Arch Jap Chir 48 (5), 602～617, Sept., 1979

Evaluation of Myocardial Contractility During Open Heart Surgery for Assessing Prognosis in the Patients with Tetralogy of Fallot

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Received for Publication, July 10, 1979

Introduction

In recent years, indices of myocardial contractility such as maximal rate of rise of ventricular pressure (max dp/dt), peak measured shortening velocity of contractile elements (Vpm) and maximal shortening velocity of contractile elements (Vmax) have been considered for clinical use. As indicators of hemodynamic function during open heart surgery, however, arterial pressure, central venous pressure, cardiac output and electrocardiogram have generally been used. Although measurement of myocardial contractility during surgery may have a great clinical significance, it is rarely practised because it is troublesome and its prompt evaluation is difficult. The author developed a method which enables easy measurement and prompt evaluation of cardiac function, particularly contractility, in the operating room using an analog computer with digital displays through analog-to-digital (A/D) converters.

The purpose of the present study is to investigate the relation between cardiac contractility measured during surgery and prognosis in the patients undergoing total repair of tetralogy of Fallot, and to define the usefulness of various indices of contractility in evaluating prognosis.

Since WIGGERS introduced the concept of dp/dt for measuring myocardial contractility, max dp/dt has been widely used as an index of contractility[27]. However, since max dp/dt is directly influenced by changes in preload and afterload, many investigators have developed various modified indices such as (max dp/dt)/IP (shortening velocity of contractile elements at max dp/dt, IP=isovolumic ventricular pressure) which is rather independent of loading conditions[15][19][20]. In addition, HILL started an investigation on the physical nature of skeletal muscle i. e., the force-velocity relation of contractility[10]. ABBOTT and MOMMAERTS, and SONNENBLICK applied this relation to cardiac muscle and proposed using Vmax as an index of contractility, which is theoretically independent of changes in preload and afterload [1][24] This measurement of Vmax has gained wide acceptance in spite of fairly wild assumption and time-consuming calculation. There are two methods for calculating Vmax: VmaxT is measured using total pressure, and VmaxD is measured using developed pressure

Key words : Myocardial contractility, Tetralogy of Fallot, Linear discriminant function.
索引語：心筋収縮性，ファロー四徴症，線型判別関数
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(total pressure minus end-diastolic pressure). VmaxD was proposed to eliminate the influence of the parallel elastic element on active pressure in MAXWELL's muscle model. and may be less affected by the alteration of preload than VmaxT[8)16)18)19)]. Vpm, which is obtained in the calculation of VmaxT, is relatively independent of changes in preload and afterload, and its change correlates well with the alteration of VmaxT[17)19)]. In this study, all the above mentioned indices were measured.

Methods

Figure 1 shows the outline of the total system to measure cardiac function. Ventricular pressure (P) was measured by ventricular puncture with a 21-gauge needle attached to a Statham P37 or P50 microtransducer. This transducer-needle system was initially balanced in the ambient air while being held in the measuring position. The output of pressure from a pressure amplifier of the Hewlett Packard model 8800 series monitoring system was filtered to 50Hz and fed into an analog computer; dp/dt was obtained through a derivative amplifier with a time constant of 0.5 msec. (dp/dt)/P (=dlog P/dt) was obtained by a logarithmic converter with another derivative amplifier[7)]. Vmax was calculated by manual extrapolation of the isovolumic portion on P-(dp/dt)/P loop to P=0. Pmax (ventricular systolic pressure), max dp/dt and Vpm were obtained by analog peak holders. End-diastolic pressure (EDP) and (max dp/dt)/IP were calculated by sample holders. The former was

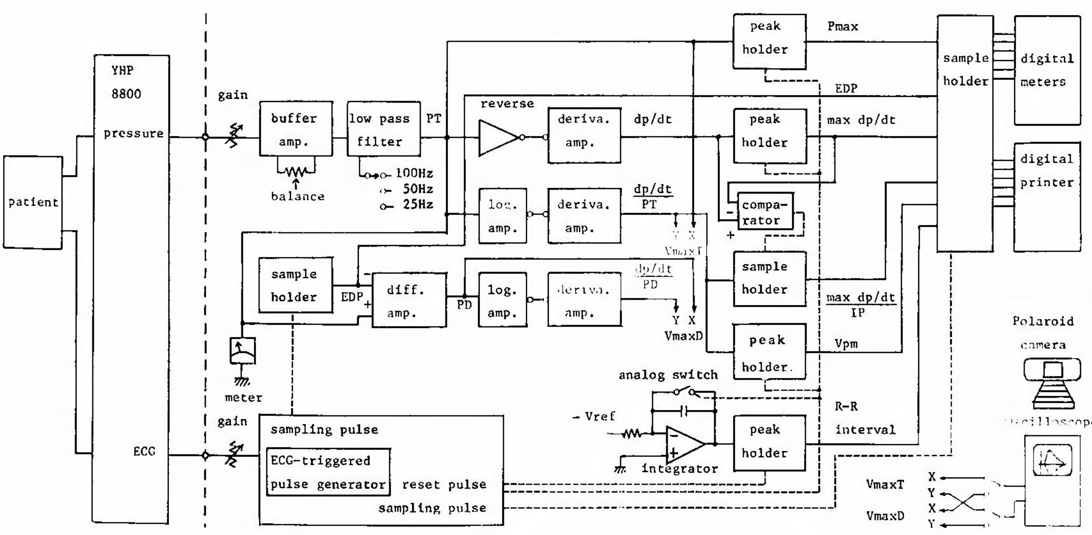

Fig. 1 The block-schema of monitoring system for evaluation of cardiac function.

amp.=amplifier, deriva. amp.=derivative amplifier, diff. amp.=differential amplifier, ECG=electrocardiogram, EDP=end-diastolic pressure, IP=isovolumic pressure, PD=developed pressure, PT=total pressure, Pmax=peak pressure, log. amp.=logarithmic amplifier, Vmax T (Vmax D) = maximal shortening velocity of contractile elements measured using total (developed) pressure, Vpm=peak measured shortening velocity of contractile elements, Vref=voltage reference.

obtained from ventricular pressure sampled at 30 msec after the onset of R-wave, and the latter from the (dp/dt)/P at the time of maximal dp/dt. R-R interval was obtained by integration of voltage reference. The signals thus obtained were displayed and recorded digitally through A/D converters.

Other data measured throughout surgery included radial arterial pressure, central venous pressure, rectal temperature, blood pH, electrolytes and serum osmotic pressure.

Measured results were analyzed statistically by using discriminant function[2)23)].

Discriminant function can be used to forecast whether a given subject will fall into a group, A or another group, B. In frequency distribution curves (Fig. 2) of known data of

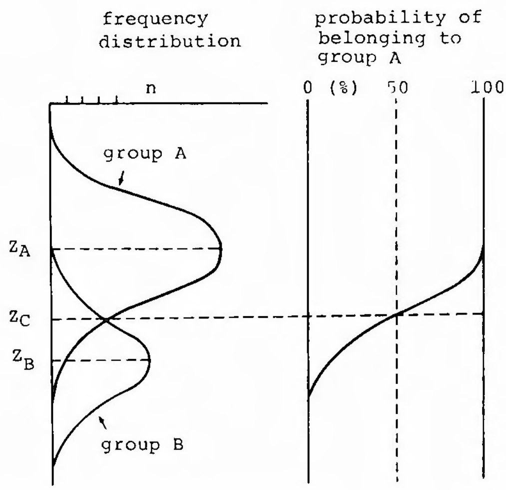

Fig. 2. Z_A and Z_B are the means of group A and B, respectively. Z_C is the crossing point of the two curves and is regarded as the point representing 50% probability of belonging to each group. n : frequency.

groups A and B, the lesser the overlapping and the farther apart the peaks, the more reliable is the forecast. The normalized distance between the distributions of two groups is expressed as follows :

$$\Delta = \frac{|Z_A - Z_B|}{\sqrt{\dfrac{(Z_{Ai}-Z_A)^2+(Z_{Bi}-Z_B)^2}{(n_A-1)+(n_B-1)}}}$$

where n_A, n_B are the numbers, Z_{Ai} ($i=1, 2, \cdots\cdots n_A$), Z_{Bi} ($i=1, 2, \cdots\cdots n_B$) are the basic data and Z_A, Z_B are the mean values in groups A and B respectively. In the forecast using an actual datum, Z, the crossing point of the two curves, Z_C is regarded as the point representing 50% probability for group A. For any given case the probability of belonging to group A, P_A, is expressed as follows :

$$P_A = \frac{\frac{n_A}{\sigma_A} e^{-\frac{(Z-Z_A)^2}{2\sigma_A}}}{\frac{n_A}{\sigma_A} e^{-\frac{(Z-Z_A)^2}{2\sigma_A}} + \frac{n_B}{\sigma_B} e^{-\frac{(Z-Z_B)^2}{2\sigma_B}}}$$

where σ_A and σ_B represent standard deviation of groups A and B respectively. The above discrimination can be used for a single parameter, where the Δ-value is called the standardized distance. The curves should be well separated if Δ-value is more than 3, but this rarely occurs clinically. If the basic data are not distributed normally it is worthwile to try to normalize them by a logarithmic transformation.

Patients

In a period from August, 1974 to September, 1976, total repair of tetralogy of Fallot was accomplished in 67 pediatric patients under 12 years of age including 8 hospital deaths. The mortality rate was 11.9%. Cardiac function was measured in 38 of these patients including 5 deaths for the assesment of prognosis. This measurement was performed shortly before and shortly after extracorporeal circulation (ECC) during surgery. According to the postoperative courses, they were classified into two groups (A and B) and the relation between cardiac function and prognosis was studied. Group A comprised 29 cases with favorable prognosis and no occurence of significant cardiac failure after surgery. Group B included 5 patients who died of cardiac failure early after the operation (within one month) and 4 patients who required administration of inotropic agents for more than 5 days due to severe low cardiac output syndrome (LOS). Most of the patients were catheterized less than one year before and about one month after surgery. The standard hemodynamic data as well as age, sex and weight of these 38 patients are listed in Table 1, while Table 2 gives the average age, weight and the hemodynamic data prior to surgery for groups A and B. There was no significant difference in age and body weight between the two groups ($P<0.01$). Hematocrit averaged 43.9% and 50.3% respectively for groups A and B. There were 11 acyanotic patients in group A and one in group B. The mean value of pulmonary-systemic flow ratio (Qp/Qs) for group A was 1.15, indicating predominant left-to-right shunt, while it was 0.78 for group B, indicating the reverse. Ratio of diameter of the pulmonary artery to that of the aorta at the level of the valvular ring (PA/Ao ratio) on cardioangiograms averaged 0.54 for group B, which was lower than 0.66 for group A, while the mean PA/Ao ratio measured during surgery was 0.81 for group A and 0.60 for group B. There were insignificant differences between the average cardiothoracic ratios of group A (0.56), and group B (0.52); ($P<0.01$).

Operative technique and managements

Propranolol (1-2 mg/kg/day) which was administered prior to surgery to those patients who had suffered from anoxic spells was suspended at least 24-48 hrs preoperatively except when anoxic spells occurred frequently.

Table 1. Hemodynamic data of all the patients

Group	Case no.	Age year	Sex	Body Weight kg	Anesthesia	preoperative examination Ht %	CTR	Qp/Qs	PA/Ao	extracorporeal circulation Flow Index L/min/m²	Sum of bypass time min	Total bypass time min	Aortic clamping time min	postoperative examination Cardiac Index L/min/m²	RVP/LVP	CTR
Group A	1	5.8	f	15.5	H	39	0.63	2.60	0.54	2.60	126	93	32	4.10	0.43	0.60
	2	6.4	m	16.0	K	40	0.53	0.95	0.81	2.70	96	81	31	8.20	0.39	0.59
	3	4.4	m	14.7	H	41	0.57	1.39	1.20	2.70	72	57	11	5.10	0.55	0.59
	4	8.4	m	22.4	K	50	0.62	0.73	0.50	2.60	80	63	27	4.70	0.60	0.50
	5	7.4	m	12.2	K	37	0.54	2.70	—	2.70	77	55	23	5.77	0.42	0.59
	6	3.7	f	13.5	K	41	0.55	0.44	0.95	2.60	82	58	21	—	—	—
	7	3.8	m	12.2	H	42	0.63	1.80	0.83	2.70	98	73	27	4.60	0.54	0.64
	8	2.2	m	10.0	K	38	0.59	2.00	0.94	2.80	69	51	12	5.00	0.33	0.58
	9	3.4	m	14.1	H	35	0.58	1.90	0.70	2.80	85	70	30	6.60	0.34	0.63
	10	2.1	m	11.3	K	38	0.62	1.07	0.57	2.70	88	66	25	—	0.30	0.59
	11	2.7	m	11.2	K	44	0.65	1.10	0.88	2.50	71	54	22	3.90	—	0.64
	12	7.5	m	19.3	K	41	0.60	0.97	—	3.00	77	61	19	5.87	0.33	0.54
	13	3.4	m	13.4	K	40	0.47	0.28	0.86	2.80	72	53	11	—	—	0.58
	14	4.2	m	16.0	K	40	0.53	1.00	0.69	2.40	86	60	24	6.09	0.33	0.55
	15	2.8	m	13.0	H	49	0.65	0.79	0.56	2.50	95	62	21	—	0.75	0.61
	16	3.9	m	13.4	H	—	0.54	1.44	0.56	2.80	135	88	29	6.70	0.48	0.60
	17	4.5	m	14.0	H	46	0.44	0.46	0.85	2.80	125	80	29	4.90	0.53	—
	18	6.3	f	17.9	H	59	0.45	0.27	0.48	3.20	148	110	39	6.00	0.44	0.58
	19	4.9	f	14.8	H	39	0.63	2.60	0.50	2.40	107	78	28	—	0.23	—
	20	2.8	m	11.8	H	47	0.56	0.42	0.43	2.80	118	82	24	7.20	0.38	0.60
	21	5.3	m	14.1	H	49	0.50	0.50	0.58	2.60	85	70	18	6.49	0.78	0.58
	22	2.4	m	11.6	H	52	0.55	0.30	0.53	2.80	136	112	43	5.30	0.86	0.68
	23	2.9	m	9.5	H	57	0.52	0.29	0.57	3.00	94	72	22	4.80	0.80	0.59
	24	3.2	m	13.5	K	—	0.49	1.60	0.36	2.70	110	85	25	4.10	0.80	0.57
	25	1.8	f	10.6	K	42	0.49	1.13	0.59	2.40	90	73	24	3.75	—	0.59
	26	3.7	m	13.4	K	37	0.61	1.70	0.65	2.80	108	85	16	6.98	—	0.58
	27	2.9	f	13.6	K	56	0.62	0.54	0.50	2.90	176	122	32	4.09	0.91	0.61
	28	3.8	m	15.1	K	43	0.46	—	0.59	2.60	137	109	33	7.75	0.45	0.62
	29	3.8	m	10.9	K	—	0.62	—	—	2.80	115	87	23	5.00	0.41	0.67
Group B	LOS															
	1	11.0	m	26.8	H	67	0.53	0.42	0.59	2.90	102	80	34	6.60	0.66	0.54
	2	2.6	m	12.1	H	43	0.54	1.10	0.44	2.60	166	92	27	4.43	0.39	—
	3	2.9	m	11.5	K	42	0.51	0.65	0.55	2.80	157	113	40	4.66	0.60	0.59
	4	3.0	f	13.5	K	56	0.56	0.18	0.74	2.80	135	95	25	4.96	0.45	0.58
	Death															
	5	3.2	m	11.9	H	38	0.61	2.60	—	2.40	117	91	35			
	6	1.5	m	9.8	K	63	0.48	0.13	0.63	2.50	112	88	35			
	7	5.0	f	15.0	H	—	0.46	0.68	0.31	2.80	167	103	30			
	8	4.2	m	15.7	H	44	0.53	0.74	0.48	2.80	117	73	26			
	9	1.6	m	9.0	H	49	0.50	0.56	0.56	2.60	85	56	19			

CTR—cardiothoracic ratio, Ht hematocrit, LOS low cardiac output syndrome, PA/Ao ratio of diameter of pulmonary valvular ring to that of aortic root, Qp/Qs pulmonary-systemic flow ratio, RVP/LVP—pressure ratio of right ventricle to left ventricle, f female, m=male, H=halothane anesthesia, K ketamine drip infusion anesthesia.

Table 2. Preoperative examinations

parameters	group A mean	s. d.	no.	group B mean	s. d.	no.	Δ
age (year)	4.15	1.72	29	3.89	2.89	9	0.129
body weight (kg)	13.8	2.8	29	13.9	5.3	9	0.047
hematocrit (%)	43.9	6.6	26	50.3	10.6	8	0.827
CTR	0.56	0.06	29	0.52	0.04	9	0.594
Qp/Qs	1.15	0.75	27	0.78	0.74	9	0.484
PA/Ao (angiogram)	0.66	0.20	26	0.54	0.13	8	0.678
PA/Ao (directly)	0.81	0.19	29	0.60	0.17	8	1.146

CTR=cardiothoracic ratio, Δ=standardized distance, no.= number, PA/Ao=ratio of diameter of pulmonary valvular ring to that of aortic root, QP/Qs=pulmonary-systemic flow ratio, s. d.= standard deviation.

Half of the patients were anesthetized by halothane and half by the ketamine micro-mini drip infusion method[9)26)]. During anesthesia electroencephalogram and plethysmogram, in addition to arterial pressure, central venous pressure, electrocardiogram, body temperature, blood gases and urine output, were monitored.

ECC was conducted by the hemodilution method with moderate hypothermia to 30°C. Pump flow rate (PFR) was 2.4—3.0 L/min/m², the range in which the arterial blood pressure seldom dropped below 40 mmHg (Table 3). There was no significant difference in the mean PFR between group A and B. However, the mean of total bypass time, partial-bypass time and the sum of these two bypass time were significantly longer for group B than for group A ($P<0.01$). The priming solution used for ECC was a mixture of lactate Ringer's solution, mannitol and ACD (acid citrate dextrose) blood. Hematocrit was thus adjusted to 20-30% and serum osmotic pressure to 300-310 mOsm during ECC, the average of which were almost the same in both groups. Body temperature had been warmed up to 35-37°C and hematocrit was concentrated to 35-45% shortly after ECC.

Radical repair of tetralogy of Fallot comprises closure of ventricular septal defect (VSD) and elimination of pulmonary stenosis. A longitudinal ventriculotomy was used in 32 cases, and a transverse ventriculotomy was used in 6 cases. A duplicated pericardial patch was

Table 3. Conditions of extracorporeal circulation

parameters	group A mean	s. d.	no.	group B mean	s. d.	no.	Δ
pump flow index (L/min/m²)	2.71	0.19	29	2.69	0.17	9	0.137
total bypass time (min)	76.2	19.2		87.9	16.7		0.627
patial bypass time (min)	22.8	10.3		37.9	18.2		1.210
sum of bypass time (min)	102.0	26.8		128.7	29.3		0.975
aortic clamping time (min)	24.8	7.6		30.1	6.5		0.726
hematocrit (%)	24.1	3.1		23.9	3.6		0.067

Δ=standardized distance, no.=number, s. d.=standard deviation.

Table 4. Cardiac performance during surgery

Group	Case no.	before extracorporeal circulation R-R interval sec	QRS width sec	CVP cmH₂O	(LV) Pmax/EDP mmHg	maxdp/dt mmHg/sec	max dp/dt / IP /sec	(RV) Pmax/EDP mmHg/sec	max dp/dt mmHg/sec	max dp/dt / IP /sec	R-R interval sec	QRS width sec	CVP cmH₂O
Group A	1	0.67	0.06	12	72/ 4	580	16	71/ 3	580	16	0.50	0.12	—
	2	0.42	0.05	15	83/ 7	1300	25	84/ 6	1230	35	0.44	0.10	14
	3	0.41	0.07	11	66/ 5	1030	29	63/ 3	770	19	0.42	0.10	11
	4	0.46	0.07	13	101/ 4	2150	44	96/ 3	1770	58	0.56	0.12	8
	5	0.43	0.06	15	90/14	1640	43	85/ 8	1660	37	0.46	0.11	15
	6	0.42	0.07	—	75/ 4	1150	25	78/ 5	1400	29	0.47	0.11	16
	7	0.39	—	13	91/12	1030	18	91/13	1100	18	0.48	—	15
	8	0.36	0.06	12	68/ 5	1270	32	61/ 1	1160	29	0.37	0.11	16
	9	0.38	0.05	11	88/11	2240	48	88/ 9	1760	37	0.38	0.10	—
	10	0.40	0.06	15	88/16	1440	28	91/14	1680	24	0.41	0.09	15
	11	0.31	0.06	12	119/ 2	3880	73	111/ 3	3380	60	0.38	0.10	13
	12	0.43	0.08	13	68/ 5	1280	26	69/ 7	930	18	0.47	0.10	12
	13	0.46	0.06	15	57/ 4	900	25	59/ 5	1070	30	0.47	0.08	13
	14	0.50	—	10	89/ 6	1500	25	87/ 5	1370	22	0.48	—	13
	15	0.48	0.08	14	60/11	1240	30	60/12	1440	33	0.44	0.11	18
	16	—	—	22	—	—	—	—	—	—	0.40	0.10	17
	17	0.46	0.06	16	62/ 8	790	20	54/ 7	540	18	0.47	0.12	18
	18	0.53	0.06	—	85/10	870	14	85/11	790	15	0.58	0.11	13
	19	0.41	0.06	13	90/ 5	1410	28	80/ 8	1310	29	0.53*	0.06	10
	20	—	—	14	60/—	—	—	—	—	—	0.60*	0.11	—
	21	0.47	0.07	11	84/ 6	1240	19	83/ 6	1140	21	0.46	0.10	10
	22	—	—	—	—	—	—	—	—	—	0.36	0.10	15
	23	0.46	0.06	17	—	—	—	—	—	—	0.40	0.06	16
	24	0.77	0.07	16	92/10	1390	25	92/10	1390	25	0.51	0.08	16
	25	0.30	0.10	14	81/ 8	1630	31	81/ 8	1520	32	0.36	0.10	13
	26	0.42	0.07	14	75/ 2	1240	28	73/ 4	1250	38	0.47	0.07	15
	27	0.39	0.08	16	78/12	1020	22	84/ 4	1190	25	0.50*	0.10	15
	28	0.50	0.06	18	—	—	—	—	—	—	0.53	0.12	21
	29	0.40	0.07	11	77/ 4	1120	27	74/ 1	1280	29	0.50	0.08	16
Group B	1	—	—	—	—	—	—	—	—	—	0.70	0.17	—
	2	0.47	0.08	12	79/ 7	930	18	78/11	900	17	0.48*	0.08	18
	3	0.43	0.06	11	91/ 4	1420	33	96/ 3	1700	33	0.43*	0.11	19
	4	0.42	0.07	10	72/ 7	1420	25	73/ 5	1270	33	0.42	0.12	16
	5	0.41	0.06	10	—	—	—	—	—	—	0.40*	0.11	10
	6	0.37	—	18	133/ 7	1740	28	123/ 2	3000	59	0.39	0.08	18
	7	—	—	14	—	—	—	—	—	—	0.44	0.12	17
	8	—	—	—	—	—	—	—	—	—	0.56	0.12	12
	9	—	—	—	—	—	—	—	—	—	0.53*	—	16

† : Orciprenalin was administered during surgery.

†† : Dopamine or isoproterenol was administered during surgery.

* : pacing rhythm

CVP=central venous pressure, EDP=end-diastolic pressure, LOS=low cardiac output syndrome, LV=left ventricle, max dp/dt=maximal rate of rise of ventricular pressure, (max dp/dt)/IP=shortening velocity of contractile elements at max dp/dt, Pmax=ventricular systolic pressure, RV=right ventricle, VmaxT(VmaxD)=maximal shortening velocity of contractile elements measured using total (developed) pressure, Vpm=peak measured shortening velocity of contractile elements. K : constant.

after extracorporeal circulation									
(LV) Pmax/EDP mmHg	max dp/dt mmHg/sec	max dp/dt / IP /sec	K·Vpm /sec	K·Vmax /sec	K·VmaxD /sec	(RV) Pmax/EDP mmHg	max dp/dt mmHg/sec	max dp/dt / IP /sec	remarks
78/ 7	1320	28	45	55	76	80/ 8	1090	26	
92/13	1440	29	41	75	87	68/ 8	800	20	
67/ 4	1160	25	44	50	72	75/ 6	820	19	
100/ 7	1650	26	54	60	74	68/ 6	670	19	
93/12	2100	61	90	90	110	42/ 5	530	21	
132/24	2040	25	39	—	—	36/ 8	590	24	
103/ 9	1100	19	40	60	75	56/ 5	560	26	
88/ 5	1690	39	72	80	110	69/ 7	830	31	
102/ 5	2640	52	—	—	—	64/ 4	1280	44	
84/ 6	1560	49	60	80	93	28/ 1	560	33	
116/ 8	2370	28	41	63	140	37/ 7	610	21	
88/ 6	1200	21	41	60	100	29/ 9	450	17	+
72/11	1500	45	58	80	100	36/ 2	560	23	
110/ 8	2110	47	57	105	110	33/ 1	670	24	
64/ 9	1840	39	34	68	100	68/ 8	960	19	+
83/ 8	1220	21	48	90	100	55/ 3	570	19	+
76/ 8	1360	33	41	70	90	50/ 4	530	20	+
80/10	940	14	30	68	98	63/ 4	570	33	+
118/ 9	1580	20	30	48	94	69/ 6	1140	29	+
101/17	1480	20	29	65	80	75/ 8	1190	23	+
60/ 6	1100	30	50	—	—	80/ 6	960	27	+
89/ 6	2360	41	64	100	135	67/ 2	980	23	
81/ 9	1110	36	42	50	90	82/16	1080	28	
108/ 6	1760	46	100	115	115	96/ 3	1000	28	+
80/13	1230	25	33	55	160	43/ 6	650	26	
86/22	1150	24	30	—	—	60/ 6	720	27	
86/ 2	1700	32	35	85	105	117/16	1590	24	++
78/ 5	950	20	39	52	78	31/ 2	440	28	
70/ 4	880	24	50	60	73	71/ 3	910	28	
65/ 5	990	20	37	50	70	22/ 2	180	9	+ LOS (5 days)
88/—	1180	19	—	—	—	57/26	600	15	+ LOS (7 days)
76/12	1390	27	34	85	100	74/13	820	16	+ LOS (3 days)
65/19	940	26	34	50	75	49/11	640	17	++ LOS (6 days)
68/ 9	910	20	31	46	95	57/ 8	930	52	++ LOS (24 hrs)*
69/12	1320	27	32	53	75	41/ 5	630	30	++ LOS (24 hrs)*
82/12	690	13	23	29	44	85/ 7	820	20	+ LOS (24 hrs)*
72/16	740	18	19	30	55	43/ 5	530	21	+ LOS (24 hrs)*
56/13	580	16	20	42	70	48/12	590	18	+ LOS (6 days)*

( ) : duration

( )* : time to death

applied to the outfulow of the right ventricle in 18 cases. Type I VSD, according to KIRKLIN's classification, was found in one case, Type Ⅱ in 34 cases and Type Ⅰ+Ⅱ in 3 cases[13]. It was closed with a Dacron patch. Aortic cross-clamping was applied as needed, but its duration was limited to less than 20 min for each clamping, and at least 4 min was allotted between two clampings. The mean aortic cross-clamping time for group B was significantly longer than that for group A ($P<0.01$). If atrio-ventricular (A-V) block occurred, a temporary pacing wire was implanted at the anterior wall of the right ventricle and demand-pacing was continued after surgical repair. There were three cases in group A and four cases in group B with pacing rhythm when cardiac functions were measured after ECC. In two patients in group B complete A-V block continued until their early death, and in all the other cases A-V block disappeared within two days.

After surgery, the patients were closely monitored in the intensive care unit for more than two days. Therapeutic measures against LOS included the administration of inotropic agents such as dopamine, orciprenalin, isoproterenol, metaraminol and adrenalin, and diuretics such as furosemide and mannitol, and the use of a pacemaker adjusted to over 120/min in heart rate. Blood pressure was maintained at such a level that urine output would exceed 1.0 ml/kg/hr. Renal insufficiency accompanying advanced LOS (occurring in case 8 of group B) was treated by earlier peritoneal dialysis. Respiration was maintained immediately after surgery by a Bennet MA-Ⅰ (volume-limited) ventilator with high oxygen concentration through an endotracheal tube left inserted. When hemodynamic and respiratory condition became favorable, the endotracheal tube was withdrawn and the patient was accommodated in an oxygen tent. Digilanogen C, diuretics and antibiotics were administered as long as needed after the operation.

Results

Table 4 shows the results of measurement of cardiac function immediately before and shortly after ECC in all the patients, while Table 5 compares these results between group A and B. Left ventricular end-diastolic pressure (LVEDP) increased postoperatively in both groups, but contractility generally improved in group A and deteriorated in group B. Central venous pressure also increased in both groups. Right ventricular end-diastolic pressure (RVEDP) increased, especially in group B. Therefore, Starling curves in both ventricles seemed to be shifted toward the upper right. Decreased contractility in the right ventricle may be due to surgical interventions such as right ventriculotomy and infundibulectomy. The R-R interval, a factor strongly influencing contractility, shortened insignificantly after ECC for both groups. The QRS-width increased considerably after ECC, especially in group B, where it increased from an average of 68 msec to 114 msec.

Table 5 also shows the results of analysis of those data for estimating prognosis. As shown in this table, the larger the Δ-value (standardized distance), the greater the probability of accurately estimating the prognosis. While Δ-values of all the indices measured before ECC were less than 1, indicating that the confidence of an accurate

Table 5. Comparison of myocardial contractility during open heart surgery of tetralogy of Fallot between group A and B

variables of cardiac performance	before extracorporeal circulation							after extracorporeal circulation									
	group A			group B			Δ	group A			group B			probability of belonging to group A			Δ
	mean	s. d.	no.	mean	s. d.	no.		mean	s. d.	no.	mean	s. d.	no.	95%	50%	5 %	
Heart Rate (/min)	141	22	26	148	11	5	0.307	133	16	29	130	21	9				0.154
QRS-width (msec)	66	11	24	68	10	4	0.116	98	17	27	114	28	8				0.764
CVP (cmH_2O)	14.0	2.6	26	12.5	3.1	6	0.539	14.4	2.8	22	15.8	3.2	8				0.474
[LV]																	
Pmax (mmHg)	80.0	14.4	25	93.8	27.3	4	0.845	89.1	17.1	29	71.2	9.7	9	92.2	70.4	—	1.137
EDP (mmHg)	7.3	3.9	24	6.3	1.5	4	0.284	9.3	4.9	29	12.3	4.2	8				0.626
max dp/dt (mmHg/sec)	1389	652	24	1378	334	4	0.019	1536	466	29	970	279	9	1568	999	—	1.311
max dp/dt / IP (/sec)	29.2	12.5	24	26.0	6.3	4	0.269	31.7	11.7	29	20.7	5.0	9	32.1	21.9	—	1.041
K·Vpm*	1.622	0.210		1.608	0.160			1.656	0.138		1.446	0.114		1.668	1.454		
(/sec)	41.9		22	40.6		4	0.072	45.3		28	27.9		8	46.6	28.4	—	1.569
K·VmaxT*	1.798	0.193		1.805	0.138			1.841	0.107		1.654	0.159		1.977	1.658	1.505	
(/sec)	62.8		20	63.8		2	0.038	69.3		25	45.1		8	94.8	45.5	32.0	1.543
K·VmaxD*	1.947	0.155		1.943	0.139			1.984	0.091		1.850	0.116		2.111	1.832	1.687	
(/sec)	88.5		20	87.7		2	0.022	96.4		25	70.8		8	130	67.9	48.6	1.375
[RV]																	
Pmax (mmHg)	79.2	13.6	24	92.5	22.6	4	0.894	60.3	21.4	29	52.9	18.5	9				0.355
EDP (mmHg)	6.5	3.6	24	5.3	4.0	4	0.339	5.9	3.6	29	9.9	7.0	9				0.828
max dp/dt (mmHg/sec)	1371	553	24	1718	915	4	0.654	804	283	29	638	217	9				0.616
max dp/dt / IP (/sec)	29.0	11.6	24	35.5	17.4	4	0.522	25.2	5.6	29	22.0	12.6	9				0.410

K : constant.

* : Asterisks show the parameters for which discriminant functions were calculated by logarithmic conversions. Small letters show the logarithmic values.

CVP - central venous pressure, Δ=standardized distance, EDP=end-diastolic pressure, LV=left ventricle, max dp/dt=maximal rate of rise of ventricular pressure, (max dp/dt)/IP - shortening velocity of contractile elements at max dp/dt, no.=number, Pmax - ventricular systolic pressure, RV=right ventricle, s. d.=standard deviation, VmaxT (VmaxD)=maximal shortening velocity of contractile elements measured using total (developed) pressure, Vpm - peak measured shortening velocity of contractile elements.

prognosis made on the basis of these values was slim, indices measured after ECC yielded fairly high Δ-values : 1.569 for K•Vpm, 1.543 for K•VmaxT, 1.375 for K•VmaxD, 1.311 for max dp/dt, 1.137 for Pmax and 1.041 for (max dp/dt)/IP of the left ventricle. The distributions of the values of these indices in Figure 3 showed good separations between group A and B. The probability for a good prognosis was 95% when the values of left ventricular function were as follows : Pmax, 92.2 mmHg; max dp/dt, 1,568 mmHg/sec; (max dp/dt)/IP, 32.1/sec; K•Vpm, 46.6/sec; K•VmaxT, 94.8/sec and K•VmaxD, 130/sec. The probability was 50% when these values were approximately as follows : Pmax, 70.4 mmHg; max dp/dt, 999 mmHg/sec; (max dp/dt)/IP, 21.9/sec; K•Vpm, 28.4/sec; K•VmaxT, 45.5/sec and K•VmaxD 67.9/sec. In such cases, careful attention should be paid to

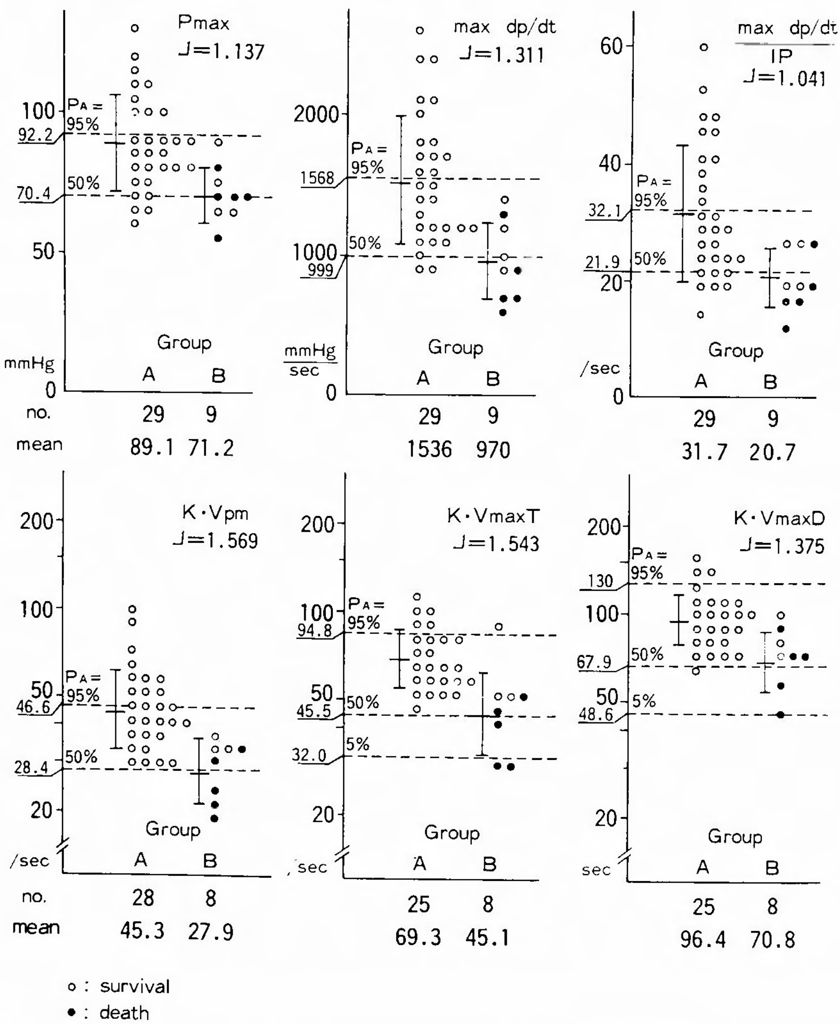

Fig. 3. Comparison of left ventricular contractility affter extracorporeal circulation between group A and B

Each horizontal dotted line represents 95%, 50% or 5% probabilty (PA) for group A. Δ = standardized distance, K : constant.

postoperative management of the patients. In the calculation of the discriminant function, logarithmic values of Vpm and Vmax were used because of their exponential distributions. These values yielded larger Δ-values than did ordinary numerical values. The values indicated by small letters in this table show these logarithmic values.

As for right ventricular function, the Δ-value obtained from each index was less than 1, which indicated that these indices had minimal significance in predicting postoperative course.

Discussion

The major determinants of prognosis are the extent of cardiac impediment due to the operation and the management of postoperative care in addition to the seriousness of the disease in general. In order to achieve good results of the operation, it is important to obtain the precise information concerning cardiac performance as early as possible after correction. Many authors have reported about cardiac performance after the correction of tetralogy of Fallot. KIRKLIN described it as comparing left ventricular function with right ventricular function[14]. JARMAKANI, et al reported about the left ventricular function in children with tetralogy of Fallot using cineangiogram late after surgery[11]. But there were few reportes about cardiac function obtained from pressure measurement shortly after surgery in the operating room[4]. This study showed that the measurement of cardiac function of the left ventricle shortly after ECC was more useful for assessing the prognosis than that of the right ventricle which is considered to be a very important factor for succesful surgery of tetralogy of Fallot.

The contractility indices of which the postoperative measurements yielded fairly large Δ-values were Vpm, VmaxT and VmaxD of the left ventricle In tetralogy of Fallot, the postoperative decrease in left ventricular function generally occurs in the following cases :

(1) Left ventricle is hypoplastic and left ventricular failure occurs due to volume overload.

(2) Cardiac muscles are injured by improper ECC, prolonged aortic cross-clamping or intermittent air embolism into the right coronary artery.

(3) There is a decrease in cardiac output due to postoperative right heart failure, surgical heart block, etc., which may also cause the decrease in coronary blood flow.

(4) Circulatory blood volume is decreased.

(5) Blood gases, acid-base balance and electrolyte balance are out of the physiological range due to various causes, such as respiratory and renal insufficiency[3,11,12,14,25,28,29].

Following is a discussion of the causes of markedly decreased cardiac function in group B patients. The ratios of RV-max dp/dt to LV-max dp/dt (RV/LV-max dp/dt ratio) before ECC in two mortality patients (cases 3 and 6) were large : 1.2 and 1.7 respectively. The former patient died due to LOS and the latter due to pulmonary edema, both of which possibly occurred because of left ventricular failure due to hypoplasty of the left ventricle. This was suggested by the angiocardiogram of case 6. In cases 1, 3, 5, 6 and 7, total of aortic cross-clamping time amounted to over 30 min; at least one clamping time lasted for 15 min. Particularly in cases 3 and 7 it was noted that the value of serum glutamic oxaloacetic transaminase on the day following surgery was over 500 units, suggesting destruction of muscle[6]. The average of bypass time of cases 2, 3 and 7 exceeded 100 min, which was much longer than that of group A (76 min). Postoperative heart failure may result from pressure overload of the right ventricle due to residual pulmonary stenosis, where right ventricular contractility is promoted by the increase of afterload and RV/LV-pressure ratio is high. Cases 3, 5, 7 and 9 may belong to this category. It may also result from excessive incision of right ventricular muscle or from insertion of an unreasonably large patch in the right ventricular outflow tract. These factors may accout for the remarkably low RV/LV-pressure ratio, RV/LV-max dp/dt ratio and RV-max dp/dt of case 1. In addition, it may result from volume overload due to pulmonary regurgitation induced by improper commissurotomy or using transvalvular outflow patch. Namely, fatal postoperative right heart failure may occur irrespective of high or low values of the right ventricular function measured immediately after ECC. This may explain that Δ-values of contractility indices of the right ventricle obtained after ECC were small. The excessive excision of ventricular muscle during correction of pulmonary stenosis in relation to right heart failure has often been discussed[14]. It is suggested that the degree of elimination of pulmonary stenosis should be determined by taking into accout not only RV/LV-pressure ratio, but also the factors related to contractility such as RV/LV-max dp/dt ratio and RV-max dp/dt.

In case of wide QRS on electrocardiogram, the spread of excitation to all prtions of the ventricular walls is so slow that the ventricular contraction cannot produce effective pumping action. The QRS-widths in 6 cases of group B (cases 3 and 5 : in pacemaker rhythm) were more than 0.11 sec.

Since contractility is affected by various kinds of drugs, especially inotropic drugs, ideally any drug should be withheld before measuring cardiac functions, but this is often impossible clinically. In this study, however, the improvement of contractility due to these drugs did not adversely affect the estimation of prognosis; there were marked drops in cardiac function for group B in spite of the administration of inotropic agents, particularly in large amounts in cases 4, 5 and 6.

In order to forecast postoperative heart failure and treat it at an early stage, the measurements of cardiac function should be performed as early as possible after surgery. On the other hand, the later the measurements are performed, the greater the reliability of their values in determining prognosis. In this study, myocardial contractility was measured in most cases more than 15 minutes after the termination of ECC, when hemodynamic conditions seemed to have stabilized. Myocardial contractility usually increases above normal during partial bypass circulation, which has an assisting-pump-effect on cardiac action. Therefore, high values of contractility could be recorded even for a patient with unfavorable prognosis due to the remaining effect of perfusion in its early post-ECC period. On the other hand, even for a patient with favorable prognosis, inappropriate ECC could cause a temporary decrease in contractility, which would gradually return to normal. The author postulates that the former situation occurred for cases 2, 3 and 6 in group B with comparatively large increases in cardiac function, and the latter situation for cases 18, 28 and 29 in group A with decreases.

Conclusion

Instantaneous assessment of cardiac performance during open heart surgery was made on 38 pediatric patients with tetralogy of Fallot : they were classified into group A with favorable prognosis (29 cases) and group B with poor prognosis (9 cases including 5 deaths). Statistical analysis with the linear discriminant function revealed that the indices of myocardial contractility measured after extracorporeal circulation yielded distinct differences in the distribution of data between these two groups; the Δ-value (standardized distance), which was related to the predictability of prognosis, was large by the order of Vpm (peak measured velocity of contractile elements), Vmax based on total pressure (VmaxT), Vmax based on developed pressure (VmaxD), max dp/dt, (max dp/dt)/IP (IP=isovolumic pressure) and Pmax (systolic pressure) of the left ventricle. The values which predicted favorable prognosis with a probability of 95 (50)% were Pmax, 92.2 (70.4) mmHg; max dp/dt, 1,568 (999) mmHg/sec; (max dp/dt)/IP, 32.1 (21.9)/sec; K•Vpm, 46.6 (28.4)/sec; K•VmaxT, 94.8 (45.5)/sec and K•VmaxD, 130 (67.9)/sec, where K was a constant. This study suggests that the evaluation of myocardial contractility during open heart surgery is useful for estimating prognosis and establishing the therapeutic policy.

Acknowledgement

The author wishes to thank Prof. Y. Hikasa, the Second Department of Surgery, Kyoto University School of Medicine, and Prof. H. Koie, the First Department of Surgery, Hirosaki University School of Medicine, for their valuable suggestions and cooperations in preparing this manuscript.

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和文抄録

ファロー四徴症における開心術時心機能評価，特に予後との関係について

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一般に開心術時の心機能評価には，血圧，静脈圧，心拍出量などの指標が用いられている．一方，max dp/dt をはじめ心収縮性を表わす指標も臨床的に非常に有用と思われるにもかかわらず，その計測の煩わしさあるいは即時評価の難しさのため，ほとんど用いられていない．著者は手術室においてそれらの計測結果を容易に即時評価できるよう，デジタル表示できるアナログ演算器を用いた装置を制作し，術時における心機能を測定した．本研究は，術時の心機能と術後経過の良否との関係より，心機能を表わすどの指標が，術後経過を予測し早期治療を可能にする上で役立つかを検討する目的で行なった．

方法　心機能，特に心収縮性を表わす指標として max dp/dt，(max dp/dt)/IP (IP＝isovolumic pressure)，Vpm (＝peak measured shortening velocity of contractile elements)，VmaxT (Vmax based on total pressure, Vmax＝maximal shortening velocity of contractile elements)，VmaxD (Vmax based on developed pressure) を選び，これらを圧力トランスデューサに直接21G金属針を装着し心室穿刺により得られた心室内圧より求めた．対象は，天理よろづ相談所病院にて昭和49年より51年までに行なわれた12才以下のファロー四徴症根治術67例（死亡8例）の中，心機能の計測を行ない得た38例とした．これらを術後経過良好の29例および術後著明な低心拍出量症候群を示した術後経過不良の9例（死亡5例）の2群に分類し，判別関数を用いて分析した．

結果および結論　術後経過を予測する場合，その信頼性は両群の分布の差を示す標準化距離 Δ（＝standardized distance）が大きい程高くなるが，術前の心機能を表わす各指標に対するΔ値および術後の右心機能のそれは非常に小さく，これらは術後経過の予測にほとんど関与しないことが明らかとなった．一方，術後の左心機能の各指標に対するΔ値は大きく，Vpm，VmaxT，VmaxD，max dp/dt，(max dp/dt)/IP，Pmax（＝peak ventricular pressure）の順であった．また95%（50%）の確率で術後経過が良好となる値として，Pmax 92.2 (70.4) mmHg，max dp/dt 1,568 (999) mmHg/sec，(max dp/dt)/IP 32.1 (21.9)/sec，K･Vpm 46.6 (28.4)/sec，K･VmaxT 94.8 (44.4)/sec，K･VmaxD 130 (67.9)/sec が得られた．（Kは定数）