The Electrocardiographic Pentalogy of Pulmonary Emphysema

A Correlation of Roentgenographic Findings and Pulmonary Function Studies

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The clinical applicability of the routine electrocardiogram and the chest roentgenogram in assessing advanced pulmonary emphysema is shown by a correlative study on 150 adults with moderately severe and severe pulmonary emphysema determined by pulmonary function studies. From these data a rather uniform electrocardiographic pattern has emerged entitled "the electrocardiographic pentalogy of pulmonary emphysema" which by itself suggests the presence of an advanced emphysematous state.

A previous publication1 established the presence of exaggerated P waves and resultant T-a wave inscription in leads II, III, and aV\(_r\) of the adult electrocardiogram in patients with severe emphysema. Continued focus upon the electrocardiogram of patients with advanced pulmonary emphysema has resulted in the identification of an electrocardiographic pattern which, by itself, suggests the presence of an advanced emphysematous state. This pattern will be referred to as the "electrocardiographic pentalogy of pulmonary emphysema;" it consists of (1) exaggerated P waves in leads II, III, and aV\(_r\), (2) prominent T-a waves in leads II, III, and aV\(_r\), (3) vertical cardiac position, which at times may be extreme, (4) clockwise rotation on the longitudinal cardiac axis, and (5) tendency to low voltage, particularly in the left ventricular leads V\(_4\) to V\(_7\).

The present report is concerned with the electrocardiographic analysis of 150 adults with moderately severe and severe pulmonary emphysema, selected solely on the basis of tests of pulmonary function and the correlation of roentgenographic interpretation of pulmonary emphysema with the pulmonary function data.

Materials and Methods

One hundred and fifty emphysematous adult patients were selected for study on whom 1 or more routine electrocardiograms and chest roentgenograms were available. All patients had moderately severe or severe pulmonary emphysema as established by pulmonary function tests.2 The arbitrary classification based on alteration of function is shown on Table 1.

The routine 12-lead electrocardiogram was classified into 6 groups according to the presenting pattern, namely, (1) the electrocardiographic pentalogy of pulmonary emphysema, as previously outlined, (2) the partial pentalogy, in which the degree of clockwise rotation and low voltage across the left precordium was less marked, (3) absent T-a-wave patterns, with marked degrees of vertical position, clockwise rotation, and low voltage, (4) the pattern of the short P-R interval and depressed RST segment, with vertical cardiac position, variable degrees of clockwise rotation, and left ventricular low voltage, which has previously been described,3 (5) instances of right ventricular preponderance, patterns of right ventricular dilatation and patterns of right bundle-branch block, and (6) essentially normal electrocardiograms. Included in groups I and II are 9 instances of unusual cardiac axis presentation that superficially suggest left axis deviation but, in fact, are expressions of severe vertical position.

Posteroanterior roentgenograms were available on all patients, the majority having lateral films as
TABLE 1.—Arbitrary Classification of Pulmonary Emphysema Based on Alterations of Pulmonary Function

<table>
<thead>
<tr>
<th>Classification of emphysema</th>
<th>2-second vital capacity (%)</th>
<th>Maximum breathing capacity* (%)</th>
<th>Single-breath O2 test (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderately severe emphysema</td>
<td>45 - 70</td>
<td>45 - 70</td>
<td>4 - 8N₂</td>
</tr>
<tr>
<td>Severe emphysema</td>
<td>&lt;45</td>
<td>&lt;45</td>
<td>&gt;8N₂</td>
</tr>
</tbody>
</table>

*All patients had elevation of their spirogram to the hyperinflation level denoted by circled E.

well. They were classified as normal, or as showing minimal, moderate, moderately severe or severe emphysema by gradation of the following criteria:

Signs Due to Increase in Thoracic Volume. Deformation and flattening of diaphragm; increased anteroposterior thoracic diameter often associated with increased dorsal kyphosis; elevation of the sternum with increase in angulation between manubrium and body; widening of the intercostal spaces.

Signs Due to Alterations in Pulmonary Parenchyma. General increase in radiolucency of lung fields along with local emphysematous bleb and bulla formation, usually at the bases or apices; superior retrosternal radiolucency increased in lateral projection; increase in interstitial markings resulting from increased contrast between hyperinflated alveoli and supporting structures (interstitial fibrosis is also a factor in some cases).

Cardiovascular Changes. Decrease in peripheral vascular markings per unit area; vertical cardiac position; enlargement of pulmonary artery in severe emphysema.

Although the films were on a select group of patients, the observer was unaware of the clinical state or laboratory data, and these films were intermixed with films of nonemphysematous patients. Fifty films of the study group were subsequently re-read to check the accuracy of recording.

Of the 150 patients in the present study, there were 71 and 79 instances of moderately severe and severe emphysema, respectively. The average age for the entire group was 57 years, with a range from 23 to 78 years. Cardiac position and cardiac rates were determined on all electrocardiograms. T-a waves of 1 mm. or more in leads II, III, and aV₃, were required for inclusion in groups I and II.

RESULTS

The incidence of the various patterns, the degree of presenting emphysema, and the roentgen findings in the 6 groups are shown in table 2.

The results are considered according to individual electrocardiographic patterns.

Pentalogy Pattern. The typical electrocardiographic findings are exemplified in figure 1. Thirty-four of the 51 patients in this category had severe pulmonary emphysema on pulmonary function tests, and 36 of the 51 x-rays were interpreted as showing moderately severe to severe emphysema, with 9 additional roentgen interpretations of moderate emphysema.

Partial Pentalogy Pattern. The range of this pattern is shown in figure 2. The amplitude of the left precardial potentials was consistently less than 8 mm. The moderately severe and severe emphysematous grouping was equal on function testing. Roentgenographically, 14 of the 30 patients had moderately severe to severe emphysema, with 9 additional instances of moderate emphysema.

Absent T-a-Wave Pattern. Save for the lack of P-wave and T-a-wave augmentation, the over-all electrocardiographic tracing simulated that of group I (fig. 3). The T-a waves were either less than 1 mm. or were absent. There were approximately equal numbers of moderately severe and severe emphysema on function testing, with 8 instances of moderately severe to severe emphysema and 6 instances of moderate emphysema identified on roentgen examination. Conversely, 6 x-rays were interpreted as normal or showing minimal emphysema. Single instances of atrial fibrillation and an ectopic atrial pacemaker accounted for 2 of the failures of T-a-wave inscription in this group.

Short PR Interval-Depressed RST Segment. This interesting pattern is responsible for marked RST segment depression in leads II, III, and aV₃, due to the T-a-wave expression distal to the QRS complex. The P-R interval is usually 0.12 second or less in duration. Although 6 of the 9 patients had severe emphysema, the roentgenograms were interpreted as moderately severe to severe emphysema in only 4.

Right Ventricular Preponderance, Dilatation, and Right Bundle-Branch Block. Contrary to previous reports in the literature,
ELECTROCARDIOGRAM IN PULMONARY EMPHYSEMA

TABLE 2—Incidence of Presenting Electrocardiographic Patterns, Degree of Pulmonary Emphysema and Roentgen Findings in 150 Patients with Moderately Severe and Severe Emphysema

<table>
<thead>
<tr>
<th>Electrocardiographic classification</th>
<th>Electo-</th>
<th>No. of patients</th>
<th>Moderately severe emphysema on pulmonary function tests</th>
<th>Severe emphysema on pulmonary function tests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>% of total</td>
<td>Degree of emphysema identified on chest roentgenograms</td>
<td>None</td>
</tr>
<tr>
<td>Pentalogy</td>
<td>51</td>
<td>34</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Partial pentalogy</td>
<td>30</td>
<td>20</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>Absent T-a wave</td>
<td>20</td>
<td>14</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Short PR interval-depressed RST segment</td>
<td>9</td>
<td>6</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Right vent. preponderance, dilatation, and right bundle-branch block</td>
<td>8</td>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Normal electrocardiogram</td>
<td>32</td>
<td>21</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td>Totals</td>
<td>150</td>
<td>100</td>
<td>71</td>
<td>7</td>
</tr>
</tbody>
</table>

These 3 patterns were in a distinct minority in the current study. There were 2 instances of right ventricular preponderance, both verified by autopsy findings of right ventricular hypertrophy, 2 instances of acute right ventricular dilatation, 1 of whom had evidence of pulmonary hypertension at the time of cardiac catheterization, and 4 instances of right bundle-branch block, 2 of which were of the incomplete variety (QRS < 0.12 second).

Normal Electrocardiograms. This group included 32 patients in whom the routine electrocardiogram was essentially normal, save for 1 instance of first degree heart block and 1 with an ectopic atrial pacemaker. The only 3 instances of a nonvertical heart in the entire study were in this category. A preponderance of moderately severe emphysema existed on pulmonary function survey (25 of the 32 patients), and there were only 5 instances of moderately severe to severe emphysema detected on roentgen evaluation.

Roentgen Changes. Evaluation of the roentgenographic findings suggests that with moderately severe pulmonary emphysema as identified on function study, the chest x-ray is most likely to be interpreted as showing minimal, moderate, or moderately severe emphysema (61 of 71). Of the remaining 10 patients, 7 x-rays were interpreted as normal, with 3 instances of severe emphysema.

Of the 79 patients with pulmonary function evidence of severe pulmonary emphysema, 51 carried moderately severe to severe roentgenographic interpretations of emphysema, with another 15 instances of moderate emphysema. On consideration only of groups I, II, and III, 56 of 60 patients had moderate, moderately severe, or severe emphysema on the roentgenogram.

The presence of extensive parenchymal pulmonary disease, thoracoplasty defects, and lack of technically adequate lateral chest films were the major factors in the failure to identify more than minimal emphysema in the severe emphysematous group.

The patients with normal electrocardiograms and moderately severe emphysema on pulmonary function study exhibited the greatest incidence of nonexistent or minimal emphysema radiographically.

The mean cardiac rates in the 6 electrocardiographic groupings were 100, 92, 89, 100, 107, and 88, respectively.

Discussion

The earliest recognition of a rather distinct
Total vital capacity = 60%
2 seconds vital capacity = 26%
Maximum breathing capacity = 22%
Single breath oxygen test: (750 - 1250 cc) = 12% N₂

X-ray: Severe pulmonary emphysema
Autopsy: Severe diffuse bullous emphysema

H. K. Age 57

Total vital capacity = 52%
2 seconds vital capacity = 49%
Maximum breathing capacity = 44%
Single breath O₂ test: (750 - 1250 cc) = 3.5% N₂

X-ray: Severe pulmonary emphysema.

Fig. 1. Typical electrocardiographic pentalogy of pulmonary emphysema patterns. The tendency to generalized low voltage of the QRS complexes is readily appreciated.

electrocardiographic pattern in chronic cor pulmonale is credited to Zuehlemann et al., who thought that this clinical state could frequently be entertained by electrocardiographic survey before it could by routine clinical methods. Their data were concerned with 50 patients with chronic cor pulmonale in whom the diagnosis was established by clinical and roentgen examinations.

The current data were intentionally based solely on pulmonary function testing, with less than 10 per cent of the total cases presenting clinically evident chronic cor pulmonale, albeit, severe pulmonary function
ELECTROCARDIOGRAM IN PULMONARY EMPHYSEMA

G. B. Age 46

Total vital capacity = 47%
2 seconds vital capacity = 55%
Maximum breathing capacity = 43%
Single breath O₂ test: (750 - 1200 cc) = 10% N₂

X-ray: Severe pulmonary emphysema

W. W. Age 61

Total vital capacity = 68%
2 seconds vital capacity = 44%
Maximum breathing capacity = 30%
Single breath O₂ test: (750 - 1250 cc) = 3.5% N₂

X-ray: Severe pulmonary emphysema

Fig. 2. The degree of clockwise rotation across the precordium and the lowering of the left ventricular QRS voltage is of lesser degree than that in group 1.

deterioration. By inclusion only of patients in the severe emphysematous group, with a 2-second vital capacity of less than 45 per cent, a maximum breathing capacity of less than 45 per cent, performed at the hyperinflation level, and a rise of the single-breath
Total vital capacity = 79%

2 seconds vital capacity = 39%
Maximum breathing capacity = 32%
Single breath O₂ test: (750 - 1250 cc) = 5%

X-ray: Moderately severe pulmonary emphysema

Total vital capacity = 65%

2 seconds vital capacity = 46%
Maximum breathing capacity = 24%
Single breath O₂ test: (750 - 1250 cc) = 11% N₂

X-ray: Severe pulmonary emphysema

FIG. 3 Top. Save for the lack of P wave and T-a-wave augmentation, the over-all pattern in group III simulates that of group I. T-a-wave inscription was either nonexistent or measured less than 1 mm. in this group.

FIG. 4 Bottom. Although often interpreted as showing left axis deviation and horizontal cardiac position, this pattern results from extreme vertical position of the heart, with posterosuperior reflection of the left ventricular potential to the augmented limb leads, aV₃ and aV₅. Note the extremely low QRS potential in lead I and the entirely similar potentials in aV₃ and aV₅ with inverted P and T waves.
oxygen test of more than 8 per cent nitrogen, a most select group of patients was made available.

As shown in table 2, the electrocardiographic pentalogy of pulmonary emphysema presents multifaceted evidence of an advanced emphysematous state, namely, predominantly severe emphysema on both pulmonary function testing and roentgenographic interpretation. Thus, the finding of this electrocardiographic pattern in a known emphysematous subject suggests a severe degree of pulmonary emphysema. Seven of the 9 patients with apparent left axis deviation were in this pentalogy grouping. It is suggested that they are, in fact, examples of extreme vertical hearts. Although Grant interpreted the potential changes as due to left axis deviation, it is merely the result of the right ventricular potential reflection (rS) to leads II, III, and aVR and left ventricular potential in a posterosuperior fashion to aVR and aVL. The finding of an inverted P and T wave in aVL and the extremely low voltage QRS complex in lead I is crucial to the identification of vertical heart position (fig. 4). Radiographically, all 9 patients exhibited marked vertical hearts.

The precordial QRS complexes on occasion are grossly distorted in the pentalogy group, simulating residual myocardial damage, as previously noted by Kossmann. Initial q waves may be identified in the right and mid precordial leads, or there may be failure to inscribe progressive left ventricular potentials across the precordium due to marked shift of the transitional zone to the left (fig. 5). Merely by placement of the unipolar chest lead several interspaces lower than the conventional position, normal left ventricular potential is identified (fig. 6). In some instances, left ventricular potential is best identified at the subprime positions of V7, V8, and V9.

In general, the factors of vertical cardiac position, clockwise rotation, and left ventricular low voltage are considered expressions of marked vertical position of the heart attendant to the advanced emphysematous state and resultant low diaphragmatic position. The production of exaggerated P waves and resultant T-a-wave inscription is less easily explained by purely positional changes, as the classic electrocardiographic pentalogy pattern is not identified in instances of extreme vertical hearts associated with an asthenic habitus. One can only suggest the presence of inipient atrial dilatation, as entirely similar T-a-wave inscription is seen in instances of organic mitral and pulmonic stenosis. Wood has previously favored an organic atrial change for the production of the T-a wave.

The partial pentality patterns suggest that, in general, the emphysematous state will be less severe as a group on pulmonary function testing and on roentgenographic survey.

Inasmuch as the exact mechanism for exaggerated T-a waves in pulmonary emphysema remains unknown, no explanation can be tendered for the failure to identify this phenomenon of atrial repolarization in group III. The remaining findings of vertical cardiac position, clockwise rotation, and low voltage in the standard and augmented limb leads and the left ventricular unipolar chest leads are entirely similar to those seen in group I. The short PR interval-depressed RST segment pattern often causes confusion in electrocardiographic interpretation, as the degree of RST-segment depression may be extreme, simulating changes ascribed to coronary artery disease. Failure to appreciate these changes as an expression of T-a-wave inscription secondary to pulmonary emphysema may completely alter the therapeutic approach.

Contrary to the report of Armen, Kantor, and Weiser, who reported a 27-per cent incidence of right ventricular hypertrophy on electrocardiographic survey of 67 patients, with "pulmonary heart disease," an incidence of less than 2 per cent was identified in the current study. This variance may, in part, be due to an increased incidence of patients
B. B.  Age 67

Total vital capacity = 58%
2 seconds vital capacity = 48%
Maximum breathing capacity = 32%
Single breath $O_2$ test: (750 - 1250 cc) = 14% $N_2$

H. S.  Age 61

Timed vital capacity = 60%
2 seconds vital capacity = 55%
Maximum breathing capacity = 42%
Single breath $O_2$ test: (750 - 1250 cc) = 11% $N_2$

Fig. 5 Top. Failure to inscribe the normal progressive increase in R-wave amplitude across the precordial leads is a common situation in the severely emphysematous patient. The distortion of the mid and left precordial QRS complexes, often simulating residual myocardial infarction, is merely the result of marked shift of the transitional zone to the left plus low

(Continued on bottom of next page)
with right heart failure in their group and to different criteria for the electrocardiographic identification of right ventricular hypertrophy. Although it is not within the scope of this paper to discuss the electrocardiographic criteria for right ventricular preponderance, the mere findings of marked right axis deviation, various Rs'r or rR' right preordial QRS patterns, and severe degrees of clockwise rotation are insufficient criteria, as these may all result from the vertical position of the heart attendant to advanced emphysematous disease. The electrocardiographic findings in 9 patients with severe chronic cor pulmonale were previously studied and the presence of a markedly elevated pulmonary artery pressure was documented where there was electrocardiographic evidence of right ventricular preponderance. Thus, it appears that the pattern of right ventricular preponderance occurs in the terminal phase of chronic pulmonary heart disease when there is hemodynamic evidence of cardiopulmonary failure. Mounsey et al., Thomas, and Kilpatrick have previously commented on the failure to document right ventricular hypertrophy on electrocardiographic analysis or autopsy data in advanced emphysematous disease.

Interestingly, only 2 instances of complete right bundle-branch block were identified in the entire series of 150 patients. In the discussion of the final group, the normal electrocardiograms, it appears that from the pulmonary function and radiographic standpoints, if a normal electrocardiogram is seen in a known emphysematous patient, the degree of emphysema is apt to be of minimal to moderate severity, although individual exceptions do exist.

In general, the detection and classification of emphysema on roentgenographic interpretation correlated well with the pulmonary function data. Although there were predominant moderately severe, moderate, and minimal roentgen interpretations in the group showing moderately severe emphysema on function testing, the severe and moderately severe x-ray classifications accounted for the majority of patients with severe emphysema as detected by pulmonary function survey. Again, the presence of extensive parenchymal disease, thoracoplasty defects, and lack of lateral chest films were the major factors in failing to detect more than minimal emphysema in the severely emphysematous group. This observation is in accord with the findings of Knott and Christie, who stressed the need for a lateral chest film in the roentgen interpretation of pulmonary emphysema. It is noteworthy that there was but a single instance of a roentgen report of no emphysema in the 81 patients described in the pentalogy and partial pentalogy patterns. Perhaps by continued focus on the radiographic evaluation of pulmonary emphysema, this method of examination may assume a more useful role in the evaluation of the emphysematous state.

**SUMMARY**

The electrocardiographic analysis of 150 adults with moderately severe and severe pulmonary emphysema selected on pulmonary function survey has led to the identification of an electrocardiographic pattern that is highly suggestive of an advanced...
emphysematous state. This pattern is entitled "the electrocardiographic pentalogy of pulmonary emphysema," consisting of (1) prominent P waves in leads II, III, and aVF, (2) exaggerated T-a waves greater than 1 mm. in leads II, III, aVF, (3) vertical cardiac position, which on occasion may be extreme, (4) marked clockwise rotation, and (5) tendency to generalized low voltage, particularly in the left precordial leads V4 through V7. In general, this pattern is thought to result from the extreme vertical position of the heart attendant to the advanced emphysematous state and low diaphragmatic placement, although the presence of incipient atrial dilatation cannot be discounted as a factor in the production of the exaggerated P and T-a waves.

Roentgenographic recognition of pulmonary emphysema correlated well with the pulmonary function data. In the presence of moderately severe pulmonary emphysema, the chest x-ray is most apt to be interpreted as showing minimal, moderate, or moderately severe emphysema. In the presence of severe pulmonary emphysema, moderately severe and severe emphysema will predominate on roentgenographic interpretation. The limitations of roentgenographic interpretation of pulmonary emphysema are discussed.

The T-a-wave inscription and the precordial QRS complex alteration may be of such an extreme degree that myocardial disease is suggested. Failure to appreciate these electrocardiographic changes as expressions of advanced emphysematous states may alter the therapeutic approach.

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SUMMARIO IN INTERLINGUA
Le analyse electrocardiographic de 150 adultos con emphysema pulmonar de grados moderamente severo o severo, seligite super le base de exames pulmuno-functional, resultava in le identification de un configuration electrocardiographic que suggere fortemente le presentia de un avantia state emphysematose. Iste configuration es designate como le "pentalogia electrocardiographic de emphysema pulmonar" e consiste de (1) prominent undas P in de derivationes II, III, e aVF, (2) exaggerate undas T-a, in excesso de 1 mm in le derivationes II, III, e aVF, (3) un position cardiac vertical, a vices de grado extreme, (4) marcate rotation dextrorse, et (5) le tendendia de un voltage generalistamente basse, specialmente in le derivationes precordial V4 et.

In general, iste configuration pare esser le effecto del position extremevente vertical del corde le qual es associate con le avantia state emphysematose e le basse placamento del diaphragma, ben que le presentia de un incipiente dilatation atrial non pote esser negligite como factor in le production del exaggerate undas P e T-a.

Le recognition roentgenographic de emphysema pulmonar monstrava un bon grado de correlation con le datos pulmuno-functional. In le presentia de grados moderate-mente sever de emphysema pulmonar, le interpretation del roentgenogramma thoracice arriva typicamente al verdicto que le emphysema presente es de grados minimal, moderate, o moderamente sever. In le presentia de grados sever de emphysema pulmo-nar, le interpretation roentgenographic nota emphysema de grados moderamente sever e sever. Es discutite le limitationes del interpretation roentgenographic de emphysema pulmonar.

Le inscription del unda T-a e le alteration del complexo QRS precordial pote attinger grados si extreme que morbo myocardial es suscitite. Quando iste alterationes electrocardiographic non es reconocesite como expressiones de avantia states emphysematose, le resultato pote esser le election de un non-appropriate programma therapeutique.
REFERENCES


Medical Eponyms

By ROBERT W. BUCK, M.D.

Biot's Breathing. Camille Biot, while interne at Lyon, made a “Contribution to the Study of the Cheyne-Stokes Respiratory Phenomenon” (Contribution à l’étude du phénomène respiratoire de Cheyne-Stokes) which appeared in the Lyon Médical 23: 517-528 (December 10), 561-567 (December 17), 1876. In postscript he says:

“It would seem . . . that in meningitis the respiration is not truly Cheyne-Stokes in type, but a somewhat similar form which is more or less regular.”

His observations were continued and published in a volume entitled Clinical Experimental Studies of Cheyne-Stokes Respiration (Etude clinique et expérimentale sur la respiration de Cheyne-Stokes), Paris, 1878. In this volume he concludes (page 19):

“The meningitic or encephalitis type of breathing . . . is characterized by an aperiodic irregularity, by irregular pauses and sighs, without any phases of gradual increase or diminution in the respiratory movements before and after the pauses.”
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