A PROSTHETIC MYOCARDIUM: HEMODYNAMIC ADVANTAGES

HIROJI IMAMURA, M.D.

When a large left ventricular aneurysm or infarct is excised, a frequent complication is inability of the left ventricle to regain adequate performance. Reduction in ventricular volume and impairment of myocardial contractility, either of which can diminish cardiac output to levels incompatible with life, are probably the main factors that lead to left ventricular failure after such surgery.

A prototype prosthetic myocardium, designed to mimic the actions of the left ventricular myocardium, offers a direct means of restoring both ventricular volume and contractility after excision of a large portion of the left ventricle. In dog experiments $17 \pm 1.1\%$ ($AV \pm SE$) of the left ventricle was infarcted and excised under cardiopulmonary bypass. The prosthetic myocardium was implanted and activated, and changes in hemodynamic parameters produced by the assist device were studied. "On" to "off" changes in 11 dogs in congestive failure averaged over the course of the experiment were as follows:

m-AoP was increased $19 \pm 1.7\%$ (Mean $\pm$ SE); LV Syst. Press. was increased $24 \pm 1.7\%$; SV was increased $34 \pm 3.2\%$, LVEDP and m-LAP were reduced $43 \pm 2.4\%$ and $22 \pm 1.4\%$ respectively; and LVSW increased $88 \pm 8.8\%$.

With these hemodynamic benefits this prototype represents an encouraging step toward the development of a device for orthotopic replacement of damaged myocardium.

SURGICAL excision and repair of left ventricular aneurysm have produced good results unless removal of large portions of the left ventricle is necessary. When aneurysmectomy or infarctectomy is ineffective, the usual cause of death is the inability of the left ventricle to regain adequate performance upon discontinuation of cardiopulmonary bypass. Some patients have low cardiac output syndrome and die soon

after the operation. Others may recover from surgery and experience symptomatic improvement, but live no longer than patients given medical therapy^{1,29,32}. Diminution of ventricular chamber volume and impairment of myocardial contractility, either of which can reduce cardiac output, are probably the basic contributory factors in fatal outcomes.

The results of experimental and clinical studies in which large infarcted areas and aneurysms were excised have been reported by Bailey², Heinbecker^{3,4}, Jude⁵, Glass⁶, and others^{7,8}. These investigators used a direct suture technique for repair of the ventricle. Their

Key Words:

Prosthetic myocardium
Myocardial infarction
Ventricular aneurysm
Infarctectomy

(Received on August 20, 1979; Accepted on October 25, 1979)

Sinai Hospital of Detroit, 6767 W. Outer Drive, Detroit, Michigan, U.S.A.

Author's Present Address: Depart. of Surgery School of Medicine, Keio University, 35 Shinanomachi, Shinjuku-ku Tokyo 160, Japan

Read at the 50th scientific sessions of American Heart Association Miami Beach, Florida, November 28 – December 1, 1977.

methods, however, appear to be applicable only to those cases where reduction in the volume of the ventricle is limited. When the defect is greater than 20 to 25 percent of the total left ventricular surface area, the physiologic limits of fiber shortening required to maintain adequate stroke volume are exceeded and the Starling mechanism seems to fail.⁹ For this reason Collins and Collins¹⁰ investigated techniques to replace the excised myocardium with an implanted passive prosthesis, a woven Teflon patch, so as to restore left ventricular volume to adequate levels. However, their results were very similar to those with the direct suture method and they concluded that "until improved techniques of myocardial replacement are developed and effective myocardial support are achieved, myocardial resection appears to have a very limited clinical applicability." Williams and his colleagues¹¹ reported that excision with primary closure or prosthetic replacement of the myocardium with a passive "prosthetic device" was effective to a relatively small extent.

Replacement of a non-functional area of the left ventricle with an active device would offer a direct means of restoring both ventricular volume and contractility, and would improve perfusion of the remaining myocardium. At the same time it would eliminate or minimize the probability of ventricular rupture and electrical irritability. Such a system has been under investigation in this laboratory since 1968. Following preliminary studies by Schüpbach,¹² Hamada¹³ demonstrated that augmenting myocardial function by traction on sutures placed around the rim of a patch-covered myocardial defect was feasible. However, because the negative pressure exerted by the left ventricle during diastole¹⁵⁻¹⁸ caused the patch surface to invaginate, left ventricular filling was compromised and the hemodynamic response of the device was limited. To prevent invagination, we designed the present prosthesis prototype which actively contracts and expands mimicking myocardial systole and diastole.

The present report describes the results of experiments in which the hemodynamic performance of the new prosthesis was studied after excision of a large non-functioning portion of the left ventricle.

MATERIALS AND METHODS

An experimental model of a myocardial prosthesis of the latest design was constructed for in vivo evaluation.¹⁴ This model simulates some,

Fig.1. Isometric view of prototype prosthetic myocardium with 2 of the 6 tilting arms illustrated.

but not all, of the motions that a normal portion of the myocardium would undergo during contraction and relaxation. An exploded isometric view of the device is shown in Figure 1. Figure 2 shows a cross-section of the device in diastole. The myocardium is attached to the top of the tilting arms at points indicated schematically as holes. As a result of the force applied by the piston by means of the cam to the tilting arms,

- * Metomatic, Ohio Medical Products
- + Metofane, Pitman-Moore, Inc.
- ‡ 5000 Series, Biotronix Laboratory, Inc.
- § 00368 Series, Gould, Inc.
- π Olson Medical Products, Inc.
- Π Cobe Laboratories, Inc.
- # Sigma Chemical Company
- ** All results are given with standard deviations.

Fig.2. Section through prototype prosthetic myocardium showing it in diastole.

Fig.3. Section through prototype prosthetic myocardium showing it in systole.

Fig.4. Working prototype of prosthetic myocardium implanted in left ventricle of experimental animal.

they are forced to stay in their maximally dilated position. Thus during diastole, the device contributes to negative intraventricular pressure and ventricular filling is aided.¹⁵⁻¹⁸ During systole, as shown in Figure 3, the piston moves down (away from the heart) and the tips of the tilting arms approximate, reducing both the diameter and the area of the ventricular defect.

Figure 4 shows the prosthetic myocardium implanted into the left ventricle of a dog. This prototype is activated by compressed air from an external drive system which used the electrocardiogram to synchronize the device to the ventricular cycle.

Twenty-four unconditioned mongrel dogs weighing 25–48 kg were used. After induction of anesthesia with intravenous Thiamylal sodium (25 mg/kg), atropin sulfate (0.5 mg) was injected intramuscularly. Anesthesia and ventilation were maintained through a cuffed endotracheal tube by a pressure-and volume-controlled respirator;* a mixture of 100% oxygen and up to 4% Methoxyflurane[†] was given at a rate of 20 to 30 resp/min. with a tidal volume of 500 to 800 cc. The chest was opened through a median sterno-

tomy and the heart was suspended in a pericardial cradle.

An electromagnetic flow probe[‡] was placed around the root of the ascending aorta and appropriate cannulations were performed to allow observation of left atrial, left ventricular, and aortic pressures. Aortic and left ventricular pressures were measured with Statham p23Db strain gauge transducers. Left atrial pressure was measured with both a strain gauge and a water manometer. Percutaneous needle electrodes were used to monitor the ECG. Through the course of the experiment these parameters were continuously recorded on a multi-channel recorder.§

An acute myocardial infarction of the left ventricle 5 cm in diameter was produced by multiple ligations of the anterior descending branches of the left coronary artery⁶ (Figure 5). The branch chosen did not carry the predominant blood supply to any other area, and its ligation did not affect papillary muscle function.

Thirty minutes after ligation, Heparin (3 mg/kg) was administered, and the right atrium was cannulated for cardiopulmonary bypass.

Fig. 5. Multiple ligations of the anterior descending branches of the left coronary artery to produce an infarct of the required size.

Oxygenated blood was returned to the right common femoral artery by a roller pump^π from an Optiflo bubble oxygenator^π which had been primed with a mixture of 1000 cc lactated Ringer's solution, 500 cc of 5% dextrose, 50 cc of 8.4% sodium bicarbonate and 50 cc of 20% Mannitol. A flow rate of 50 to 70 ml per kilogram per minute at normothermia was used.

Ventricular fibrillation was then established and the infarct was excised. The excision included apparently viable myocardium as indicated by bleeding at the wound edge. The excised section was weighed. A 5.5 cm diameter patch of Electrolour (Dacron velour with an electrically conductive urethane calendered to the surface not in contact with the blood) was sutured over the defect. The sutures were interrupted and reinforced with individual Teflon felt pledgets. Sufficient space was left between the pledgets to allow for reduction in wound periphery during device activation. Before complete closure of the defect, air was displaced from the left ventricle. The heart was then defibrillated but partial cardiopulmonary bypass was continued. Twelve 2-0 Tevdek sutures reinforced

with individual Teflon pledgets were used to attach the six arms of the prosthesis to the rim of the defect outside the ring of sutures holding the patch in place (Fig. 4).

After the blood volume was adjusted to restore satisfactory arterial and venous pressures, cardiopulmonary bypass was discontinued and the prosthetic myocardium was immediately activated. Hemodynamic parameters and the position of the piston within the actuator were recorded continuously. Every 30 minutes the prosthetic myocardium was turned off for 5 minutes. Data recorded during hemodynamically stable periods immediately before and after the device was turned off included the following parameters: central aortic pressure, left ventricular pressure, left atrial pressure, and aortic flow.

After 3 to 5 hours of cardiac assistance, the dog was sacrificed. Upon removal of the heart the free wall of the right ventricle and both atria were cut away, leaving the left ventricle including the septum. This tissue was weighed. The weight of the resected infarct was then expressed as a percentage of the left ventricle. The left ventricular wall was then stained with Nitro Blue

Fig.6. Hemodynamic data obtained with the prosthetic myocardium active (left) and inactive (right).

Tetrazolium (NBT)^{#19,20} to define possible regions of necrosis at the wound edge.

Data analysis included the following steps: manual measurement of mean aortic pressure

(m-Aop), left ventricular systolic pressure (LV Syst. Press.), mean left atrial pressure (m-LAP), left ventricular end-diastolic pressure (LVEDP), and stroke volume (SV) for 7 to 10 consecutive

TABLE I EFFECTS OF PROSTHETIC MYOCARDIUM ON HEMODYNAMIC PARAMETERS 60 MINUTES AFTER IMPLANTATION

Dog No.	% MI Exc/LV Weight	m-AoP (mm Hg)			LV Syst. Press. (mm Hg)			LVEDP (mm Hg)			m-LAP (mm Hg)			SV Arbitrary Units			Δ LVSW
		Off	On	% Incr.	Off	On	% Incr.	Off	On	% Decr.	Off	On	% Decr.	Off	On	% Incr.	
8	24	48	56	16.7	56	80	42.9	6	1	83.3	9	6	33.3	37	47	27.0	66.3
9	16	65	88	35.4	94	130	38.3	16	4	75.0	25	16	36.0	38	58	52.6	162.
10	21	44	54	22.7	64	80	25.0	16	8	50.0	16	12	25.0	24	38	58.3	160.
11	20	72	94	30.6	100	120	20.0	15	12	20.0	11	9	18.2	44	51	15.9	66.7
17	14	56	60	7.1	84	96	14.3	17	15	11.8	16	15	6.2	30	32	6.7	23.1
18	16	64	80	25.0	92	114	23.9	12	6	50.0	10	7	30.0	58	68	17.2	66.8
19	15	68	78	14.7	108	120	11.1	7	5	28.6	9	6	33.3	61	69	13.1	35.4
20	16	68	72	5.9	84	92	9.5	7	3	57.1	6	4	33.3	28	31	10.7	25.2
22	11	52	60	15.4	70	80	14.3	14	11	21.4	12	11	8.3	32	46	43.7	85.4
23	16	36	50	38.9	54	72	33.3	8	4	50.0	11	7	36.4	17	27	58.8	161.
24	21	42	56	33.3	58	80	37.9	15	10	33.3	18	16	11.1	38	66	73.7	196.
Aug.	17	56	68	22.3	79	97	24.6	12	7	43.7	13	10	24.6			34.3	95.3
SD	3.6	12	15	11.3	19	21	11.9	4	4	22.9	5	4	11.6			23.7	62.8
SE	1.1	3.7	4.5	3.4	5.7	6.2	3.6	1.3	1.3	6.9	1.6	1.3	3.5			7.1	18.9

Abbreviations:

% MI Exc/LV Weight: Percent of Excised Myocardial Infarct, by weight, of left ventricle including septum.

m-AoP: Mean Aortic Pressure

LV Syst. Press: Left Ventricular Systolic Pressure

LVEDP: Left Ventricular End-Diastolic Pressure

m-LAP: Mean Left Atrial Pressure

SV: Stroke Volume

 Δ LVSW: Percent Left Ventricular Stroke Work

SD: Standard Deviation

SE: Standard Error of the Mean

Fig.7. Transverse slices of the left ventricle after exposure to NBT staining. The upper picture shows the entire left ventricle, including the excised infarct. Lower photograph shows the next three slices. The two on the right are unstained indicating extent of infarct. The sutures which held the PM in place are visible in the center section.

TABLE II SUMMARY OF EFFECTS OF PROSTHETIC MYOCARDIUM ON HEMODYNAMIC PARAMETERS IN 11 DOGS UP TO 3.5 HOURS

	Mean (% Change) <i>P</i> < 0.0005*	CI	SD	SE	Range	<i>n</i>
<i>m</i> -AoP	19	± 4.0	±12.3	1.7	3 to 58	53
LV Syst. Press.	24	± 4.0	±12.6	1.7	7 to 58	53
LVEDP	-43	± 5.8	±17.4	2.4	-83 to -12	53
<i>m</i> -LAP	-22	± 3.4	±10.0	1.4	-50 to -6	53
SV	34	± 7.7	±23.2	3.2	4 to 111	51
Δ LVSW	88	±21.0	±62.6	8.8	14 to 322	51

* By Student's *t*-test

Abbreviation:

m-AoP, LV Syst. Press., LVEDP, *m*-LAP, SV, ΔLVSW: Same as Table I.

CI: 99% Confidence Interval

SD: Standard Deviation

SE: Standard Error of Mean

beats, both with the device active and inactive. The average of the measurements was considered one data point. The average standard deviation (SD), standard error of the mean (SE), and 99% confidence interval (CI) were computed for all the above parameter, and the percent difference between them ($\frac{\text{on} - \text{off}}{\text{off}}$), as well as the percent change of left ventricular stroke work (Δ LVSW), using the following formula:

$$\Delta \text{LVSW} = \frac{[(m\text{-AoP} - \text{LVEDP}) \times \text{SV}]_{\text{on}} - [(m\text{-AoP} - \text{LVEDP}) \times \text{SV}]_{\text{off}}}{[(m\text{-AoP} - \text{LVEDP}) \times \text{SV}]_{\text{off}}} \times 100$$

The statistics for any parameter (there are 18) were computed three ways: including data at all times of measurement for one dog, including data of all dogs at a fixed time after PM implantation, and including all data for all dogs and all times.

RESULTS

Thirteen of the 24 dogs (dogs 1-7, 12-16, 21) died before the prosthetic myocardium could be implanted or activated. Of these, 5 dogs died of ventricular fibrillation immediately after myocardial infarction was produced. Eight animals could not be weaned from cardiopulmonary bypass after implantation of the Electrolour patch. The causes of death were irreversible ventricular fibrillation, severe mitral insufficiency and low output syndrome. In the remaining 11 dogs $17 \pm 1.1\%$ (AV ± SE) of the left ventricle was excised and replaced by the prosthesis.

After implantation of the device the dogs were hypotensive.

Hemodynamic data from dog 9 is shown in Figure 6. Table I shows second data set (actual values and percent changes) obtained 60 minutes after implantation. All percent changes indicated are statistically significant ($p < .0005$). Results at other times and also when averaged across time for each dog were significant (1 at $p = 0.1$, 4 at $p = 0.05$, 103 at $p < 0.01$). Table II gives a summary of all results. Some sets of data taken at scheduled intervals but while the animal's condition was unstable were excluded from analysis, resulting in 53 data sets. In two instances aortic flow was off scale. Note that *m*-AoP, LV Syst. Press., SV, and LVSW increased, and LVEDP and *m*-LAP decreased in every measurement. The *p* values given indicate the probability that sample means are non-equal by chance. Based on the data the following claims can also be made with 99% confidence: mean aortic pressure is increased by at least 14.8%, left ventricular systolic pressure is increased by at least 19.3%, left ventricular end-diastolic pressure is decreased by at least 36.9%, mean left atrial pressure is decreased by at least 18.6%, stroke volume is increased by at least 26.1%, and left ventricular stroke work is increased by at least 66.6%. NBT staining showed necrosis within the 1-1.5 cm of myocardium between the wound edge and the ring of sutures fixing the prosthesis to the heart (Figure 7). The weight of necrotic tissue averaged 5% of total left ventricular weight. No necrosis was found beyond the area defined by the sutures.

In three of the first five successful procedures a number of the sutures fixing the PM to the myocardium were found to be torn at autopsy. While the time at which the breaks occurred cannot be determined with certainty, they seem to have occurred in the last hour of the experiment. Therefore all data beyond the first 3.5 hours was disregarded. A change in the sutures used eliminated further occurrence of the problem.

DISCUSSION

Following myocardial infarction motion disturbances in the region of the aneurysm, akinesis or dyskinesis^{9,21,22} may cause variable degrees of functional impairment of left ventricular pumping action or, eventually, even failure^{23,26}. In such cases, impaired contractility of the ischemic or infarcted myocardium result in localized disturbances of ventricular contraction that vitiate overall ventricular contractile effort⁹ and reduce stroke volume⁵. In addition, during diastole the undamaged myocardial fibers are not stretched to their optimal length for maximal subsequent contraction²⁵. Furthermore, at this point, a greater contractile tension is required to generate any given intraventricular pressure and myocardial oxygen consumption increases^{27,28}. Impaired blood flow in the patent coronary vessels resulting from decreased stroke volume further contributes to poor functioning of the heart⁵. Thus, a vicious cycle may ensue which often results in extension of the original infarct and progressive left ventricular failure²⁹.

If the myocardial infarct or aneurysm involves the papillary muscles and interferes with proper mitral valve function, the mechanical effectiveness with which blood is ejected from the heart is reduced²⁹. In addition, the acute myocardial infarct acts as a site of electrical instability³⁰ or of mural thrombus formation²⁹ or it may be the site of ventricular rupture.

A number of experimental approaches^{2-8,11,31} and various clinical interventions^{3,22,26,28,32} of infarctectomy or aneurysmectomy have been studied. Although estimates of the percentage of the left ventricular wall which can be safely excised differ, there is general agreement that it is relatively small.

Successful treatment for patients with clinically significant non-functional portions of the myocardium should

- restore cardiac output to adequate levels,
- greatly reduce the probability of subsequent

aneurysm formation or ventricular rupture, and

- reduce the probability of ventricular fibrillation

In principle, the direct replacement of non-functional myocardium by a dynamic prosthesis attached to the left ventricular wall could achieve these objectives.

We have investigated the physiologic effectiveness of a prosthesis designed to simulate the actions of the left ventricular myocardium. Its implantation in dogs is not unduly difficult and requires cardiopulmonary bypass for no more than 60 minutes (including the period during which the device is attached to the rim of the defect).

When a continuous felt strip was used to reinforce the sutures of the patch to close the defect,^{12,13} the rim of myocardium was so stiffened that its motion was virtually prevented. When interrupted sutures reinforced with individual pledgets were used and enough space was left between the pledgets to allow for reduction in wound periphery, the ability of the prosthesis to augment stroke volume was greatly enhanced.

All measured parameters in each animal studied showed an improvement of the active over the inactive phase. Left ventricular stroke work increased by greater than 100% in 17 of 51 measurements. Possible reasons for the lesser improvements in the other samples include: hypovolemia (temporarily uncorrected), insufficient space between sutures and pledgets to allow for contraction, difficulties in synchronization of the PM motion to ventricular contraction, and mitral insufficiency. While every effort was made to protect the papillary muscle during the procedure, mitral insufficiency was observed in 4 animals. However, even in these animals the PM was able to increase both ventricular systolic pressure and stroke volume. In situations where the presence of a chronic infarct makes interference with papillary muscle function unavoidable, implantation of a prosthetic mitral valve would be necessary.

As shown by the results of NBT staining the present implantation technique interferes with the perfusion of myocardium inside the ring of sutures. In effect, the infarct is increased in size from 5 cm diameter, 17% of LV mass, to greater than 7 cm diameter, estimated 22% of the LV mass. Had the sutures been placed in the scar tissue surrounding a chronic infarct, we would not expect enlargement of the infarcted region

due to device implantation.

Our present results indicate that the hemodynamic effects of the current model PM are beneficial. Further studies are needed to characterize both the short and long term performance and interaction of the prosthesis-heart combination.

Acknowledgements

The author greatly appreciate Dr. Adrian Kantrowitz, Prof. of Wayne State Univ. Detroit, Michigan, USA, who gave me the opportunity for performing this research work.

REFERENCES

- LAJOS, T. Z., MONTES, M., BUNNELL, I. L., GREEN, D. G., & FALSETTI, H. L., SCHIMERT, G.: Resection of myocardial infarcts: clinical and pathologic studies. *J. Thorac. Cardiovasc. Surg.* 60: 196, 1970.
- BAILEY, C. P. & GILMAN, R. A.: Experimental and clinical resection for ventricular aneurysm. *Surg. Gyn. Obstet.* 104: 539, 1957.
- HEIMBECKER, R. O., LEMIRE, G., & CHEN, C.: Surgery for massive myocardial infarction. An experimental study of emergency infarctectomy with a preliminary report on the clinical application. *Circulation* 37, 38 (Suppl. 2): 3, 1968.
- HEIMBECKER, R. O., CHEN, C., HAMILTON, N., & MURRAY, D. W. G.: Surgery for massive myocardial infarction. An experimental study of emergency infarctectomy. *Surgery* 61: 51, 1967.
- JUDE, J. R., MOBIN-UDDIN, K., MARTINEZ-FARINAS, L. O., LOMBARDO, C. R., & SMITH, P. E.: Surgical treatment of experimental myocardial infarction. *J. A. M. A.* 203: 451, 1968.
- GLASS, B. A., CARTER, R. L., ALBERT, H. M., & ROSENBERG, D. M.: Excision of myocardial infarcts. Experimental and clinical studies. *Arch. Surg.* 97: 940, 1968.
- PAIROLERO, P. C., McCALLISTER, B. D., HALLERMAN, F. J., TITUS, J. L., & ELLIS, F. H. Jr.: Experimental left ventricular akinesis. Results of excision. *J. Thorac. Cardiovasc. Surg.* 60: 683, 1970.
- DANIELSON, K. S., RESNICOLL, S. A., & DeWEESE, J. A.: An evaluation of infarctectomy. *J. Thorac. Cardiovasc. Surg.* 59: 723, 1970.
- HERMAN, M. V., HEINLE, R. A., KLEIN, M. D., & GORLIN, R.: Localized disorders in myocardial contraction. Asynergy and its role in congestive heart failure. *N. Engl. J. Med.* 277: 222, 1967.
- COLLINS, H. A. & COLLINS, I. S.: Replacement of left ventricular myocardium. *Circulation* 37, 38 (Suppl. 2): 18, 1968.
- WILLIAMS, C. L. & WOODS, L. P.: Experimental resection of myocardial infarction. *Ann. Thorac. Surg.* 10: 344, 1970.
- SCHUPBACK, P., SUJANSKY, E., TOMECEK, J., SANTA, A., FREED, P. S., & KANTROWITZ, A.: An experimental prosthetic myocardium. *Trans. Amer. Soc. Artif. Int. Organs.* 15: 434, 1969.
- HAMADA, O., BABA, H., KISO, I., FREED, P. S., MOSKOWITZ, M. S., & KANTROWITZ, A.: Studies with an active prosthetic myocardium. *Trans. Amer. Soc. Artif. Int. Organs.* 21: 374, 1975.
- Freed, P. S., MOSKOWITZ, M. S., HAMADA, O., von RECUM, A., & KANTROWITZ, A.: Prosthetic myocardium; a functional left ventricular wall replacement. Proc. 29th ACEMB, Boston Massachusetts, November 1976, p. 395.
- BRECHER, G. A.: Experimental evidence of ventricular diastolic suction. *Circulation Res.* 4: 513, 1956.
- BRECHER, G. A.: *Venous Return*, Grune & Stratton, Inc., New York, 1956.
- BRECHER, G. A. & KISSEN, A. T.: Ventricular diastolic suction at normal arterial pressures. *Circulation Res.* 6: 100, 1958.
- O'Brien, L. J.: Negative diastolic pressure in the isolated hypothermic dog heart. *Circulation Res.* 8: 956, 1960.
- BRODY, G. L., BELDING, A., BELDING, M., & FELDMAN, S. A.: The identification and delineation of myocardial infarcts. *Arch. Path.* 84: 312, 1967.
- NACHLAS, M. N. & SHNITKA, T. K.: Macroscopic identification of early myocardial infarcts by alterations in dehydrogenase activity. *Am. J. Path.* 42: 379, 1963.
- GORLIN, R., KLEIN, M. D., & SULLIVAN, J. M.: Prospective correlative study of ventricular aneurysm. Mechanistic concept and clinical recognition. *Am. J. Med.* 42: 512, 1967.
- KLUGE, T. H., ULLAL, S. R., HILL, J. D., KERTH, W. J., & GERBODE, F.: Dyskinesia and aneurysm of the left ventricle. Surgical experience in 36 patients. *J. Cardiovasc. Surg.* 12: 273, 1971.
- DAVIS, R. W. & EBERT, P. A.: Ventricular aneurysm: a clinicalpathologic correlation. *Am. J. Cardiol.* 29: 1, 1972.
- DUBNOW, M. H., BURCHELL, H. B., & TITUS, J. L.: Postinfarction ventricular aneurysm. *Am. Heart J.* 70: 753, 1965.
- COOLEY, D. A., HALLMAN, G. L., & HENLY, W. R.: Left ventricular aneurysm due to myocardial infarction. *Arch. Surg.* 88: 114, 1964.
- COOLEY, D. A. & HALLMAN, G. L.: Surgical treatment of left ventricular aneurysm. *Prog. Cardiovasc. Dis.* 11: 222, 1968.
- GRAHAM, T. P. Jr., COVEL, J. W., SONNENBLICK, E. H., ROSS, J. Jr., & BRAUNWALD, E.: Control of myocardial oxygen consumption: relative influence of contractile state and tension development. *J. Clin. Invest.* 47: 375, 1968.
- KITAMURA, S., ECHEVARRIA, M., KAY, J. H., KROHN, B. G., REDINGTON, J. V., MENDEZ, A., ZUBIATE, P., & DUNNE, E. F.: Left ventricular performance before and after removal of the noncontractile area of the left ventricle and revascularization of the myocardium. *Circulation* 45: 1005, 1972.
- MUNDTH, E. D., BUCKLEY, M. J., DAGGETT, W. M., SANDERS, C. A., & AUSTEN, W. G.: Surgery for complications of acute myocardial infarction. *Circulation* 45: 1279, 1972.

30. BROFMAN, B. L., LEIGHNINGER, D. S., & BECK, C. S.: Electrical instability of the heart. The concept of the current of oxygen differential in coronary artery disease. *Circulation* 13: 161, 1956.
31. STEIN, M. & CORDELL, A. R.: Mechanical efficiency of the left ventricle following experimental myocardial infarction and infarctectomy. *Surg. Forum*. 20: 192, 1969.
32. KOUCHOUKOS, N. T., DOTY, D. B., BUETTNER, L. E., & KIRKLIN, J. W.: Treatment of postinfarction cardiac failure by myocardial excision and revascularization. *Circulation* 45, 46 (Suppl. 1): 72 1972.

Japanese Circulation Journal

February 1980, Vol. 44 No. 2

日本循環器学誌第44巻2号

編集者 早瀬正二・発行者 荻野耕一

印刷所 河北印刷株式会社 京都市南区唐橋門脇町二八

印刷・発行 昭和55年3月10日印刷 昭和55年3月20日発行

発行所 日本循環器学会

誌代年15000円(送料共)

1冊 1500円(送料共)

〒606 京都市左京区吉田河原町14 近畿地方発明センター内

電話 京都 (075) 751-8643 振替 京都 6119