

Evaluation of Left Ventricular Function in Atrial Fibrillation by Means of Ejection Time versus Preceding Cycle Length

Motoo YONEDA

*Division of Cardiology, Department of Medicine,
Kawasaki Medical School, Kurashiki 701-01, Japan
Accepted for Publication on February 27, 1984*

ABSTRACT. The previous observations from our laboratory on correlations between left ventricular ejection time (ET) and preceding cycle length in patients with atrial fibrillation showed that the correlation coefficients were lower in patients with dilated cardiomyopathy than in patients with lone atrial fibrillation.

These findings were considered to be related to decreased left ventricular function.

To elucidate this assumption, experimental studies were done by using 10 open-chest dogs.

After inducing atrial fibrillation by aconitine, various left ventricular contraction states were produced by administration of β -blockade or isoproterenol, and ET, preceding RR interval, stroke volume (SV) and left ventricular dp/dt were measured at each state.

The results were followings :

1) The relationship between ET and SV was found to be significantly linear, and had an over-all correlation of $r=0.91$ despite severity of left ventricular contraction states.

2) The relationship between ET and preceding RR interval showed a positive correlation, and the coefficient became lower as left ventricular function decreased.

Therefore, this method proved to be clinically useful to assess the left ventricular contraction state by non-invasive measurements of ET and preceding RR interval from carotid pulse tracing in patients with atrial fibrillation.

Key words : Atrial fibrillation — Ejection time — Stroke volume —
Cycle length — Left ventricular function

Beat-to-beat changes in stroke volume (SV) in atrial fibrillation have been ascribed to be dependent on the preceding cycle length.^{1,2)}

In one study from our laboratory,³⁾ it has been shown that there were characteristic relationships between ejection time (ET) measured from carotid arterial pulse and its preceding cycle length from the electrocardiogram in patients with atrial fibrillation under various clinical conditions. In this investigation, the relationship between ET and preceding cycle length in patients with lone atrial fibrillation showed a high correlation, while that in patients with dilated cardiomyopathy and atrial fibrillation showed a low correlation. Moreover, this correlation became lower in many patients with dilated cardiomyopathy and atrial fibrillation when the patient's condition became clinically more severe.

Accordingly, it was suggested that the relationship between ET and preceding cycle length might be related to severity of left ventricular function. To clarify this assumption, experimental study was performed using open-chest dogs.

MATERIALS AND METHODS

Ten mongrel dogs (11~32kg) were anesthetized with intravenous sodium pentobarbital (30mg/kg), and artificial respiration was maintained using a Harvard respirator. A left thoracotomy was performed and the pericardium was incised. An electromagnetic-flow-meter probe was applied around the root of the ascending aorta to measure SV. The catheter-tip manometer was inserted into the left carotid artery, and advanced into the left ventricle to measure the left ventricular pressure and its peak positive dp/dt . A 7F Cournand catheter was passed through the right femoral artery, and positioned at the root of ascending aorta to measure ET. A standard-lead electrocardiogram was recorded to measure its preceding cycle length as represented by the RR interval.

All parameters were simultaneously recorded on an ink jet recorder at a paper speed of 100 mm/sec in more than 20 consecutive beats.

Atrial fibrillation was induced by applying aconitine solution onto the right atrial surface.^{4,5)}

After atrial fibrillation was thus induced, the left ventricular dp/dt being as a indicator of left ventricular contraction,⁶⁾ three different left ventricular contraction states were produced by giving isoproterenol or β -blockade.

After collection of all data from this experimental study, it was investigated whether or not 1) ET might be able to utilize as a reliable indicator of SV, and 2) the relationship between ET and preceding RR interval might become lower with decrease in left ventricular function in atrial fibrillation.

RESULTS

When the relationship between peak dp/dt and preceding interval in three different states were plotted, there were clear differences of value of the dp/dt on each regression line at the preceding interval of 800 msec in each state (Fig. 1).

Each state was arbitrarily termed as State A, State B, and State C in the order of the contraction states.

1) Relation of ET versus SV

A relation of SV to ET in 20 consecutive beats obtained from one dog experiment was illustrated in each state as seen in Fig. 2. The relationship between ET and SV in three different contraction states showed good positive correlations ($r=0.77\sim 0.97$). The similar correlations were also observed in 9 other dog experiments as shown in Table 1.

2) Relation of ET versus preceding interval

In the same way, a relation of ET to preceding interval in 20 consecutive beats taken from one dog experiment was observed in each state as shown in Fig. 3. It is noted that the relationships were quite different in each state, and moreover, the individual correlation coefficients became lower with decrease in left ventricular contraction state (ranging from r of State A=0.93, to State B=0.76, to State C=0.62). The similar correlations were also observed in 9 other dog experiments as shown in Table 1.

Then the relation between these coefficients (ET versus preceding interval)

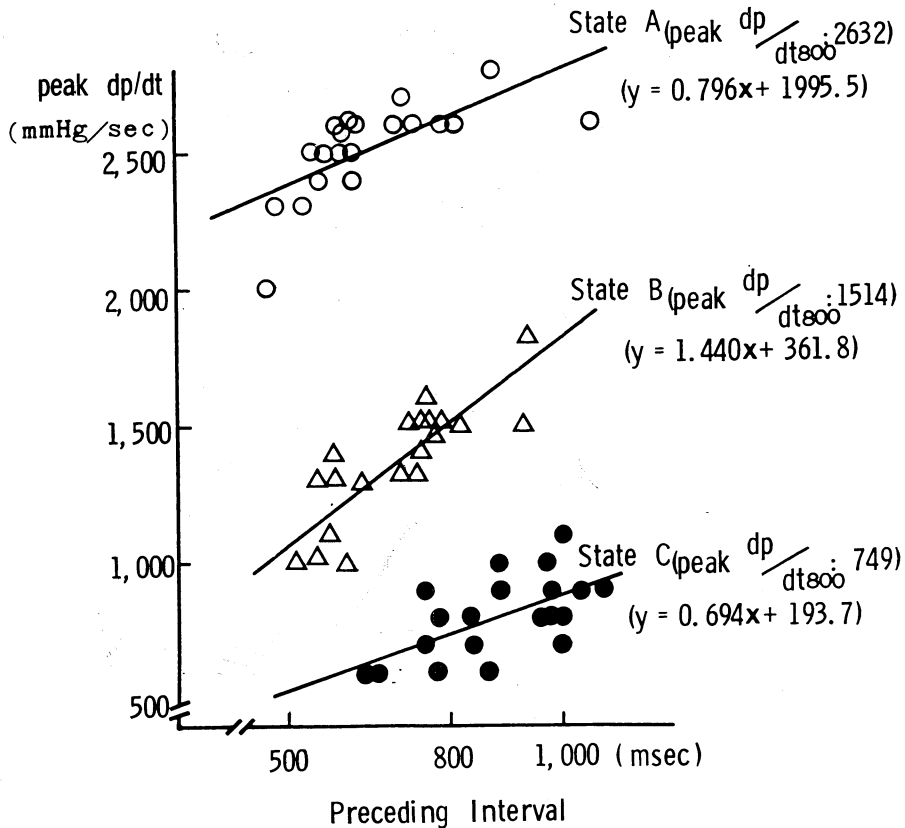


Fig. 1. Relation between left ventricular peak dp/dt and preceding interval in 20 consecutive beats in three left ventricular contraction states in a dog with atrial fibrillation. There are significant differences in the dp/dt on regression line of each state at the preceding interval of 800 msec ($\text{peak } dp/dt_{800}$). Each state is arbitrarily termed as State A, State B, and State C in order of the contraction states.

and the dp/dt at the preceding RR interval of 800 msec in three contraction states were investigated. There was a good correlation in each occasion (Fig. 4), and the correlation coefficients became lower in curvilinear fashion as left ventricular contraction state was decreased.

DISCUSSION

Atrial fibrillation is a quite common arrhythmia, and often complicated by various cardiac disorders. Therefore, evaluation of left ventricular function in atrial fibrillation is clinically mandatory. However, the investigation is limited, probably because it may be difficult to evaluate ventricular function under beat-to-beat variations in this arrhythmia. The data obtained from the present study suggested the possibility of non-invasive evaluation of left ventricular function in atrial fibrillation.

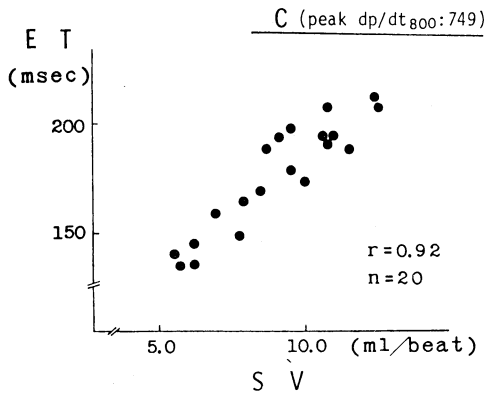
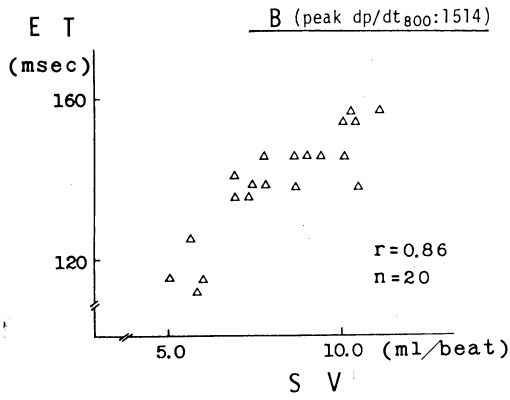
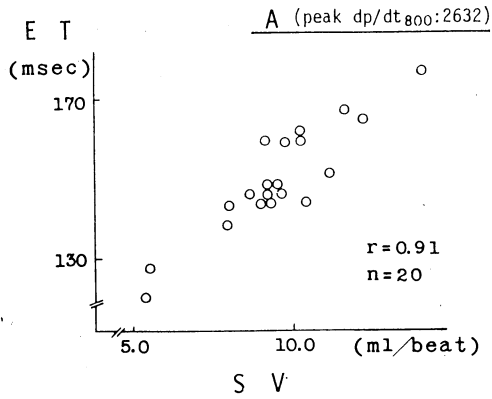


Fig. 2. Relation between ET and SV in 20 consecutive beats in three left ventricular contraction states in a dog with atrial fibrillation. From the top down, State A ($r=0.91$), State B ($r=0.86$), and State C ($r=0.92$) are illustrated. ET shows a highly significant correlation with SV despite severity of contraction states.

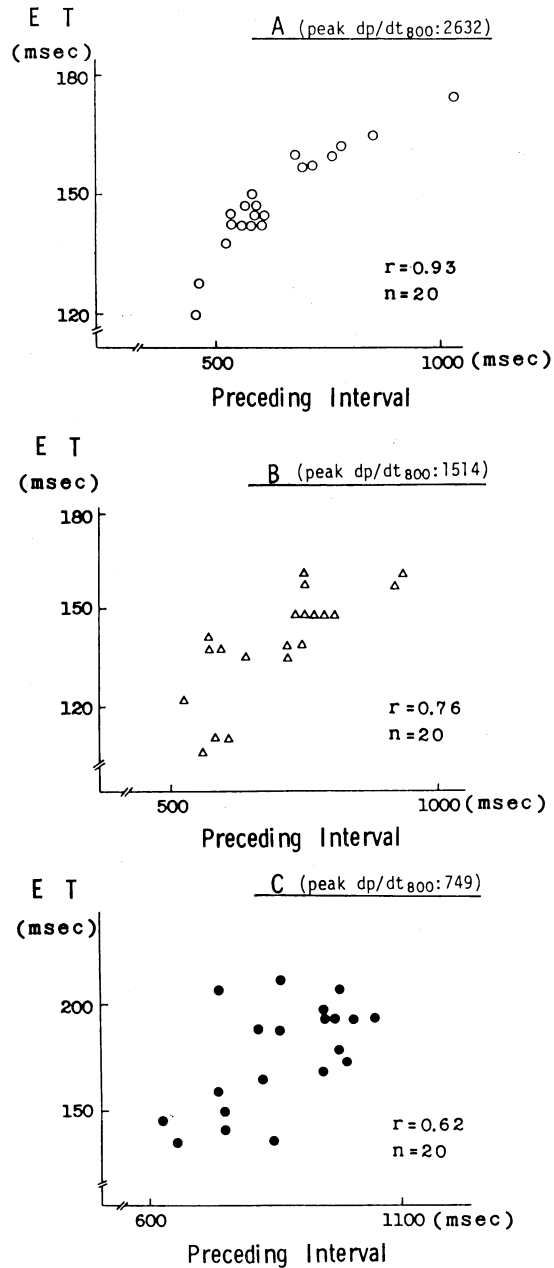


Fig. 3. Relation between ET and preceding interval in 20 consecutive beats in three left ventricular contraction states in a dog with atrial fibrillation. From the top down, State A ($r=0.93$), State B ($r=0.76$), State C ($r=0.62$) are illustrated. Correlation coefficients become significantly lower with decrease in left ventricular contraction states.

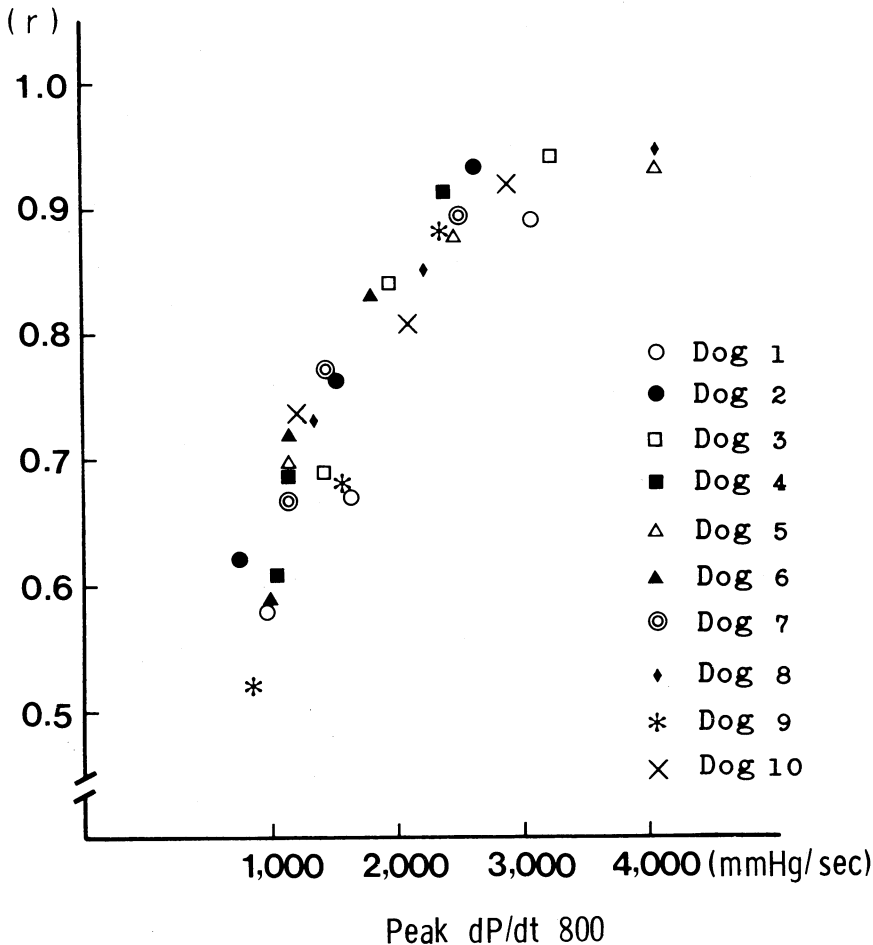


Fig. 4. Relation between the correlation coefficients of ET versus preceding interval (r) and peak dp/dt_{800} (left ventricular contraction state expressed as the dp/dt at the preceding interval of 800 msec) in 10 dogs with atrial fibrillation. There is a good correlation in each occasion, and the coefficients become lower in curvilinear fashion as left ventricular contraction state is decreased.

Possible Use of ET as an Indicator of SV

Since in 1904, Bowen⁷⁾ had first employed the carotid pulse tracing to assess the duration of left ventricular ejection in man, a direct relationship between ET and SV was demonstrated in experimental studies^{8,9)} and in clinical observation by the indicator-dilution method or the Fick principle.¹⁰⁾ These previous studies have shown that ET correlated significantly with SV. However, these observations were made on individuals in normal sinus rhythm as the difficulty to measure phasic aortic blood flow accurately and continuously in man had limited the scope of previous work on the hemodynamics of atrial fibrillation.^{11,12)} In particular no definition of the beat-to-beat relationship between SV and the duration of the phases of cardiac systole has been formulated, and experimental studies have been formulated, and experimental studies have been little done.

TABLE 1. Correlation coefficients (r) of ET versus SV and ET versus preceding interval, and peak dp/dt_{800} (the dp/dt at the preceding interval of 800 msec) in three left ventricular contraction states in 10 dogs with atrial fibrillation.

Dog's number	Contraction states	ET vs SV (r)	ET vs Preceding interval (r)	Peak dp/dt_{800} (mmHg/sec)
1	A	0.95	0.89	3087
	B	0.95	0.67	1615
	C	0.96	0.58	958
2	A	0.91	0.93	2632
	B	0.86	0.76	1514
	C	0.92	0.62	749
3	A	0.95	0.94	3220
	B	0.85	0.84	1954
	C	0.93	0.69	1412
4	A	0.86	0.91	2363
	B	0.97	0.69	1131
	C	0.93	0.61	1043
5	A	0.93	0.93	4024
	B	0.92	0.88	2489
	C	0.94	0.70	1138
6	A	0.94	0.83	1773
	B	0.96	0.72	1156
	C	0.93	0.59	979
7	A	0.95	0.88	2428
	B	0.96	0.77	1413
	C	0.92	0.68	1049
8	A	0.84	0.94	4062
	B	0.96	0.85	2223
	C	0.97	0.73	1352
9	A	0.88	0.88	2396
	B	0.94	0.68	1574
	C	0.74	0.52	872
10	A	0.91	0.92	2849
	B	0.88	0.81	2093
	C	0.77	0.74	1186

Only Greenfield *et al.*¹²⁾ showed a linear relationship ($r=0.91$) between ET and SV using the pressure gradient technique in 13 patients with atrial fibrillation.

However, whether a good correlation between ET and SV is present even in various left ventricular functions is not yet certified. In this study, therefore, firstly the relationship between ET and SV was examined in various left ventricular contraction states. ET constantly showed a highly positive correlation with SV regardless of left ventricular contraction state (Table 1). These results indicated the possible use of ET as an indicator of SV in atrial fibrillation with various left ventricular contraction states.

ET was measured from aortic pressure tracing in this experiment, but there will be no problem in clinical application of this relationship because of excellent comparison of externally and internally measured ET.¹³⁾

Relationship between ET and Preceding Interval One study from our laboratory on correlation between ET and preceding cycle length in patients with atrial

fibrillation showed that the correlation coefficients were lower in patients with dilated cardiomyopathy than in patients with lone atrial fibrillation.³⁾ It has been stated that the characteristics of dilated cardiomyopathy is a primary myocardial disease with decreased left ventricular function¹⁴⁾ as demonstrated by hemodynamic studies.^{15,16)} These findings led to an assumption that the correlation coefficients between ET and preceding cycle length might be related to left ventricular function.

The data obtained from this experiment verified this assumption. Because contraction state varied beat-to-beat in atrial fibrillation, it seemed proper that left ventricular contraction state was expressed as left ventricular dp/dt on regression line of each state at the most physiological cycle length of 800 msec. It was worthy to notice that the relationship between correlation coefficients of ET versus preceding interval and left ventricular contraction state showed good correlation with only a slight variation in ten dogs (Fig. 4).

It seems very difficult to clarify the underlying mechanism of this phenomenon because all of contraction state, preload, and afterload vary in beat-to-beat fashions in atrial fibrillation. Since the effect of atrial fibrillation upon the circulation had been first described by Lewis,¹⁷⁾ it has been proposed that the relationship between SV (as substituted by ET) and preceding cycle length in atrial fibrillation might be related to the role of Starling's law,^{18,19)} the phenomenon of post-extrasystolic potentiation,^{20,21)} or variation of afterload.²²⁾ The author is planning to clarify this point in future.

Previous studies show that in atrial fibrillation ET also varies directly with preceding cycle length, and these observations have been only utilized to evaluate the classification of various cardiovascular disorders.^{11,23)} But it has not been studied to evaluate left ventricular function by means of the relationship between ET and preceding cycle length. This experimental results indicate that a decrease in the correlations between ET and preceding cycle length as represented by the RR interval is related to a decrease in left ventricular function.

Conclusion It was concluded that ET could be used as a reliable indicator of SV even in atrial fibrillation under various left ventricular function, and left ventricular contraction state in atrial fibrillation might be assessed from the relationship between ET and preceding cycle length as represented by the RR interval. Therefore, this method proved to be clinically useful to assess the left ventricular function by non-invasive measurements of ET and preceding RR interval from carotid pulse tracing in patients with atrial fibrillation.

Acknowledgment

This study was conducted under the direction of Prof. Toshitami Sawayama, Division of Cardiology, Department of Medicine, Kawasaki Medical School. A grateful acknowledgment is made to Prof. T. Sawayama for his guidance in this research. This investigation was supported partly by the Research Project Grant from the Kawasaki Medical School (57-411), and by Mitsui-Seimei Koosei Jigyoodan.

REFERENCES

- 1) Einthoven, W. and Korteweg, A. G. : On the variability of the size of the pulse in cases of auricular fibrillation. *Heart* **6** : 107-120, 1915
- 2) Katz, L.N. and Feil, H.S. : Clinical observations on the dynamics of ventricular systole in auricular fibrillation. *Arch. Internal Med.* **32** : 672-692, 1923
- 3) Sawayama, T., Nezu, S., Tsuda, T. and Mitani, K. : Noninvasive evaluation of diastolic filling patterns in patients with atrial fibrillation by ejection time and preceding cycle length. *Am. J. Cardiol.* **45** : 1005-1012, 1980
- 4) Sherf, D. : Studies on auricular tachycardia caused by aconitine administration. *Proc. Soc. Exp. Biol. Med.* **64** : 233-239, 1947
- 5) Winburry, M.M. and Hemmer, M.L. : Action of quinidine, procaine amide and other compounds on experimental atrial and ventricular arrhythmias in the dogs. *J. Pharmacol. Exp. Ther.* **113** : 402-413, 1955
- 6) Gleason, W.L. and Braunwald, E. : Studies on the first derivative of the ventricular pressure pulse in man. *J. Clin. Invest.* **41** : 80-91, 1962
- 7) Bowen, W.P. : Changes in heart-rate, blood-pressure, and duration of systole resulting from bicycling. *Am. J. Physiol.* **11** : 59-77, 1904
- 8) Remington, J.W., Hamilton, W.F. and Ahlquist, R.P. : Interrelation between the length of systole, stroke volume and left ventricular work in the dog. *Am. J. Physiol.* **154** : 6-15, 1948
- 9) Braunwald, E., Sarnoff, S.J. and Stainsby, W.N. : Determinants of duration and mean rate of ventricular ejection. *Circulation Res.* **6** : 319-325, 1958
- 10) Weissler, A.M., Peeler, R.G. and Roehll, W.H. : Relationships between left ventricular ejection time, stroke volume, and heart rate in normal individuals and patients with cardiovascular disease. *Am. Heart J.* **62** : 367-378, 1961
- 11) Harley, A. and Greenfield, J.C. : Determination of cardiac output in man by means of impedance plethysmography. *Aerospace Med.* **39** : 248-252, 1968
- 12) Greenfield, J.C., Harley, A., Thompson, H.K. and Wallace, A.G. : Pressure-flow studies in man during atrial fibrillation. *J. Clin. Invest.* **47** : 2411-2421, 1968
- 13) Martin, C.E., Shaver, J.A., Thompson, M.E., Reddy, P.S. and Leonard, J.J. : Direct correlation of external systolic time intervals with internal indices of left ventricular function in man. *Circulation* **44** : 419-431, 1971
- 14) Goodwin, J.F. and Oakley, C.M. : The cardiomyopathies. *Br. Heart J.* **34** : 545-552, 1972
- 15) Hamby, R.I., Catangay, P., Apiado, O. and Khan, A.H. : Primary myocardial disease : Clinical, hemodynamic and angiocardiographic correlates in fifty patients. *Am. J. Cardiol.* **25** : 625-634, 1970
- 16) Feild, B.J., Baxley, W.A., Russell, R.O., Hood, W.P. and Rackley, C.E. : Left ventricular function and hypertrophy in cardiomyopathy with depressed ejection fraction. *Circulation* **47** : 1022-1031, 1973
- 17) Lewis, T. : Fibrillation of the auricles : Its effects upon the circulation. *J. Exp. Med.* **16** : 395-423, 1912
- 18) Dodge, H.T., Kirkham, F.T. and King, C.P. : Ventricular dynamics in atrial fibrillation. *Circulation* **15** : 335-347, 1957
- 19) Braunwald, E., Fry, R.L., Aygen, M.M. and Gilbert, J.W. : Studies on Starling's law of the heart. III. Observations in patients with mitral stenosis and atrial fibrillation on the relationships between left ventricular end-diastolic segment length, filling pressure, and the characteristics of ventricular contraction. *J. Clin. Invest.* **39** : 1874-1884, 1960
- 20) Rogel, S. and Mahler, Y. : Myocardial tension in atrial fibrillation. *J. Appl. Physiol.* **27** : 822-825, 1969
- 21) Edmands, R.E., Greenspan, K. and Fisch, C. : The role of inotropic variation in ventricular function during atrial fibrillation. *J. Clin. Invest.* **49** : 738-746, 1970
- 22) Koch-Wesser, J. and Blinks, J.R. : The influence of the interval between beats on myocardial contractility. *Pharmacol. Rev.* **15** : 601-652, 1963
- 23) Tavel, M.E., Baugh, D.O., Feigenbaum, H. and Nasser, W.K. : Left ventricular ejection time in atrial fibrillation. *Circulation* **46** : 744-752, 1972