STUDIES IN NEUROSURGICAL ELECTROENCEPHALOGRAPHY

1. STANDARD ELECTRODE PLACEMENT

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Practically every electroencephalographic worker has developed his own system of orientating electrodes on the heads of his patients. Providing certain fundamental technical requirements† are fulfilled, most of the systems thus evolved seem adequate for everyday requirements, and minor differences in electrode type and topography are probably of little significance.

However, this applies only in centres where the principal emphasis is on the recognition of paroxysmal dysrhythmias. When an attempt has to be made to correlate the spatial distribution of abnormal electrical activity with regional cerebral anatomy, as is the case in centres dealing largely with neurosurgical material, the actual method of electrode placement becomes of major significance. But as there is no precisely reliable method available for the accurate correlation of skull topography with regional brain anatomy, no universal standard can be prescribed.

Nevertheless, experimental results in this field depend greatly upon methods of electrode placement; so the present communication describes the method of orientating electrodes and the technique of recording employed in the studies made in the Nuffield Department of Surgery. It is to be understood that in ensuing reports the technique described in this paper has been followed, unless otherwise stated, and no further detailed description will be given. The method has been regularly employed in this Department for the last 18 months, during which time 2,200 records have been made from all types of clinical material at all ages.

No reference is made to the many other methods of electrode orientation employed elsewhere, as these have been discussed by the individual workers concerned.

TYPE OF ELECTRODE

The electrode employed is the so-called "saline pad" contact electrode, although solder disc electrodes affixed to the scalp with collodion have been used on some occasions. The former electrode consists of a silver bell-ended

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† See Walter,‡ Williams and Gibbs,§ Gibbs and Gibbs,¶ Cohn,‖ Hill and Parr,¶ and the recommendations of the American EEG Society.¶
tube mounted in a moulded polythene holder,* and covered with a convex saline pad (Fig. 1) which is kept moist in saline solution. From time to time the electrodes are rechlorided by electrolysis in saline solution; and in the intervals between use they are stored with the pads immersed in salt solution.

These electrodes are applied to the scalp, after parting the hair and cleaning the skin with ether-alcohol or methylated spirit, with or without preliminary anointing of the area with some form of contact paste ("Bentonite" or "Cambridge Electrode Jelly" is usually used in this unit). They are held in place by a cap made of rubber strands tied under the chin ("Buty-wave" type†) or, in small children, by rubber bands traversing the scalp transversely and tied to another band encircling the whole head.

With this method the electrodes sit firmly and with little discomfort to the patient, they are independent of any change of position of the head, and more electrodes can be added or their positions changed quickly. Interelectrode resistances of the order of 2,000 to 5,000 are regularly obtained, and there is no difficulty in securing satisfactory records with a minimal admixture of artifacts, under most experimental conditions. Sometimes electrodes are knocked off during a violent seizure or if the patient rolls over while asleep, but this can be avoided by controlling the position of the head; and in any case the displaced electrodes are easily restored.

This technique is entirely suitable for routine work in any centre, and is especially applicable when records have to be made from patients with recent scalp wounds, either operative or traumatic, as the electrodes can be placed around the wound more readily and more cleanly than with most other methods.

The only difficulty that may be experienced is a marked increase in electrode resistance due to rapid drying of the saline pads on hot dry days. The climate in England is such as to minimise this trouble, but in other countries it may be necessary to moisten the pads from time to time during recording; and this is easily done by dropping saline solution on them with an eye dropper, taking care to wet only the saline pad.

**SITING OF ELECTRODES**

In order to determine the electrode pattern that would give optimal coverage of the whole brain, radiographic studies of the skulls of patients

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† Manufactured by Biometica Ltd., Rampayne St., London S.W. 1.
with a variety of head sizes and shapes were made in anteroposterior and lateral projections, and theoretically desirable electrode positions were plotted on the X-ray films. Electrodes were then applied to the head in the plotted positions and the skulls were re-X-rayed.

Calculations were made in terms of various reference points on the skull surface in the hope that the most suitable patterns could be orientated by reference to such points, thus facilitating the work of the recordists. But it was found that none of the conventional methods of measurement were satisfactory in practice, and finally a pattern was determined by trial and error, the electrode distribution in which could be made with reference to the angle subtended by the plane of the electrode to Reid’s base line at the external auditory meatus (Fig. 2).

<table>
<thead>
<tr>
<th>Electrode Angle</th>
<th>Average Angle Subtended at E'</th>
<th>Electrode No.</th>
<th>Average Distance from E' on Adult Heads</th>
</tr>
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<tr>
<td>RE'A</td>
<td>45°</td>
<td>13</td>
<td>3.5</td>
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<td></td>
<td>11</td>
<td>9</td>
</tr>
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<td>RE'B</td>
<td>60°</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>RE'C</td>
<td>90°</td>
<td>17</td>
<td>7</td>
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<td></td>
<td></td>
<td>5</td>
<td>13</td>
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<tr>
<td>RE'D</td>
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<td>15</td>
<td>6</td>
</tr>
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<td></td>
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<tr>
<td>RE'E</td>
<td>30°</td>
<td>9</td>
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</tr>
</tbody>
</table>

Fig. 2. Tracing from radiograph of skull, showing orientation of the full series of 18 electrodes, and their relation to Reid’s base line (RR') and to the external auditory meatus (E'). The average positions on adult heads are given in the accompanying table.

Fig. 3 (left). Tracing from pneumoencephalogram to show the relation of the standard 16 electrode pattern to the air-filled ventricular system.

Fig. 4 (right). Tracing from first film of a percutaneous carotid angiogram to show the relation of the standard 16 electrode pattern to the principal cerebral vessels and the main arterial fields.
The position of the electrodes was checked in relation to the ventricular system by X-raying the head after the ventricles had been filled with air and the electrodes applied (Fig. 3). They were also checked in relation to the main cerebral vessels (Fig. 4) by X-raying the head during carotid angiography, after silver clips had been fixed to the scalp in the position of the electrodes, and in relation to the underlying brain in the autopsy room, by a similar method.

THE STANDARD PATTERN

As a result of this method of investigation the following pattern of electrode placement has been developed for routine use in this Department. Fourteen or more electrodes are applied to the head in the patterns indicated in Figs. 2, 5 and 6, the recordists siting them with reference to the external auditory meatus and Reid's base line. In certain cases two other electrodes are placed one in each auditory meatus, and used either as reference electrodes or as part of a bipolar pattern of exploration. Periodically, the constancy of the pattern has been checked by X-raying patients selected at random from the series examined by the various members of the Department, and it is found that the electrode positions do not vary by more than 1 to 1.5 cm. from the standard position as initially determined, once the recordists are practised in siting them. On other occasions the relation of the electrode positions to the underlying brain surface

Fig. 5. Lateral radiograph of skull showing the orientation of the standard 16 electrode pattern on an adult skull. The ear electrode is displaced downwards from its usual position in the external auditory meatus to enable it to be seen.

Fig. 6. Three views of the head of a patient showing the arrangement of the standard electrode pattern, the ear electrodes being omitted.
has been rechecked in the autopsy room, and a similar order of accuracy prevails.

METHOD OF RECORDING

The following is the routine method of recording employed at the initial examination of every patient. Variations in the technique for special reasons will be described in the relevant papers to follow.

The records are made either on a Grass 3-channel or an Ediswan 6-channel apparatus, utilising an appropriate system of selector switching based on the standard pattern of electrode placement. After calibration, 8 runs are made in longitudinal and transverse planes (Fig. 7), the effects of eye opening and closing being tested in the course of at least 5 runs (in both planes).

The runs are made in bipolar fashion, first along the two parasagittal planes, superior and inferior, on each side, and then along each of the transverse frontal, precentral, postcentral and occipital planes. In some cases additional runs are made using the ears as reference electrodes or as part of the longitudinal and transverse bipolar system. Each run is of 50 to 60 seconds' duration, but longer when some special abnormality is being sought or studied. At the end of the resting record a run is made during 2 minutes' hyperventilation and for 2 minutes thereafter. Sometimes this hyperventilation period is increased; and the particular run employed for hyperventilation depends upon the appearance of the resting record, the transverse precentral plane being the one most commonly used with profit.

At times face leads are employed, and in special cases additional runs in other planes or with eccentric electrodes are employed. As yet no studies have been made in this unit using nasopharyngeal or direct tympanic leads. Whenever the exact location of a focal abnormality is in question, the patient's head is X-rayed with the electrodes in situ and the position plotted on the film. The same procedure is sometimes followed with air studies or angiography.
CONCLUSION

This method of electrode placement and recording seems to be as satisfactory as one can get, allowing for the large variety of head shapes and sizes in patients of different ages. It seems to possess sufficient constancy in relation to a theoretical standard pattern in the hands of several operators to be of practical value, and the periodic radiographic control of electrode positions seems to be a useful measure. The technique has proved its worth not only in the study of paroxysmal dysrhythmias but also in the study of localised lesions such as tumours and abscesses, and in the search for epileptogenic foci. Details of these latter applications will follow.

Thanks are due to the members of the Staff of the Nuffield Department of Surgery and of the Department of Radiology for their cooperation in these studies, and especially to Miss F. M. Taylor and Miss B. L. Thomas, B.Sc., who have made nearly all the records upon which these studies are based. The drawings were made by Miss A. Arnott.

REFERENCES

1. AMERICAN ELECTROENCEPHALOGRAPHIC SOCIETY. Reports of special committees, annual meeting, Atlantic City, New Jersey, June 1948.