Coronary Circulation in Chronic Pulmonary Disease

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The mechanisms of the development of the chronic cor pulmonale in various chronic pulmonary diseases are one of the interesting problems to be inquired, with its relation to the development of the pulmonary hypertension.

In this study, the coronary sinus and the right cardiac catheterizations were performed simultaneously on chronic pulmonary diseases, and the coronary circulation was studied chiefly from the viewpoint of the oxygen metabolism, and pulmonary circulation hemodynamically.

It was concluded from this investigation that hypoxia of the left ventricle existed in the chronic cor pulmonale, and that chronic hypoxemia due to the pulmonary insufficiency shows a different attitude from the acute-induced hypoxia in the coronary circulation.

IN 1949, BING¹⁾ et al. investigated the coronary circulation by combining the coronary sinus catheterization technic with N₂O method for measuring the cerebral blood flow introduced by KETY & SCHMIDT²⁾ in 1945. Since then, many investigations on the coronary circulation in normal subjects and coronary arteriosclerosis were reported.

As the results of these researches, a great deal of progress has been made in the hemodynamic and metabolic aspects of the heart.

In 1965, ROSE³⁾ et al. reported the study of the coronary circulation of the 9 cases with pulmonary diseases, including the chronic cor pulmonale. HOSONO⁴⁾ in 1958, and OGAWA⁵⁾ in 1959 reported their works.

In 1961, the report of the chronic cor pulmonale⁶⁾ was offered by the expert committee in WHO, and it was pointed out in the report that the effects of chronic cor pulmonale on the left ventricle should receive more attention.

In addition to these, it has long been insisted by DEXTER⁷⁾, HECHT⁸⁾, SASAMOTO⁹⁾, and KATAYAMA¹⁰⁾ that the effect of the arterial

hypoxemia should be much more taken into consideration in the development of chronic cor pulmonale.

From these reasons, the coronary and pulmonary circulation researches were attempted in this study to detect the effects of the arterial hypoxemia on the coronary circulation in the chronic cor pulmonale.

MATERIALS AND METHODS

Thirty-four cases seen in Table I were used for the investigation and among them 7 cases of chronic cor pulmonale diagnosed clinically on the criteria mentioned below were included. They were 10 cases of bronchial asthma, 8 of pulmonary tuberculosis, 8 of bronchiectasis, 5 of chronic pulmonary emphysema and 3 of emphysematous bullae.

The criteria for the diagnosis of chronic cor pulmonale were as follows: (1) to have chronic pulmonary disease affecting the function and/or the structure of the lung, (2) not to have a primary heart disease, (3) to have signs and symptoms of the congestive heart failure in the past or at the time of the investigation, (4) to have the pulmonary hypertension. All these conditions should be satisfied at the same time.

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Measurement of the lung volume was carried out by 9-L BENEDICT-ROTH type respirometer, analysis of the expired gas by SCHOLANDER microgasanalyser, analysis of the blood gas by VAN SLYKE & NEILL method and blood pH by IL-pH meter. The coronary sinus and the right cardiac catheterizations were performed at the same time. Intracardiovascular pressure was measured by Statham P-23 Db strain gauge manometer, and recorded simultaneously with electrocardiogram. Cardiac output was measured by FICK-method. The coronary blood flow was measured by N₂O method applied by GOODALE¹¹⁾ using the desaturation curve after 20 minutes inhalation of 15% N₂O gas. Values of the coronary circulation were calculated as follows:

Myocardial Oxygen Extraction Coefficient

$$= \frac{CaO_2 - Ccvo_2}{CaO_2}$$

Coronary Arterio-Venous Oxygen Difference

$$= CaO_2 - Ccvo_2 \quad (\text{vol}\%)$$

Myocardial Oxygen Consumption

$$= (CaO_2 - Ccso_2) \times CBF$$

(cc/100 gr. of left ventricle/min)

$$\text{Coronary Blood Flow} = \frac{V_0 - V_7}{S} \times 100$$

(cc/100 gr. of left ventricle/min)

$$\text{Coronary Vascular Resistance} = \frac{\bar{P}_{BA} - \bar{P}_{CV}}{CBF}$$

(mmHg/cc/100 gr. of left ventricle/min)

CaO₂; O₂ content of arterial blood (vol%)

Ccvo₂; O₂ content of coronary venous blood (vol%)

V₀; N₂O content of coronary venous blood at the time of saturation (vol%)

V₇; N₂O content of coronary venous blood 7 minutes after desaturation (vol%)

S; area surrounded by N₂O content curves of arterial and coronary venous blood

$\bar{P}_{BA}$; mean pressure of brachial artery (mmHg)

$\bar{P}_{CV}$; mean pressure of coronary vein (mmHg)

As, in the patients with pulmonary insufficiency, N₂O gas saturation is delayed due to ventilatory disturbance, N₂O gas inhalation was continued for 20 minutes in all cases.

RESULTS

Patients in this investigation were classified into three groups as shown in Table I and II.

Group 1 showed neither arterial hypoxemia nor pulmonary hypertension. Group 2 showed the arterial hypoxemia without pulmonary hypertension. Group 3 showed both arterial

hypoxemia and pulmonary hypertension, except 2 cases having pulmonary hypertension without arterial hypoxemia. All 7 cases of chronic cor pulmonale were classified into Group 3.

1) Arterial Blood

- a) Oxygen Saturation; Sao₂ (%)
(normal; over 92 per cent)*

All cases of Group 1 showed normal oxygen saturation. Group 2 and Group 3 revealed arterial hypoxemia except 2 cases in Group 3. In 4 cases of cor pulmonale, oxygen saturation ranged from 72 per cent to 88 per cent.

- b) Carbon Dioxide Tension; Pco₂ (mmHg)
(normal; 35 to 45 mmHg)

Carbon dioxide tension was normal in Group 1 and Group 2. Eleven cases showed hypercapnia in Group 3, in which 4 cases of cor pulmonale were included.

- c) Hematocrit; Vc (%)
(normal; 38 to 45 per cent)

Case 34 was the only subject showing the distinct anemia. In Group 3, hematocrit increased in 4 cases including 3 cases of cor pulmonale.

Many cases of Group 3 revealed abnormal values in Sao₂ and Pco₂. Six cases of cor pulmonale showed asphyxia indicating the advanced disturbance of the gas exchange in the lung.

2) Pulmonary Circulation

- a) Mean Pulmonary Arterial Pressure; PPA
(mmHg) (normal; below 15 mmHg)

Mean pressure of the pulmonary artery was almost within normal limits in Group 1 and Group 2, 7 to 15 mmHg, and 5 to 15 mmHg, respectively. In Group 3, it was 17 to 35 mmHg, and in cor pulmonale, 24 to 35 mmHg.

- b) Cardiac Index; CI (L/min/m²)
(normal; 2.7 to 3.2 L/min/m²)

Four cases showed low- and 2 cases high-cardiac index in Group 1. Three cases in Group 2 showed high cardiac index. There was no case who showed low cardiac index in Group 3, and 11 cases revealed obviously high index, including 4 cases of cor pulmonale.

- c) "Pulmonary Capillary" Pressure; $\bar{P}_{pc}$
(mmHg)

* Figures in parentheses indicate normal value in our laboratory.

(normal; below 11 mmHg)

All three groups were within normal range, except 1 case in group 3.

d) Total Pulmonary Vascular Resistance; TPVR (dynes·sec·cm⁻⁵)
(normal; below 213 dynes·sec·cm⁻⁵)

A few cases had high TPVR in Group 1 and Group 2. Eleven cases were over 300 dynes·

sec·cm⁻⁵ in Group 3. TPVR was markedly elevated in cor pulmonale.

In the pulmonary circulation, most cases of Group 3 were disturbed hemodynamically, especially cor pulmonale. All 7 cases of cor pulmonale were not of low output. Case 19 (cor pulmonale) was the only instance who showed the elevated right ventricular end-

TABLE I

Name	Case No.	Age	Sex	Diag	Lung Volume					Ventilation					Blood Gas (Artery)									
					% VC	% TLC	RV/ TLC	ATI	FEV ₁	$\dot{V}_E$	$\dot{V}CO_2$	$\dot{V}O_2$	RQ	P _A O ₂	V _C	O ₂ cap	CaO ₂	SaO ₂	Pao ₂	CaCO ₂	pH	[B _B ⁺] _B	Paco ₂	
Group 1																								
YS	1	49	♂	Bul.	98			0	68	4.5	81	119	0.69	103	38	15.9	15.7	97	94	45.2	7.44	48	32	
OT	2	21	♀	Bul.	80	84	22	2.7	76	3.6	91	107	0.85	110	39	15.7	14.7	92	68	45.1	7.38	45	39	
HT	3	23	♂	Asth.	71	100	43	6.0	37	5.2	86	118	0.73	99	47	20.8	20.0	95	80	42.2	7.42	47	35	
YE	4	67	♂	CPE	90			18	43	5.2	98	99	0.99	106	37	14.3	14.4	96	89	49.4	7.38	46	43	
FY	5	45	♂	LTB	70	66	44	0	75	5.5	87	144	0.60	93	43	17.7	17.8	98	110	44.2	7.44	43	35	
SK	6	20	♂	Asth.	98			0	72	3.6	101	132	0.77	103	47	16.9	16.8	96	83	43.3	7.42	47	36	
NS	7	42	♂	LTB	92			0	70	4.5	87	125	0.70	108	46	17.2	17.4	99		45.8	7.39	46	39	
MG	8	57	♂	CPE	68	62	28	0	66	3.8	67	69	0.98	106	40	16.7	16.0	94	75	51.6	7.39	48	44	
Mean	38														42	16.9	16.6	96	73	45.8	7.42	46	37	
Group 2																								
NH	9	50	♂	Asth.	78			8.0	33	5.1	97	141	0.69	97	40	18.0	15.7	87	52	44.6	7.44	47	36	
AK	10	38	♂	Asth.	51	60	35	36.7	63	6.1	95	139	0.68	93	43	16.0	14.4	89	62	40.9	7.35	43	39	
TS	11	64	♂	Asth.	83	97	41	5.9	39	4.9	94	116	0.81	95	45	20.7	17.9	86	54	50.3	7.39	49	44	
KS	12	41	♀	Ect.	94	112	36	5.9	68	4.6	88	117	0.75	90	37	16.0	14.5	89	61	47.8	7.37	45	42	
YS	13	46	♂	Asth.	80	93	38		63	5.3	122	152	0.80	104	36	18.7	17.3	91	60	50.4	7.44	48	37	
US	14	53	♂	Ect.	86	104	43	1.1	57	4.1	104	126	0.84	108	40	16.2	14.8	90	60	39.6	7.42	49	35	
SM	15	34	♂	LTB	90	100	27	1.5	62	5.5	111	153	0.72	96	43	18.3	16.8	91	62	45.8	7.41	47	38	
YY	16	21	♂	Asth.	85			2.0	59	4.6	67	97	0.70	102	41	17.4	15.5	88	55	42.0	7.43	45	32	
SS	17	38	♂	Ect.	91	77	35	2.0	54	4.7	109	130	0.84	94	45	17.0	15.5	90	69	48.6	7.29	45	45	
Mean	42														41	17.6	16.0	89	60	45.5	7.40	45	38	
Group 3																								
TY''	18	32	♂	Ect.	36			9.3	39	5.9	164	215	0.77	87	52	21.3	16.4	77	44	48.6	7.36	48	49	
KC''	19	56	♂	Asth.						6.1	132	179	0.74	85	45	16.7	13.9	82	46	61.0	7.44	55	48	
TM''	20	26	♂	Asth.	42	90	63	10.0	50	5.8	135	151	0.90	88	41	18.0	14.6	80	50	54.1	7.31	47	55	
TR''	21	30	♂	LTB	21	39	58	4.0	98	11.3	230	254	0.91	85	42	15.2	13.5	88	61	57.2	7.35	50	53	
MD''	22	46	♂	LTB	49	66	44	15	52	5.4	108	134	0.82	85	45	17.3	12.5	72	38	58.8	7.37	53	53	
KT''	23	42	♂	CPE	74	98	42	0	38	4.7	125	134	0.93	103	56	22.6	19.3	85	53	46.4	7.37	49	44	
FY''	24	33	♂	Ect.	66	132	40	3.0	44	4.9	108	121	0.97	100	60	22.7	17.4	77	44	54.5	7.34	50	55	
TK	25	22	♂	Asth.	71	76	28	6.0	50	6.8	130	139	0.93	114	39	18.4	15.9	86	52	41.0	7.41	44	33	
YM	26	36	♀	Ect.	34	91	71	5.0	62	6.1	126	147	0.86	106	41	17.3	15.4	88	51	44.7	7.45	47	37	
SY	27	36	♂	Ect.	43			25	46	5.5	127	128	0.99	109	48	21.2	19.2	90	60	44.8	7.41	48	38	
TT	28	57	♂	LTB	35	43	43	0	77	7.7	96	157	0.89	110	40	15.4	15.3	98	102	42.6	7.43	46	34	
NS	29	60	♂	CPE	69	104	56	0	30	4.9	118	139	0.85	77	47	19.7	17.1	86	60	51.9	7.28	46	58	
HT	30	41	♂	LTB	19	30	53	0	91	6.1	90	109	0.83	89	50	20.1	17.7	87	56	54.9	7.38	52	50	
MY	31	72	♂	CPE	53			8.0	40	5.5	99	117	0.83	89	43	16.8	14.0	83	50	59.4	7.36	52	51	
MM	32	21	♂	Bul.	71	88	36	0	51	7.8	150	209	0.72	75	40	21.2	19.1	90	72	47.0	7.21	41	56	
IR	33	31	♂	LTB						5.5	128	136	0.94	105	46	19.3	19.1	97	103	45.0	7.35	43	41	
TK	34	27	♀	Ect.	42	87	61	29	60	3.5	73	88	0.83	108	31	10.5	8.6	81	46	43.8	7.40	43	36	
Mean	39														45	18.4	15.7	85	59	50.3	7.37	42	47	

Bul.; Bullae, Asth.; Asthma bronchiale, CPE; Chronic pulmonary emphysema, LTB; Lung tuberculosis, Ect; Bronchiectasis, % VC; % Vital capacity, % TLC; % Total lung capacity, ATI; Air trapping index, FEV₁; Forced expiratory volume (1 sec), V_C; Packed cell volume, " ; Cor pulmonale, O₂ cap; O₂ Capacity, CaO₂; O₂ Content, SaO₂; O₂ Saturation, [B_B⁺]_B; Buffer base.

diastolic pressure at the time of the investigation.

3) Coronary Circulation

a) Coronary Blood Flow; CBF

(cc/100gr. of left ventricle/min)

Fig. 1. (normal; 57 to 90)

Coronary blood flow was measured in 23 cases, varying over a wide range (55 to 161 cc/100gr. of left ventricle/min). CBF of 7 cases

measured in Group 1 ranged 60 to 97 cc/100 gr. of left ventricle/min (mean 65). In 7 cases of Group 2, it was from 55 to 161 cc/100gr. of left ventricle/min (mean 92). In 9 cases of Group 3, it extended from 59 to 145 cc/100gr. of left ventricle/min (mean 85). In three cases of cor pulmonale CBF was 76, 70 and 124 cc/100gr. of left ventricle/min, respectively.

b) Coronary Blood Flow-Cardiac Output

TABLE II

Name	Case No.	Age	Sex	Diag	Pressure				CI	T.P.V.R.	Coronary Circulation							
					$\bar{P}_{BA}$	$\bar{P}_{PA}$	$\bar{P}_{PC}$	$\bar{P}_{CV}$			$C_{CV_{O_2}}$	$P_{CV_{O_2}}$	ΔO_2	MOC	CBF	MOC	CVR	CBF/CO
Group 1																		
YS	1	49	♂	Bul.	72	8	6	4	2.5	188	7.2	25	8.5	0.54	82	7.0	0.84	2.4
OT	2	21	♀	Bul.	83	13	9	2	5.4	120	6.5	36	8.2	0.56				
HT	3	23	♂	Asth.	91	10	5	2	1.7	320	10.9	31	9.1	0.46	68	6.2	1.31	2.8
YE	4	67	♂	CPE	103	14	8		1.9	400	5.6	24	8.8	0.63	78	6.9		2.8
FY	5	45	♂	LTB	103	7	3		1.9	207	4.4	26	13.4	0.76	60	8.0		2.2
SK	6	20	♂	Asth.	97	15	10		4.7	140	4.9	29	11.6	0.71	97	11.2		1.1
NS	7	42	♂	LTB	77	10	9		2.6	175	7.1	25	10.3	0.59	66	6.8		1.4
MG	8	57	♂	CPE	88	13	2		1.6	452	5.7	34	10.3	0.65	67	6.9		2.8
Mean		38			90	11	7		2.7	250	6.5	28	10.0	0.60	65	7.6		2.2
Group 2																		
NH	9	50	♂	Asth.	94	7	0	3	3.6	85	4.2	15	11.5	0.74	83	9.5	1.07	1.28
AK	10	38	♂	Asth.	85	14	1	-3	5.8	133	7.1	26	7.3	0.50	65	4.7	1.35	0.78
TS	11	64	♂	Asth.	84	5	7	0	2.6	114	4.2	14	13.7	0.77				
KS	12	41	♀	Ect.	94	12	0	-3	2.7	246	3.4	18	11.1	0.77	55	6.1	1.76	1.41
YS	13	46	♂	Asth.	97	12	-2	3	4.0	152	4.4	20	12.9	0.75	65	8.4	1.44	1.04
US	14	53	♂	Ect.	76	13	8	2	3.0	221	6.0	23	8.8	0.59				
SM	15	34	♂	LTB	93	15	2	4	3.3	225	7.1	27	9.7	0.58	128	12.4	0.70	2.72
YY	16	21	♂	Asth.	92	14	8	4	3.5	228	5.8	20	9.7	0.62	161	15.6	0.54	3.3
SS	17	38	♂	Ect.	100	12	3	3	4.2	155	7.8	34	7.7	0.50	85	6.5	1.14	1.4
Mean		42			91	12	3	1.4	3.6	173	5.5	22	10.3	0.65	92	9.0	1.14	1.7
Group 3																		
TY ^{II}	18	32	♂	Ect.	92	30	2	-2	3.4	475	4.9	17	11.5	0.70				
KC ^{II}	19	56	♂	Asth.	96	28	9	2	4.6	346	3.4	16	10.5	0.75	76	8.0	1.24	1.2
TM ^{II}	20	26	♂	Asth.	95	35	9	5	3.0	683	3.4	14	11.2	0.77	70	7.8	1.28	1.7
TR ^I	21	30	♂	LTB	95	24	11	0	7.0	196	3.1	15	10.4	0.77				
MD ^I	22	46	♂	LTB	103	34	15	0	5.0	338	5.9	21	6.6	0.53	124	8.1	0.83	1.53
KT ^I	23	42	♂	CPE	75	34	10	4	5.2	306	10.0	25	9.3	0.48				
FY ^{II}	24	33	♂	Ect.	86	29	3	-2	4.0	387	6.4	19	11.0	0.63				
TK	25	22	♂	Asth.	96	17	7	3	6.7	137	4.7	16	11.2	0.71				
YM	26	36	♀	Ect.	100	20		3	2.4	516	3.9	14	11.5	0.75				
SY	27	36	♂	Ect.	91	19		1	3.5	287	3.9	16	15.3	0.80				
TT	28	57	♂	LTB	97	25		1	5.4	252	4.1	17	11.2	0.73	145	16.2	0.66	1.8
NS	29	60	♂	CPE	107	18	7	7	3.0	300	5.1	20	12.0	0.70	59	7.1	1.70	1.2
HT	30	41	♂	LTB	113	20	10	2	3.5	267	6.2	20	11.5	0.65				
MY	31	72	♂	CPE	92	20	10	5	3.4	362	5.7	21	8.3	0.59	78	6.5	1.11	1.8
MM	32	21	♂	Bul.	76	17	3		3.6	129	6.3	21	12.8	0.67	59	7.5		1.13
IR	33	31	♂	LTB	96	20		1	4.2	254	8.7	28	10.4	0.55	70	7.3	1.36	1.1
TK	34	27	♀	Ect.	93	19		3	3.3	323	3.6	20	5.0	0.58	79	4.0	1.24	1.4
Mean		39			94	24	8	2	4.4	327	5.2	19	10.5	0.67	84	8.0	1.18	1.4

P: mean pressure, BA; Brachial artery, PA; Pulmonary artery, PC; Pulmonary capillary, CV; Coronary vein, CI; Cardiac index, TPVR; Total pulmonary vascular resistance, ΔO_2 ; $Ca_{O_2}-C_{CV_{O_2}}$; MOEC; Myocardial O_2 extraction coefficient, CBF; Coronary blood flow, MOC; Myocardial O_2 consumption, CVR; Coronary vascular resistance, " ; Cor pulmonale.

ratio; (CBF/CO)

Fig. 2. (normal; 0.9 to 1.9)

Most cases of Group 1 showed high ratio. Two cases had the extremely high ratio in Group 2. Group 3 including all cases of cor pulmonale were within normal limits.

c) Coronary Arterio-Venous Oxygen Difference; ΔO_2 (vol%)

Fig. 3. (normal; 8.3 to 13.5 vol%)

All cases in three groups ranged within normal limits, except three cases in Group 3.

d) Myocardial Oxygen Consumption; MOC (cc/100 gr. of left ventricle/min)

Fig. 4 (normal; 6.0 to 11.0)

There was no significant difference among

three groups showing almost normal oxygen consumption with a few cases of exception.

e) Myocardial Oxygen Extraction Coefficient; MOEC

Fig. 5. (normal; 0.52 to 0.68)

MOEC was almost within normal limits in Group 1 and 2. Nine cases showed an elevated MOEC in Group 3. Four cases of cor pulmonale were over 0.68.

f) Coronary Venous Oxygen Tension; P_{cvo_2} (mmHg)

Fig. 6. (normal; 20 mmHg or over)

Group 1 was normal in all cases. In Group 2, three cases showed lowered oxygen tension. In 10 of 17 cases in Group 3, oxygen tension was below 20 mmHg, including 5 cases of cor pulmonale.

Fig. 1.

Fig. 3.

Fig. 2.

Fig. 4.

g) Mean Coronary Venous Pressure; $\bar{P}_{Cv}$
(mmHg)

(normal; below 5 mmHg)

All three groups indicated normal pressure except 1 case in Group 3.

h) Coronary Vascular Resistance; CVR
(mmHg/cc/100gr. of left ventricle/min)
(normal; 0.9 to 1.5)

Two cases showed elevated CVR in Group 2 and 3. There was almost no difference among Group 2 and Group 3.

In the coronary circulation, there was no marked hemodynamic difference among these three groups, but judging from the aspect of oxygen metabolism, many cases of Group 3 were suspected to be functioning in the myocardial hypoxic state, especially in cor pulmonale.

MOEC

Fig. 5.

Fig. 6.

DISCUSSION

It is generally believed that blood is circulating to maintain the constancy of the internal environment of tissues or organs in the body. But if the internal environment in any organ is disturbed so enough to influence the constancy, there occurs the compensating mechanisms to control the disturbed balance. For instance, under the anoxic state produced experimentally, or under increased oxygen demand in skeletal muscles and heart muscles by exercise, the blood flow increases to meet the increased oxygen demand and oxygen debt. When increase in the blood flow is inadequate, either absolutely or relatively, oxygen supply to meet the inadequacy is carried out by elevating the oxygen extraction rate¹⁸⁾ (in the heart, MOEC). Vital organs in the body is believed to be endowed with such elaborate compensating phenomena.

It is well known that the heart muscles function under the most aerobic condition compared with other organs. Therefore it is considered that muscles of the heart cannot so long endure under the anaerobic condition. In fact, the skeletal muscles continue to work effectively under the anaerobic circumstances, producing the lactic acid¹²⁾. However it is impossible for the heart muscles to maintain its normal function longer than the skeletal muscles in the anaerobic metabolism.

Both in patients of chronic cor pulmonale and mitral stenosis, the pulmonary hypertension is detected by the cardiac catheterization.

However, signs and symptoms of congestive heart failure appear in chronic cor pulmonale at the far lower level of pulmonary arterial pressure than in mitral stenosis. For instance, pulmonary arterial pressure at the stage of congestive failure may be 20 to 30 mmHg in most cases of chronic cor pulmonale, while in mitral stenosis clinical signs of congestive failure may not be manifested even over 40 to 50 mmHg of pulmonary arterial pressure.

One of the apparent differences found between these two diseases is, as SASAMOTO⁹⁾ stated, the longstanding arterial hypoxemia or hypercapnia in chronic cor pulmonale. KATAYAMA¹⁰⁾ pointed out that the development of

the heart failure in chronic pulmonary diseases was related to the degree of arterial hypoxemia or hypercapnia, but not to the degree of the pulmonary hypertension.

In the chronic far-advanced pulmonary diseases, arterial hypoxemia, sometimes with hypercapnia, is produced by the disturbed gas exchange in the lung. This hypoxic or asphyxic blood perfuses the vital organs including the heart. When the right ventricle works against the increased pulmonary vascular resistance produced by the various factors including the anoxic effect on the pulmonary vessels, the oxygen supply to the heart muscles must be maintained enough to satisfy the oxygen needs of the heart muscles. In normal subjects, the increased oxygen supply, if necessary, is accomplished by the increased coronary blood flow, sometimes by elevating the oxygen extraction coefficient¹³⁻¹⁷.

In cases with severe pulmonary diseases the oxygen supply to the heart muscles must be carried out by the above-mentioned hypoxic or asphyxic blood. However, in practice, coronary blood flow is reported to increase not always in chronic pulmonary diseases^{9,10}, even in cor pulmonale⁸. ROSE⁹ stated that the existence of chronic cor pulmonale did not give a profound influence on the coronary circulation.

In this investigation, coronary blood flow, myocardial oxygen consumption and coronary arterio-venous oxygen difference in 34 cases of chronic pulmonary diseases including 7 cases

of chronic cor pulmonale were about the same with the report of ROSE⁹. However, some different results were obtained in this study.

As shown in Fig. 2, coronary blood flow in Group 1, 2 and 3 revealed no significant difference compared with the normal group. Coronary blood flow increased in case 15 and 16 of Group 2, and in case 22 and 28 in Group 3. In case 15, 16 and 22, oxygen saturation was 91 per cent, 88 per cent, and 72 per cent respectively, and this hypoxemia was thought responsible for the increase in coronary blood flow. Case 28 who was cyanotic on lips and nails at the first visit to the hospital showed no hypoxia in spite of the existence of pulmonary hypertension after 2 weeks treatment of the pulmonary infection. As this patient had anemia with slight hyperventilation, these factors should be evaluated in the estimation of the data. Thus, arterial hypoxemia or asphyxia did not always follow the increase in the coronary blood flow, which is different from the acute-induced hypoxia by the low oxygen inhalation (Fig. 2 & 7).

Besides, the coronary venous oxygen tension, which is regarded as presumably the myocardial oxygen tension, was low (below 20 mmHg) in many cases of Group 3 (Fig. 6), suggesting that myocardial oxygenation was inadequate in those cases. As mentioned before, the consumed oxygen is met by elevating oxygen extraction coefficient in case of the inadequate increase in blood flow. That the heart is not the exception

Fig. 7.

is comprehensive from Fig. 8. The coronary venous oxygen tension correlated inversely to myocardial oxygen extraction coefficient. Cases with normal or elevated coronary venous oxygen tension revealed low myocardial oxygen extraction coefficient, and cases with coronary venous oxygen tension lower than normal showed more elevated myocardial oxygen extraction coefficient. Four cases of cor pulmonale were found in the latter.

On the other hand, it must be considered that low arterial oxygen tension due to the pulmonary insufficiency (anoxic anoxemia) may have given an effect on the coronary venous oxygen tension.

However, Fig. 9 shows that coronary arterio-venous oxygen difference was greater in some

cases of Group 3, especially in cor pulmonale, than cases of Group 2, at the same content of arterial oxygen. This fact means that heart muscles unsparingly extract the amount of oxygen necessary from blood with low oxygen content.

In cor pulmonale without increased coronary blood flow, the oxygen needs are met by the augmentation of arterio-venous oxygen difference, thus maintaining normal oxygen consumption.

It is concluded from these considerations that existence of hypoxemia in heart muscles is expressed by the augmented coronary arterio-venous oxygen difference with low coronary venous oxygen tension, and the lowered coronary venous oxygen tension was not due solely to the low oxygen content in the arterial blood.

In case 22 (cor pulmonale) the arterial oxygen saturation was 72 per cent and the carbon dioxide tension 53 mmHg (asphyxia). Increased coronary blood flow was probably caused by the lowered arterial oxygen saturation. This compensated increase in coronary blood flow resulted in normal myocardial oxygen consumption, and normal coronary venous oxygen tension, in spite of the existence of severe arterial hypoxemia. Myocardial oxygen extraction coefficient was within normal limits (0.53) and the coronary arterio-venous oxygen difference was not augmented. This case was considered as the typical case showing the effective compensation, and the case 23 with

Fig. 8.

Fig. 9.

low myocardial oxygen extraction coefficient and normal coronary venous oxygen tension would probably be a case with the increased coronary blood flow if it was successfully measured. Case 18, 19, 20 and 21 (cor pulmonale) revealed low coronary venous oxygen tension and increased myocardial oxygen extraction coefficient, suggesting the myocardial hypoxia.

Indeed the coronary circulation research by N_2O method may detect the function of the left side of the heart, but, in the case of the coexistence of the arterial hypoxemia (or asphyxia) and the pulmonary hypertension, hypoxia was disclosed in the left ventricular muscles of these cases, among whom cor pulmonale was found.

These facts indicate that not only the pulmonary hypertension (hemodynamic factor) but the myocardial hypoxia (metabolic factor) may be responsible for the development of cor pulmonale from the chronic pulmonary diseases.

Seven cases of cor pulmonale in 34 cases were relatively younger, ranging from 26 to 56 year-old (mean 38). Correlation between cor pulmonale, age and the coronary arteriosclerotic factor due to aging was not detectable.

SUMMARY

1) Coronary sinus and right cardiac catheterizations were carried out in 34 cases of chronic pulmonary diseases (7 cases of chronic cor pulmonale were included). These 34 cases, classified into three groups by pulmonary arterial pressure and arterial oxygen saturation, were investigated on blood gas, coronary and pulmonary circulation from the viewpoint of the oxygen metabolism and the hemodynamics.

2) Group 1 with neither hypoxemia nor pulmonary hypertension showed normal coronary circulation. Group 2 with hypoxia, without pulmonary hypertension, showed disturbed myocardial oxygen metabolism in a few cases. Group 3 with both hypoxemia and pulmonary hypertension revealed low coronary venous oxygen tension with augmented coronary arterio-venous oxygen difference about in a half cases.

3) In chronic hypoxemia due to pulmonary insufficiency, the myocardial oxygen metab-

olism is presumably controlled chiefly by myocardial oxygen extraction coefficient rather than by increase in coronary blood flow.

4) In chronic cor pulmonale, myocardial oxygen extraction coefficient increased, coronary venous oxygen tension lowered and coronary arterio-venous oxygen difference augmented. All of these indicate the myocardial oxygen lack.

5) It was concluded that the disturbance of the oxygen metabolism in the myocardium should be more emphasized in the developmental process of chronic cor pulmonale, in addition to the hemodynamic disturbance in the pulmonary circulation. Chronic cor pulmonale was found frequently in the cases showing the hypoxia of the left ventricle, which suggests the role of both ventricles in the pathogenesis of chronic cor pulmonale.

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