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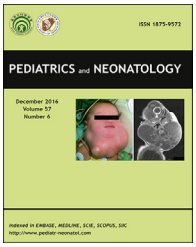

ORIGINAL ARTICLE

Impact of Extracorporeal Membrane Oxygenation on Acute Fulminant Myocarditis-related Hemodynamic Compromise Arrhythmia in Children

Kuan-Miao Lin [a,†], Ming-Hsiu Li [b,†], Kai-Sheng Hsieh [c], Hsuan-Chang Kuo [c], Ming-Chou Cheng [c], Jiunn-Jye Sheu [d], Ying-Jui Lin [c,*]

[a] *Department of Pediatrics, Chang Gung Memorial Hospital, Chiayi, Taiwan*
[b] *Department of Family Medicine, Chang Gung Memorial Hospital, Chiayi, Taiwan*
[c] *Division of Critical Care Medicine, Department of Pediatrics, Kaohsiung Chang Gung Memorial Hospital and Chang Gung University College of Medicine, Kaohsiung, Taiwan*
[d] *Department of Cardiovascular Surgery, Kaohsiung Chang Gung Memorial Hospital and Chang Gung University College of Medicine, Kaohsiung, Taiwan*

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atrioventricular block;
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pediatrics;
ventricular tachycardia

Background: Acute fulminant myocarditis (AFM) commonly presents as abrupt cardiogenic shock with or without dysrhythmia. This study evaluated the impact of extracorporeal membrane oxygenation (ECMO) on AFM-related hemodynamic compromise dysrhythmias. We also reported the clinical experience of AFM at our hospital.
Methods: Eighteen children diagnosed with AFM were enrolled. Demographic variables, laboratory data, and clinical courses were reviewed. Thirteen surviving patients with hemodynamic compromise arrhythmia [complete atrioventricular block (CAVB) or ventricular tachycardia (VT)] during hospitalization were divided into Group A (ECMO group; $n = 7$) and Group B (non-ECMO group; $n = 6$).
Results: The overall survival rate was 78% (14/18). There were no cases of mortality after ECMO was introduced at our hospital. Common symptoms at diagnosis included general malaise (94%), gastrointestinal symptoms (89%), chest pain (56%), shortness of breath (56%), and seizure/syncope (56%). In addition to abnormal cardiac enzyme levels, all patients displayed elevated alanine aminotransferase levels during early disease stages. Electrocardiography at diagnosis revealed dysrhythmia in 15 patients, namely, CAVB in 11 patients (61%) and VT in four

* Corresponding author. Division of Cardiology, Department of Pediatrics, Kaohsiung Chang Gung Memorial Hospital and Chang Gung University College of Medicine, 123, Ta-Pei Road, Niao-Sung District, Kaohsiung City 833, Taiwan.
E-mail addresses: rayray@adm.cgmh.org.tw, linyingjui@gmail.com (Y.-J. Lin).
† Kuan-Miao Lin and Ming-Hsiu Li contributed equally to this work.

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patients (22%). During hospitalization, the dysrhythmia shifted from CAVB to VT in 10 patients and from sinus tachycardia to VT in one patient. New episodes of VT were common (overall occurrence rate, 83%). Although myocardial damage and dysfunction were more severe in Group A, the time to rhythm recovery in this group was shorter than that in Group B (median time, 1.7 days vs. 7.35 days, $p = 0.045$). All surviving patients had normal ventricular function at 6-month follow-up.

Conclusion: Hemodynamic compromise arrhythmia is common in AFM patients and may cause rapid deterioration. Simply correcting sinus rhythm is not always sufficient because of myocardium instability. Timely use of ECMO can improve the survival rate and shorten the time to recapture sinus rhythm in AFM patients with CAVB or VT.

1. Introduction

Acute fulminant myocarditis (AFM) is an inflammatory disease of the myocardium that presents with nonspecific symptoms such as initial flu-like symptoms with an onset of <14 days.[1,2] AFM is rare but life threatening in children because of its rapid and aggressive progression to congestive heart failure or cardiogenic shock.[1,3–7] Intensive cardiovascular support including the administration of inotropic agents, pacing devices, mechanical ventilation, or mechanical circulatory support can be lifesaving. AFM is commonly associated with hemodynamic compromise dysrhythmias such as complete atrioventricular block (CAVB) or ventricular tachycardia (VT), which present with severe symptoms. Such dysrhythmias can arise at the first visit or following inotropic or antiarrhythmic agent administration. In some cases, pacemaker implantation or cardioversion is not effective in correcting cardiogenic shock, and emergency extracorporeal membrane oxygenation (ECMO) may be required. The prognosis and survival rate of pediatric patients with AFM have improved with recent advances in mechanical circulatory support and teamwork in pediatric units.[1,8–12] The goal of this study was to retrospectively review the impact of ECMO on AFM-related hemodynamic compromise dysrhythmias. The clinical presentations, cardiac rhythm, criteria of diagnosis, treatment, and outcome of pediatric patients with AFM were also reviewed.

2. Materials and methods

2.1. Study population

From July 1998 to October 2012, 18 children (younger than 18 years) with a diagnosis of AFM were enrolled in this study. The study was retrospective, and data collection was approved by the Institutional Review Board of Chang Gung Memorial Hospital.

The diagnostic criteria for AFM were as follows: (1) acute heart failure (left ventricular dysfunction or arrhythmia with hemodynamic compromise) and rapid deterioration; (2) history of flu-like illness within the preceding 2 weeks; (3) no history of cardiomyopathy or heart disease; and (4) elevation of cardiac enzyme levels [troponin I (TnI) or creatine kinase (CK)-MB].[1,2,11,13] Children with acute cardiopulmonary failure with fulminant enterovirus 71 infection were excluded because their heart failure may not have been caused by myocarditis, but may have possibly been associated with neurogenic cardiac damage.[14] One patient with a drug reaction exhibiting eosinophilia and systemic syndrome-related fulminant myocarditis, who was treated successfully with ECMO, was excluded because of the distinct pathologic etiology of the disease.[15]

2.2. Data collection

The collected data included demographic data, clinical history, initial presentation on admission, and the results of a series of laboratory tests. The record of clinical presentation included fever, general malaise, fatigue, dizziness, chest pain, shortness of breath, gastrointestinal (GI) tract symptoms (nausea, vomiting, or abdominal pain), and neurologic signs (seizure or syncope). Hypotension was identified as systolic blood pressure $\leq$70 mmHg + (age × 2) in children more than 1 year old.

Laboratory investigations for complete white blood cell counts and the levels of C-reactive protein, glucose, aspartate aminotransferase (AST), alanine aminotransferase, blood urea nitrogen, creatinine, CK, CK-MB, and TnI were performed at diagnosis and during hospitalization.

Electrocardiography (ECG) and transthoracic echocardiography were performed to evaluate rhythm and ventricular function, respectively, at diagnosis, during hospitalization, and before discharge. Owing to their critical conditions, cardiac catheterization and endomyocardial biopsy were not performed in any patients.

The indication for implantation of a temporary pacemaker was CAVB with hypotension or low cardiac output. The indications for ECMO included (1) ventricular arrhythmia refractory to antiarrhythmic agents or defibrillation, (2) ventricular dysfunction with persistent hypotension that could not be restored by conventional therapy and maximal dosages of inotropic agents, and (3) CAVB status post-pacemaker implantation with unstable hemodynamics.

Hemodynamic compromise arrhythmia was identified as CAVB, VT, or ventricular fibrillation with signs of low cardiac output. Of the 14 surviving patients, 13 experienced

hemodynamic compromise arrhythmia during hospitalization. These patients were divided into two groups: Group A (ECMO group; $n = 7$) and Group B (non-ECMO group; $n = 6$). Demographics, laboratory data, clinical course, treatment, and prognosis were compared between the two groups to assess differences between therapies and the advantages of treatment options.

2.3. Statistical analysis

All statistical analyses were performed using Statistical Package for Social Sciences version 19 (SPSS, Chicago, IL, USA). Nonparametric data were expressed as the mean ± standard error or median (range). Demographic details, laboratory data at admission, variables of clinical courses, and treatment were analyzed. Clinical parameters were compared as categorical variables between the two groups using the Chi-square test or Fisher's exact test, as appropriate. Quantitative variables as comparisons of serial differences were performed using the Mann–Whitney *U* test. A p value of <0.05 was considered significant.

3. Results

3.1. Clinical manifestation at diagnosis

The median age of the 18 children (9 boys and 9 girls) was 11.0 years (range, 4.0–15.3 years). Their median body weight was 34.0 kg (range, 16.5–92.0 kg).

The clinical symptoms and physical findings identified in the initial medical evaluation included general malaise or dizziness (94%); GI symptoms such as poor appetite, nausea, vomiting, and abdominal pain (89%); fever in the previous 2 weeks (78%); chest pain/palpitation (56%); shortness of breath (56%); and neurologic signs such as syncope and seizure (56%).

Laboratory data at diagnosis are presented in Table 1. Leukocytosis (white blood cell count exceeding 11,000/mm^3) was detected in seven patients (39%). Fourteen patients (78%) had mild C-reactive protein elevation (≥5 mg/dL), but only three patients had C-reactive protein levels >50 mg/dL. Hyperglycemia with a random serum glucose level exceeding 140 mg/dL was detected in 11 patients (61%). Hypoperfusion of end organs was evaluated by liver enzyme, blood urea nitrogen, and creatinine levels. All 18 patients had abnormal AST levels at diagnosis (median, 173 U/L; range, 59–12,624 U/L), and 13 patients (72%) had levels of three times the upper limit of the normal range, with six patients (33%) transiently exhibiting AST levels of 10 times the upper limit of the normal range during hospitalization. Of the 14 surviving patients, eight had an abnormal alanine aminotransferase level at diagnosis, and only one (7%) had a level of three times the upper limit of the normal range. Six patients (33%) had impaired renal function at diagnosis. One patient (Case No. 15) received continuous venovenous hemodialysis during ECMO support on the 4th day of admission to treat rapidly deteriorating renal function. The patient's renal function had recovered at discharge. Elevation of at least one cardiac enzyme including TnI and/or CK-MB/CK was identified at diagnosis. Of the 18 patients, 12 had an elevation in absolute TnI levels (range, 13.59–104.56 ng/mL). Absolute CK-MB levels were elevated in all patients (range, 17.0–273.3 ng/mL), nine (50%) of whom also had abnormal CK-MB/CK ratios (≥5%). Cardiac enzyme levels, liver function, and renal function returned to normal in all surviving patients before discharge.

Table 1 Demographics and laboratory findings of patients with acute fulminant myocarditis at diagnosis.

Patient no.	Onset y	Sex	Age (y)	BW (kg)	WBC count (1000/μL)	CRP (mg/L)	BUN/Cr (mg/dL)	AST/ALT (U/L)	Sugar (mg/dL)	TnI (ng/mL)	CK-MB/CK (U/L)	CK-MB/CK (%)
1	1998	F	10.9	30	21.4	27.9	95/5	12,624/ND	203	ND	47.1/3384	1.4
2	1998	M	7.8	30	6.0	3.4	9/ND	91/ND	254	ND	47.9/1020	4.7
3	1999	M	5.9	21	10.1	26.6	20/ND	75/ND	122	ND	17/417	2.4
4	2000	M	8.6	26	9.3	3.4	16/0.9	173/30	101	ND	219/1751	12.5
5	2001	F	6.8	28	12.4	9.6	23/ND	145/ND	140	ND	40.3/737	5.5
6	2002	M	10.1	35	11.4	3.4	11/1.2	155/43	164	>50	44.0/957	4.6
7	2003	M	11.7	34	9.1	30.6	15/0.6	298/ND	ND	ND	122.4/4491	2.7
8	2003	M	14	92	12.8	90.9	8/0.9	59/27	ND	>50	43.7/849	5.1
9	2004	F	13.4	42	5.1	11.4	16/0.8	171/51	127	>50	45.7/1121	4.1
10	2005	F	7.9	25	13.8	10.4	16/1	518/178	252	>50	273.3/15,961	1.7
11	2005	F	10.2	40	13.8	2.2	21/0.8	105/24	126	21.96	32/764	4.2
12	2006	F	12.2	60	8.0	11.9	12/1.3	239/55	286	>22.78	45.6/2093	2.2
13	2010	F	15	43	8.2	75.7	18/0.76	381/66	181	104.56	229.2/3140	7.3
14	2011	F	11.3	27	11.6	5.8	16/0.48	85/18	107	13.59	72.8/480	15.2
15	2011	F	11	45	6.7	6.4	16/0.79	217/98	149	58.51	187.7/ND	
16	2011	M	12.3	50	6.5	6.1	16/1.05	189/77	260	34.37	86.8/1024	8.5
17	2011	M	15.3	57	9.7	72	20/1.87	189/116	282	25.3	76.2/606	12.6
18	2012	M	4	16.5	7.9	8.4	33/0.88	149/28	214	30.75	95.2/1421	6.7

ALT = alanine aminotransferase; AST = aspartate aminotransferase; BUN = blood urea nitrogen; BW = body weight; CK = creatine kinase; CK-MB = creatine kinase MB isoenzyme; Cr = creatine; CRP = C-reactive protein; F = female; M = male; ND = not determined; TnI = troponin I; WBC = white blood cell.

3.2. Twelve-lead ECG and transthoracic two-dimensional echocardiography at diagnosis and during hospitalization

ECG at diagnosis revealed that 11 patients (61.1%) had CAVB. Specifically, four patients (22.2%) had VT, and three patients (16.7%) had sinus tachycardia with ST segment change and T-wave inversion. Cardiac rhythm shifts to new episodes of VT commonly followed pacemaker implantation, pacing, or inotropic agent infusion. VT during hospitalization occurred in 15 patients (83.3%). Overall, 10 of 11 patients with initial CAVB and one of three patients with sinus tachycardia at diagnosis later developed transient VT. The overall incidence of hemodynamic compromise arrhythmia was 88.9% (Figure 1).

Standard transthoracic two-dimensional echocardiography was performed in 16 patients because of hemodynamic instability at diagnosis. The median left ventricular ejection fraction in these patients was 28.4% (range, 12.3—69.6%). The median fractional shortening was 13.4% (range, 5.8—38.9%). The left ventricular diastolic dimension, as measured by M-mode echocardiography in the parasternal long axis view and corrected using body surface area, did not exceed the upper limit, as a median of 40.3 mm (range, 35.2—59.0 mm) was recorded. The qualitative degree of mitral regurgitation (MR) was assessed in 16 patients, with moderate MR being noted in one patient and trivial to mild MR in 14 patients. The remaining patient had no MR at diagnosis.

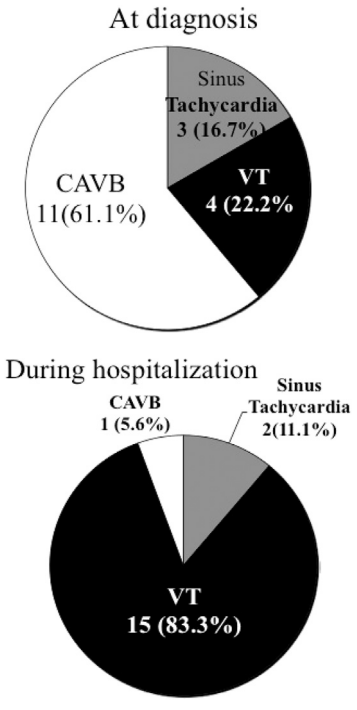

Figure 1 Electrocardiographic presentation at diagnosis and during hospitalization. CAVB = complete atrioventricular block; VT = ventricular tachycardia.

3.3. Clinical course and treatment during hospitalization

All patients required a high dosage of inotropic agents (dopamine, dobutamine, milrinone, epinephrine, isoproterenol, or atropine) to maintain blood pressure and cardiac function at admission. Cardioversion and antiarrhythmic agents such as amiodarone or lidocaine were used to treat VT. Of the 18 patients, eight (44%) received immune modulation therapy, four received intravenous immunoglobulin at a dose of 1 g/kg, which was repeated on the following day, and four received steroid therapy (methylprednisolone: 30 mg/kg/dose, maximum 1 g/dose) for three consecutive days. Cardiopulmonary resuscitation was performed for eight patients (44%) (Table 2).

Four patients with VT at admission received cardioversion and antiarrhythmic agents. Of these patients, two (Case Nos. 5 and 10) died of refractory VT without the timely use of ECMO, whereas the other two (Case Nos. 12 and 18) received ECMO support and survived with recovered heart function.

Of the 18 patients, 11 had CAVB at admission, 10 of whom developed VT later. VT was recorded in seven patients after temporary pacemaker implantation. Of these patients, four (Case Nos. 1, 6, 9, and 11) were stabilized with antiarrhythmic agents, two (Case Nos. 14 and 16) required ECMO support because of refractory VT, and one (Case No. 4) died without ECMO support. Dysrhythmias shifted from CAVB to VT in three patients under treatment with inotropic agents before pacemaker implantation. Of these, two patients (Case Nos. 15 and 17) received ECMO support, and the remaining patient (Case No. 3) recovered soon after the administration of antiarrhythmic agents. ECG in the latter patient (Case No. 3) revealed occasional VT and second-degree atrioventricular block alternatively after lidocaine injection. The time to recapture sinus rhythm was also relatively short (0.8 days). The patient did not undergo pacemaker implantation because of the relatively stable condition following treatment with conventional therapies and the short duration of dysrhythmia.

Three patients had sinus tachycardia at admission. The condition shifted to VT in one of these patients (Case No. 13) after the infusion of inotropic agents, and this patient received ECMO support. Meanwhile, the condition of one patient (Case No. 8) stabilized under inotropic therapy, and the remaining patient died despite therapy to control refractory heart failure within 12 hours.

Seven patients received ECMO support. The median time from admission to ECMO cannulation was 4 hours (range, 1—21 hours). The cannulation sites for ECMO were the femoral artery and vein in five patients and the right carotid artery and internal jugular vein in two patients. The indication of weaning off ECMO was evaluated in all patients after recapturing the sinus rhythm with evidence of improvement in left ventricular contractility. All patients were successfully weaned off ECMO with a median time of 98 hours (range, 70—141 hours). Complications of ECMO included pseudoaneurysm at the cannulated site in one patient and minor neurologic injury caused by peripheral neuropathy in two patients.

Table 2 Clinical treatment and outcome of patients with acute fulminant myocarditis.

Patient no.	Rhythm at diagnosis	LVEF(%) at diagnosis	Pacemaker	VT after pacing or inotropes	CPR	IVIG	Steroid therapy	ECMO (h)	Recapture of sinus rhythm (d)	Outcome	EKG at discharge	LVEF at discharge (%)	LVEF at 6 mo (%)
1	CAVB	17.8	+	+	–	–	–	—	7.3	Survived	NSR	84.2	59.7
2	CAVB	54	+	–	–	–	–	—	11.8	Survived	NSR	—	73.5
3	CAVB	65	–	+	+	–	–	—	0.8	Survived	NSR	68.6	58.7
4	CAVB	58	+	+	+	+	–	—	—	Died	—	—	—
5	VT	ND	–	+	+	–	–	—	—	Died	—	—	—
6	CAVB	24.4	+	+	–	+	–	—	8.6	Survived	RBBB	59.7	69.6
7	Sinus tachycardia, ST-T depression	37.3	–	–	+	–	–	—	—	Died	—	—	—
8	ST-T change in I, II, AVF, AVL, V3-V6	30.6	–	–	–	–	–	—	—	Survived	NSR	53.6	66.0
9	CAVB	69.6	+	+	–	–	–	—	5.0	Survived	RBBB	72.1	66.0
10	VT	ND	–	+	+	–	–	—	—	Died	—	—	—
11	CAVB	52.8	+	+	–	–	–	—	7.4	Survived	RBBB	78.1	64.8
12	VT	17.1	–	+	–	+	–	70	1.5	Survived	NSR	65.0	61.1
13	Sinus tachycardia, ST elevation in V123, inverted T in II, III AVF	16.3	–	+	–	–	+	141	2	Survived	NSR	55.3	66.1
14	CAVB	25.7	+	+	+	+	–	132	4.3	Survived	NSR	47.2	60.0
15	CAVB	26.1	–	+	–	–	+	98	3.2	Survived	RBBB	77.8	64.1
16	CAVB	46.3	+	+	+	–	+	92	1.5	Survived	NSR	70.3	66.1
17	CAVB	12.3	–	+	+	–	+	97	1.2	Survived	NSR	49.8	68.0
18	VT	15.9	–	+	–	–	–	107	1.7	Survived	NSR	46.5	59.8

CAVB = complete atrioventricular block; CPR = cardiopulmonary resuscitation; ECMO = extracorporeal membrane oxygenation; EKG = electrocardiogram; IVIG = intravenous immunoglobulin; LVEF = left ventricular ejection fraction; NSR = normal sinus rhythm; RBBB = right bundle branch block; ST-T = EKG ST segment and T wave change; VT = ventricular tachycardia.

Regarding the laboratory data in the groups, the CK-MB level at diagnosis was significantly higher in Group A than in Group B (median: 86.8 U/L vs. 44.9 U/L, $p = 0.01$). Left ventricular function, as evaluated by left ventricular ejection fraction, was weaker in Group A than in Group B at diagnosis (median: 17.1% vs. 53.4%, $p = 0.032$). However, the time to recapture sinus rhythm was shorter in Group A than in Group B (median time: 1.7 days vs. 7.35 days, $p = 0.045$) (Table 3). Thus, although myocardial damage and dysfunction were more severe in Group A, the time to rhythm recovery was shorter in Group A than in Group B.

Meanwhile, 78% of patients survived to hospital discharge. All seven patients who were supported with ECMO survived. Of the four nonsurviving patients, three died due to VT. ECG performed before discharge in surviving patients revealed a normal sinus rhythm in 10 patients and right bundle branch block in four patients. There were no statistically significant differences between the groups regarding left ventricular contractility before and 6 months after discharge. All surviving patients exhibited recovery of normal ventricular function at the 6-month follow-up visit. No patients received long-term oral medication to control heart failure or required heart transplantation.

4. Discussion

Based on the published literature, myocarditis is difficult to categorize into acute nonfulminant and acute fulminant types, and endomyocardial biopsy is required for pathologic classification and predictions of prognosis.[1–3] Endomyocardial biopsy is not routinely performed in patients suspected to have AFM because of the risks of the procedure in patients in critical condition.[16] In this study, AFM was diagnosed on the basis of patient history, characteristics of acute heart failure or arrhythmia with hemodynamic compromise and rapid deterioration, and a recent (within 2 weeks) history of flu-like illness. The differential diagnosis of AFM, cardiomyopathy, or other heart diseases can be evaluated by echocardiography. Left ventricular cavity size (left ventricular diastolic dimension) can be used to evaluate left ventricular dimensions, and the dimensions of this area are relatively normal in patients with suspected fulminant myocarditis.[17,18] In addition, brain natriuretic peptide and cardiac enzyme (TnI or CK-MB) levels during the acute stage can help differentiate between acute nonfulminant myocarditis, AFM, and cardiomyopathy.

In addition to a rapid and aggressive course, AFM can initially present with nonspecific symptoms and signs that pose diagnostic challenges for physicians. Chien et al[19] described hypotension and Stokes–Adam seizures as more specific manifestations of acute myocarditis with CAVB. Hsiao et al[5] also mentioned GI symptoms as common initial presentations and predictors of poor prognosis. Among studied laboratory tests, Freedman et al[20] reported that AST testing might be a useful adjunctive analysis for patients with early-stage AFM. In our study, early GI symptoms and neurologic signs were important clues of end-organ hypoperfusion. In some cases, these chief complaints were more specific and they appeared earlier than chest pain, palpitation, or dyspnea when patients visited the emergency department. Our laboratory findings illustrated that AST measurement was the most sensitive and nonspecific test excluding cardiac enzyme analyses, with all patients displaying abnormal findings at the initial diagnosis. In such cases, careful evaluation of heart rhythm and other signs of heart failure are important before obtaining data for specific cardiac enzymes.

Dysrhythmias are common and severe in patients with AFM. Abe et al[21] described CAVB as the development of conduction system injury via inflammation and reported that 14 (58%) of 24 patients with acute myocarditis had

Table 3 Admission laboratory values and clinical course of surviving patients with hemodynamic compromise arrhythmia according to the receipt of ECMO.

	Group A: ECMO ($n = 7$)	Group B: Non-ECMO ($n = 6$)	p
Age (y)	12.2 (4.0–15.3)	10.2 (5.9–14.0)	0.116
BW (kg)	45.0 (16.5–60.0)	32.5 (21.0–42.0)	0.153
WBC (k/μL)	8.5 (6.5–11.6)	10.8 (5.1–21.4)	0.475
CRP (mg/dL)	8.4 (5.8–75.7)	7.4 (2.2–27.9)	0.317
AST (U/L)	189 (85–381)	130 (75–12,624)	0.252
Cr (mg/dL)	0.80 (0.48–1.87)	1.00 (0.80–5.00)	0.340
CK-MB (U/L)	86.8 (45.6–239.7)	44.9 (17.0–47.9)	0.010
CK (U/L)	1222.5 (480.0–3140.0)	988.5 (417.0–3384.0)	0.631
LVEF at diagnosis (%)	17.1 (12.3–46.3)	53.4 (17.8–69.6)	0.032
VT episodes	7 (100%)	5 (83%)	0.462
CPR episodes	3 (43%)	1 (17%)	0.559
Pacemaker implantation	2 (29%)	5 (83%)	>0.99
Duration of returning to sinus rhythm (d)	1.7 (1.2–4.3)	7.35 (0.8–11.8)	0.045
LVEF before discharge (%)	55.3 (46.5–77.8)	72.1 (59.7–84.2)	0.062
LVEF after 6 mo (%)	64.1 (59.8–68.0)	65.4 (58.7–73.5)	0.886

Continuous variables are expressed as the median (interquartile range).
AST = aspartate aminotransferase; BW = body weight; CK = creatine kinase; CK-MB = creatine kinase-MB; CPR = cardiopulmonary resuscitation; Cr = creatine; CRP = C-reactive protein; ECMO = extracorporeal membrane oxygenation; LVEF = left ventricular ejection fraction; VT = ventricular tachycardia; WBC = white blood cell.

advanced atrioventricular block, CAVB, or VT at the acute stage. Teele et al[1] also documented abnormal rhythm, as shown by VT or CAVB in 11 (55%) of 20 patients with AFM on admission, and 80% of patients developed additional hemodynamic compromise arrhythmia during hospitalization. In our study, the overall occurrence rate of hemodynamic compromise arrhythmia admission was 88.9% in patients with AFM, most of whom (83%) had VT.

The mechanism underlying VT resulting from AFM with CAVB or sinus tachycardia remains unclear. Klein et al[22] found that inflammatory processes in the myocardium can directly lead to fluctuations in membrane potential. Ectopic pacemakers, late potentials, and re-entry as a result of inhomogeneous stimulus conduction can develop because of fibrosis and scaring of myocardial tissue, and secondary hypertrophy and atrophy of myocytes. Furthermore, left ventricular dysfunction may aggravate wall tension, increase myocardial oxygen consumption, and diminish coronary reserve, increasing the risk of arrhythmias.[23] The combination of myocardial instability and left ventricular dysfunction may explain the common and sudden induction of VT after inotropic agent or isoproterenol administration in our study.

In some cases, antiarrhythmic agents or cardioversion is not effective in resolving VT and preserving heart function. As reported in the previous literature, ECMO was instituted emergently in our patients because of refractory cardiogenic shock and end-organ dysfunction.[6,8–11,13,24–26] ECMO facilitates ventricular recovery by reducing myocardial wall tension, increasing coronary perfusion pressure, and providing adequate systemic perfusion. During ECMO support, the dose of inotropes can be decreased to prevent overload on the myocardium in the acute stage. Better cardiac support may promote the recovery of cardiac conduction. This may explain the shorter duration of dysrhythmias in the ECMO group than in the non-ECMO group in our study.

Despite having a more aggressive disease course and a higher risk of life-threatening disease, patients with AFM had better outcomes in terms of recovery of ventricular function and atrioventricular conduction than those with the nonfulminant type. Among the surviving patients in this study, all cases of arrhythmias resolved within 2 weeks, with no patients requiring a permanent pacemaker or heart transplantation. Meanwhile, three of the four nonsurviving patients, who died of VT and heart failure refractory to medical treatment, were treated prior to the introduction of ECMO support. Owing to advances in critical care and the introduction of ECMO in the clinic, the survival and long-term prognosis of patients with AFM have increased.[27] In our study, there were no cases of mortality among patients with AFM at our hospital after ECMO was introduced if support was provided in a timely manner.

This study has several limitations. First, the data and clinical findings were collected retrospectively via chart reviews. In addition, we enrolled patients with AFM strictly to distinguish them from patients with the nonfulminant type. This may have led to a small sample size, which limits complex statistical analysis.

In conclusion, hemodynamic compromise arrhythmia is common in patients with AFM, and it can cause rapid deterioration during hospitalization. Simply correcting rhythm is not always sufficient because of myocardium instability. Timely use of ECMO can improve survival rates and shorten the time to recapture sinus rhythm in AFM patients with CAVB or VT. Among our surviving patients, all arrhythmias resolved, and no patient required a permanent pacemaker or heart transplantation.

Conflicts of interest

The authors declare no conflicts of interest relevant to this article.

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