HANDBOOK OF ELECTROENCEPHALOGRAPHY AND CLINICAL NEUROPHYSIOLOGY

EDITOR-IN-CHIEF A. REMOND

VOLUME 3

Techniques and Methods of Data Acquisition of EEG and EMG

EDITOR: M. R. DeLUCCHI

Baylor College of Medicine, Houston, Texas (U.S.A.)

PART C

Traditional Methods of Examination in Clinical EEG

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ELSEVIER

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PART C

TRADITIONAL METHODS OF EXAMINATION IN CLINICAL EEG

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General introduction

Routine techniques, simply because they are routine, tend to become a bore and are easily neglected. However, even the routine EEG recording requires a fair amount of skill and acumen in its taking and the clinical electroencephalographer who neglects these details does so at his peril. The clinical interpretation of the EEG is a subtle skill and an understanding of the techniques by which the trace is produced is an essential prerequisite of competence in this field.

In writing this Part of the Handbook, the authors have had in mind the tyro and the EEG technician on whom rests the burden of recording. There is little here that the experienced electroencephalographer does not already know but it may be found useful as an *aide-mémoire* for teaching purposes and as a check on acceptable standards. We have avoided theoretical expositions of technical problems dealt with elsewhere in the Handbook and have emphasized rather the general principles and details of practical technique. The exposition of principles is by line diagrams which are best for this purpose, and although we would have liked to include more real EEG traces, this would have added considerably to the cost. It should not be difficult to find examples of the points made in most clinical EEG practices.

Our experience is that what may seem to be trivia to the initiated are not so to the novice and we would ask the experienced reader to bear this in mind rather than expostulate on the inclusion of minutiae or the obvious. Details count and we make no apology for including them.

Section I. Electrodes and Their Use

Electrical signals arising in the brain are conducted through the tissues by electrolytes in aqueous solution and are recorded at various points by electrodes connected to the recording equipment. The interface between the electrodes and the tissues is the weakest link in the recording system and poor technique in the preparation and application of electrodes is probably responsible for more inadequate or misleading records than any other single factor in EEG recording. Geddes (1972) has recently reviewed the properties of electrodes and they are discussed in Vol. 3A of the Handbook. In this Section we are concerned with the common types of electrodes and the practicalities of their routine use in electroencephalography.

A. GENERAL PRINCIPLES

All the commonly used electrodes are made of metals. A metal in contact with an electrolyte solution develops a charge across the interface, the value of which depends primarily on the type of metal, the physical properties of the metal surface, and the nature of the electrolyte solution, as well as several other factors of lesser importance such as the temperature, presence of impurities and contaminants and so on, which need not be detailed. These charges are usually very large (in the order of mV) compared to EEG signals. They can be quite different between electrodes even of similar materials and may vary from moment to moment and particularly if the surface of the electrolyte/metal interface is physically altered.

The presence of charges at the electrode surface introduces electrical capacitative properties so that the tissue–electrode interface must be considered as having both resistive and capacitative elements, *i.e.*, a time constant, which is a part of the whole recording system and cannot be ignored. For example, it is pointless attempting to record low frequencies, say at 1 c/sec, with a long time constant set on the EEG machine, from fine stainless steel wires which have an inherent time constant of 0.1 sec or less. Once electrodes are connected to the recording machine, a circuit is completed and currents flow. Pairs of electrodes can produce several millivolts of potential difference between them and currents will flow through the amplifiers and between the electrodes through the scalp which completes the circuit. These currents vary with the resistance in the circuit, particularly at the point of contact between the electrode and tissues which is the least stable point, and can give rise to large and spurious potential changes. The potentials recorded by the EEG machine depend on the minute current flows in the circuit comprising the tissues, the tissue–electrode interface and the amplifiers of the machine. The potentials actually recorded are determined by the potential drop across the amplifier terminals. If the tissue–electrode interface resistance is high, then there will be a large proportional potential drop at this point and the amplifiers will record correspondingly less of the total potential. A low resistance at the electrode–tissue interface relative to the amplifier input resistance is an important factor in achieving satisfactory EEG recordings. It is generally accepted that the electrode resistance should be less than 1/100 of the input resistance of the amplifier, *e.g.*, for a 2 meg ohms input resistance, electrodes should measure less than 20 K ohms and a figure of 10 K ohms is preferable.

These are rather simplified general points (the reader should be aware that the theory of electrodes is extremely complex and the subject of innumerable papers and texts) but nonetheless important for the recordist to bear in mind when handling and applying electrodes.

B. PROPERTIES OF ELECTRODES

The general properties of electrodes suitable for routine use are:

A stable electrode potential: where an electrode is new or scored or chipped so that fresh metal is exposed, vigirous chemical activity tends to occur in contact with electrolyte solutions and the electrode potential varies widely from moment to moment. "Noisy" electrodes of this type become "quiet" with age when the surface reactions stabilize. This process is helped by storing electrodes together in weak electrolyte solutions, by proper chloriding of silver electrodes (see below) by protecting the surface (as in pad electrodes) and avoiding physical damage. It should be noted that transferring electrodes to solutions containing different ions or very different concentrations of electrolytes produces a new environment in which the electrode potential has to restabilize and may add a complication of potential changes due to electrolyte diffusion gradients.

Equalized electrode potential: this can be achieved to some extent by having all the electrodes physically similar, particularly in regard to their contact area with electrolyte conducting media, and more especially by storing them in electrolyte solutions with the leads shorted. The common practice of storing electrodes in a bowl of weak electrolyte serves this purpose quite well provided care is taken to avoid contaminating metals of a different nature from the electrode, *e.g.*, copper. Widely differing electrode potentials may produce sufficient current flow between electrodes when connected as a recording pair, to change the electrode potential itself by polarization effects making the pair "noisy" and much more susceptible to movement artefacts as well as changing the inherent resistance and recording time constants. Changing the electrode resolves this problem but it is better practice to avoid it in the first instance.

Convenience of use: electrodes should be robust, of simple construction and cheap; they should be easy to apply, provide a mechanically stable tissue contact and be easily removed without discomfort to the subject. They should be light in weight, as should the leads and harness if used, both for comfort and to reduce inertia effects from patient movement. Connection to the recorder should be simple and reliable. Contacts between the leads and the electrodes are often of dissimilar metals and must be kept dry: electrolyte bridges between different metals can produce potentials in the order of hundreds of millivolts. For this reason (and to avoid corrosion) the junction between leads and electrodes permanently connected should be completely waterproofed with reliable varnish, plastic or epoxy coatings.

C. ELECTRODE MATERIALS

A variety of metals which have in common a low chemical reactivity to electrolyte solutions, such as gold, lead, tin, solder, stainless steel and other alloys, are used quite satisfactorily for routine EEG recording. Whilst there are theoretical disadvantages to many of these, particularly for their tendency to become polarized and have short time constants, these defects do not obtrude a great deal in clinical practice, especially when the electrode contact area is of a reasonable area, *e.g.*, > 30 mm^2. Where contact areas are small, for example with fine needle electrodes, the short electrode time constant significantly reduces the ability to record low (< 1 c/sec) frequencies. Electrodes which are non-polarizable and with negligible standing potentials can be produced by special techniques, *e.g.*, the tin/stannous chloride electrode (Kado and Adey 1968) developed for possible use on astronauts and which allows recording under adverse movement stresses, but these are expensive and unsuitable for routine use. From a practical point of view, the relatively non-polarizable silver/silver chloride electrode offers the best electrode properties. The advantages of the silver/silver chloride electrode are its stability and low noise when properly prepared, the ease with which electrode potentials can be equalized, its non-polarizing properties and low impedance which allow recording without too much difficulty to virtually DC frequencies. Whilst compacted silver/silver chloride forms an ideal electrode material, very satisfactory results in the clinic are obtained from a simple silver electrode chlorided in the following way: the electrode is immersed in 5% saline and connected to the positive pole (anode) of a 1.5 V dry cell. A spare electrode or piece of silver is used as a cathode to complete the circuit (only silver metal should be in the saline). Chloriding is complete in 30 seconds, when the electrode will appear white or grey. Exposure to light reduces some of the chloride to metallic silver and the colour turns dark brown or purple.

In use, the layer of chloride will eventually chip and break away and the electrode will produce artefacts. Re-chloriding after stripping the electrode by passing 4.5 V from the negative (cathode) pole of a battery through the electrode in 5% saline until it is clean will restore the electrode. Note that sodium hydroxide is produced during stripping and this saline should be discarded.

More careful chloriding by slow deposition under controlled current flow (see excellent discussion in Venables and Martin 1967; Coles and Binnie 1968; Geddes 1972) gives better results for particular purposes, especially where electrode potential equalization is important, *e.g.*, recording very slow (CNV, PGR) potentials. Cooper (1956) has described an ingenious self chloriding and "equalizing" storage device for silver pedestal electrodes (Fig. 2, *E*).

Examples of several varieties of electrodes are illustrated in Fig. 1–5. The figures are not meant to be exhaustive nor meant to be recommendations, but rather to illustrate principles.

D. APPLICATION OF ELECTRODES

Many patients attending an EEG Department for the first time are naturally apprehensive due to the unknown nature of the examination and the presence of complicated electrical equipment. The good technician will be sensitive to these anxieties. A sympathetic and reassuring approach, coupled with the deft and confident application of electrodes, is essential to produce a relaxed and co-operative patient and a good record: should recordists fail in this initial contact they will rarely produce satisfactory records.

At the time an appointment is made for an EEG examination, it is appropriate to instruct the patient if possible to wash the hair before the test and to avoid the use of greasy hair dressings, spray-on lacquers and elaborate coiffures. A printed slip attached to the appointment card is a convenient way of imparting these instructions and may include a brief statement about the nature of the test. Instructions must be simple and explicit. We are aware of a patient who turned up with scalp clean-shaven having read a scribbled "no hair oil" as "no hair on"!

Wigs and hair-pieces are unlikely to present more than momentary confusion but care needs to be taken with hair weaving, and some partial toupées may become detached with injudicious application of solvents.

Most electrode systems (see Section III) require some form of scalp marking with a wax-based skin pencil which may be removed with acetone or ether-meths mixture. Note that these solvents are inflammable and that acetone vapour is heavy and tends to flow over the scalp irritating the eyes, which should be kept closed. It should be unnecessary, even for the novice, to turn the scalp into a cross-word puzzle. Whilst the skilled technician may place a "head" very accurately by eye with the aid of a few measurements, and whilst it is true that the uncertainty of the precise location of underlying cerebral structures is such that it is pointless attempting millimeter precision, particular attention must be given to symmetry about the midline and between electrodes, as these two factors can markedly affect interpretation of the record (see Section III). It is important that the technician should stand back and look at the array of electrodes to check the accuracy and particularly the symmetry of placement.

In the following paragraphs we describe the application of electrodes in general terms. Attention paid to apparently trivial detail of technique often makes the difference between bad or erratic results and good records. The recordist should aim at a symmetrical low resistance array of electrodes cleanly and firmly attached in the proper place without fuss and bother. For convenience we describe the electrodes in terms of their method of application, *viz*., (1) pressure contact electrodes; (2) stick-on and suction types; and (3) insertion electrodes requiring skin penetration. At the end there is a description of special purpose electrodes (4), some of which are now virtually obsolete but mentioned for completeness.

1. Pressure contact electrodes (Fig. 1 and 2)

These electrodes are held in place by a light rubber or cord harness or head-cap depending on the type of electrode used, and usually applied after critical scalp

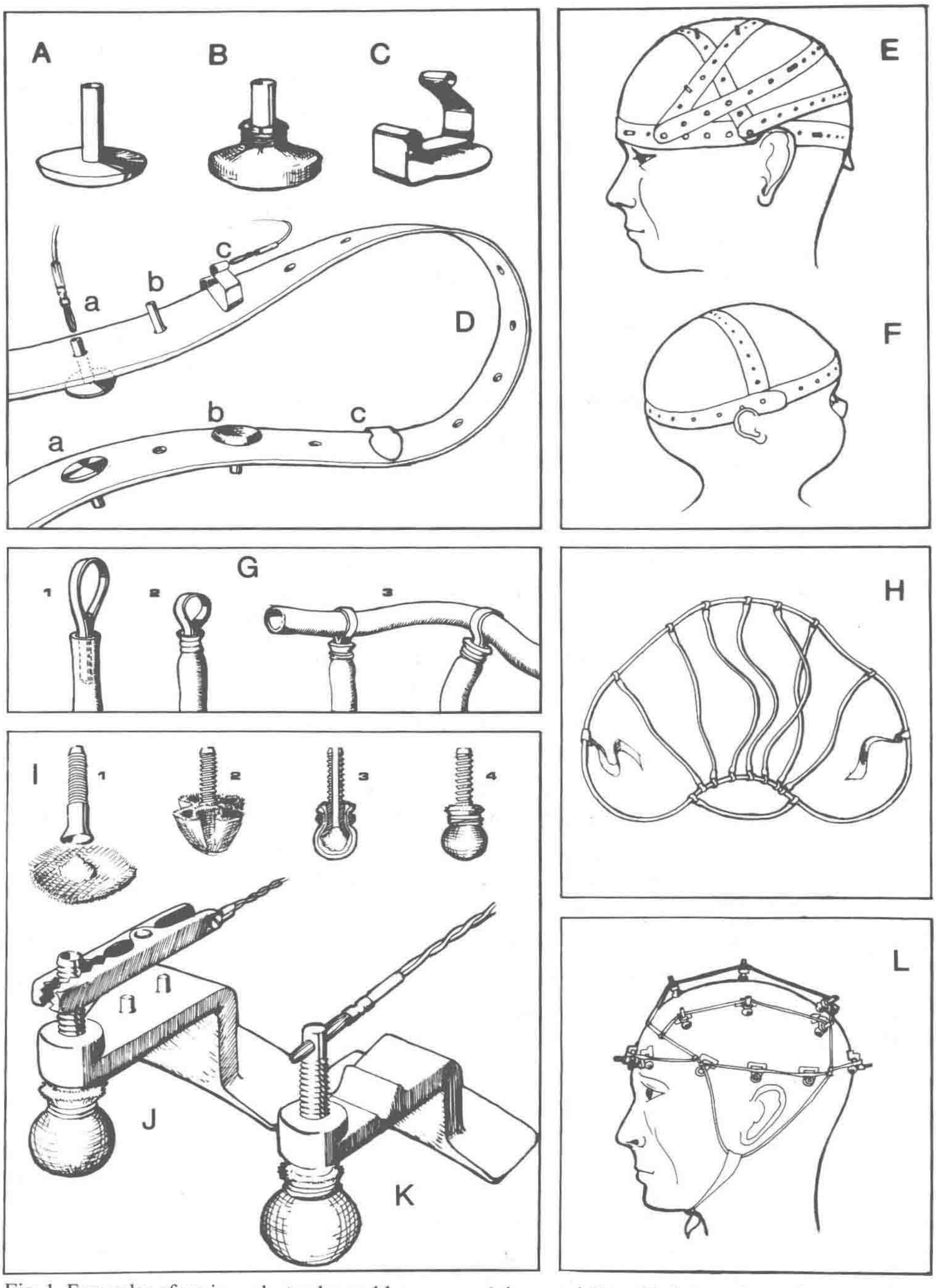

Fig. 1. Examples of various electrodes and harnesses. *A*, bare and *B*, padded stem electrodes; *C*, "J" type clip electrode. Methods of use illustrated in *a–c* below in *D*. *E* and *F*, flat rubber strip harness arrangements for these electrodes. *H*, rubber tubing harness, method of construction (*G*) and application (*L*) for use with pedestal electrodes *J*, *K*, *I*. In *H*, the occipital link is shown below, the frontal electrodes may be held by a permanent link as at *L* but more conveniently by a separate piece attached by crocodile clips which can be adjusted to suit different heads. The method of applying a pad to a silver pedestal electrode is shown in *I*: 1, small cotton wool pledget and lint pad is folded 2, and tied 3, 4, by stout cotton or small rubber bands about the foot of the electrode.

measurements have been marked. The harness must be adjusted for adequate control of the electrodes but must not be so tight as to cause discomfort, otherwise persistent muscle activity and movement artefacts will occur. Most pad electrodes become uncomfortable in 30–40 min even with a properly adjusted harness; this technique is therefore unsuitable for prolonged recording.

At each point on the head where an electrode is to be placed, the hair is parted; a sharp ended plastic comb is helpful and a pencil or, preferably, an applicator stick which can be discarded may be used. The scalp should be cleaned firmly with a pledget of cotton wool using methylated spirits, ether-meths or acetone (all water miscible) if there is a lot of oil or sebaceous secretion. A little electrode jelly is rubbed into the skin at the site, and the electrode correctly placed and fitted to the harness. Some care must be taken not to shift the electrode from the prepared site when placing other electrodes or attaching them to the harness—a common cause of high resistance. Skin resistances of less than 10 K ohms are usually obtained with this technique, but where the skin is thick (in unwashed or in bald individuals exposed to the elements) it may be necessary to use an abrasive jelly with more vigour. Dermabrasion using a battery-powered burr or a small sand blasting nozzle has been used (Rémond and Torres 1965) for particular purposes (small closely applied electrodes) but is not a routine procedure. Electrode jelly is often not used for pad electrodes which rely on soaked up saline for contact, but is of course necessary under uncovered metal contact electrodes (*e.g.*, stud and J type electrodes and unpadded pedestal electrodes—Fig. 1). The functions of the lint pad on electrodes are to act as a saline soak, to protect the silver chloride from light and abrasion and to accommodate to the contour of the scalp.

Electrodes having high resistance on testing or showing persistent artefacts should be re-applied with more vigorous rubbing of the skin with electrode jelly or simply with the addition of jelly to the contact point. Note that the effective contact area of an electrode is determined by the area of the electrode jelly on the scalp which should not exceed that of the electrode itself.

Lead connections to individual electrodes made with crocodile clips can be a source of trouble if the metal contact is poor or contaminated with jelly (producing a voltaic cell, see "Artefacts" Section IV). Fixed leads (as in the tripod type of electrode) or "self-cleaning" plugs are less troublesome, but the latter must be kept scrupulously clean, notwithstanding their name, which applies only to the contact-wiping action on insertion.

Removal

The electrodes are singly disconnected and removed, the hair cleaned with gauze or tissue and combed back into position after removal of the harness. Dry electrode jelly can usually be brushed out but may be softened with water if necessary. Depressions on the forehead where pad electrodes have been pressing will disappear within a few minutes of their removal.

Cleaning and storage

The electrodes should be rinsed in saline or water (non-pad type) and the metal

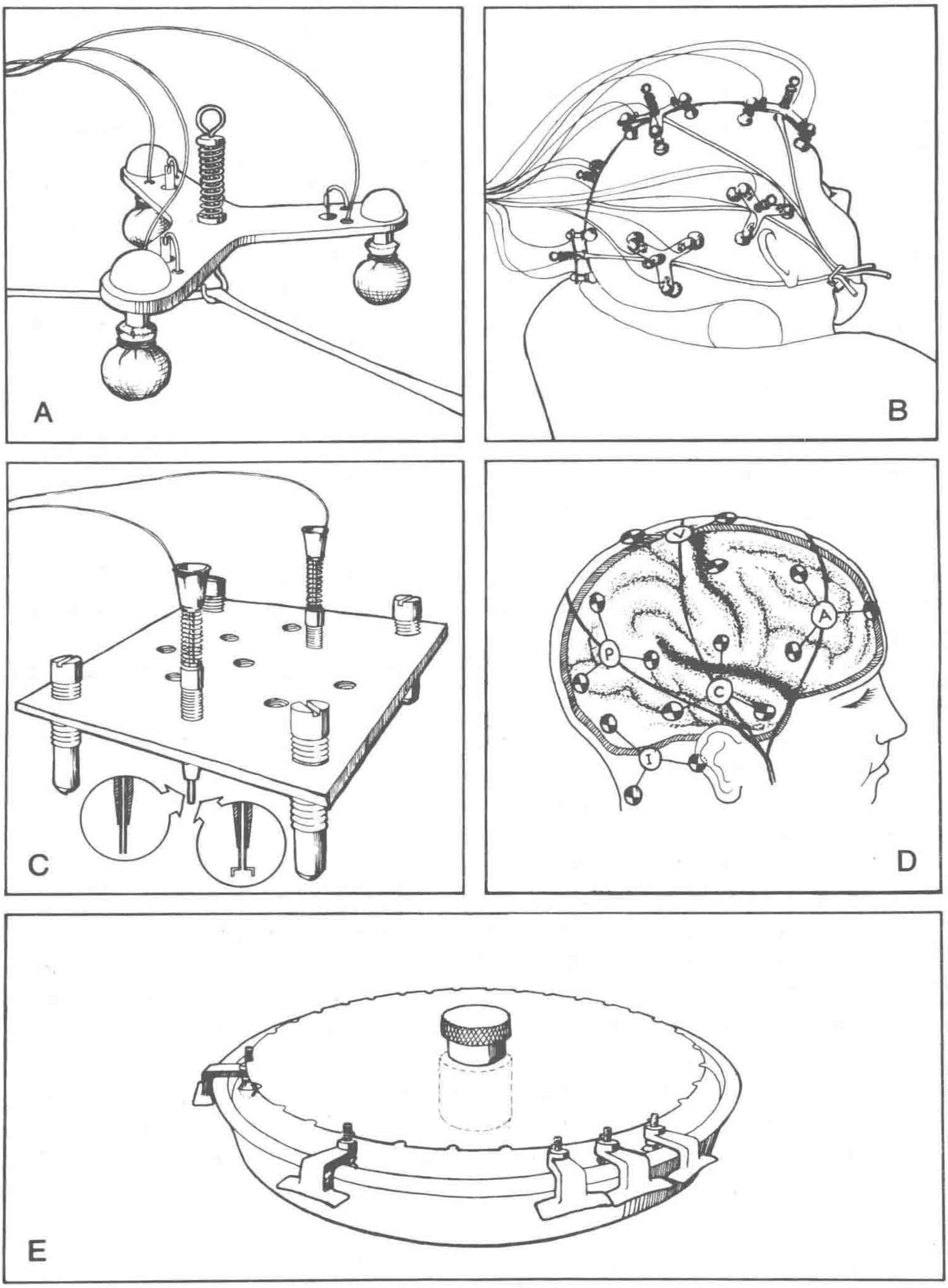

Fig. 2. *A*, *B*, tripod type pedestal electrodes, their method of application and approximate locations in relation to the underlying brain (*D*). *C* illustrates a method of applying a number of electrodes close together to examine some local phenomenon suggested by Dawson (1954). The electrodes are spring loaded stainless steel needles or silver tube constructions mounted in a screwed bush inserted into tapped holes in a plastic plate secured to the head by rubber straps. At each corner of the plate, adjusting screws accommodate to the contour of the scalp. Electrode jelly is inserted from the top by syringe. There is some advantage in increasing the size of the electrode tip by fitting a cup as shown. *E*, self chloriding dish for storing pedestal electrodes (Cooper 1956). The notched stainless steel or chromed plate completes a circuit between the top of the silver electrode, a central carbon cathode and saline in the dish to the active electrode foot. The chloriding current is self generated.

parts dried after use. Pedestal and mushroom electrodes thrown into a bowl of saline for temporary storage will have their connection surfaces wetted with saline: unless they are carefully cleaned, voltaic contact potentials will be produced when they are connected to the leads with clips or plugs. Saline is a common cause of corrosion of electrical equipment and connectors. For short term storage, pad and pedestal electrodes may simply rest in a shallow petri dish with the pads immersed in 5% saline. Pad electrodes stored in saline should be blotted before application to remove excess fluid. For longer term storage, they should be rinsed in water and allowed to dry. Pad electrodes are made of silver and should be chlorided periodically and the pads renewed as required. Discolouration of the pad is a clear indication for renewal.

General comments

The pedestal type or mushroom electrodes are the commonest in general use in Great Britain and in parts of Europe, although virtually unknown in some countries. They have many of the ideal properties listed, are simple to apply and require little practice, but suffer a number of disadvantages. Drying out of the pads and discomfort due to the harness limit the recording to some 30 minutes. It is difficult to obtain electrical resistances much below 10 K ohms and mechanical stability is poor. Consequently these electrodes readily give rise to movement artefacts, as do the crocodile clips, which produce characteristic high voltage, short duration transients if they slip against the surface of the electrode. These pressure contact electrodes also tend to ride upwards under the harness and their positions need to be checked during the course of a recording; it is particularly difficult to keep them in place over the basal parts of the scalp.

It should be apparent from the above that pad electrodes in general are unsuitable for prolonged investigations and sleep recordings and are not satisfactory for use in restless or disturbed subjects; they are generally inappropriate for any quantitative studies in which accurate location is important. Nevertheless they are easy to prepare, maintain and apply, particularly by an inexperienced user, and are widely considered to be acceptable for most routine clinical purposes. An array of some 20 pad electrodes can be applied in 6–10 min.

Reference may be made here to a disposable soft cap containing pre-filled sponge electrodes designed by Frost (1973) and worn successfully by American astronauts on long duration flights for sleep monitoring. This technique has been successfully used in clinics at the Methodist Hospital, Houston, Texas.

2. *Stick-on electrodes*

(a) Using adhesives

The electrode site is cleaned with alcohol, ether-meths or acetone—*not* a water-based detergent. The cup type disc electrode (Fig. 3, *A*) is held in place by the tip of a pencil, a small wooden stick or by the special applicator illustrated (Fig. 3, *J*, 1). Collodion, the consistency of which is important for easy application (14% nitro cellulose in solvent ether (0.73 g/ml)) is applied around the edges. This is dried by the

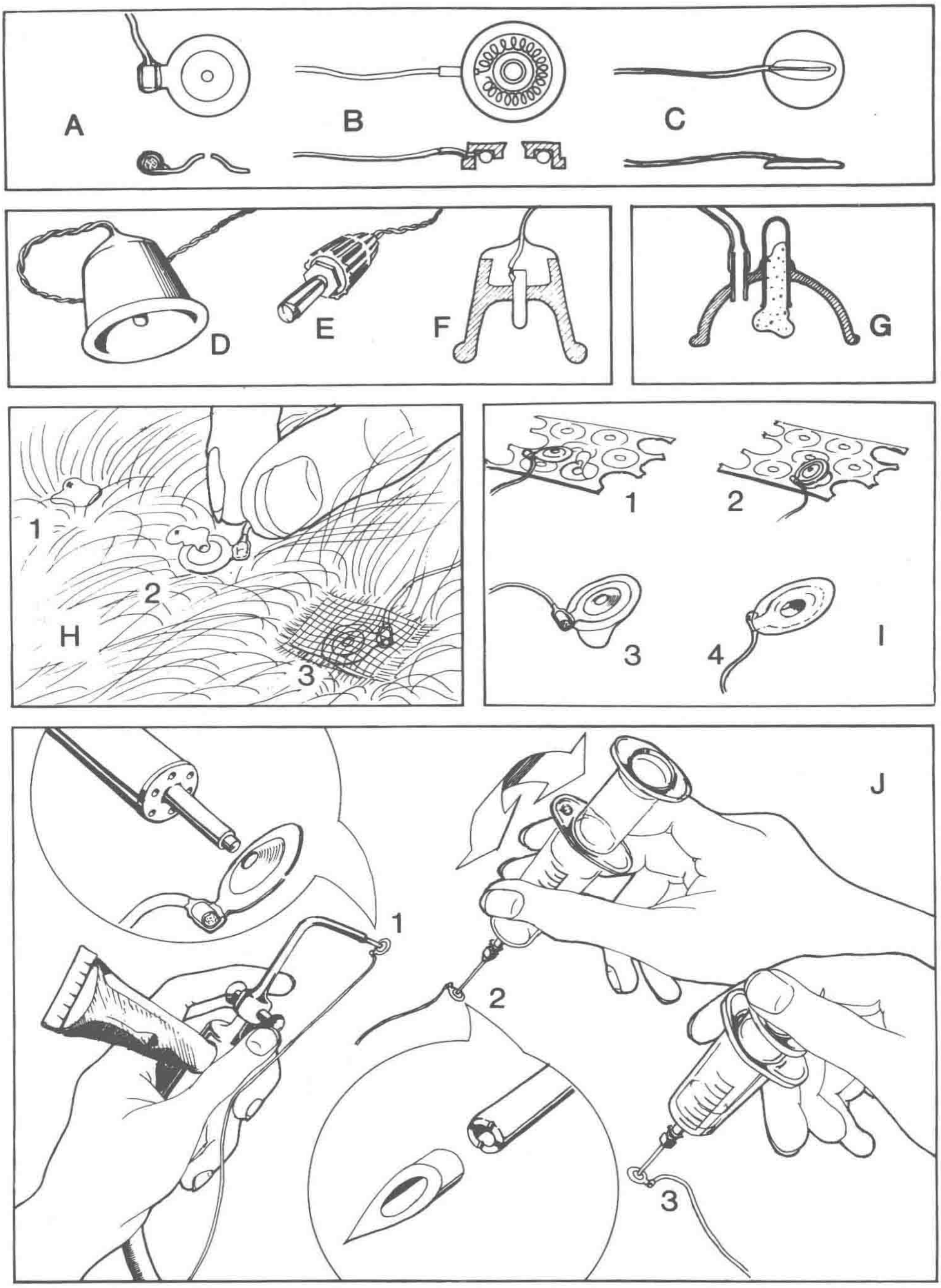

Fig. 3. Examples of stick on and suction type electrodes. *A*. silver disc; *B*, plastic electrode with silver coil insert; *C*, gold or solder solid disc button electrode; *D* and *F*, rubber cup suction electrode with central silver core; *E*, O-Z plug for connection to headbox; *G*, active suction electrode consisting of soft rubber cup, central silver electrode element with sponge pledget for electrolyte solution and evacuator tube attached to low pressure vacuum pump to hold electrode in place; *H*, application of disc type electrode using bentonite or proprietary paste: 1, electrode paste applied to cleaned scalp; 2, electrode pressed into position and, 3, covered with small gauze square; *I*, using double sided "sellotape" discs: the protective covering is removed, 1, electrode centred on the exposed tacky surface and the disc removed, 2, 3 and applied to non-hairy skin after the second protective cover is removed from the under surface. Electrode jelly is inserted through the hole as in *J* below. *J* shows the method of attaching disc electrodes with collodion using a special holder, 1, with compressed air for drying; in 2 and 3 electrode jelly is inserted through the hole by means of a syringe and needle, prepared as in the inset, which is rotated, 2, to reduce scalp resistance.

compressed air applicator or naturally (during which it helps to spread the collodion with a finger tip or stick), by gentle blowing (cheap but not hygienic), or by use of a hair drier. When the collodion has set, electrode jelly is inserted with a syringe and large bore blunt needle through the hole in the top, the needle end being used gently to abrade the scalp to ensure low contact resistance (Fig. 3, *J*, 2 and 3). The electrode jelly should fill the cup and just extrude from the hole but not squirt out at the sides between the electrode and the scalp.

These electrodes are comfortable and may be used for long periods of up to two days—but should then be moved as the skin is likely to become soggy and liable to infection. Their mechanical stability is excellent for sleep recording or activation procedures and they can be left in place when repeated recordings are required over a day or two.

Solid or cup electrodes without a hole in the top may be applied with collodion as above, but should be placed on a thin layer of electrode jelly. Some workers use a single layer of gauze to which collodion is applied over the electrode to hold it in place.

All these electrodes may be fixed in place using bentonite or similar proprietary pastes which provide adhesion as well as electrical contact (Fig. 3, *H*). The electrode may be stuck to the hairless skin (frontal, mastoid, ear lobes) by double-sided adhesive discs (Fig. 3, *I*) in the same way as disposable EEG electrodes. A currently popular technique is to cover each electrode with a patch of "micropore" paper adhesive tape prior to injection of the jelly. This is very effective on bare skin (from which its removal is painless); it can even be used to attach electrodes above the hairline in some subjects and is particularly useful in infants because of its simplicity of application and removal.

(b) Using suction

The skin is cleaned as above and electrode paste applied. Simple rubber suction electrodes of the type illustrated (Fig. 3, *D*, *F*) may be directly applied by squeezing the rubber bell, using the electrode jelly as a seal. An alternative method is to fill the rubber cup with jelly, apply the electrode to the cleaned site, squeeze and release. A special suction electrode for use with neonates has been described by Cooper and Walter (1957) (Fig. 3, *G*).

Removal

Collodion sets hard and is difficult to remove and it should be dissolved with acetone on cotton pledgets. Note that the electrodes should be cleaned after use and rinsed and dried for storage. Silver disc electrodes perform best when chlorided and care must be taken during cleaning to minimize damage to the chlorided surface (*e.g.*, collodion should not be scraped off with a metal implement—if softened in warm water it peels off easily by hand).

General comments

The unskilled find stick-on electrodes more difficult and slower to apply than pads