Symposium on
Circulatory Disorders of the Lung*

Cardio-vascular Dynamical Analysis of the
Pulmonary Hypertension

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A. The cardio-vascular dynamical analysis of the pulmonary circulation was
investigated in 112 cases of chronic obstructive pulmonary emphysema.

The patients were classified into four grades by their severity according to the
temporary criteria discussed in several meetings of the Japanese Emphysema Research
Association. By means of intravenous catheterization, in addition to the determina-
tion of cardiac index and total pulmonary resistance according to the Fick-Cournand
method, the pulmonary volume elasticity coefficient E'/p was estimated by R. Knebel's
method and the right ventricular dynamical values were measured by O. Bayer's
method. However, these all determinations were able to be simultaneously performed
only in 47 among 112 cases.

The right ventricular dynamics and the severity of the disease:

While DAZ' ("Druckanstiegszeit", isometric pressure rising period of the right
ventricle) was considerably prolonged in the patients with the severity of the 3rd
grade, UFZ' ("Umformungszeit", isometric transformation period of the right ventri-
cle) was not so markedly affected. The definite prolongation of ASZ' ("Anspannungs-
zeit", isometric tension period of the right heart), that is, the total sum of UFZ' and
DAZ' was noted in the patients with the severity of the 2nd and the 3rd grade
being accompanied by the shortening of ATZ' ("Austreibungszeit", ejection period
of the right ventricle). Consequently as the grade of the severity is advanced, the
pressure load reaction in the sense of KI. Blumberger seemed to be valid for the
right ventricular dynamics of the precapillary hypertensive due to the marked ob-
structive pulmonary emphysema.

The vascular dynamics and the severity of the disease:

The cardiac index (C.I.) within a normal range was obtained in the patients with
the severity of the 1st grade. While in the 2nd grade C.I. was sometimes augmented,

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it remained within normal extent or was subnormally decreased in most of the 3rd grade. In the patients with the severity of the 1st grade the pulmonary arterial pressure, both systolic and diastolic, remained normal. The obvious pulmonary hypertension was observed in some cases of the grade 2, whereas in all of the patients with the grade 3 the pulmonary arterial pressure was found beyond the normal level. Both the peripheral streaming resistance $W_p$ and the volume elasticity coefficient $E'_p$ of the pulmonary artery were increased among the patients with the severity of the grade 3. Consequently it may be safe to say that while the pulmonary hypertension found in the 2nd grade severity might be mainly characterized by the increase in peripheral streaming resistance, the pulmonary hypertension seen in the 3rd grade severity might be additionally accompanied by the increase in pulmonary volume elasticity coefficient.

B. The contour of the pulmonary arterial pulse and its Fourier analysis.

There was considered so-called Huerthle's phenomenon which was already repeatedly described in the pulmonary as well as the systemic artery by us. However,
the following points, i.e. dissimilarity of contours of pressure waves in different parts of pulmonary vascular tree, various kinds of characteristics on propagation line of damped oscillation, viscosity of blood, elasticity of vascular wall and problem on reflection waves remain still unknown especially in clinical praxis. Owing to the incompleteness of the pressure measurement commonly used at present or the deformity of pressure wave due to artefact, the analysis of so-called Huerthle’s phenomenon is so much complicated that its investigation becomes very difficult. Therefore, when the pulmonary pressure wave is analyzed by the Fourier-Bessel expansion and assumed to be a resultant of a lot of single oscillation, some parts of this complexity can be expected to be elucidated. On this occasion, the regularity of cardiac beats must be presupposed. Although the Hook law can not always be observed between the loading affected to vessels and their deformity, especially, in clinical study, yet, since the distensibility rate of vessels is estimated to be less than 5%, the non-lineality of vessels on loading-deformity diagram may be neglected for the clinical research. Therefore, the pressure wave was represented according to the formula described as follows.

Fig. 2. Pulmonary hemodynamical values and severity in normal and emphysema thor.
Both the coefficient $c_n$ and the phase angle $\theta$ were calculated, respecting every single oscillation. Taking into consideration of the characteristics of the manometer used by us and the signal-to-noise ratio of the transducer, all calculation were performed within the range of six harmonics, i.e. until 10 cps for the purpose of the examination of oscillation number or frequency. The fundamental observation upon these procedures were already published by our collaborators in this congress last year.

The relationship between relative amplitude and frequency:

The relative amplitude in pulmonary arterial stem decreased in its magnitude at 5 cps among the pulmonary normotensive, whereas it was estimated from 1.5 to 6.2 mm. Hg at the same frequency among the pulmonary hypertensive complicated with pulmonary emphysema. This suggests that in the pulmonary hypertension or the

\[
P(f) = a_0 + \sum_{n=1}^{\infty} (a_n \cos nt + b_n \sin nt)
\]

where:

\[
a_n = \frac{1}{\pi} \int_{0}^{2\pi} p(t) \cos nt \, dt
\]

\[
b_n = \frac{1}{\pi} \int_{0}^{2\pi} p(t) \sin nt \, dt
\]

\[
c_n = (a_n^2 + b_n^2)^{1/2}
\]

\[
\theta_n = \tan \left( \frac{b_n}{a_n} \right)
\]

Fig. 3. Relative amplitude ratio (branch/stem) with harmonic number.
pathological state of pulmonary artery, the waves of the frequencies higher than the normal may influence upon contour of pressure waves. This influence could be seen more evidently in pulmonary arterial branch than its stem, that is, in the former a small elevation on the amplitude-frequency curve tended to appear at the frequencies from the 3 to the 6 cps. Fig. 3 shows the in- or decreasing ratio of the relative amplitude between stem and branch of the pulmonary artery. In contrast with normal health, mitral stenosis and bronchial asthma free from pulmonary hypertension, the coefficients of the 1st and the 2nd harmonics were all positive among the cases of pulmonary emphysema complicated with pulmonary hypertension, and especially those of the 3rd and the 4th harmonics were very markedly positive in the latter group. This suggests that the relative amplitudes in the harmonics mentioned above may be, to a certain extent, importantly related to the occurrence of the peaking phenomenon.

The relationship between apparent phase velocity and frequency in the pulmonary artery:

There could not be found any marked difference of the mode of the relationship between proximal and distal portions of the pulmonary artery in normal health, mitral stenosis (post-capillary disturbance) and bronchial asthma free from pulmonary hypertension. However, in the cases of pulmonary emphysema complicated with pulmonary hypertension, the apparent phase velocities were found large at the 1st to the 3rd harmonics, and they became very small at the 6th harmonics in the proximal portion of pulmonary artery, whereas in its distal portion the apparent phase velocities at the 3rd and the 4th harmonics in which the relative amplitudes were markedly augmented were found larger than those at the frequencies below 3 cps as well as above 6 cps.