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Surgical technique for the insertion of grids and strips for invasive monitoring in children with intractable epilepsy

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Abstract Despite improved imaging, and electrical and magnetic external mapping, there are a large number of children with intractable epilepsy in whom a focus cannot be defined by non-invasive techniques. Invasive monitoring with depth electrodes, electrode grids and/or strips is required in up to 50% of children with a suspected focal seizure disorder. In children with suspected temporal lobe epilepsy the invasive techniques are required to identify which temporal lobe is the primary focus, to separate temporal from frontal foci, and to define the extent of involvement of the lateral temporal cortex. In children and infants with non-temporal epilepsy, invasive monitoring is required to define the epileptogenic zone and to map areas of cortical specialization. The current techniques used for surgical implantation are described here. In a correctly selected population invasive monitoring will define the epileptogenic focus or foci in 90% of children; 80% will have surgically treatable epilepsy. Infection rates are less than 1% for subdural strips and 6% for grids. In 88 cases no incidence of meningitis occurred.

Keywords Epilepsy · Children · Invasive monitoring · Subdural electrodes · Surgical technique · Infection · Morbidity

Introduction

Cortical resection for the control of epilepsy can only be performed if an epileptic zone can be identified. An epileptic zone is defined as a region of cortex that can generate epileptic discharges and its total removal is necessary to eliminate seizures. The reasons for performing invasive monitoring with grids, strips or depth electrodes in children with epilepsy are to localize the epileptogenic zone in the cortex and to map the functional areas of the cortex that are in close proximity to the epileptogenic zone. The scalp video-EEG offers a good overview of the cortex, indicating if a single or multiple epileptic areas are present. The scalp EEG detects areas of synchronization of the cortex that exceed 6 cm^2 [1] and is therefore not very useful for defining the boundaries for surgical resection. This review explores the current use of invasive monitoring, the techniques of insertion, the value of the technique and the associated complications. In addition a brief overview of current non-invasive techniques for obtaining similar data will be reported.

Despite improved external monitoring using video-EEG analysis in children with epilepsy there is still a high proportion of children in whom this technique does not supply a sufficient localization for surgery to be performed. The addition of MRI [2, 3, 4, 5, 6], PET [7, 8, 9, 10, 11, 12] and single photon emission computed tomography (SPECT) [13, 14, 15, 16, 17, 18, 19] scanning can help to localize the epileptogenic zone in some children but there are many children in whom invasive monitoring is still required to clarify whether surgery is an option or not and to accurately define the epileptogenic zone. Recent reports of the use of magnetoencephalography (MEG) [20, 21, 22, 23, 24] in children to define the epileptogenic zone and to identify functional cortex are

encouraging and this technique may prove to have a real advantage over other non-invasive techniques in children.

Temporal lobe epilepsy

Invasive monitoring is performed in children with suspected temporal lobe epilepsy in two main settings. The first is where there appears to be bilateral onset of seizure discharge or variability in which side the seizure starts. Even the presence of an abnormal MRI scan may not be sufficient evidence on which to base the decision for surgical resection if the electrical studies are not conclusive. In this setting subdural strips are used to clarify whether the focus is unilateral or not and, if unilateral, from which temporal lobe the seizures arise. Subdural strips as opposed to depth electrodes are usually preferable in children because of the frequent involvement of inferior and lateral temporal cortex [25, 26]. In those few patients in whom simultaneous onset of seizures occurs, the addition of depth electrodes may be helpful and the combination of depth electrodes and subdural strips can be complementary in some cases [27, 28, 29, 30, 31].

The second scenario is in children in whom unilateral seizure onset is established by video-EEG monitoring but the exact location – frontal, parietal or temporal – is not clear. In this setting an abnormal MRI can preclude the need for monitoring, as can a focally positive PET scan or ictal SPECT scan. In our epilepsy center we require at least three pieces of supporting evidence for localization prior to surgical resection, e.g. video-EEG, MRI scan and PET scan. In approximately 75% of children with a question of temporal versus frontal epilepsy invasive monitoring is still used. The obvious exceptions are children with a focal lesion on MRI. In these children intraoperative corticography is often all that is required. In the other children invasive monitoring is required. This is usually done with a combination of subdural grids and strips. These are inserted via craniotomy. Intraoperative corticography is usually used to help in the placement of the electrodes.

Non-temporal lobe epilepsy

In the majority of children with non-temporal lobe epilepsy, invasive monitoring is required to define the epileptogenic zone. In those children with a positive MRI that shows tumor or cortical dysplasia, direct surgery with intraoperative corticography can frequently be done and invasive monitoring avoided. Defining the margins of the epileptogenic zone can be difficult in children with cortical dysplasia and many of these children require invasive monitoring to define the region of resection. When the MRI shows areas of cortical atrophy or schizencephaly, or is normal, invasive monitoring is required since the assumption that the seizures arise in the region of MRI abnormality is not always true [32]. In addition there is often a need to map the eloquent regions of cortex to maximize the safety of the resection and to define what procedure is indicated, e.g. resection versus subpial incisions. When invasive monitoring is required it is usually with a combination of subdural grids and strips to cover the area of suspected tissue involvement, any areas of eloquent cortex that are in the region, and adequate tissue at the margins of the suspected epileptogenic zone (Fig. 1) [21, 33, 34, 35, 36]. In some cases it is necessary to monitor the mesial temporal regions and/or the opposite hemisphere as well with strip electrodes (Fig. 2). The exact area to be covered will be defined by the non-invasive monitoring techniques that have been used. The subdural electrodes are used to do functional mapping in the monitoring unit with the child awake and as comfortable with the surroundings as possible. In children under 5 years motor mapping can be impossible using direct cortical stimulation, and somatosensory mapping using sensory evoked potentials is easier and more reliable.

Surgical technique

Subdural strips

The most frequent area for the use of subdural strips alone is in the temporal region. They are placed bilaterally; usually three electrode strips are inserted per side. The incision is gently curving from immediately anterior to the ear, posteriorly and superiorly for approximately 5 cm. The scalp is incised through the galea and undermined anteriorly. The temporalis muscle is incised, parallel to its fibers, from just superior to the zygomatic arch for a distance of 5 cm. The periosteum is freed and the burr hole placed approximately 2 cm anterior to the ear and 2–3 cm superior to the zygoma. The burr hole is enlarged with the Kerrison punch to allow enough working room for the three electrode strips to be placed. The dura is opened, trying to preserve the arachnoid. In children under 10 years a 6-electrode strip is used, in older children usually an 8-strip is preferred. The strip is passed gently, without any prior dissection, round the lateral temporal lobe to come to rest with the distal electrode immediately inferior to the parahippocampal gyrus. If the passage of the electrode is difficult it is usually because it is hanging up on the irregularities of the floor of the middle fossa. The best way around this is to remove it and replace it heading either more anteriorly or more posteriorly. If the electrode will not make the curve around the lateral aspect of the lobe a Penfield 3 dissector can be used to pass over the lateral lobe and the electrode is then passed over the top of the Penfield, not below it, as the later is more likely to result in damage to the cortex. The inferior temporal electrode is placed first. We then pass a 4- or 6-strip posteriorly over the lateral aspect of the temporal lobe and a third 6-strip is passed anteriorly so that it crosses into the frontal fossa (Fig. 3). The three leads are then tunneled below the muscle and brought out through a single stab incision approximately 6 cm posterior and superior to the temporal skin.

In the subfrontal region it can be difficult to find a satisfactory location for a burr hole, and this does result in a visible scar anterior to the hair line. We avoid the problem by using a depth electrode as a subdural electrode and placing it through a stab wound

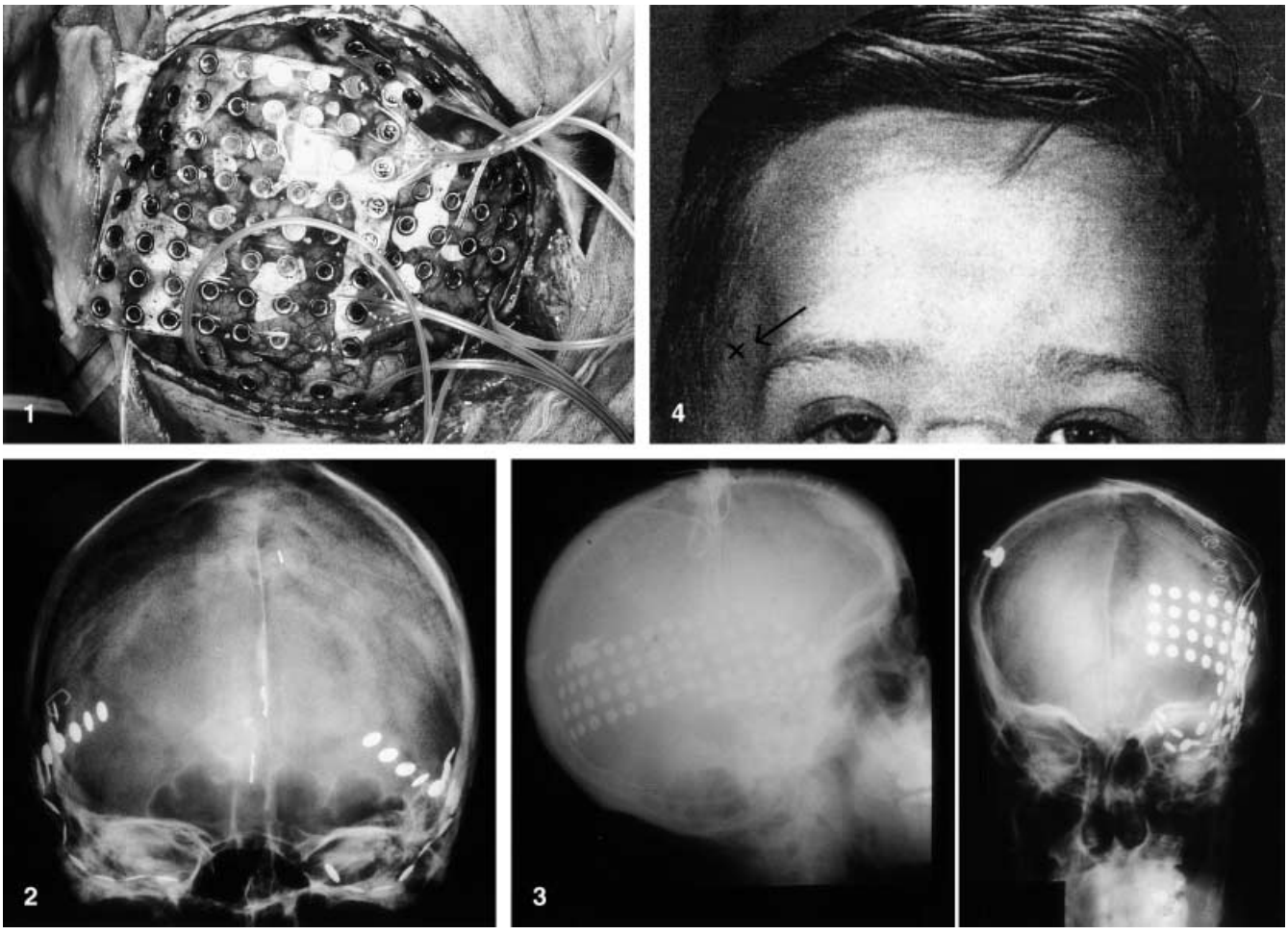


Fig. 1 Operative photograph showing grids and strips being placed over a large area of cortex

Fig. 2 AP skull X-ray demonstrating strips covering the bilateral temporal regions. Three electrodes per side

Fig. 3 AP and lateral skull X-rays. There are electrode grids covering the lateral and temporal and inferior parietal areas and strips in the mesial temporal region

Fig. 4 Photograph showing approximate site for subfrontal electrode to be placed via a stab wound and twist drill hole. The *arrow* points to the *x* which is the site for insertion. This will vary a little with the anatomy of the frontal fossa

and a small twist drill hole at the lateral margin of the posterior aspect of the frontal fossa (Fig 4). Other strips, if required, are placed through appropriate burr holes. The electrode leads are never brought through the skin in the primary incision. The electrodes are sutured in place with 3'0 nylon suture.

Subdural grids

Subdural grids need to be placed through a craniotomy opening. They are most frequently indicated for neocortical epilepsy where a large area of cortex requires to be monitored. Before surgical intervention every effort is made to localize the epileptogenic zone or zones. MRI is always used but in approximately 50% of the children it is negative for a focal lesion and, as noted above, when the lesion is a focal area of atrophy it is rare (in our experience, only 17% of the time) that the epileptogenic zone will be in the region of atrophy. Recent reports on the use of MEG to localize the focus in children are encouraging [20, 21, 22]. In our own unit the last three children who had MEG performed had good correlation between the site identified by MEG and the sites identified by invasive monitoring. In one child the use of MEG changed the area of cortex that was monitored from the area that would have been covered based on the video-EEG information. When areas such as inferior frontal, medial frontal or interhemispheric, e.g. cingulate gyrus, require coverage it is necessary to combine subdural grids with subdural strips. If the opposite hemisphere also needs coverage it is usually done with subdural strips placed through separate burr holes.

A large craniotomy flap is usually required to expose all the cortex of interest. The incision is made through the hair and is kept off the forehead. The burr holes for the flap are placed to allow them to be used as exit sites for the leads of the grids. We save all the bone dust to use as a seal for the exiting electrodes. The dural opening covers three sides of the bone flap. Intraoperative corticography is often used to assist in the placement of the grids. The placement of the grids on the brain must be done in a fashion that avoids any venous compression by the edges of the grids. This is most likely to occur in the medial frontal region and over the posterolateral aspect of the temporal lobe. If several grids or grids and strips are used together the interface between the individual grids must be such that there is contact between the grids

and strips so that the brain cannot herniate up between the grids (Fig. 5), since this can result in infarction or lacerations of the cortex. It is often helpful to suture the various grids and strips together so that they cannot be displaced during the closure of the dura. If the grids are cut to a smaller size to fit the region that needs to be covered there must be no sharp edges on the grids (Fig. 6), since they too can cause a cortical laceration. When multiple grids and strips are used the leads should always run superficially to the electrodes to prevent focal indentation of the cortical surface (Fig. 5). It is sometimes necessary to have an overlap of the grids in order to have them lie flat and yet cover the necessary brain surface. This is not a problem but the overlapping areas need to be recorded so that the postoperative evaluation is accurate. We take an intraoperative picture of the final location of the grids. This is then printed as a Polaroid, 6×8, and kept in the monitoring unit as a reference for the location of the grids and strips. This is in addition to the intraoperative recording of the locations and postoperative skull X-rays. The grids all have the same color for the electrode leads and to ensure that there is no confusion between one set and the others we tie a different-colored suture around each external lead and record that in surgery.

Once the leads are satisfactorily placed the dura is closed in as watertight a fashion as possible, using 5'0 prolene sutures. The dural closure and exit site of the electrodes through the dura is further sealed with tissue glue. Once the bone flap is replaced, the bone dust from the initial opening is placed in the burr holes and glued to minimize CSF leakage (Fig. 7). All the leads are brought out through separate incisions away from the primary craniotomy incision (Fig. 8). This minimizes any leakage from the sites and decreases the risk of infection at the bone flap. Despite all these maneuvers there is usually some leakage around the electrode exit sites. The skin incision is closed with staples since it is to be reopened in a few days. If there is an incision anterior to the ear this is closed with 5'0 plain catgut.

Depth electrodes

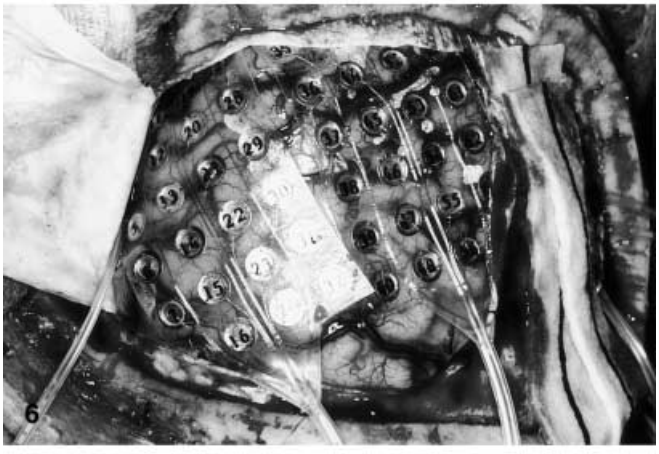
These are rarely used as the only monitoring method in children. We use them occasionally to monitor the bilateral orbitofrontal cortex, in association with bilateral frontal strips to identify the side of onset of frontal seizures. They are usually placed freehand without the stereotaxic frame. Freehand placement is also used in the temporal lobe in the rare case where depth electrodes and strips are required. This is usually where there is apparently simultaneous onset of seizures from both mesial temporal lobes. Accurate placement has been described with this freehand technique [37].

The children are sent to the pediatric ICU for the first postoperative night. The EEG recordings are begun as soon as the children are admitted to the ICU so that any early seizures can be recorded. One room in the ICU is set up for monitoring with a video camera and wired to the computer.

Postoperative care of the incisions consists of daily cleaning with 50% hydrogen peroxide in water and application of polysporin ointment to each exit site. Monitoring has been continued for up to 3 weeks when necessary, without evidence of an increased risk of infection. Antibiotics are continued for this period although there is no evidence from which to conclude whether this is necessary. Corticosteroids are not used at any time in these children.

Complications

There have been no intracranial infections and no episodes of meningitis in the 85 children who have under-



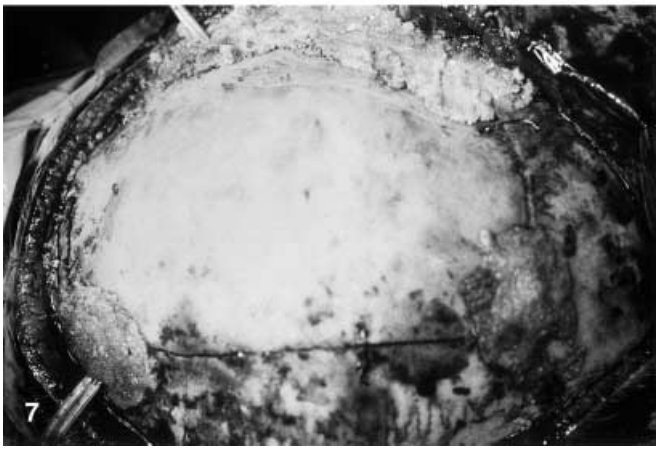


Fig. 5 Intraoperative photograph showing the close approximation of the subdural grids needed to avoid cortical herniation between them. In addition the electrode leads are all superficial to the grids

Fig. 6 Intraoperative photograph taken during insertion of grids. Note the sharp edge that is present on a grid that has been cut into two segments. This edge needs to be trimmed into a round edge to avoid cortical laceration

Fig. 7 Intraoperative photograph demonstrating how the bone dust produced during opening has been used in an attempt to prevent leakage along the electrode leads. The dust is held in place with tissue glue

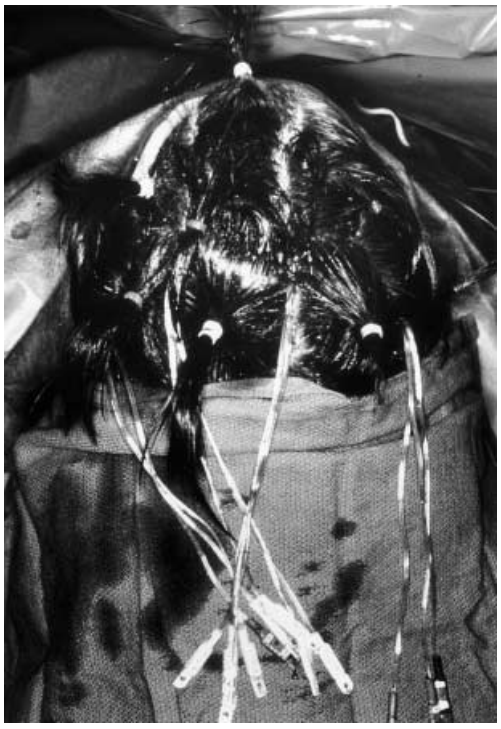


Fig. 8 Postoperative photograph showing the electrode leads exiting from multiple stab incisions. The patient is in the supine position

gone invasive monitoring in our unit over the last 8 years (1990–1998). The mean age of the children was 11.3±4.7 years with a range from 2 to 18 years. Three patients needed bone flap removal because of delayed infection. Two had grids and strips and one had strips only. The first two patients were operated on in the same week during the early stages of our Epilepsy Center and this may have been a sterilization error since both had a low-grade pseudomonas infection presenting 1 to 3 months postoperatively. The second of these two patients was a repeat surgery for continuing lateral temporal epilepsy. At the time of the infection she was diagnosed with lupus erythematosus. Two other patients with superficial infections required treatment with antibiotics, giving an overall infection rate of 6%. This is similar to the rate reported by Wylie et al. [36] and higher than the zero infection rate reported by Adelson et al. [33]. There have been no intracranial hematomas and no symptomatic brain swelling. None of the electrodes have been accidentally removed or displaced during the monitoring period. Five per cent of the children have required insertion of extra electrodes, usually because the epileptic zone was found at the edge of the monitored brain and therefore could not be fully mapped because of inadequate coverage with electrodes. The complication rate with depth electrodes has recently been reported to be no different to that with subdural electrodes [38]. There were no children with deep venous thrombosis or pneumonia in our series.

Results

In 90% of the children one or several epileptic zones have been identified. In 80% it has been possible to proceed with resective surgery. The limiting factors to surgical resection have been the presence of bilateral onset of epilepsy, multifocal onset of the epilepsy, and involvement of eloquent cortex. The latter is a relative contraindication and some of these children are now candidates for subpial transection. Overall 73% of children with extratemporal epilepsy have had an Engel outcome classification of I–III. Those with a focal lesion on MRI have had a better outcome. Only 25% of the children, however, are off antiepileptic medications. Preoperatively diagnosed brain tumors were excluded from these figures since in most cases resection of the tumor results in cessation of the epilepsy and discontinuation of medication.

Conclusion

The primary diagnosis of intractable focal epilepsy is via scalp EEG recordings. In children this is rarely sufficiently localizing for surgical resection. Ancillary tests can be helpful, particularly the MRI scan. In addition MRI spectroscopy and MRI volumetric studies may add further information. PET scanning may demonstrate an area of reduced metabolism during the interictal state that can help to localize the epileptogenic zone. SPECT scanning, particularly ictal SPECT, has been demonstrated to aid in localization. Computer subtraction techniques, comparing the interictal and ictal studies, are increasing the frequency with which a focal area of cortex involved in seizure onset can be identified. MEG, in the few reported observations in children, appears to have a very strong potential for identifying the epileptic zone and mapping areas of eloquent cortex, and may prove to be quite superior to standard EEG monitoring. This may be true only in those children with an identifiable interictal focus. In our own cases we have found that with external EEG monitoring there is a better correlation between the interictal focus and the epileptogenic zone, as defined by invasive electrodes, than with the ictal focus.

There are a large number of children with suspected focal epilepsy in whom non-invasive localization techniques do not supply sufficient relevant information to direct a surgical resection. In 80% of these children the use of invasive monitoring using subdural strips or grids can supply the extra information needed to direct a surgical resection. The complication rates are low (6%) and

the mortality rate zero. The strips and grids are well tolerated in children as young as a few months of age. Surgical technique is important to avoid cortical lacerations, hematomas and infections.

The increased use of MEG and functional MRI may reduce the need for invasive monitoring over the next few years but for the immediate future this type of monitoring will remain a valuable technique for localization of the epileptogenic zone and functional mapping in children with epilepsy. In addition the verification of the newer non-invasive techniques will have to be done using invasive monitoring.

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