of forced expiration, which prevented calculation of the MMF). After inhaling the lowest concentration (0.01–0.1 %) of acetylcholine, there was a significant decrease of mean PEF ($P < 0.001$), while no significant effect was ascertained for $FEV_{1.0}$, MMF and $FIV_{1.0}$. The decrease was more pronounced when inhaling a higher concentration of acetylcholine (0.5 %), the $FEV_{1.0}$ and MMF were then significantly reduced compared with the pre-drug values ($P < 0.001$ and $P < 0.025$ respectively). Due to one subject, who probably

TABLE 4
Effect on $FEV_{1.0}$ and $FIV_{1.0}$ by drug induced bronchoconstriction and dilation.

Subjects M:10 F:5	$FEV_{1.0}$			FVC			$FEV_{1.0}$		FIVC		$FIV_{1.0}$	$FEV_{1.0}/FIV_{1.0}$		FVC/FVC
	Max. $FEV_{1.0}$	% pred.	% change by drug	Max. FVC	% pred.	% change by drug	Max. $FEV_{1.0}$	% change by drug	Max. FIVC	% change by drug		Max. $FEV_{1.0}$	% change by drug	
Pre-drug values	2.20§	72		3.44*	84		2.89§		3.31*			0.76		1.04
After acetylcholine inhalation	1.76§		—20 (+410 cc)	2.89*		—16	2.35§	—19 (+540 cc)	2.75*	—20		0.75		1.05
After isoprenaline inhalation	2.17§		+23 (+410 cc)	3.31*		+14	2.71§	+15 (+360 cc)	3.13*	+14		0.80		1.06

Significant difference between pairs: § $FEV_{1.0}-FIV_{1.0}$; * FVC-FIVC respectively ($P < 0.001$).

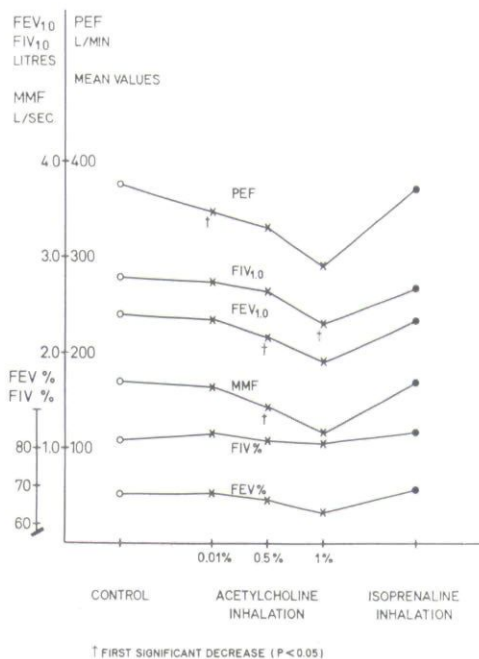


Fig. 1.

Effect on different ventilatory parameters by inhalation of increasing doses of Acetylcholine.

had erroneously low basal FIV values, the effect on FIV_{1.0} was first significant after inhalation of 1 % acetylcholine ($P < 0.005$). Fig. 1.

DISCUSSION

The aim of this study was to find out if forced inspirograms could help in the discriminating of the mechanics of airways obstruction in various patients groups.

In the present study the FIV_{1.0} in normals was significantly larger than FEV_{1.0}, while the FIVC and FVC were not significantly different. In spite of the possibly weaker muscular power available for inspiration, the FIV_{1.0} thus gets larger than FEV_{1.0}. This is due to airway dilation during inspiration

as compared to a compression and increased bronchomotor tone during *expiration* (64, 65, 93). When the diaphragm rapidly moves down during maximum inspiration, the intra-peritoneal pressure rises (17). Limited expansion of the abdominal wall may diminish the $FIV_{1.0}$ and $FIV\%$.

Campbell, Martin and Riley made a study of mechanisms of airways obstruction emphasizing differences in the cause of obstruction in emphysema and "asthma" (18). Their studies indicated a "maximum effective intrathoracic pressure", at which maximum expiratory flow rate was obtained. Above this optimal pressure a gradual decrease of expiratory flow occurred together with a large increase in flow resistance. The effective pressure was found to be greatly reduced in patients with emphysema, and moderately reduced in asthma patients; in both, the maximum expiratory flow rate was reduced. Inspiratory flow resistance at quiet breathing showed a higher value in asthmatic than in emphysematous patients (18). The difference is conceivably due to increased bronchomotor tone in "asthmatics" opposed to what is mainly airways-collapse in emphysema.

Among patients with *generalized airways obstruction* the FEV/FIV ratio in group A (0.46) indicates a severe bronchial collapse during expiration. Radiologically, this group had more signs of emphysema, especially of diminished vascularity than group B. There was a moderate effect from isoprenaline on expiratory and inspiratory volumes.

In Group B the $FIV_{1.0}$ was much smaller than in Group A in spite of the same expiratory obstruction. The average $FIV\%$, 66 %, may indicate an increased *inspiratory* intraluminal flow resistance. Clinically this group was characterized by a lower incidence of, especially, decreased vascularity. Bronchoscopically there was marked oedema with concomitant expiratory collapse in 3/4 subjects studied.

The type of airways obstruction seems to be somewhat different in the two groups. There are less indications of emphysematous changes in Group B. The low $FIV\%$ and the tendency to a better response to bronchodilation in Group B

indicates a larger extent of inspiratory and intrabronchial obstruction, while the lower FEV/FIV ratio in Group A reflects a more extensive expiratory collapse. In some patients there may also be restricted movement of the diaphragm or the thoracic cage (EA, JS, EB).

One patient, FB, (Table 2B), was a heavy smoker with intense oedema and reddened bronchial mucosae. Air flow was impeded on both expiration and inspiration and did not react to bronchodilators. His bronchial obstruction was probably due to oedema rather than bronchospasm.

In emphysematous lungs, static compliance is high (1, 64, 50) due to loss of elastic parenchyma, which normally supports the walls in the airways (26, 55), and deficiencies in the surface-active substance in the alveoli (63, 92). The tension thus increases very slowly during inspiration, and this allows for a rapid inspiratory flow (25, 55). Accordingly, post mortem inflation of emphysematous lungs is faster than that of normal lungs, while expiration is very prolonged due to the airways collapse (92).

Expiratory and inspiratory flow mechanics in normals, patients with emphysema and subjects with intraluminal airways obstruction are depicted in Fig. 2. The intrathoracic pressure (P_T) plus the elasticity of the lung (P_{EL}) give rise to the alveolar pressure (P_{ALV}). At *expiration* the pressure gradient between alveoli and mouth creates the airflow. The largest resistance is normally offered in the small bronchioles. At *inspiration* the negative pressure in the thorax ($P_T - P_{EL}$) acts dilating on airways and alveoli, giving a flow towards the alveoli.

In *emphysematous* lungs the P_{LE} is reduced (50). The alveolar pressure during *expiration* therefore may be lower than in normals. The resistance in the airways may be larger than normal, due to bronchiolitis in the smaller airways and lack of elastic support in the larger airways (92). Due to the low elasticity, P_{ALV} may become low as in normal lungs during *inspiration*, even if P_T is less negative than in normal lungs due to a low-standing and less mobile diaphragm (64, 17). The airways are opened easily due to the flaccid cartilage, thus allowing a good inspiratory flow.

In subjects with increased bronchomotor tone and mucosal oedema the alveolar pressure during *expiration* usually is in-

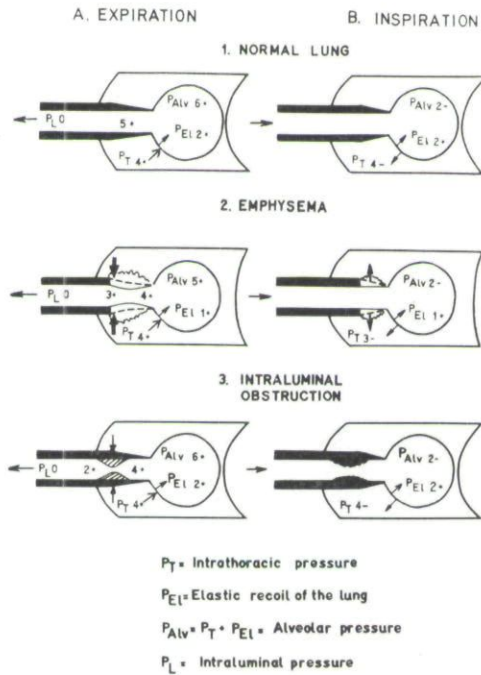


Fig. 2.

Simplified lung mechanics during expiration and inspiration in subjects with airways collapse and intraluminal obstruction.

creased. The flow resistance is high, and the intraluminal pressure (P_L) might decrease at some levels to below the extraluminal pressure, P_T , which tends to narrow the airways. The increased bronchomotor tone and the oedema act to lower the inspiratory air flow in these cases; this is in contrast to what occurs during inspiration in emphysematous lungs (3).

The effects of airways collapse (A) and bronchomotor tone (B) on expiratory and inspiratory volumes are in agreement with the findings summarized in Table 5.

During acetylcholine-induced airways constriction, expiratory and inspiratory volumes decreased equally much (Table 4), which is in line with the lowest part of the diagram in Fig. 2.

Discrepancies between expiratory and inspiratory capacities

including "peak flows" have been studied with spirometry by *Darras, Miller and Cushing, Ehrner* and recently by *Fletcher et al.* (23, 66, 31, 33, 70). Inspiratory flow rates were reported to be almost normal in emphysema patients, while the flow was impeded in "asthmatics".—The PEF/PIF in normals varied between 1.1–1.4, while the ratio in patients with emphysema was 0.4–0.6.

Patients with *pulmonary sarcoidosis* and/or fibrosis showed restrictive impairment with normal or high FEV%, and with one exception (GJ), normal FIV%. The values correspond well to those reported by *Svanborg* (85). In spite of the reduced lung volumes, the FEV/FIV ratio was high (0.83). Thus there was no marked expiratory collapse even at low lung volumes, which might be due to the increased stiffness in fibrotic lungs (25).

When measuring inspiratory capacities the spirometers must have a low inspiratory resistance because these volumes are decreased by added external resistance. A special type of such resistance is tracheal or laryngeal obstruction, which acts mainly on the inspiratory capacities. Expiratory capacities are less sensitive; in case of expiratory collapse they may even increase by added expiratory resistance (61, 41). Inspiratory flow may also be impeded by muscular weakness, impaired mobility of the diaphragm, the thoracic cage and abdominal wall.

Comparison between FEV_{1.0}, FIV_{1.0}, PEF and MMF. The results imply that mean PEF is the most sensitive measure of induced airways constriction, followed by FEV_{1.0} and MMF. This confirms the results reported in paper II in this series. The average FIV_{1.0} in this study showed less sensitivity due to uneven basal values in one subject (FT). When the maximal volumes were compared, the FEV_{1.0}, MMF and FIV_{1.0} were equally discriminating (Tables 4–5). The results are contrary to reports in which MMF has been claimed to be the most discriminating of the parameters mentioned, and in accordance with comparisons between FEV_{1.0} and MMF from this laboratory (56, 5, 10).

Of special interest is the insignificant effect on FEV% and

FIV% noted after bronchoconstriction, as the FEV% has been used as the spirometric parameter in several comparisons of methods for measuring airways obstruction (24, 27). In intraindividual evaluations of changes in air flow resistance, the FEV% has a very low discriminatory power, while the $FEV_{1.0}$, $FIV_{1.0}$ and the so-easily obtained PEF give a much better evaluation.

CONCLUSIONS

The ratio $FEV_{1.0}/FIV_{1.0}$ is useful in differentiating between airways obstruction due to expiratory collapse and that due mainly to increased bronchomotor tone. The differentiation is further facilitated by the effect achieved by bronchodilating agents on expiratory and inspiratory capacities.

In drug-induced bronchoconstriction forced inspiratory capacities decrease simultaneously with expiratory capacities. The ratio FEV/FVC (FEV%) and FIV/FIVC (FIV%) are not sensitive discriminators of intraindividual changes in airways obstruction. Peak expiratory flow with Wright's Peak Flow Meter may be a better discriminator than $FEV_{1.0}$ and MMF.

SUMMARY

Forced expiratory capacities ($FEV_{1.0}$, FVC, FEV%) were compared to forced inspiratory capacities ($FIV_{1.0}$, FIVC, FIV%) in normal subjects and in patients with generalized airways obstruction or sarcoidosis.

The $FIV_{1.0}$ was larger than the $FEV_{1.0}$, the ratio FEV/FIV in normals was 0.88 and in patients with sarcoidosis 0.83.

Two groups of obstructive patients were discernible, both had low $FEV_{1.0}$ and FEV%. Group A had a high $FIV_{1.0}$ and FIV%, while group B had low $FIV_{1.0}$ and FIV%.

In group A there were more subjects with decreased vascularity on roentgenograms of the lungs. In group B the patients seemed to respond better to isoprenaline inhalation.

The FEV/FIV was 0.46 in group A compared to 0.68 in group B, reflecting a more pronounced expiratory airways

collapse in group A and more intrabronchial obstruction in group B.

After acetylcholine induced airways constriction in 15 subjects, $FEV_{1.0}$, FVC, $FIV_{1.0}$ and FIVC decreased about 20 %. The $FEV\%$ and $FIV\%$ thus did not change significantly.

A comparison of the discriminatory power of $FEV_{1.0}$, $FIV_{1.0}$, PEF and MMF to detect acetylcholin-induced bronchoconstriction revealed average PEF to be the best followed by $FEV_{1.0}$, MMF and $FIV_{1.0}$.

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