ALTERNATION OF THE VENTRICLE

Clinical Implications and Pathophysiologic Mechanisms

Parkland Memorial Hospital

Medical Grand Rounds

March 4, 1965

Case I [redacted]

History: The patient is a 29-year-old [redacted] male whose chief complaints were exertional dyspnea, orthopnea, and paroxysmal nocturnal dyspnea. He states that he was in good health until one month before admission. At that time he first noted shortness of breath after walking several blocks and began sleeping on two pillows. He was awakened at night short of breath and would have to sit up for some time to relieve this condition. He denied any swelling of the feet and ankles or history of rheumatic fever, lues, or substernal chest pain. The patient gave a history of heavy alcoholic intake, hard labor and inadequate diet.

Physical examination: Physical examination revealed a well-developed, well-nourished colored male in no acute distress. Pulse was 80 and regular. Blood pressure 190/120 with pulsus alternans of 30 mm Hg. Eye grounds showed arteriolar narrowing and A-V nicking but no hemorrhages or exudates. Cervical veins were not distended. The thyroid was not enlarged. Lungs revealed fine crepitant rales in both bases. The heart was slightly enlarged without murmurs or gallop rhythm. The liver, spleen and kidneys were not palpable. No bruits were heard over renal areas. There was no edema of the feet or ankles.

Laboratory: The chest films showed cardiomegaly with predominant left ventricular enlargement. The electrocardiogram was interpreted as left ventricular hypertrophy and with no alternation of the QRS complex. VMA and IVP test was negative. Angiotensin infusion test was indicative of essential hypertension. The patient had a right-sided cardiac catheterization and direct arterial pressure recording. Mechanical alternation was recorded in both systemic and pulmonary circulations.

Diagnoses:
1) Essential hypertension
2) Hypertensive cardiovascular disease
3) Possible nutritional heart disease

Comment: Pulsus alternans at a heart rate of 80 in a patient with left ventricular failure is a poor prognostic sign.

Case II [redacted] [redacted]

History: The patient is a 62-year-old [redacted] male whose chief complaint was "fast heart" action. This attack began one day prior to admission and was associated with shortness of breath and left lateral chest pain. Similar episodes of "fast heart" action have been present for the past 15 years but have gotten progressively worse during the last one or two years. They last 30 to 40 minutes and usually respond to the Valsalva maneuver or carotid sinus massage. He has been taking Quinidine for the past ten years and has terminated attacks by increasing the dosage of this drug. The patient denied shortness of breath (except with rapid heart action), orthopnea, paroxysmal nocturnal dyspnea and swelling of feet and ankles. No history of previous chest pain, rheumatic fever, or lues was elicited.

Physical examination: Physical examination revealed a rather obese white male in no acute distress. The pulse was 170 and regular. The blood pressure was 130/70 with mechanical alternans. The eye grounds were normal. No cervical venous distention was present. The thyroid was not palpable. The lungs were clear to percussion and auscultation. The heart was not enlarged and the rhythm was regular at 170/min. There were no murmurs and a gallop rhythm was not present. The liver, spleen and kidneys were not palpable. There was no edema of the feet and ankles.

Laboratory: The chest films showed the heart to be of normal size. Electrocardiogram revealed paroxysmal atrial tachycardia at 180/min with no ischemic changes and no alternation of the QRS complex. The SGOT remained within normal limits.

Diagnoses: 1) Paroxysmal atrial tachycardia
2) Organic heart disease ?

Comment: The presence of mechanical alternans during supraventricular tachycardia does not indicate the presence of heart disease.

I. Introduction to Alternation of the Ventricle

1. Traube, L.: Ein Fall von Pulsus bigeminus. Berl. klin. Wschr. 9:185, 1872.

2. Hering, H. E.: Experimentelle Studien an Säugethieren über das Elektrocardiogramm II. Z. exp. Path. Ther. 7: 363, 1909.

3. Bellet, S.: Clinical Disorders of the Heart Beat. Ed. 2. Philadelphia: Lea and Febiger, 1963. Pp. 551-566.

4. Corday, E. and Irving, D. W.: Disturbances of Heart Rate, Rhythm, and Conduction. Philadelphia: W. B. Saunders Co., 1961. Pp. 192-194.

5. Friedberg, C. K.: Diseases of the Heart. Ed. 2. Philadelphia: W. B. Saunders Co., 1956. Pp. 146, 206-207.

6. Levine, S. A.: Clinical Heart Disease. Ed. 5. Philadelphia: W. B. Saunders Co., 1958. Pp. 624-625.

7. Levine, S. A. and Harvey, W. P.: Clinical Auscultation of the Heart. Ed. 2. Philadelphia: W. B. Saunders Co., 1959. Pp. 623-627.

8. Lewis, T.: Mechanism of the Heart Beat. London: Shaw and Sons, 1911. Pp. 271-279.

9. Lewis, T.: The Mechanism of Graphic Registration of the Heart Beat. London: Shaw and Sons, 1925. Pp. 434-447.

10. Littmann, D.: Alternation of the heart. Circulation 27:280, 1963.

11. White, P. D.: Heart Disease. Ed. 4. New York: The Macmillan Company, 1951. Pp. 116, 161.

12. Wood, P.: Diseases of the Heart and Circulation. Ed. 2. Philadelphia: J. B. Lippincott Company, 1956. Pp. 30-31, 283-284.

Alternation of the ventricle is a general term used to describe alternating mechanical and/or electrical activity of the ventricle. The first condition of this type was described by Traube in 1872 and termed pulsus alternans. In this condition of pulsus or mechanical alternans there is an alternation between weak and strong ventricular systoles in the presence of a regular rhythm. In 1904 Herring first described alternation in the electrical activity of the ventricle and this was termed electrical alternans. In this condition there is an alternation in the magnitude of the QRS complex with a normal rhythm. Since these early descriptions of these conditions there have been many observations and studies reported both in experimental animals and in man.

II. Classification of Alternation of the Ventricle

A. General

3. Loc. cit.

10. Loc. cit.

13. Ferrer, M. I., Harvey, R. M., Cournand, A. and Richards, D. W.: Cardiocirculatory studies in pulsus alternans of the systemic and pulmonary circulations. Circulation 14:163, 1956.

14. DeRabago, P., Kohout, F. W. and Katz, L. N.: An unusual case of pulsus alternans recorded during cardiac catheterization from the pulmonary and systemic blood vessels. Am. Heart J. 49:472, 1955.

15. McIntosh, H. D.: Discordant pulsus alternans. Circulation 21:214, 1960.

ALTERNATION OF THE VENTRICLE

I. Mechanical Alternation (Pulsus Alternans)
- A. Right ventricular
- B. Left ventricular
- C. Combined
  1. Concordant
  2. Discordant

Pseudoalternans (Bigeminal rhythm)

II. Electrical Alternation (Electrical Alternans)

Mechanical alternation may occur in the right ventricle, in the left ventricle or in both ventricles. When the condition occurs in both ventricles, the weak and strong beats in the two ventricles may occur at the same time (concordant) or these weak and strong beats may occur at opposite times in the two ventricles (discordant). Bigeminal rhythm can be confused with mechanical alternation and has been termed pseudoalternans. Electrical alternation has not been classified in terms of ventricular localization.

B. Relation Between Mechanical and Electrical Alternation

5. Loc. cit.

16. Wiggers, C. J.: The independence of electrical and mechanical reactions in the mammalian heart. Am. Heart J. 1:173, 1925.

17. Wiggers, C. J.: Physiology in Health and Disease. Philadelphia: Lea and Febiger, 1939.

18. Katz, L. N.: Electrocardiography. Philadelphia: Lea and Febiger, 1943.

19. Kalter, H. H. and Grishman, A.: The electrical alternans. J. Mt. Sinai Hosp. 10:459, 1943.

20. Groedel, F. M. and Miller, M.: Pulsus alternans and electrical alternation. Exper. Med. and Surg. 7:153, 1949.

Wiggers has stated, "A curious feature of alternation is that its presence may at times be very obvious as variations in ventricular contractions or the pulse while electrocardiograms reveal no changes. Again, the alternation may be present in both or be indicated solely in electrocardiographic tracings." And Katz, "There are two general varieties of cardiac alternans, viz., mechanical alternans and electrical alternans. While the two may co-exist, one may be present, when the other is absent."

Mechanical and electrical alternation can occur either independently or simultaneously. Mechanical alternation frequently occurs alone but is occasionally accompanied by electrical alternans. Electrical alternation occasionally occurs alone but is usually accompanied by mechanical alternans.

III. Diagnostic Procedures in Alternation of the Ventricle

3. Loc. cit.

7. Loc. cit.

10. Loc. cit.

21. Morris, R. A.: The clinical recognition of pulsus alternans. J.A.M.A. 87:463, 1926.

22. Cossio, P., Lascalea, M. and Fongi, E. G.: Alternation of the heart sounds. Arch. Int. Med. 58:812, 1936.

23. Brody, J. G. and Rossman, P. L.: Electrical alternans. J.A.M.A. 108:799, 1937.

DIAGNOSTIC PROCEDURES IN ALTERNATION OF THE VENTRICLE

I. Mechanical Alternation

- A. Left ventricular
  1. Palpation of the pulse (alternate strong and weak pulses)
  2. Sphygmomanometry (expressed by difference in mm Hg between systolic levels of strong and weak pulses)
  3. Auscultation of the heart (alternate strong and weak sounds or intensity of murmurs)
  4. Arterial pressure tracing
  5. Left heart catheterization
- B. Right ventricular

  Right heart catheterization

II. Electrical Alternation

Electrocardiogram

IV. Etiological Factors in Alternation of the Ventricle

3. Loc. cit.

5. Loc. cit.

10. Loc. cit.

24. Cooper, T., Braunwald, E. and Morrow, A. G.: Pulsus alternans in aortic stenosis. Circulation 18:64, 1958.

25. Feldman, L.: Electrical alternans with pericardial effusion. Am. Heart J. 15:100, 1938.

26. McGregor, M. and Baskind, E.: Electrical alternation in pericardial effusion. Circulation 11:837, 1955.

27. Littmann, D. and Spodick, D. H.: Total electrical alternation in pericardial disease. Circulation 17:912, 1958.

ETIOLOGICAL FACTORS IN ALTERNATION OF THE VENTRICLE

I. Mechanical Alternation

- A. Left ventricular alternans
  1. Systemic hypertension
  2. Aortic stenosis
  3. Coronary artery disease
  4. Idiopathic myocardial hypertrophy
  5. Left ventricular failure
  6. Paroxysmal atrial and ventricular tachycardia
- B. Right ventricular alternans
  1. Pulmonary hypertension
  2. Pulmonic stenosis
  3. Right ventricular failure
- C. Combined ventricular alternans

  Usually occurs with combined left and right heart failure

II. Electrical Alternation

A. Pericardial disease with or without effusion

B. Same as those for mechanical alternans

V. Incidence of Alternation of the Ventricle

3. Loc. cit.

11. Loc. cit.

28. Windle, J. D.: The incidence and prognostic value of the pulsus alternans in myocardial and arterial disease. Quart. J. Med. 6:453, 1913.

29. White, P. D.: Alternation of the pulse: a common clinical condition. Am. J. M. Sc. 150:82, 1915.

30. Thompson, W. P. and Levine, S. A.: Pulsus alternans. Am. Heart J. 11:135, 1936.

The frequency of this condition depends upon how carefully one searches for its presence. White found alternation in one-third of all patients showing any degree of cardiac failure. This appears to be a rare phenomenon at Parkland Memorial Hospital.

VI. Clinical Implications of Alternation of the Ventricle

3. Loc. cit.

5. Loc. cit.

6. Loc. cit.

11. Loc. cit.

31. Lewis, T.: Notes upon alternation of the heart. Quart. J. Med. 4:141, 1910.

32. Mackenzie, J.: Diseases of the Heart. Ed. 3. London: Oxford University Press, 1913.

33. Blumberger, K.: Untersuchungen über die Dynamik des Herzens beim Herzalternans. Arch. Kreisl.-Forsch. 20: 25, 1953.

34. Saunders, D. E., Jr. and Ord, J. W.: The hemodynamic effects of paroxysmal supraventricular tachycardia in patients with the Wolff-Parkinson-White syndrome. Am. J. Cardiol. 9:223, 1962.

In 1910 Lewis stated, "Heart alternation occurs under two circumstances. It is seen when the cardiac muscle is not of necessity altered structurally, as an accompaniment of great acceleration of the rate of the rhythm. It is also found when the pulse is of normal rate, and under such circumstances the muscle is either markedly degenerate or the heart shows evidence of embarrassment as a result of poisoning or some other factor."

It is generally recognized that mechanical alternans at a slow heart rate is a sign of a severely damaged ventricle. The prognosis is extremely poor. However, the occurrence of mechanical alternans during an attack of paroxysmal tachycardia does not necessarily mean myocardial disease. Saunders and Ord have studied three patients with the Wolff-Parkinson-White syndrome and no other cardiovascular abnormality during episodes of paroxysmal supraventricular tachycardia. All three of these patients exhibited mechanical alternans at the beginning of their episodes of tachycardia with subsequent disappearance despite continuation of the same rapid heart rate.

VII. Pathophysiologic Mechanisms of Alternation of the Ventricle

A. General

3. Loc. cit.

5. Loc. cit.

33. Loc. cit.

35. Wiggers, C. J.: The dynamics of ventricular alternation. Ann. Clin. Med. 5:1022, 1926.

36. Wiggers, C. J.: Circulatory Dynamics. New York: Grune and Stratton, 1952.

37. Wiggers, C. J.: Reminiscences and Adventures in Circulation Research. New York: Grune and Stratton, 1958.

PATHOPHYSIOLOGIC MECHANISM OF MECHANICAL ALTERNATION

I. Alternate Failure of Contraction of Certain Myocardial Segments

II. Alternate Conditions of Filling of the Ventricle - Wenckebach's View

III. Alternate Failure of Metabolic Recovery - Straub's View

B. Mechanisms of Mechanical Alternation

1. Alternate failure of contraction of certain myocardial segments

2. Loc. cit.

36. Loc. cit.

37. Loc. cit.

38. Gaskell, W. H.: On the rhythm of the heart of the frog, and on the nature of the action of the vagus nerve. Phil. Trans. B. 173:993, 1882.

39. Mines, G. R.: On dynamic equilibrium of the heart. J. Physiol. 46:349, 1913.

40. Mines, G. R.: On pulsus alternans. Proc. Cambridge Phil. Soc. 17:34, 1913.

41. Green, H. D.: The nature of ventricular alternation resulting from reduced coronary blood flow. Am. J. Physiol. 114:407, 1935-36.

Alternate failure of contraction of certain myocardial segments as a causative factor in mechanical alternans is a view which is still current. Wiggers has stated, "It appears highly probable that ventricular alternation always involves the defection of some fractionate contractions during the smaller beat."

2. Alternate conditions of filling of the ventricle

42. Wenckebach, K. F.: Zur Analyse des unregelmässigen Pulsus. IV. Ueber den Pulsus alternans. Z. klin. Med. 44:218, 1910.

43. Wenckebach, K. F.: Die unregelmässige Herztätigkeit und ihre klinische Bedeutung. Berlin: Engelmann, 1914.

44. Wiggers, C. J.: The cause of temporary ventricular alternation following a long diastolic pause. Proc. Soc. Exper. Biol. and Med. 24:386, 1927.

Wenckebach believed that extracardiac factors influencing the degree of ventricular filling and therefore ventricular end-diastolic pressure and volume were the major determinants of alternation, the weak beat being initiated from a lower pressure and a smaller volume. Wiggers found this mechanism to be responsible for the temporary mechanical alternation of the ventricle following a long diastolic pause.

3. Alternate failure of metabolic recovery

45. Straub, H.: Dynamik des Herzalternans. Arch. klin. Med. 123:403, 1917.

Straub believed that the weak beat is initiated from a smaller ventricular end-diastolic volume but a higher pressure which was attributable to incomplete metabolic recovery from the previous strong beat.

C. Recent Studies on Mechanical Alternation

Studies have recently been reported on mechanical alternation in cardiac papillary muscle strips, in isovolumic contracting ventricles, in the pumping ventricle, and in ventricles of intact man.

1. Mechanical alternation in cardiac papillary muscle strips

46. Mitchell, J. H., Sonnenblick, E. H. and Sarnoff, S. J.: The dynamics of pulsus alternans: alternating end-diastolic fiber length as a causative factor. J. Clin. Invest. 42:55, 1963.

47. Sonnenblick, E. H.: Force-velocity relations in mammalian heart muscle. Am. J. Physiol. 202:931, 1962.

48. Sonnenblick, E. H.: Implications of muscle mechanics in the heart. Fed. Proc. 21:975, 1962.

49. Hill, A. V.: The heat of shortening and dynamic constants of muscle. Proc. Roy. Soc. B 126:136, 1938.

50. Hill, A. V.: The abrupt transition from rest to activity in muscle. Proc. Roy. Soc. B 136:399, 1949.

In isotonically contracting cardiac papillary muscle strips the weak contractions originated from a shorter initial fiber length. In isometrically contracting strips, in which the external length was fixed, the weak contraction originated from a higher initial tension, that is to say, from a state of incomplete relaxation. This phenomenon can be explained in terms of the muscle model proposed by Hill for skeletal muscle and recently applied by Sonnenblick to cardiac muscle. Using this model one could postulate that although the external length is fixed, a muscle in which the tension has not completely subsided has different distribution of extension or stretch in its internal elements, i.e., contractile element and series elastic element, than is the case when the resting tension is fully achieved. In the former case when the resting tension is higher, the length of the contractile element is less than in the latter case when the resting tension is lower. Thus the shorter length of the contractile element which is present before the weak beat accounts for the diminished force of contraction.

2. Mechanical alternation in isovolumically contracting ventricles

51. Lendrum, B., Feinberg, H., Boyd, E. and Katz, L. N.: Rhythm effects on contractility of the beating isovolumic left ventricle. Am. J. Physiol. 199:1115, 1960.

52. Siegel, J. H. and Sonnenblick, E. H.: Isometric time-tension relationships as an index of myocardial contractility. Circulation Res. 12:597, 1963.

Lendrum et al. have recently demonstrated mechanical alternans in an isovolumic ventricle and were impressed by the occurrence of the ventricular "alternans phenomenon unassociated with changes in fiber length". Siegel and Sonnenblick found that the weak beat in the alternating isovolumic ventricle consistently originated from a higher end-diastolic pressure. Thus mechanical alternans in an isovolumically contracting ventricle can be explained by the same mechanism as described for an isometrically contracting cardiac papillary muscle preparation.

3. Mechanical alternation in an isolated supported pumping ventricle

46. Loc. cit.

53. Linden, R. J. and Mitchell, J. H.: Relation between left ventricular diastolic pressure and myocardial segment length and observations on the contribution of atrial systole. Circulation Res. 8:1092, 1960.

54. Mitchell, J. H., Mullins, C. B., Gupta, D. N. and Payne, R. M.: Ventricular performance in pulsus alternans. Clin. Res. 13:61, 1965.

It has been shown that in mechanical alternans the weak beat can occur from a lower, the same or a higher ventricular end-diastolic pressure; however, the initial myocardial segment length is always shorter before the weak beat. This condition occurs when the continuous level of myocardial contractility was not sufficient for a given imposed heart rate, stroke volume and aortic pressure to allow an adequate time for diastole before the weak beat and is obliterated when myocardial contractility is increased.

4. Mechanical alternans in man

55. Friedman, B., Daily, W. M. and Sheffield, R. S.: Orthostatic factors in pulsus alternans. Circulation 8:864, 1953.

56. Gleason, W. L. and Braunwald, E.: Studies on Starling's law of the heart. VI. Relationships between left ventricular end-diastolic volume and stroke volume in man with observations on the mechanics of pulsus alternans. Circulation 25:841, 1962.

Friedman et al. demonstrated that mechanical alternation is influenced by certain hemodynamic factors and can be abolished by digitalis or norepinephrine. Gleason and Braunwald showed that the weak beat in pulsus alternans occurs from a small end-diastolic volume.

B. Mechanism of Electrical Alternation

57. Kleinfeld, M., Stein, E. and Magin, J.: Electrical alternans in single ventricular fibers of the frog heart. Am. J. Physiol. 187:139, 1956.

Electrical alternans has been produced in single ventricular fibers; however, the mechanism of this phenomenon has not been explained.