Cardiac Abnormalities in Subarachnoid Hemorrhage: A Resumé

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Abstract:
There have been numerous reports demonstrating electrocardiographical changes secondary to subarachnoid hemorrhage, consisting of atrial and ventricular arrhythmias, alterations in QRS configuration, Q-T interval prolongation, T-wave abnormalities, and S-T segment elevation or depression. Abnormalities of cardiac muscle and subendocardial hemorrhage have been seen in patients dying of subarachnoid hemorrhage. Experimental work has shown that electrical impulses in the sympathetic nervous system and hypothalamus produce most of these changes, and the implication is that these changes can be prevented by sympathetic blockade. Pulmonary edema also has been shown to occur frequently after subarachnoid hemorrhage, and again the sympathetic nervous system is implicated in the pathophysiology. Studies done illustrating these points are discussed and conclusions drawn with reference to therapy.

Introduction
Cardiac abnormalities are present in more than 50% of patients with subarachnoid hemorrhage. The purpose of this article is to bring together current information concerning the effects of subarachnoid hemorrhage on the heart, and to point out its significance in terms of therapy of the individual patient with subarachnoid hemorrhage. The effect of other cerebral lesions on the heart also will be discussed.

The first published association of an abnormal EKG with cerebral hemorrhage was reported by Byer et al. in 1947. A 37-year-old woman with a two-year history of recurrent chest pain and two episodes of loss of consciousness developed sudden left hemiparesis and had bloody spinal fluid under increased pressure. The EKG showed a prolonged Q-T interval and large T-waves in standard leads II and III, which disappeared within nine days. This report was followed by that of Levine in 1953, who mentioned a 69-year-old woman with subarachnoid hemorrhage and EKG changes simulating an acute myocardial infarction, but with a normal heart at autopsy. The pertinent EKG findings are summarized in table 1 along with other significant electrocardiographical studies in subarachnoid hemorrhage. Since that time EKG changes have been found in a variety of intracranial disturbances, mainly meningitis, brain tumors, intracerebral hemorrhage, cerebral infarcts and head trauma. Pulmonary edema also has been found frequently in association with intracerebral lesions. Air encephalography and lumbar spinal subarachnoid hemorrhage also have been shown to produce EKG changes. In some cases EKG changes have been mistaken for those of myocardial infarction with resulting inappropriate treatment, especially the use of anticoagulants or delay of surgery. Therefore, it is important to determine whether or not there is primary heart disease and subarachnoid hemorrhage or reversible cardiac abnormalities secondary to subarachnoid hemorrhage. Studies illustrating these points will be reviewed and postulated mechanisms of the cardiac abnormalities will be discussed.

Clinical Studies
In an early review by Burch (1954) of patients with cerebral hemorrhage, subarachnoid hemorrhage, or unclassified cerebrovascular accidents, 17 had EKGs. Abnormalities found were prolonged Q-T intervals, large T-wave amplitude similar to ischemic T-wave, and prominent U-waves. Improvement in the EKG occurred with clinical improvement. No electrolyte determinations were made, not enough serial EKGs were done, and no specific conclusions were drawn. In the next report in 1956, nine of 12 patients with cerebral vascular accidents had intracerebral or subarachnoid hemorrhage. It is important to note that 11 of the 12 had primary heart disease. However, all 12 had EKG evidence of prolonged Q-T intervals and 11 had inverted T-waves in the standard and precordial leads not accounted for by electrolyte disturbances. A

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Supported by U.S. Public Health Service Grant Nos. NS06655 and NS11101.
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CARDIAC ABNORMALITIES IN SUBARACHNOID HEMORRHAGE

medullary or hypothalamic control mechanism was postulated.

An unusual case was reported in 1959\(^1\) in a patient presenting with chest pain and an EKG suggestive of acute anterior wall myocardial infarction without Q-waves. The patient was anticoagulated and sent home in three weeks. She was readmitted and in seven days had surgery for a ruptured right internal carotid artery aneurysm. The patient died three days after surgery and had a normal myocardium and coronary arteries at autopsy. This illustrates a patient with subarachnoid hemorrhage and EKG changes, but without evidence of heart disease postmortem.

The study by Millar and Abildskov\(^2\) of 40 young patients with central nervous system lesions revealed that of 119 EKGs, 89 were abnormal; on the other hand, Surawicz\(^3\) reviewed EKGs of 10,000 consecutive patients hospitalized for all types of stroke and found only 46 patients with a type of EKG abnormality similar to that described by Burch.\(^4\) In yet another study a "gross excess" of coronary occlusion was found by Sarner and Crawford\(^5\) in men aged 45 to 59 dying from ruptured intracranial aneurysms. However, in another investigation\(^6\) 15 of 21 cases of subarachnoid and intracerebral hemorrhage were found to have Q-T prolongation and S-T segment depression in their EKGs not explicable by other factors. Hence, one might conclude that EKG changes in this study were secondary to the intracranial hemorrhages.

Surgical manipulation of the circle of Willis in five consecutive cases has been demonstrated by Pool\(^7\) to produce arrhythmias, T-wave and S-T segment changes on the EKG. He suggested the pathogenesis as hypothalamic effects of stimulation of the intrinsic nerves of the blood vessels of the circle of Willis.

In an attempt to correlate site of cerebral lesion with EKG alterations, Cropp and Manning\(^8\) described 29 cases of subarachnoid hemorrhage. In 22 of 28 with angiography the site of bleeding was demonstrated. Nineteen had craniotomy, and of the eight who died, five were autopsied. Two-thirds of the EKG tracings were suggestive of myocardial damage, and 15 had T-wave abnormalities suggestive of myocardial ischemia. Four of the five autopsied cases had abnormal EKGs, two simulating an acute myocardial infarction, but all five had normal coronary arteries at autopsy. In 11 of 15 cases the site of bleeding was in the anterior fossa. The authors hypothesized that lesions of the orbital surface of the frontal lobes near the carotid siphon may produce vagal stimulation, thereby causing EKG abnormality. The cortical representation of the vagus nerve is thought to be located in the orbital surface of the frontal lobes.\(^9\)

To define the role of the autonomic nervous system causing cardiac abnormalities in subarachnoid hemorrhage, various studies have been carried out recently. The use of atropine, stellate block, and carotid sinus pressure was evaluated by Shuster\(^10\) and shown to have no effect on preventing the EKG changes induced by subarachnoid hemorrhage. Nineteen patients with subarachnoid hemorrhage were studied. The pertinent EKG findings are summarized in table 1. There was no relation of the EKG changes to: (1) the site of aneurysm, (2) the site and degree of brain damage, determined clinically and by EEG, and (3) CSF pressure changes. Electrolytes were normal. Parenthetically, in this series Q-T intervals were reported shorter than normal, lending support to the suspicion that previous workers had measured Q-U intervals instead of Q-T intervals. Conversely, in two reports,\(^11-13\) one of six cases of "cerebral disease" and one of four cases of subarachnoid hemorrhage, there were common EKG findings of Q-U interval prolongation, wide, deep T-waves and prominent U-waves, but there was no mention of autonomic nervous system influence. Robb and Turman\(^14\) have shown that sympathetic stimulation may produce Q-T prolongation and massive sympathetic release has been implicated in the cardiac changes secondary to subarachnoid hemorrhage.

In an investigation by Hersch,\(^15\) 20 Bantus with subarachnoid hemorrhage were compared with two control groups, as well as 20 patients in other groups with meningitis and space-occupying lesions, respectively. In the subarachnoid hemorrhage group it was found that the EKG changes best correlated with level of consciousness and hypokalemia, changes consisting of Q-T interval prolongation, S-T segment depression, abnormal U-waves, and arrhythmias. The author postulates sympathetic and vagal mechanisms from stimulation of the hypothalamus and orbital surface of the frontal lobes, respectively — again, mechanisms known to produce these EKG changes experimentally.\(^16\)

Autopsy evidence of subendocardial hemorrhage was seen in three patients with subarachnoid hemorrhage, ischemic T-wave changes on EKG, and normal coronary arteries.\(^17\) The authors felt that the EKG changes were signs of myocardial ischemia. They postulated a vagal mechanism which after rapid rise in intracranial pressure would produce bradycardia, elevated blood pressure, sudden elevation of the left ventricular pressure and subsequent anoxia of the subendocardial layer of this chamber. In another autopsy series of 235 patients with fatal intracranial disease\(^18\) subendocardial hemorrhage was seen in 29, five of the 39 with spontaneous intracerebral hemorrhage and zero of 11 with spontaneous subarachnoid hemorrhage. Of 607 additional autopsies, only three cases of subendocardial hemorrhage were found. This cardiac abnormality was seen most frequently with posttraumatic and postoperative tumor patients, conditions known to cause sudden rises in intracranial pressure followed by vagal inhibition, a period of cardiac arrest, then forceful ventricular con-
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### CARDIAC ABNORMALITIES IN SUBARACHNOID HEMORRHAGE

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Tractions and blood pressure elevation, a chain of events inducing subendocardial anoxia and hemorrhage. This hypothesis is supported by the experimental work of others.32-34

The frequency of EKG changes and possible pathogenesis was investigated in a prospective study of 20 selected patients with subarachnoid hemorrhage, without antecedent heart disease or hypertension.36 All had determinations of CPK and SGOT, serum potassium and arterial Pco₂. Twelve patients had abnormal EKGs which could not be correlated with electrolyte abnormalities, alkalosis, enzyme abnormalities, site of hemorrhage or anoxia. In most patients with CPK elevation, it tended to rise later and remained elevated longer than in acute myocardial infarction. The authors implicated both vagal and sympathetic influence in the etiology of EKG changes and suggested that the absence of development of Q-waves would help differentiate these EKG changes from those of myocardial infarction.

Elevated CPK levels have been found in three separate investigations in a significant number of patients with other cerebral dysfunction,36-38 for example, meningitis, cerebral infarction, head injury, and encephalitis. The CPK levels were elevated greater than 60% in one of the studies.38 Connor38 has shown histochemically that the CPK elevation is due to foci of myocytolysis* of the myocardium, not skeletal muscle, and he determined that a significant number of sections of the heart must be studied to demonstrate this.

In 1972 Eisalo et al.40 studied other laboratory data in 20 patients with subarachnoid hemorrhage, namely, urinary catecholamines, metanephrines, plasma corticosteroids, blood sugar, serum cholesterol, serum triglycerides, transaminase, lactic acid, and serum electrolytes, all of which failed to show correlation with EKG abnormalities. Also in 1972, Smith41 summarized EKG changes associated with subarachnoid hemorrhage (table 2).

Microscopic changes in the heart have been found in patients dying after subarachnoid hemorrhage. In a case of ruptured aneurysm reported by Hammermeister and Reichenbach,42 a patient had pulmonary edema and EKG evidence of transmural infarction. Autopsy revealed a grossly normal heart but microscopy revealed multiple foci of myocytolysis, reminiscent of the “norepinephrine myocarditis” described by Szakacs and Cannon.43 Sections of the posterior hypothalamus showed vary-

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*Myocytolysis: loss of sarcoplasm from small areas of muscle with retention of sarcolemmal stoma, muscle nuclei, lipofuscin granules, without coagulation necrosis.
TABLE 2

Electrocardiographical Changes in Subarachnoid Hemorrhage

General EKG changes in subarachnoid hemorrhage
1. Prolonged Q-Tc or Q-U intervals
2. Elevated or depressed S-T segment
3. Deeply inverted or tall upright T or broad T-U fusion waves
4. Large positive or negative U-waves
5. Q-waves in both limb and precordial leads
6. Marked increase in the amplitude of the U-wave in the postextrasystolic beats
7. Notched or bifid T-waves

Changes in cardiac rhythm in subarachnoid hemorrhage
1. Sinus bradycardia
2. Wandering atrial pacemaker
3. Paroxysmal atrial tachycardia
4. Atrial fibrillation
5. Two-to-one atrial ventricular block
6. Atrioventricular dissociation
7. Nodal bradycardia
8. Premature ventricular contractions

stimulation of the midbrain reticular formation; the pathological changes in the myocardium are presumed to be caused by brain stem sympathetic stimulation, which, in turn, causes intramyocardial release of catecholamines from the "norepinephrine cardiac nerve network" described by Norberg.

Pulmonary edema has been shown frequently to accompany central nervous system lesions, but pulmonary edema was found in 46 of 88 subjects dying of intracranial lesions and 30 of 101 controls. There was no correlation with the site of involvement, hypertension, heart disease, or pneumonia. The same authors studied histologically the anterior hypothalamic region in 101 consecutive subjects with ruptured intracranial aneurysms, and again failed to reveal any consistent lesions associated with pulmonary edema. Anterior hypothalamic lesions were found in 65 subjects — pulmonary edema was found in one-third with and one-third without hypothalamic lesions. Cameron in another autopsy series found a total of 19 cases of intracranial disease in 100 cases of pulmonary edema, and in a group of 104 cases of cerebral hemorrhage or skull fracture there were 68 cases with pulmonary edema. In contradistinction, Paine et al., in a large autopsy series, demonstrated that the majority of those dying of central nervous system disease associated with pulmonary edema showed evidence of heart disease. Other neural states reported by Visscher to be frequently or occasionally associated with pulmonary edema are brain tumor, head trauma, vertebral injury, insulin hypoglycemic coma, cerebral embolus and thrombosis, encephalitis, vagus nerve disease, polyneuritis, tubes dorsalis, effects of lumbar puncture, or cervical sympathectomy, epileptic seizure, emotional disorders, and hysteria.

An autopsy series of 56 patients dying with head injury sustained in combat demonstrated that 48 had evidence of pulmonary edema, alveolar hemorrhage, or pulmonary congestion. These findings were seen in 17 of 20 who died instantly but did not occur in those subjects with associated massive hemorrhage from other sites in the body or with accompanying cervical cord transection, which blocks sympathetic outflow from higher centers. The authors explained this phenomenon as an extension of the Cushing reflex, with increased venous return, massive peripheral vasoconstriction, and loss of left ventricular compliance conspiring with systemic hypoxemia and acidosis to produce pulmonary edema. The authors concluded that pulmonary edema in these cases occurs secondary to sympathetic stimulation emanating from...
CARDIAC ABNORMALITIES IN SUBARACHNOID HEMORRHAGE

the brain and that a rational approach to therapy would include alpha or beta adrenergic blocking agents or stellate ganglion blockage. Therefore, a common pathway seems to exist for the production of electrocardiographical abnormalities and pulmonary edema secondary to central nervous system lesions, which might invoke a common mode of therapy.

Animal Experiments
Considerable experimental work has been done in animals to localize the cerebral site for the production of pulmonary edema, but this is beyond the scope of this article. However, experimental work concerning cerebral lesions and cardiac changes will be discussed.

Considerable experimental work has been done to better understand pathogenesis of these cardiac changes induced by central nervous system lesions. It was shown by Manning et al. that vagal stimulation in dogs produced EKG changes and myocardial damage, which is blocked by atropine and accentuated by eserine. Groover and Stout made similar observations in baboons. Atropine also was proved to block alterations in P-wave and T-wave configuration in experimental head injury in mice. In contradistinction, alterations in the sympathetic tone by either stellate ganglion stimulation or ablation in dogs paralleled the EKG abnormalities seen in CNS lesions, suggesting a functional relationship. Klouda and Brynjolfsson demonstrated subendocardial hemorrhage and focal myocardial necrosis in dogs subjected to stellate ganglion stimulation. Norepinephrine infusion produced similar changes in the myocardium.

Because the rostral connections for the sympathetic nervous system are located in the hypothalamus, numerous experiments were devised to study the effects of hypothalamic stimulation on sympathetic function. Various authors noted after hypothalamic stimulation in cats, electrocardiographical changes similar to those seen in humans with central nervous system lesions. These changes were abolished by cervical spine transection, not by bilateral vagotomy.  

Other areas stimulated which influenced the EKG were midbrain reticular formation, ventral hippocampus, and medial nuclei of the amygdala. Korteweg, Boeles and TenCate showed that basal ganglia and thalamic stimulation caused no electrocardiographical effects in cats. However, stimulation of the anterior hypothalamus caused deceleration of sinus rhythm and was prevented by vagotomy. Stimulation of the posterior hypothalamus and corpora quadrigemini caused ventricular arrhythmias and T-wave changes unaffected by vagotomy. Attar et al. also demonstrated different effects of anterior and posterior hypothalamic stimulation. The consensus is that the autonomic nervous system is responsible for the cardiac changes caused by central nervous system lesions with a sympathetic nervous system effect predominating.

Under the electron microscope Hall et al. demonstrated numerous foci of discrete single myocardial cell degeneration in dogs within four hours of hypothalamic stimulation. Histochemical examinations of the myocardium of mice subjected to subarachnoid hemorrhage revealed varying degrees of depletion of succinic dehydrogenase, increased 5' nucleotidase activity and increased lipid accumulation associated with varying degrees of myocardial degeneration and necrosis. This type of myocardial damage correlates well with the "norepinephrine network" described by Norberg. The lipid accumulation was explained on the basis of mitochondrial hypoxia. Increased myocardial catecholamines and decreased adrenal catecholamines were found in rabbits after intraventricular air injection, which correlates well with the ischemic electrocardiographical changes, tachyarrhythmias, and foci of myocardial degenerative changes. These observations led Connor to suggest that catecholamines be used cautiously in his neurosurgical unit, and led other authors to devise experiments and attempt to prevent these changes. Propranolol was used to prevent arrhythmias induced by midbrain and diencephalic stimulation in beagle dogs. It was effective, whereas bilateral cervical vagotomy was not. In rabbit experiments and rat experiments on subarachnoid hemorrhage propranolol prevented electrocardiographical abnormalities similar to those seen in humans. Elevated levels of catecholamines were found in heart muscle of the rats and depressed levels in the adrenals. Reserpine has also been effective. Hawkins and Clower pretreated mice with reserpine, atropine, or adrenalectomy prior to inducing intracranial hemorrhage. They found that those mice in the reserpine pretreatment group had almost no heart damage. The atropine group had a significant decrease in myocardial damage. They postulated that atropine prevents a sympathetic rebound. McNair et al. reached similar conclusions.

Summary
From the preceding discussion there is clear evidence that intracranial lesions produce profound effects upon the heart, presumably through a sympathetic mechanism. Numerous reports have demonstrated electrocardiographical changes secondary to subarachnoid hemorrhage. These changes consist of atrial and ventricular arrhythmias, alterations in QRS configuration, Q-T interval prolongation, T-wave abnormalities, and S-T segment elevation or depression. Other studies have shown subendocardial hemorrhage as a result of subarachnoid hemorrhage, and CPK elevation has been seen after subarachnoid hemorrhage.
elevation which emanates from cardiac muscle, not brain or skeletal muscle. This correlates well with the demonstrated myocytolysis and fuchsinophilic degeneration seen in cardiac muscle microscopically.

Attempts to correlate cardiac abnormalities with site of lesion have been unsuccessful1; however, the consensus is that the hypothalamus is in some way affected in subarachnoid hemorrhage and causes primarily a sympathetic outpouring with the vagus playing a more passive role. Various experiments in animals have substantiated this hypothesis. Pulmonary edema also has been shown to occur after subarachnoid hemorrhage, and again a sympathetic mechanism is implicated.

Animal experiments imply that the EKG abnormality can be prevented by the use of beta adrenergic blockade, reserpine, and occasionally atropine. To date this has not been accomplished in man. This leads us to some important considerations.

Conclusions

It is the authors' opinion that all patients with subarachnoid hemorrhage have continuous cardiac monitoring, serial EKGs, and serial CPK studies. It is not known what effect on mortality in man these cardiac abnormalities have because they are not recognized and treated. Certainly the mortality of subarachnoid hemorrhage is too high to tolerate at the present time. Therefore, it seems appropriate that a prophylactic beta adrenergic blocking agents with or without atropine may be reasonable to alter the criteria for aneurysm surgery in the presence of electrocardiographic abnormalities. Surgery may have to be delayed until these abnormalities are corrected. Perhaps these patients should be considered the same as those with acute myocardial infarction and surgery delayed three to six months.

A last consideration, as suggested by Hammermeister and Reichenbach, in this modern day of cardiac transplantation: it is quite probable that donors with primary intracranial pathology might have damaged hearts, which are unsuitable for transplantation.

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Stroke, Vol. 5, May-June 1974
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doi: 10.1161/01.STR.5.3.384

Stroke is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0039-2499. Online ISSN: 1524-4628

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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