A critical evaluation of rheoencephalography in control subjects and in proven cases of cerebrovascular disease

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When an alternating current passes through a part of the body, modulated changes of impedance occur due to the pulsatile flow of blood, and the possibility of correlating such changes with modifications of the peripheral circulation (Mann, 1937) stimulated the development of the technique. Several modifications of the technique have been used for studies of peripheral circulation (Nyboer, 1944; Holzer and Polzer, 1945) in various parts of the body. The principles and application were later summarized in Nyboer's monograph (1959).

Recording changes of electrical impedance with electrodes applied to the head was first reported by Polzer and Schuhfried (1950). Several authors have published results using similar techniques, including Auinger, Kaindl, and Neumayr (1953), Kaindl, Kraus, and Pärtan (1955), Oehninger, Stanham, Cortes, Fiandra, and Ferrari (1955), Spunda (1955), Serra and Urso (1956), Colonna and Ricciardi (1957), Garbini and Poppi (1957), Gentili, Garbini, and Orlandi (1957), Pratesi, Nuti, and Sciagra (1957), Orlandi, Garbini, and Gentili (1957), Gastaut, Rodler, Lechner, Bostem, and Naquet (1959), Kunert (1961), Lifshitz (1963), and others. Jenkner (1957) has termed this procedure 'rheoencephalography', and his work over a period of years has culminated in the publication of a monograph (Jenkner, 1962) in which he has summarized his observations in over 10,000 clinical records.

Development of a method for continuous recording of cerebrovascular changes by a simple and harmless procedure, if reliable, would be of great clinical usefulness. For this reason we have evaluated rheoencephalography (R.E.G.) in a number of proven cases of cerebrovascular disease and compared the records with those from a group of normal controls.

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MATERIAL AND METHODS

The study involved two groups. The first group consisted of 19 control subjects who were free of neurological disease and were 18 to 30 years of age. They were all apparently in good health and were selected from nursing personnel, medical students, and laboratory technicians in our unit. The second group consisted of 28 patients with proven cerebrovascular disease and neurological deficit. In all 28 patients the entire cerebral circulation was studied by serial arteriograms from the aortic arch to the brain after recording rheoencephalography. In one additional case, coarctation of the aortic arch distal to the great vessels was demonstrated by aortography.

The final classification of the 28 patients was:

<table>
<thead>
<tr>
<th>Neurological Disorder</th>
<th>No. of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unilateral occlusion of the internal carotid artery</td>
<td>2</td>
</tr>
<tr>
<td>Bilateral occlusion of the internal carotid artery</td>
<td>3</td>
</tr>
<tr>
<td>Unilateral stenosis of the internal carotid artery plus</td>
<td>3</td>
</tr>
<tr>
<td>arteriographically demonstrated pathology of the</td>
<td></td>
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<tr>
<td>vertebro-basilar system</td>
<td></td>
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<tr>
<td>Unilateral stenosis of the internal carotid artery plus</td>
<td>6</td>
</tr>
<tr>
<td>involvement of the vertebro-basilar system</td>
<td></td>
</tr>
<tr>
<td>Bilateral stenosis of the internal carotid arteries plus</td>
<td>3</td>
</tr>
<tr>
<td>vertebro-basilar involvement</td>
<td></td>
</tr>
<tr>
<td>Occlusion or absence of one vertebral artery</td>
<td>4</td>
</tr>
<tr>
<td>Stenosis of the vertebro-basilar system without artery</td>
<td>2</td>
</tr>
<tr>
<td>involvement</td>
<td></td>
</tr>
<tr>
<td>Diffuse cerebral arteriosclerosis (small vessel disease)</td>
<td>5</td>
</tr>
</tbody>
</table>

The ages of the patients ranged from 36 to 77 years, most of them being in the age group 50 to 60 years.

Rheoencephalographs were obtained with a Physical Instruments rheoencephalograph (model 450) which uses a 2 mA current with an average input of 3V across the head of the patient, and a frequency of 30 K.C. utilizing two simultaneous bridge circuits or the so-called '2 electrode system'. The electrodes were placed one on the forehead (midline) and the two others on the mastoid regions of either side. Care was taken in measuring the inter-electrode distance so that the electrodes were placed symmetrically.

Electroencephalographic and rheoencephalographic recordings were monitored with a Grass model 6 electro-
encephalographic machine. Simultaneous recordings were obtained as follows: right and left hemisphere R.E.G. curves, right and left central to occipital E.E.G. tracings. The E.K.G. was also recorded on the graph. In some cases a pressure cuff was wrapped around the head below the level of the electrode and was inflated above arterial pressure during the recordings.

The R.E.G. curves were analysed as follows:

AMPLITUDE This was measured in ohms (based on the calibration signal) from the baseline to the highest point of the curve, which was usually the first peak.

ANGLE OF INCLINATION The angle of inclination of the rising part of the curve (called 'angle' hereafter) was measured directly in degrees, tracing the angle as defined by Jenkner (1962) from the point of origin of the curve to the steepest part of the ascending limb, referred to as the horizontal baseline.

TIME Time was the moment at which the first peak was reached (referred to from now on as 'time') as measured in milliseconds from the Q wave of the simultaneously recorded E.K.G. to the first peak of the R.E.G. wave. Records made at paper speed of 3 and 6 cm./sec. were used for this purpose.

WAVE FORM Consideration was given to the number of peaks present in a single pulse, the regularity of the wave, and the inclination of the descending part of the curve.

Several manoeuvres were routinely performed during the recording, including carotid compression (one at a time), jugular compression (both simultaneously), hyperventilation, breath holding, 100% O₂ respiration, and respiration of 5% CO₂ in O₂. Not all these manoeuvres were achieved in all patients because of their clinical state or lack of cooperation.

RESULTS

R.E.G. IN NORMAL CONTROLS The amplitude of the R.E.G. pulse ranged from 0-10 to 0-25 ohms; in most cases, however, it was between 0-10 and 0-18 with a mean value of 0-15. Four of the 19 controls (21%) showed asymmetry of amplitude between the records on the two sides of the head (5 to 25%). The amplitude of the waves varied from moment to moment in the same record so that the mean was taken of at least five consecutive waves. The amplitude sometimes showed significant changes in the same record when there was cardiac arrhythmia. In such cases the highest waves corresponded to the heart beat which followed the longest period of asystole. In instances of premature ventricular contractions, the R.E.G. wave was very small or not present at all.

The angle varied between 75° and 89° with a mean of 81° and the steepest curves corresponded, usually, although not always, to the highest amplitude waves. Although time showed a wide range of variation from 200 to 430 msec., most of the records showed time from 250 to 350 msec. with a mean of 290 msec. No time difference was found, at rest, between the simultaneous records of the two sides in the same person.

The wave form also varied considerably in normal subjects. Curves were seen with one peak and straight regular lines, two peaks (Fig. 1) with sharp descending curves, three peaks, and even curves with plateaux (Fig. 2) and other irregular aspects.

When the pressure cuff about the head was inflated above arterial pressure during the recordings, drastic changes occurred which consisted mainly in

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**FIG. 1.** Rheoencephalograms in a 22-year-old normal volunteer. In this as in all other figures the samples in B, C, and D correspond to the same selection shown in A.
Compression changes, but in reduced with 40% in the symmetry between the R.E.G. and recovered (10-10% occasions resulted in the carotid artery with increased homolateral pressure. In some cases, similar changes, but usually an increase in amplitude, was produced with pressures below the systolic blood pressure.

Unilateral carotid compression produced homolateral decrease in amplitude of the R.E.G. curve on 11 occasions (Fig. 1), bilateral depression on 10 occasions (Fig. 2), and homolateral or bilateral increase on three occasions. No significant changes resulted on four occasions. The changes usually lasted only a few seconds and recovered quickly. In some cases they were accompanied by the appearance or increase (Fig. 2) of the second and third peaks and changes in the wave forms to plateaux or rounded waves. No homolateral or bilateral increase in time was seen in normal subjects during carotid compression. In some instances, while compression of one carotid artery produced little or no change, compression of the opposite artery sometimes produced gross homolateral or contralateral depression.

Compression of both jugular veins performed in 15 subjects produced bilateral decrease of amplitude of the R.E.G. in seven (Fig. 2), increase in amplitude in four, and no change in four. Both decrease and increase in amplitude was seen as a transient phenomenon with quick recovery and in some there was asymmetry between the two sides.

Hyperventilation produced depression of amplitude and diminished angle in eight of 15 subjects (Fig. 1), increase of both amplitude and angle in four, and no changes in three. The changes often were asymmetrical and in some cases the change was transitory and the record appeared normal at the end of the test.

Breath holding produced an increase in amplitude and angle in seven of 15 subjects, increase of both parameters in six (Fig. 2), and no changes in two.

Respiration of 100% O₂ for three minutes produced depression of amplitude and angle in nine (16 subjects (Fig. 1), increase in three, and no changes in four.

Respiration of a mixture of 5% CO₂ in O₂ for three minutes performed on 14 subjects produced depression of amplitude and angle in five cases, increase in four, and no change in five.

R.E.G. IN CEREBROVASCULAR DISEASE Analysis of the resting R.E.G. in the entire group of patients with cerebrovascular disease was as follows: The amplitude varied between 0.06 and 0.25 ohms, with the majority (20 of 29) having an amplitude equal to or above the mean found in our normal material (0.15 ohms). Of the remainder, four were between 0.10 and 0.15 ohms and only five had a lower amplitude than was found in the ‘normal’ group.

Twelve showed asymmetry of amplitude ranging between 10 and 50%, with only five patients showing an asymmetry greater than 25%.

In 28 patients the angle varied between 75° and 90° and the mean was 81.5°. In only one case was there an angle below 75°. In only two instances were asynchronous first peaks found at rest.
R.E.G. IN UNILATERAL OCCLUSIONS OF THE INTERNAL CAROTID ARTERY Of two patients, one showed an asymmetric record with lower amplitude on the right, despite the fact that the occluded carotid artery was on the left side. The second patient showed a high amplitude symmetrical record. Compression of either common carotid artery in the neck produced bilateral depression. Since the internal carotid artery was occluded but the external carotid artery was patent, it seems evident that the R.E.G. on the side of the occlusion was influenced by the collateral circulation from the external carotid artery through the scalp. There was no difference in time between the two sides. According to the descriptions available in the literature (Jenker, 1962), it was not possible to diagnose either of these two patients on the basis of the rheoencephalogram.

R.E.G. IN BILATERAL OCCLUSION OF THE INTERNAL CAROTID ARTERY Of three patients, one showed a low amplitude R.E.G. record bilaterally which was compatible with the arteriographic diagnosis. A second patient showed a high amplitude and symmetrical record with synchronous peaks. Carotid compression of either side produced bilateral depression; since the external carotid arteries were patent, this again suggests participation of the extra-cerebral circulation in the R.E.G. wave. There was a great increase of external circulation in the arteriograms, and by inspection, the arteries of the scalp were tortuous and dilated. Breath holding in this patient produced gross depression of the R.E.G. waves. The third patient showed a high amplitude but asymmetric record, the left side having the higher amplitude. This patient had suffered a known thrombosis of the right internal carotid artery several years previously and came to the hospital because of recent thrombosis of the left internal carotid artery. The external carotid arteries were patent. Carotid compression on either side produced great depression of the R.E.G., again indicating participation of the scalp circulation in the rheoencephalogram. The last two cases could not be diagnosed by the R.E.G. trace.

R.E.G. IN UNILATERAL INTERNAL CAROTID OCCLUSION WITH STENOSIS OF VERTEBRO-BASILAR SYSTEM Of three patients, one showed a 50% asymmetry of amplitude with the higher amplitude on the left. Although there was no asynchrony of the peaks, this was considered to be diagnostic of occlusion of the right carotid artery and this proved to be the case. However, the right carotid artery was known to have been occluded some years earlier and the patient was admitted because of a recent infarct in the left cerebral hemisphere with stenosis of the left carotid system and right hemiplegia. The remaining two patients showed medium voltage symmetrical, synchronous records from which it was not possible to diagnose carotid occlusion (Fig. 3). In one of the latter cases, carotid compression in the neck on the side opposite the occluded carotid artery produced unilateral depression of the rheoencephalogram. When the occluded vessel was compressed there was bilateral decrease in amplitude.

Analysis of the data for the total series of patients with unilateral or bilateral occlusion of the internal carotid artery (eight cases) was as follows: In two cases the R.E.G. was suggestive of the correct diagnosis; four were not diagnostic and were in-
distinguishable from normal records; the remaining two showed abnormal R.E.G. records over the hemisphere opposite the affected carotid artery. Carotid compression on the affected side produced bilateral depression in three out of six instances, homolateral depression in two, homolateral increase in one, and no change in one. Carotid compression on the unaffected side produced homolateral depression in one patient and bilateral depression in the other. Jugular compression produced bilateral depression in all cases in which this manoeuvre was performed.

Hyperventilation also produced bilateral depression in all patients tested. Breathing holding caused bilateral depression in two of three patients and bilateral increase in R.E.G. amplitude in one.

Breathing 100% oxygen produced bilateral depression in one of three patients and no changes in the other two. Breathing 5% CO₂ in oxygen produced bilateral increase in four of five patients and no change in one.

R.E.G. in unilateral stenosis of the internal carotid artery with vertebro-basilar stenosis

Of six patients, three showed asymmetry with lower R.E.G. amplitude on the side of the stenosed carotid artery. In these cases the diagnosis could be suspected from the trace. In two of these patients the peaks were synchronous. In the third, besides the asymmetry, the affected side showed a plateau wave with three peaks, and by measurement, the affected side showed a shorter time interval for the first peak but the second peak of this plateau wave was synchronous with the first on the normal side. Compression of the affected carotid artery produced homolateral increase in amplitude. Of the three remaining patients, two showed records that were considered normal, having medium voltage, symmetrical and synchronous records. The third showed bilateral reduction of amplitude with irregular waves but synchronous peaks that were not of lateralizing value.

R.E.G. in bilateral stenosis of the carotid arteries with vertebro-basilar stenosis

Of three patients, two had normal, symmetrical, medium or high amplitude records. In one of these, compression of the right carotid artery produced bilateral increase in amplitude while compression of the left carotid artery caused bilateral depression.

In the third patient, there was an asymmetrical (40%) record with higher amplitude on the left. Compression of the left carotid artery produced bilateral depression, while compression of the right carotid artery produced no change. In this case there were atherosclerotic plaques of both internal carotid arteries with the left side being the more involved.

The right vertebral artery was occluded. The R.E.G. was considered misleading since it would suggest that the severest lesion was on the less affected side.

Analysis of the data in the total series of unilateral or bilateral stenosis of the carotid artery showed that of nine patients, the R.E.G. in three would be considered diagnostic and in six not diagnostic. Carotid compression on the affected side produced bilateral depression in one of four cases, unilateral depression in one, and bilateral increase in two.

Jugular compression produced bilateral depression in four of seven patients, bilateral increase in two, and unilateral increase (corresponding to the affected side) in one.

Hyperventilation produced bilateral depression in one of five patients, bilateral increase in two, unilateral increase in one, and no change in one.

Breath holding caused bilateral depression in two of six patients, bilateral increase in two, and no change in two. Breathing 100% oxygen produced bilateral increase in three of five patients, bilateral depression in one, and no change in one. Breathing 5% CO₂ in oxygen caused bilateral increase in three, and no change in two.

R.E.G. in vertebral artery occlusion

Of four patients, two were considered to have normal R.E.G. records with symmetrical and synchronous, medium amplitude waves. One showed an asymmetrical record with higher amplitude on the left (left vertebral artery occluded). In this case compression of the right carotid artery produced a slight homolateral depression with great increase in amplitude on the left. Compression of the left carotid artery produced a bilateral increase in amplitude. The fourth patient showed an asymmetrical record with higher amplitude on the left. (The right vertebral artery was occluded.)

R.E.G. in stenosis of the vertebral artery

Of two patients, one with right vertebral artery stenosis showed a high amplitude symmetrical record. When the right carotid artery was compressed, there was homolateral depression and with compression of the left carotid artery there was no change. The second patient had bilateral stenosis of the vertebral arteries. This case showed an asymmetrical R.E.G. record with higher amplitude on the left and increase in time at the left. Right carotid compression produced bilateral depression and left carotid compression produced homolateral depression.

Analysis of the data on all the patients with occlusion or stenosis in the vertebro-basilar system (six cases) showed that three had R.E.G. records considered to be normal; one had R.E.G. depression on the side of the occluded vertebral artery; one had...
R.E.G. depression on the side contralateral to the occluded vertebral artery; and one record in a case of bilateral vertebral stenosis was asymmetrical.

Carotid compression on the side of the affected vertebral artery produced homolateral depression in four of seven instances, bilateral depression in one, contralateral depression in one, and bilateral increase in one. Carotid compression on the side opposite to the affected vertebral artery caused homolateral depression in one of four instances, bilateral depression in one, contralateral increase in one, and no change in one. Jugular compression produced bilateral increase in five out of six patients and bilateral depression in one. Hyperventilation produced bilateral increase in two out of five patients, bilateral decrease in one, and no change in two. Breath holding caused no change in the three patients tested. Breathing 100% O₂ produced bilateral increase in two of four patients, bilateral depression in one, and unilateral depression in one. Breathing 5% CO₂ in oxygen produced bilateral increase in four of five patients and bilateral depression in the other one.

R.E.G. in diffuse cerebral arteriosclerosis Of five patients, four showed medium or high voltage, symmetrical and well-regulated records that were not different from those found in normal controls. One patient showed a low-voltage, asymmetrical (10%) record with irregular wave form and three peaks. Carotid compression produced homolateral depression in two of nine instances, bilateral depression in two, bilateral increase in three, and no change in two. Jugular compression produced unilateral depression in one of four patients, no change in one, bilateral depression in one, and bilateral increase in one. Hyperventilation produced bilateral depression in two of three patients and no change in the other. Breath holding produced bilateral depression in two of four patients, bilateral increase in one, and no change in one. Breathing 100% O₂ caused bilateral depression in three of five patients and no change in two. Breathing 5% CO₂ in oxygen produced bilateral increase in three of five patients and no change in two.

R.E.G. in coarctation of the aorta In one patient with coarctation of the aorta there was a high-amplitude symmetrical record with a synchronous peak of 415 msec. Carotid compression produced homolateral depression. Jugular compression produced bilateral depression with a diminished time course. Hyperventilation resulted in a great increase in amplitude with a diminished time course. Breath holding caused bilateral depression with the appearance of plateau waves and increased time course. Breathing 100% O₂ caused bilateral depression and breathing 5% CO₂ in oxygen caused a bilateral increase in the rheoencephalogram.

DISCUSSION

Review of our records made with normal controls shows that it is difficult to define which R.E.G. records should be considered abnormal. All parameters varied within such a wide range that practically all the recordings in patients with cerebrovascular disease, with few exceptions, could be compared with one or more of the normal tracings. From our data it would seem advisable that only asymmetry greater than 25% and asynchronous first peaks should be classified as definitely abnormal.

The results obtained with the different manoeuvres used were also different from those described by others in normals (Jenner, 1962). Carotid compression produced an increase in amplitude and angle in a number of subjects and no changes in others. Furthermore, in the same subject the changes produced in the R.E.G. by compression of one side could be much greater than those produced by compression of the contralateral artery, suggesting that in normal individuals the cranial circulation (external as well as internal) can be considerably greater on one side than on the other.

Jugular compression, hyperventilation, breath holding, 100% O₂ breathing, and 5% CO₂ breathing produced paradoxical results in approximately 50% of cases, that is, an effect opposite to what has been described as normal. Analysis of the records in patients with cerebrovascular disease showed that only in seven of them (25%) was the R.E.G. compatible with the clinical and arteriographic diagnosis, while in four the R.E.G. was misleading, suggesting circulatory disorder on the side opposite to the actual side of pathology. In the rest, R.E.G. records could not be differentiated from those obtained in normal cases despite the fact that proven advanced cerebrovascular pathology was present.

The special manoeuvres performed in the study of cerebrovascular disease also were not helpful. In fact, they produced paradoxical results in many cases and did not follow the pattern that might have been anticipated if the R.E.G. depended on cerebral circulation alone. Compression of the occluded carotid artery produced homolateral or bilateral depression in five of seven instances.

Several considerations have to be made in the interpretation of these data. Technical factors may be partly responsible. The two-electrode R.E.G. systems being used at present in the commercially...
available machines may not be the best method of recording cerebral changes in impedance through the intact skull. However, in our experience, trial of a four-electrode system has not overcome these technical problems. Much more important is the inescapable fact that the external carotid circulation participates considerably in the R.E.G. waves. This is evidenced by the fact that there is a diminution in amplitude by as much as 40% and decline in angle of the R.E.G. wave when a pressure cuff is inflated on the head below the placement of the electrodes. The recordings of normal or high-amplitude R.E.G. waves on the side of an occluded internal carotid artery must mean that the external carotid circulation is being recorded. In the latter case, compression of the carotid artery in the neck diminishes the amplitude of the homolateral R.E.G. wave. The participation of the external circulation is also present to some degree in normal individuals but it is increased after internal carotid occlusion by the collateral circulation through the scalp that has been shown in some of the patients by arteriographic studies and by visual inspection of the superficial temporal arteries. It was of interest in these cases that no difference in time course was found between the two sides of the head. It is believed that the venous circulation of the head must have considerable influence on the R.E.G. curve. This is well illustrated in the cases in which inflation of the cuff above venous pressure (but below the systolic pressure) produced considerable change in the R.E.G. waves, usually an increase in amplitude.

The variability of the results of the different tests (breath holding, jugular compression, hyperventilation, etc.), both in normal subjects and in patients with cerebrovascular disease, also enhances the impression that there are several factors, besides the cerebral arterial circulation, that participate in the production of the R.E.G. waves. Until these can be better understood, R.E.G. recording appears to have little clinical usefulness in the diagnosis of cerebrovascular disease.

**SUMMARY**

With techniques available commercially R.E.G.s were made on 19 control subjects and 28 patients with proven cerebrovascular disease. After analysis of these data it did not appear that the R.E.G. is a technique which provides reliable or consistent clinical information of use in the diagnosis of cerebrovascular disease. It seems evident that a significant proportion of the pulse wave is derived from extracranial blood flow. Despite the ease of its application and its harmlessness, more basic information is required to define the complex factors influencing the R.E.G. waves as recorded from the intact scalp. Only then may its clinical usefulness become apparent. At present, rheoencephalography is of no obvious diagnostic value and may actually be misleading in the diagnosis and localization of cerebral vascular disease.

**REFERENCES**


