Subarachnoid Hemorrhage and Myocardial Damage
Clinical and Experimental Studies

Kiyotaka Sato, MD, Takashi Masuda, MD,
and Tohru Izumi, MD

Summary

Subarachnoid hemorrhage (SAH) due to aneurysmal rupture is frequently complicated by cardiopulmonary episodes, including sudden death. We investigated the pathogenesis of cardiopulmonary complications from clinical observation of 715 cases with SAH. There was transient left ventricular asynergy in 9.4% (67/715) of the cases, which consisted of mechanical heart failure and myocardial necrosis. Plasma catecholamine concentration was higher in these patients compared with those without left ventricular asynergy. Transient left ventricular asynergy was considered to result from myocardial derangement: “a panic myocardium,” due to a sudden burst of catecholamine. Concerning arrhythmia in SAH, cases with life-threatening arrhythmia, such as ventricular tachycardia or ventricular fibrillation, had higher concentrations not only of plasma catecholamine but also of serum CK-MB, myosin light chain and troponin T, compared with patients who had no ventricular arrhythmia. This implies that life-threatening arrhythmia in SAH would result from myocardial damage due to catecholamine. We devised a novel animal model of SAH in order to clarify the relation between sympathetic nervous activity and myocardial damage immediately after the onset of SAH. The animal experiments showed that sympathetic nervous activity as well as cardiac contractility were transiently elevated, but cardiac function subsequently declined. Serum CK-MB was increased from the onset of SAH and a high value was maintained throughout the entire experimental period. In conclusion, extraordinary transient enhancement of sympathetic nervous activity induces myocardial damage resulting from what is characterized by “a panic myocardium.” (Jpn Heart J 1999; 40: 683–701)

Key words: Subarachnoid hemorrhage, Left ventricular asynergy, Pulmonary edema, Catecholamine, Life-threatening arrhythmia

As first reported by Wisman (1939), SAH has been recognized as being complicated by various cardiac symptoms and pulmonary edema. The tra-
ditional explanation of these complications has been functional derangement,\textsuperscript{2-4} such as an electrolyte imbalance or autonomic nervous system disturbance. Pulmonary edema was considered to be the result of retention of lymph fluid within the lung tissue due to enhanced permeability of alveolar-capillary septa.\textsuperscript{5,6} However, echocardiograms recorded in the early stage of SAH have shown left ventricular asynergy, giving rise to a new concept\textsuperscript{7-13} that a cardiogenic factor may play an important role in pulmonary edema, which until now had been explained by a neurogenic theory.

Among disorders, SAH is a leading cause of sudden death, and it has a high incidence in causing intrinsic cardiopulmonary arrest, especially among young and middle-aged persons.\textsuperscript{14,15} The mechanism of sudden death in SAH had been explained by disturbance of the respiratory center due to organic cerebral changes, especially vascular damage.\textsuperscript{16,17} However, recently it has been pointed out\textsuperscript{15} that life-threatening arrhythmia occurring immediately after the onset of SAH can contribute to sudden death.

Electrocardiographic abnormalities, pulmonary edema and the occurrence of sudden death are associated with myocardial changes in SAH, although the features of and the pathogenesis of the myocardial damage in SAH have not been clarified. The present article describes clinical observations in cases with SAH accompanied by myocardial damage and also reports the mechanisms of damage from the viewpoint of clinical and experimental examinations.

**Clinical Cases with Left Ventricular Asynergy (A Panic Myocardium)**

First we will present a representative case of myocardial damage in the early stage of SAH. A 28-year-old woman without any past history was admitted in an unconscious state. The grade of consciousness was 300 on the Japan Coma Scale (JCS) and Grade V by the WFNS classification.\textsuperscript{18} She expectorated pinkish foaming sputa. Her blood pressure was 120/60 mmHg, pulse was irregular at 80 beats/min, and wet rales were audible in both lung fields. The CT scan of her brain revealed evidence of thick subarachnoid clots around the brain stem, and the chest X-ray film showed a cardiothoracic ratio of 46% and massive pulmonary edema. Electrocardiographic findings were prolongation of the QT interval (corrected QT time of 0.48 sec), ST-segment elevation on leads I, aVL, V2, and V3, and frequent premature ventricular contractions. An echocardiogram revealed circumferential left ventricular asynergy in the mid-portion of the left ventricle except for the base and apex (Figure 1. A: end-diastole, B: end-systole). Coronary arteriography was performed because acute myocardial infarction was suspected 5 hours after the onset of SAH. Left and right coronary arteries were normal and no coronary spasm was observed (Figure 1. C: right coronary artery,
Figure 1. Two-dimensional echocardiogram and coronary arteriogram on admission in a patient. The echocardiogram was recorded from the apical long-axis view (A = end-diastole; B = end-systole) and arrows show left ventricular asynergy in wide regions. C is the right coronary artery and D is the left coronary artery. LA is the left atrium and LV is the left ventricle.

Figure 2. Left ventriculograms in the acute stage (A = end-diastole; B = end-systole) and just before discharge from the hospital (C = end-diastole; D = end-systole) in a patient with SAH. Dyskinesias observed in the acute stage in segments 2 and 4 according to AHA classification 19 had improved at discharge.
D: left coronary artery). A left ventriculogram showed dyskinesis in segments 2
and 4 according to the AHA classification, and the calculated left ventricular
ejection fraction was small, at 26% (Figure 2. A: end-diastole, B: end-systole). On
the second day, serum CK increased to a maximal value of 719 IU/l, MB-CK
isoenzyme was 3.5%, and myosin light chain was elevated to 8.0 ng/ml. There-
after, left ventricular asynergy gradually improved and had almost resolved by
the twelfth day. Ejection fraction was 65% as determined by a ventriculogram on
Day 27. Coronary spasms were not induced by intracoronary administration of
acetylcholine.

Based on extensive clinical experience, in addition to that involving the
above-described case, we have noticed characteristic differences in left ventricular
asynergy in SAH from that of other cardiac diseases. SAH induces markedly
enhanced sympathetic nervous activity, so that transient left ventricular asynergy
occurs. The deranged myocardium behaves as in a panic due to a sudden burst
of catecholamine. Therefore we applied the term “panic myocardium” to left
ventricular asynergy that accompanied SAH. 13)

As to the term left ventricular asynergy, there is both a stunned myocard-
dium and hibernating myocardium. Both are associated with myocardial
ischemia from an etiological standpoint, and therefore are different from that
involved in SAH. Some authors 20) have used the term “neurogenic stunned myo-
cardium” for left ventricular asynergy after SAH, but they did not provide diag-
nostic criteria or the relation to myocardial ischemia. The use of the terms
“stunned myocardium” or “hibernating myocardium” to describe left ventricular
asynergy in SAH is not adequate, because these terms are associated with myo-
cardial ischemia or changes in the coronary arteries.

Our diagnostic criteria of a panic myocardium are 1) left ventricular
asynergy occurring after the onset of SAH and 2) gradual improvement of the
asynergy over time. Background factors were investigated using clinical cases
with SAH. The subjects were 715 of the 1180 cases of aneurysmal SAH admitted
within 24 hours after onset to Kitasato University Hospital from April 1, 1986 to
March 31, 1995. The study excluded 465 cases with cardiopulmonary arrest on
arrival and a history of arrhythmia and cardiac, respiratory, and renal diseases.
The diagnosis of SAH was made by typical clinical symptoms and brain CT scan
findings. All patients underwent routine echocardiography and were divided into
2 groups: those with a panic myocardium (+ PM group) and those without a
panic myocardium (−PM group). The + PM group underwent daily echographic
examination to confirm gradual improvement of the asynergy. The + PM group
consisted of 67 (9.4%) of the 715 patients (18 males, 49 females; mean age,
57 ± 12 years) in the acute stage of SAH. The −PM group consisted of 648
patients (285 males, 363 females; mean age 56 ± 13 years). The frequency of
occurrence of a panic myocardium was not related to age among these patients, and probably had no relationship to conditions related to age such as coronary atherosclerosis or myocardial ischemia. However, the frequency of a panic myocardium was significantly higher in women than in men \((p < 0.01)\). Since it is known\(^{11}\) that a panic myocardium frequently occurs in severe cases of SAH, further study will be needed concerning gender differences in the pathophysiological findings in SAH, including cardiopulmonary arrest. A panic myocardium was found at a high percentage in patients with a severe grade of SAH, when the clinical severity grade was determined on admission according to the WFNS classification and by the extent of SAH according to the Fisher classification.\(^{21}\) However, there were no differences in the extent and severity of SAH between the + PM group and the −PM group among our patients.\(^{11}\) In aneurysmal SAH, the more severe the clinical symptoms on admission were, the poorer the prognosis.\(^{11}\) The severity of SAH by the WFNS classification is based on neurological findings, not on organ complications. Since patients in the + PM group were almost all ranked as grades IV or V of the WFNS classification, a panic myocardium appears most likely to be a complication of severe SAH.

On the other hand, it has been reported\(^{22,23}\) that a hypothalamic lesion was related to electrocardiographic changes or myocardial disturbance when the relation between the location of the intracranial lesion and cardiac symptoms was investigated. However, our previous study\(^{11}\) did not show any significant relation between the incidence of a panic myocardium and the extent and severity of SAH according to the Fisher classification. When the location of a ruptured aneurysm was examined in 67 cases of a panic myocardium, the aneurysm was not restricted to the region of the basilar artery and there was no specific pattern of distribution. The occurrence of a panic myocardium could not be explained by the location or volume of hemorrhage of SAH or the site of the ruptured aneurysm. It is presumed that an unknown mechanism has a role in producing a panic myocardium in addition to the actual site of the hemorrhage.

**ROLE OF CORONARY SPASM**

A panic myocardium occurs in the acute stage of SAH and improves with the passage of time.\(^{6,13,20,24}\) In this section, we will discuss the contribution of coronary spasms to the occurrence of a panic myocardium. Yokota et al.\(^{25}\) confirmed coronary spasms by post-operative ergonovine infusion in one of 2 cases with ST-segment elevation during surgery for cerebral artery aneurysm in SAH. However, there have been no reported cases\(^{9,10,24}\) in which coronary artery spasms were demonstrated by coronary angiography when left ventricular asynergy was present in SAH. It is presumed possible that coronary spasms had
improved by the time coronary angiography could be performed and only left ventricular asynery remained. Some authors\textsuperscript{9,20,24} have suggested that a mechanism similar to a stunned myocardium following acute myocardial ischemia is a precursor of a panic myocardium. We investigated the severity of a panic myocardium and its distribution in the left ventricle in 67 patients with a panic myocardium in order to clarify the contribution of changes in the coronary arteries. We investigated the severity of a panic myocardium and its distribution in the left ventricle in 67 patients with a panic myocardium, in order to clarify the contribution of the changes in the coronary artery. As a result, a panic myocardium was observed in all of the circumferential walls of the left ventricle and in both anterior and poster-inferior walls in 48 of the 67 cases. This indicates that the distribution of a panic myocardium in the left ventricle does not correspond to the area of a single coronary artery in the majority of clinical cases.\textsuperscript{9} In our previous study, emergency coronary angiography did not reveal occlusion and spasms of a coronary artery in 11 cases with electrocardiographic abnormality and a panic myocardium.\textsuperscript{8-10} Thus, it can be considered that there is no evidence of coronary spasms as a precursor of a panic myocardium in SAH; although there is typically a delay in performance of coronary angiography after onset and the provocation test for coronary spasms is not ideal. It is considered\textsuperscript{8-10} that coronary spasms are not the cause of a panic myocardium, at least in the coronary arteries visible by coronary angiography.

**Mechanical Myocardial Failure**

Pulmonary edema produced in central nervous system diseases has to result from a neurogenic cause, which is due to enhanced permeability of the capillary-alveolar septum.\textsuperscript{5,6,26} In SAH, on the other hand, a mechanical myocardial failure has been pointed out.\textsuperscript{7,9,11,12} Ducker et al.\textsuperscript{27} demonstrated that cardiac output decreased, peripheral vascular resistance increased, and pulmonary edema occurred following the elevation of pulmonary arterial and venous pressure when an elevation in intracranial pressure was experimentally produced in chimpanzees. This shows that not only the enhancement of pulmonary vascular permeability but also pump failure of the heart can produce pulmonary edema when there is an elevation of intracranial pressure.

For our previous study, 37 patients with SAH complicated with a panic myocardium underwent examination by Swan-Ganz catheterization on admission.\textsuperscript{11} Echocardiographic parameters as well as hemodynamics were taken in these patients to determine the pathophysiology of mechanical myocardial failure. Pulmonary pressure and pulmonary capillary wedge pressure were elevated in all patients with a panic myocardium, and the mean cardiac index was
2.6 ± 0.7 l/min/m² (Figure 3). The left ventricular ejection fraction was decreased to 37 ± 13% when it was calculated with the area-length method using a long-axis two-dimensional echocardiogram of the left ventricle. However, the state of a panic myocardium improved as time elapsed and the left ventricular ejection fraction increased significantly to 65 ± 9% (p < 0.001) an average of 6 ± 4 days later in 25 patients except for 12 cases who had died. The pulmonary pressure and pulmonary capillary wedge pressure became normal within several days and cardiac index increased to 4.6 ± 0.9 l/min/m² on average (p < 0.001). Thus, it is clear that the myocardium was involved in mechanical failure in the acute process from the onset of SAH, because of left ventricular asynergy, low cardiac output and the elevation of pulmonary capillary wedge pressure.

On the contrary, many cases of SAH without left ventricular asynergy showed an increase in cardiac output and decrease in systemic vascular resistance, indicating a distinct difference in cardiovascular response in the acute stage between groups with and without asynergy.28
DYNAMICS OF CATECHOLAMINE

The concentration of catecholamine was shown to increase in blood and urine in the acute stage of SAH, and values were higher in cases with a poor prognosis and abnormal electrocardiograms compared to those without these factors present. We measured levels of plasma noradrenaline, plasma adrenaline and 3-methoxy-4-hydroxy-phenylethylene glycol (MHPG), which is a metabolite of brain noradrenaline, as indexes of sympathetic nervous activity after the onset of SAH. These values were compared with grades of clinical severity in SAH according to the WFNS classification in 343 patients. Plasma noradrenaline, adrenaline and MHPG concentrations were significantly elevated in all patients of Grade V of the WFNS classification, which indicates the most severe type of SAH. It was found that the more severe the neurological symptoms, the higher both the central and peripheral sympathetic nervous activity was. When the patients with SAH were classified into + PM and −PM groups, the values of plasma noradrenaline, adrenaline and MHPG concentration were significantly higher (p < 0.001, p < 0.01, p < 0.001, respectively) in the former than in the latter group, although values were high in both groups (Figure 4). It is considered that the high concentrations of catecholamine were suddenly released in a burst immediately after the onset of SAH producing circulatory disturbances in

![Graph](image)

**Figure 4.** Relation between a panic myocardium and the plasma catecholamine concentration. PM (−) = 267 patients without a panic myocardium; PM (+) = 67 with a panic myocardium. MHPG is 3-methoxy-4-hydroxy-phenylethylene glycol. Data are mean ± SD, *p < 0.001, **p < 0.01.
the peripheral coronary arteries, which then induced myocardial damage, bringing about a panic myocardium. A large amount of noradrenaline disturbs the mechanics of myocardial contraction via the myocardial β-receptor, thus promoting the occurrence of a panic myocardium.

**Electrocardiographic Abnormalities**

Electrocardiographic abnormalities observed in the acute stage of SAH are a prolongation of QT interval, abnormality of ST-T wave, abnormal Q wave and arrhythmias. Arrhythmias include sinus tachycardia, sinus bradycardia, atrial fibrillation, A-V block, ventricular premature contraction, ventricular tachycardia, and ventricular fibrillation. The incidence of arrhythmia was variable from 50% to 100%, depending on the report. This difference may depend on the time when these variables were measured, because they included data acquired more than 24 hours after the onset of SAH. Thus, these results may not exactly reflect the true incidence of electrocardiographic abnormalities in the early stage of SAH. As shown in the electrocardiograms of a 42-year-old woman in Figure 5, for example, ST-segment changes vary depending on the time elapsed after the onset of SAH. The electrocardiogram showed an elevation of the ST-segment on leads I, II, aVL, aVF, and V2-V6 one hour after onset.

![Figure 5. Electrocardiographic changes in the acute stage of a patient with SAH. A = ECG at one hour after onset of SAH; B = that at 3 hours; C = that at 6 hours.](image-url)
Figure 6. Life-threatening arrhythmias in a patient with SAH. A = ECG when a rupture occurred 2 hours after admission; B = ECG when another rupture occurred during artificial respiratory control.

(Figure 5A), but the ST-segment elevation improved at 3 hours (Figure 5B) and then the ST-segment became negative at 6 hours (Figure 5C). Because ST-T waves are extremely changeable within a short time immediately after the onset of SAH, care should be taken concerning the time of the examination in evaluating electrocardiograms in patients with SAH.

It has been reported that aneurysmal SAH induces sudden death and that sudden death occurred before hospital admission in 15% of patients with SAH. On the contrary, sudden death is rarely observed in hypertensive intracranial hemorrhage and cerebral infarction in spite of cerebrovascular disease, and therefore, sudden death is characteristic of SAH. Life-threatening arrhythmia is considered a cause of sudden death. Figure 6 shows representative electrocardiographic changes in a 26-year-old woman. Her electrocardiogram showed a sudden change from sinus tachycardia to ventricular tachycardia of 190 beats per minute when recurrence of aneurysmal rupture occurred (Figure 6A), and cardioversion stopped the ventricular tachycardia. The patient was on a respirator with tracheal incubation when another aneurysmal rupture occurred. Immediately after the second episode, continuous ventricular tachycardia occurred after a short run of ventricular premature contractions (Figure 6B). This case shows that life-threatening arrhythmia can occur following aneurysmal rupture.
with the risk of sudden cardiac arrest despite adequate respiratory support.

The mechanism of electrocardiographic abnormalities as a complication of SAH has been discussed from several viewpoints, such as electrolyte disturbances, the influence of aneurysmal rupture on the hypothalamus, and myocardial damage due to excessive catecholamine stimulation. We investigated whether arrhythmia observed in the acute stage of SAH was induced by a functional abnormality of the sympathetic nervous system or by an organic change such as myocardial damage. We divided the 677 patients with SAH into 3 groups according to findings by electrocardiographic monitoring 24 hours after admission. Group A consisted of 281 patients without abnormal findings; Group B, 274 patients with supraventricular arrhythmia including A-V block; and Group C, 122 with ventricular arrhythmia consisting of either ventricular premature contraction, ventricular tachycardia, or ventricular fibrillation. There was no significant difference in the distribution of ruptured basilar artery aneurysms among the 3 groups. Therefore, a vascular lesion surrounding the hypothalamus seems not to contribute to the occurrence of arrhythmia.

The plasma noradrenaline concentration at admission was significantly increased in Groups B and C ($p < 0.05$, $p < 0.01$, respectively) compared with that of Group A. Group C had a significantly higher concentration of noradrenaline.

**Figure 7.** Catecholamine concentration and occurrence of arrhythmia. A = 281 patients without arrhythmia; B = 274 with supraventricular arrhythmia including A-V block; C = 122 with ventricular arrhythmia of ventricular premature contractions, ventricular tachycardia or ventricular fibrillation. MHPG is 3-methoxy-4-hydroxyphenylethylene glycol. Data are mean ± SD, **$p < 0.01$, *$p < 0.05$.**
than Group B ($p < 0.01$) (Figure 7). The adrenaline concentration was also significantly increased in Groups B and C ($p < 0.01$ for both) compared with that of Group A. Also, the plasma MHPG concentration was significantly higher in Groups B and C ($p < 0.05$, $p < 0.01$, respectively) compared with that of Group A (Figure 7). Furthermore, the peak values of serum CK-MB, myosin light chain and troponin T concentration after admission were significantly higher in Group C than in Groups A and B ($p < 0.01$, $p < 0.01$, respectively for all parameters). This indicates an extreme enhancement of central and peripheral sympathetic nervous activity in Group C. The cause of life-threatening arrhythmia, such as ventricular tachycardia and ventricular fibrillation, may be considered to result from myocardial damage$^{10,27}$ due to the catecholamine released from the sympathetic nerve terminals.

**HISTOLOGICAL CHANGES OF THE MYOCARDIUM**

Concerning the relationship between intracranial disorders and myocardial damage, there have been many reports$^{22,38}$ of histological changes in autopsy studies of cerebrovascular diseases, traumatic brain hemorrhage, and brain tumors. Smith et al.$^{39}$ first reported the histology of subendocardial hemorrhage in the autopsied hearts of SAH patients in 1954. Since that time, contraction band

**Figure 8.** Pathohistological findings of the left ventricular myocardium of a case with SAH. A shows ruptures of myocardial fibers in the left ventricle and B super contraction band necrosis. Data are mean ± SD, **$p < 0.01$, *$p < 0.05$.**
necrosis, myocardial fusion and fragmentation of myocardial fibers have been reported. Doshi et al. pointed out the relationship between hypothalamic lesions and histological myocardial changes and stated that central damage of the autonomic nerve system contributes to myocardial damage.

Our previous reports described that the hearts of patients with SAH complicated with a panic myocardium and those of patients with cardiopulmonary arrest demonstrated a diffuse-wide fragmentation of myocardial fibers (Figure 8A) and contraction band necrosis (Figure 8B). From the findings described above, it is likely that both irreversible myocardial necrosis and reversible and functional myocardial damage are mixed together in the acute stage of SAH. As a result, a panic myocardium would be produced as demonstrated by echocardiographic examination. However, the extent of myocardial necrosis would be relatively small, because the elevation of serum concentrations in CK-MB, myosin light chain and troponin T are slight. This is supported by histological findings of only sporadic myocardial necrosis. Since a panic myocardium is reversible and subsides over time in surviving patients, it is likely that the myocardial change in SAH is not due to organic change related to myocardial necrosis but to a functional myocardial disturbance.

**Experimental Animal Model**

A novel experimental animal model was devised to demonstrate the above-mentioned clinical findings in SAH. The former model of SAH was produced by injection of autologous blood into the subarachnoid space to induce SAH. However, this model does not reflect the truc pathophysiological features of aneurysmal SAH. In clinical cases, it is considered that systemic blood pressure directly influences intracranial pressure by the rupture of an aneurysm and that the subsequent hemorrhagic change influences cardio-hemodynamic function. In the old model, the elevation of intracranial pressure occurs first by the infusion of autologous blood into the subarachnoid space, and this causes important influences on cardiac and hemodynamic function. Our new model is considered to overcome that shortcoming and to reflect exactly the pathophysiological changes in SAH. We observed sequential changes of sympathetic nervous activity and myocardial damage immediately after the onset of SAH using this model.

Using beagle dogs weighing about 15 kg, a micro-catheter was introduced into a vertebral basilar artery under fluoroscopic guidance, and, after confirmation of the Willis ring by arteriography (Figure 9A), the basilar artery was perforated with an adequate guide wire throughout the catheter, producing artificial SAH (Figure 9B). Extra-vascular contrast medium was observed by arteriogram (Figure 9C). Autopsy revealed subarachnoid hemorrhage over a

wide surface of the brain (Figure 9D) and severe bleeding on the basilar portion of the brain (Figure 9E).

Sympathetic nervous activity and the grade of myocardial damage were observed from just before the onset of SAH to 180 minutes after onset in 13 dogs. Figure 10 depicts serial pressure changes before and after SAH in a representative SAH dog. The intracranial pressure increased to 210 mmHg 5 minutes after the onset of SAH and subsequently aortic pressure and pulmonary arterial pressure increased to 270/170 mmHg and 41/20 mmHg, respectively. At 2 or 3 minutes after SAH, frequent ventricular premature contractions were observed.

It is considered that the present model represents the most severe form of SAH in humans, because the extent of hemorrhage is large and intracranial pressure is markedly higher than in most clinical cases. Both plasma noradrenaline and adrenaline concentrations 5 minutes after SAH rose more than 10-fold compared with those before SAH (p < 0.01 for both), and 30 minutes afterwards, the values had returned to the previous values (Figure 11). Serum CK-MB was elevated significantly (p < 0.05) 5 minutes after the onset and continued to increase until 180 minutes later (Figure 11). Thus, the present model seems excel-
Figure 10. Temporal changes of ECG and pressures before and after the onset of SAH. Abbreviations: ECG = electrocardiogram; AoP = systemic arterial pressure; PAP = pulmonary arterial pressure; CVP = central venous pressure; ICP = intracranial pressure; SAH = subarachnoid hemorrhage.

Lent because it truly simulates sympathetic nervous activity in the acute stage of human SAH.

Left ventricular function was studied using an ultrasonic crystal and Swan-Ganz catheter in the present model. The left ventricular motion and cardiac output significantly increased by about 30% ($p < 0.05$, $p < 0.01$, respectively) 5 minutes after SAH. However, both those values significantly decreased ($p < 0.01$ for both) by 30% to 50% at 30 to 120 minutes after SAH. This indicates that this animal model simulates the clinical cases of SAH complicated with a panic myocardium when we investigated cardiac and hemodynamic parameters.

**Conclusions**

In previous reports, cardiac symptoms in SAH have been discussed from the viewpoints of electrocardiographic abnormalities, pulmonary edema, myocardial damage, etc. However, their mechanisms were not only poorly investigated, but were explained only by the neurogenic theory without consideration of other possible mechanisms. We have elucidated that left ventricular asynergy
associated with SAH, which was referred to as a panic myocardium, resulted from both organic myocardial necrosis and functional myocardial damage. Based on clinical observations, we devised a novel animal model that simulated human SAH. Further investigation will be needed to clarify the pathophysiology of cardiovascular symptoms in SAH using this model as well as the mechanism and prevention of myocardial damage, which would be induced by excessive release of intrinsic catecholamine. The present animal model may be expected to elicit important information on organ preservation, because patients with brain death due to SAH could become candidates for organ donation for transplantation.
ACKNOWLEDGMENTS

The authors would like to thank Prof. Takashi Ohwada and Associate Prof. Ikkoku Souma and Takao Kitahara of the Department of Emergency and Critical Care Medicine, Kitasato University School of Medicine for their valuable advice, Associate Prof. Sadahiko Kuwao of the Department of Pathology and Dr. Shinichiro Yamamoto of the Department of Emergency and Critical Care Medicine and Dr. Narihisa Matsuyama of the Department of Clinical Pathology for their excellent support.

REFERENCES


