Cardiac Abnormalities in Subarachnoid Hemorrhage: A Resume

BY BERNARD M. WEINTRAUB, M.D.,* AND LAWRENCE C. McHENRY, JR., M.D.†

Abstract:
Cardiac Abnormalities in Subarachnoid Hemorrhage: A Resume

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.

Additional Key Words: myocytolysis pulmonary edema Q-T interval prolongation propranolol sympathetic nervous system reserpine hypothalamus

Introduction

Cardiac abnormalities are present in more than 50% of patients with subarachnoid hemorrhage.¹ 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 1947.² 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 1953,³ 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.⁴⁻¹³ Pulmonary edema also has been found frequently in association with intracerebral lesions.¹⁴⁻¹⁶ Air encephalography¹⁷ and lumbar spinal subarachnoid hemorrhage¹⁸ also have been shown to produce EKG changes. In some cases EKG changes have been mistaken for those of myocardial infarction¹⁹,²⁰ with resulting inappropriate treatment, especially the use of anticoagulants¹⁹⁻²¹ or delay of surgery.¹ 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)⁶ 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 1956,²¹ 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
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\(^6\) 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\(^11\),\(^12\) 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\(^13\) 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\(^14\), 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.\(^15\)

Autopsy evidence of subendocardial hemorrhage was seen in three patients with subarachnoid hemorrhage, ischemic T-wave changes on EKG, and normal coronary arteries.\(^16\) 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\(^17\) 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-
<table>
<thead>
<tr>
<th>Author, year</th>
<th>No. patients</th>
<th>No. patients with cardiovascular abnormalities</th>
<th>No. autopsied with pertinent cardiovascular findings</th>
<th>No. deaths</th>
<th>EKG changes</th>
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<td>6 deep, wide T-wave inversion in leads I, II and V-4 to V-6 (T-U fusion waves)</td>
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<td>11 prolonged Q-T interval</td>
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<td>10 S-T segment depression</td>
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<td>7 sinus bradycardia</td>
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<td>2 transient premature ventricular beats</td>
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<td>2 atrial fibrillation</td>
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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. 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, for example, meningitis, cerebral infarction, head injury, and encephalitis. The CPK levels were elevated greater than 60% in one of the studies. Connor 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. 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, Smith 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, 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. Sections of the posterior hypothalamus showed vari-

*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**

<table>
<thead>
<tr>
<th>General EKG changes in subarachnoid hemorrhage</th>
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<tbody>
<tr>
<td>1. Prolonged Q-Tc or Q-U intervals</td>
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<tr>
<td>2. Elevated or depressed S-T segment</td>
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<tr>
<td>3. Deeply inverted or tall upright T or broad T-U fusion waves</td>
</tr>
<tr>
<td>4. Large positive or negative U-waves</td>
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<tr>
<td>5. Q-waves in both limb and precordial leads</td>
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<tr>
<td>6. Marked increase in the amplitude of the U-wave in the postextrasystolic beats</td>
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<td>7. Notched or bifid T-waves</td>
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<table>
<thead>
<tr>
<th>Changes in cardiac rhythm in subarachnoid hemorrhage</th>
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</thead>
<tbody>
<tr>
<td>1. Sinus bradycardia</td>
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<tr>
<td>2. Wandering atrial pacemaker</td>
</tr>
<tr>
<td>3. Paroxysmal atrial tachycardia</td>
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<tr>
<td>4. Atrial fibrillation</td>
</tr>
<tr>
<td>5. Two-to-one atrial ventricular block</td>
</tr>
<tr>
<td>6. Atioventricular dissociation</td>
</tr>
<tr>
<td>7. Nodal bradycardia</td>
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<tr>
<td>8. Premature ventricular contractions</td>
</tr>
</tbody>
</table>

The authors suggested that patients with severe EKG changes should be treated as if a myocardial infarction is present. In another report by Reichenbach and Benditt, all 20 patients dying of subarachnoid hemorrhage had some degree of myofibrillar degeneration of the heart in various stages of evolution. Of 231 autopsies in a neurosurgical unit, 18 patients had foci of myocytolysis of the heart and 13 of these patients died from intracranial hemorrhage. The same investigator studied myocardial sections intensively in a large autopsy series from the neurosurgical unit. Foci of myocytolysis were found in 8%; 22% showed a lesser degree of change, that of fuchsinophilic degeneration. Cerebral hemorrhage was the most common cause of these changes. Similar lesions have been seen following adrenalin injections and with hyperthyroidism, again implicating a sympathetic mechanism.

Other pathological changes in the myocardium were described. In a review of 20 randomly selected cases of patients dying of subarachnoid hemorrhage, six had no evidence of prior heart disease and four had normal EKGs prior to death. All six had microscopic myocardial changes consisting of collapse of reticulum, scattered areas of cell loss and cytoplasmic banding. In three of their own patients Greenhoot and Reichenbach demonstrated myofibrillar degeneration in two and subendocardial hemorrhage in one. These changes were reproduced in cats by stereotactic 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. Weissman demonstrated lung edema as an important autopsy finding in two-thirds of 686 cases of intracranial hemorrhage, whereas Ciongoli and Poser described three cases of pulmonary edema associated with subarachnoid hemorrhage without evidence of previous heart disease. From Richards' survey in a neurosurgical unit, 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 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 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, tabes 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

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1. Fuchsinophilic degeneration: areas of coagulated sarcoplasm which stain red in the cresyl violet-acid fuchsirn technique.

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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 con-
erning 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 obser-
vations in baboons. Atropine also was proved to block
alterations in P-wave and T-wave configuration in ex-
perimental 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 sympa-
thetic nervous system are located in the
hypothalamus, numerous experiments were devised to
study the effects of hypothalamic stimulation on sympa-
thetic function. Various authors noted after
hypothalamic stimulation in cats, electrocar-
diographical 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 hippocam-
pus, and medial nuclei of the amygdala. Korteweg, Boeles and TenCate showed that basal
ganglia and thalamic stimulation caused no elec-
brocardiographical 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 cor-
pora 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 ex-
aminations 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 accumu-
lation 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 Con-
nor 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 ex-
periments and rat experiments on subarachnoid
hemorrhage propranolol prevented electrocar-
diographical 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 in-
tracranial 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 sub-
arachnoid 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 sub-
arachnoid hemorrhage. CPK elevation has been seen after subarachnoid hemorrhage; an
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