

Intraoperative brain mapping to identify corticospinal projections during resective epilepsy surgery in children with congenital hemiparesis

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Abstract

Purpose The purpose of the study is to determine corticospinal organization using intraoperative neurophysiologic monitoring (IONM) during resective epilepsy surgery for patients with congenital hemiparesis and intractable epilepsy.

Methods Ten patients, aged 3–17, with intractable epilepsy underwent resective surgery. Transcranial stimulation (TCS) was achieved using a pair of cork screws at Cz and C3/C4, respectively. A 1×4 stimulating electrode strip was placed on the presumed motor cortex of the affected hemisphere for direct cortical stimulation (DCS) after craniotomy. Multipulse TCS and DCS train stimulation was delivered, with simultaneous recordings from bilateral abductor pollicis brevis and abductor hallucis, to determine the corticospinal projection pattern of the paretic limbs.

Results The above mapping techniques revealed ipsilateral corticospinal projections from the contralesional hemisphere

to target muscles in the paretic limbs in three patients, projections from both hemispheres to target muscles in three, and preserved crossed projections from the affected hemisphere in four. Nine patients were seizure free after surgery. Five had unchanged postoperative functional status, and three showed minimally improved use of the paretic hand. Two developed new motor deficits after surgery, which may have been due to a premotor syndrome in one patient, since it completely resolved within 2 weeks. The other experienced increased weakness of the paretic lower limb because a small part of the eloquent cortex was removed for better seizure control.

Conclusions Using IONM to define the corticospinal projection pattern is a valuable technique that can potentially replace preoperative fMRI and transcranial magnetic stimulation in resective epilepsy surgery, particularly for younger patients.

Keywords Corticospinal projections · Intractable epilepsy · Congenital hemiparesis · Motor evoked potential

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Introduction

Patients with congenital or early acquired brain lesions frequently present with contralateral hemiparesis, mental handicap, and daily seizures [1, 2]. Underlying etiologies may include focal cortical dysplasia (FCD), congenital vascular malformation, Sturge-Weber syndrome, perinatal infarctions, and hypoxic-ischemic injury [1, 3, 4]. Besides associated developmental issues that require long-term intensive rehabilitation and educational resources, the severity and frequency of seizure attacks are frequently disabling and have tremendous impact on the functional potential and quality of life of those affected. Under most circumstances, seizures can be controlled by anticonvulsant medications. For certain patients,

if their seizures have not responded to medication satisfactorily, resective surgery is an alternative option [5–8]. However, to remove part of the cortex for better seizure control is not without the risk of inducing new postoperative deficits. There are possibilities that the corticospinal projections of the lesioned hemisphere may have shifted to a new location, or the opposite hemisphere, due to the early onset of the lesions and greater neuroplasticity in this younger population [9, 10]. In recent decades, functional MRI (fMRI) and transcranial magnetic stimulation (TMS) have been used to determine the pattern of corticospinal projections before operation, where applicable [11–14]. However, both of these procedures require a certain degree of active participation and cooperation from the tested subjects, which is frequently not possible in some populations due to, for example, their young age or frequently occurring mental deficits.

In the present study, we use intraoperative neurophysiological monitoring (IONM) to determine the pattern of corticospinal organizations during resective surgery for patients with congenital hemiparesis and intractable epilepsy. We believe that a thorough understanding of anatomical pattern is definitely beneficial not only to surgical decision-making but also to the prediction of functional status following surgery.

Methods

Ten patients with intractable epilepsy (seven boys and three girls, aged 3 to 17 years) underwent a thorough evaluation, which included imaging studies and video-EEG, to define the source of their seizure activities and any possible underlying etiologies. The sources of the seizure activities were localized to a broad area of a single hemisphere of the brain, and the patients underwent resective surgery during the period from January 2013 to January 2014 at Taipei Veterans General Hospital. Total intravenous anesthesia (TIVA) was applied throughout the surgical course and no muscle relaxant was used except for one dose during induction. A pair of needle electrodes was placed at the bilateral abductor pollicis brevis (APB) and abductor hallucis (AH) to record motor evoked potentials (MEPs). A pair of corkscrew electrodes was placed at Cz, and C3/C4, respectively for transcranial stimulation (TCS). Responses from the bilateral APB and AH to multipulse train TCS were recorded before incision. The stimulation parameters for multipulse train TCS were 50- μ s pulse width, 4–9 pulses, ISI 2 ms, with intensity ranging from 150 to 400 V [15]. After craniotomy, we used phase reversal to localize the central sulcus by stimulating the contralateral median nerve first [16]. Then, a 1 \times 4 electrode strip was placed at the presumed site of the motor cortex as stimulating electrodes. Multipulse train direct cortical stimulation (DCS) was then applied and recorded from the bilateral APB and

AH. The stimulation parameters for multipulse train DCS were a 50- μ s pulse width, 4–6 pulses, ISI 2 ms, with intensity ranging from 50 to 100 V. If no elicited response was observed, we would use a monopolar electrode to do cortical mapping with multipulse train stimulation over the presumed motor cortex and the surgical path, in order to ensure that no eloquent cortex would be resected unintentionally. The surgical team would then make a surgical plan based on the above information provided and the finding of intraoperative electrocorticography (ECoG).

After the operation, patients were examined for the reduction of seizure severity and changes in functional status.

Results

All ten patients received epilepsy surgery with IONM to determine their individual patterns of corticospinal organization before surgical resection of their epileptogenic focus. Underlying etiologies included seven cases of FCD, one of polymicrogyria, one of perinatal middle cerebral artery infarction, and one of incontinentia pigmenti, diffuse gliosis, and scarring over the right hemisphere. Eight of the patients presented with contralateral hemiparesis, one with quadriplegia due to lesions of both hemispheres, and one with contralateral clumsiness only. Except for the one patient with quadriplegia, the rest of the patients could use their paretic hand as actively grasping and assisting hand, albeit with lower dexterity. Eight of the patients also showed some degree of mental deficit (Table 1).

Using the above mapping techniques, three of the patients were found to possess ipsilateral corticospinal projections from the contralesional hemisphere that projected to target muscles in the paretic limbs (Fig. 1). Three patients presented with corticospinal projections from both hemispheres to target muscles in the paretic limbs (Fig. 2). The remaining four cases possessed preserved crossed corticospinal projections from the affected hemisphere (Fig. 3). Based on the pattern of corticospinal projections, clinical presentations, and ECoG findings, eight patients underwent extratemporal lobectomy (ETL), one underwent peri-insular hemispherotomy, and one underwent frontal tailored lesionectomy.

Patients were seizure free after resective surgery except for one patient. Five patients remained the same in terms of their functional status after the operation; three of them showed minimally improved use of the paretic hand. Improved alertness and responding to their surroundings were also observed in two patients. Two patients showed new motor deficits after their operations, with one of the cases believed to be related to a premotor syndrome because the deficits resolved completely within 2 weeks. The remaining patient experienced more weakness of the paretic lower limb because a small part of the eloquent cortex, as detected by cortical mapping, was

Table 1 Characteristics and clinical findings of the participants

Case	Age/ Sex	Clinical findings	Lesions	Pattern of CSP	Operation	Post-op motor function	Post-op seizure severity
1	10/B	CH and MR	Polymicrogyria	Ipsilateral	ETL	Unchanged	Seizure free
2	3/G	CH	Incontinetia pigmenti with gliosis	Preserved crossed projection	Lesionectomy	Improved	Seizure free
3	9/B	CH and MR	FCD	Bilateral	ETL	Improved	Seizure free
4	4/B	CH and MR	FCD	Ipsilateral	ETL	Unchanged	Seizure free
5	12/G	CH and MR	MCA infarction	Bilateral	Peri-insular hemispherotomy	Unchanged	Seizure free
6	15/G	CH and MR	FCD	Bilateral	ETL	R/O premotor syndrome	Seizure free
7	17/B	Clumsy hand and MR	FCD	Preserved crossed projection	ETL	Unchanged	Seizure free
8	8/B	CH	FCD	Preserved crossed projection	ETL	Unchanged	Seizure free
9	4/B	CH and MR	FCD	Preserved crossed projection	ETL	Weaker paretic leg	Improved
10	3/B	Quadriplegia and MR	FCD	Ipsilateral	ETL	Improved	Seizure free

B boy, *G* girl, *CSP* corticospinal projections, *CH* contralateral hemiparesis, *MR* mental retardation, *FCD* focal cortical dysplasia, *ETL* extratemporal lobectomy, *MCA* middle cerebral artery

removed for better seizure control. He regained preoperative function several months later, after rehabilitation therapy (Table 1).

Discussion

Congenital or early onset brain lesions can significantly impair patients' functions, both physically and mentally. In addition to contralateral hemiparesis and mental deficits, they frequently suffer from seizure attacks, which further increase caregivers' burden and have tremendous impact on their quality of life as well [1, 2]. Although most seizures can be managed with medical control, some can benefit from resective surgery aimed at the removal of epileptogenic focus, where this is possible [5, 6]. Unsurprisingly, resective surgery of the cortex does carry certain risks of resulting in postoperative deficits, particularly if the focus lies in proximity to the eloquent cortex. Functional mapping and continuous MEP monitoring during supratentorial surgery have proved to increase the safety margin of the respective procedures and surgical outcome as well [17]. However, younger patients have greater neuroplasticity as compared to older subjects [11, 13]. Therefore, the possibility that the eloquent cortex does shift to the unaffected hemisphere or another part of the affected hemisphere does exist. In other words, the paretic limbs in children with congenital hemiparesis might receive corticospinal projections from the ipsilateral or bilateral hemispheres simultaneously due to neuroplasticity. Either case can certainly influence our decision-making when performing resective epilepsy surgery, because the possibility and severity of postoperative deficits will differ. For patients with

ipsilateral corticospinal projections, the possibility of new functional deficits after an operation will be close to zero. However, in patients with preserved crossed projections from the lesioned hemisphere, the possible deterioration of the paretic limbs is of great concern if resection needs to be made close to the eloquent cortex. Under these circumstances, it is of paramount importance to determine the patterns of corticospinal projections prior to resection.

In recent decades, techniques including fMRI and TMS have been used before operations for this purpose [11–14]. However, these techniques require a certain degree of cooperation and/or active participation from the tested subjects. This is almost always impossible in some patients, particularly those of a young age, or with the mental deficits frequently found in this population. Although previous research did suggest that passive range of motion fMRI can accurately localize the sensorimotor cortex in the sedated children [18], some researchers did indicate that the interpretation of sensorimotor fMRI in patients with congenital hemiparesis is possibly more difficult, since the activation might represent contralaterally preserved primary somatosensory instead of primary motor representation [12]. In the present study, we demonstrated the feasibility of intraoperative brain mapping performed just before resection. The techniques are simple because no cooperation or participation is required from our young patients, who remain under anesthesia. Routine TCS over bilateral hemispheres is applied before craniotomy and DCS over the lesioned hemisphere applied after craniotomy. The main difference here was that we recorded MEPs over the bilateral limbs muscles simultaneously instead of over contralateral muscles only, so as to determine the patterns of corticospinal projections. Based on this information, clinical

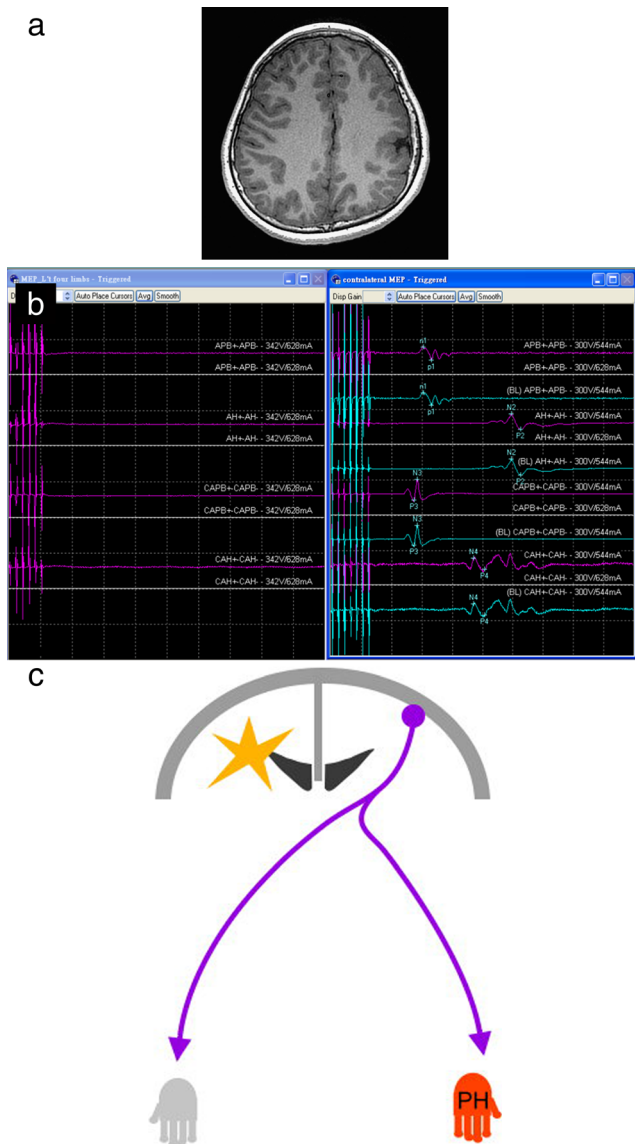


Fig. 1 A 10-year-old boy with polymicrogyria of the left hemisphere (a). No response of the right limbs to TCS over the lesioned hemisphere (b left) and bilateral muscle response to TCS over the unaffected hemisphere (b right) indicating ipsilateral corticospinal projections (c). TCS transcranial stimulation, PH paretic hand

examinations including video-EEG, and the findings of ECoG, our surgeon and neurologist would decide on the brain areas and extent of resection to achieve better seizure control, while sparing the eloquent cortex.

Following this guideline, five of our patients remained unchanged in terms of their functional status postoperatively. The paretic hand of another three patients improved slightly, which we believed was due to the decreased interference from seizure-related spikes after surgery. One patient experienced transient weakness of the contralateral limbs after their extratemporal lobectomy, which was believed to be due to a premotor syndrome. However, there were some circumstances in which the priority of seizure control was evaluated as more

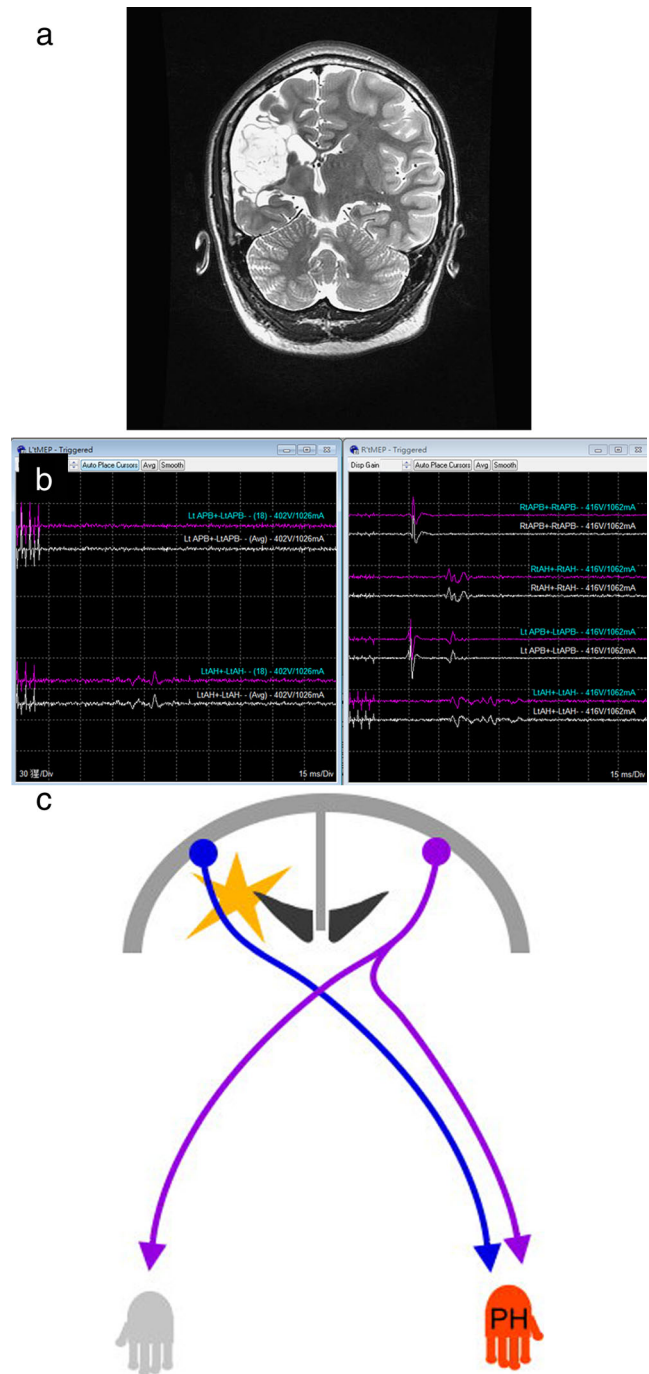


Fig. 2 A 12-year-old girl with perinatal right MCA infarction (a). Response of the left lower limb to TCS over the lesioned hemisphere (b left) and bilateral muscle response to TCS over the unaffected hemisphere (b right) indicating a bilateral corticospinal projection (c). MCA middle cerebral artery, TCS transcranial stimulation, PH paretic hand

important than functional preservation. In our series, a 4-year-old boy presented with congenital hemiparesis, mental deficits, and intractable epilepsy due to FCD. He possessed preserved crossed projections confirmed by intraoperative brain mapping and received an extratemporal lobectomy. A small part of the eloquent cortex, confirmed by direct cortical

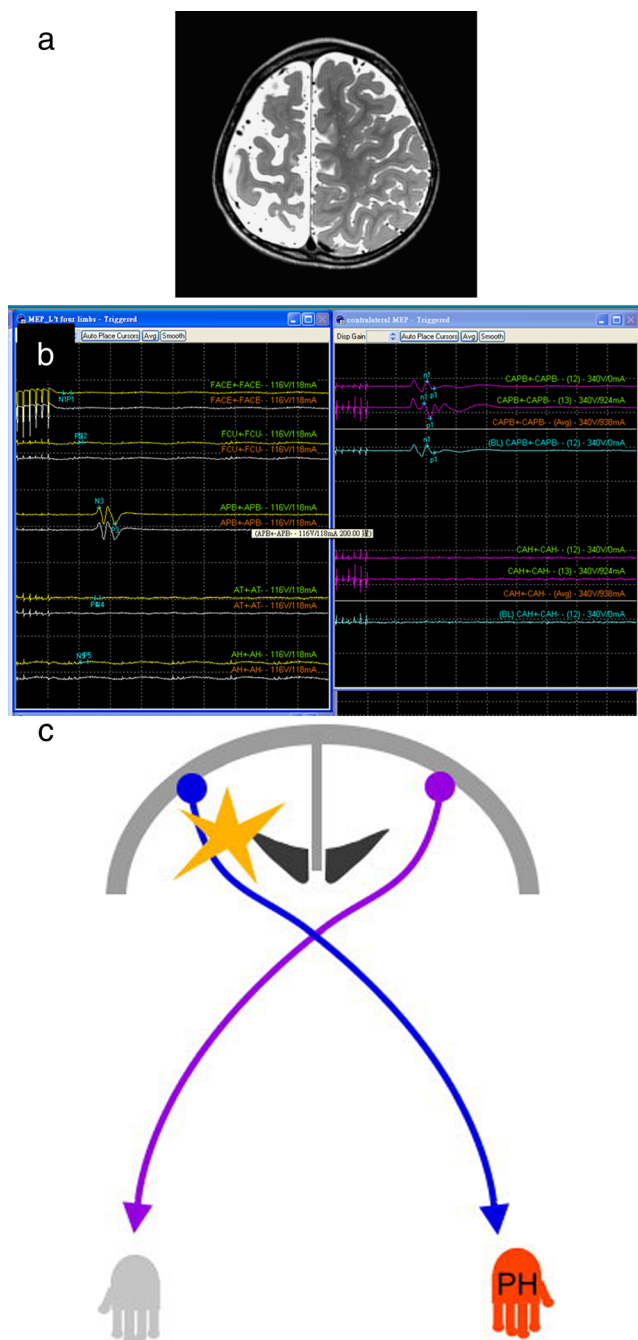


Fig. 3 A 3-year-old girl with incontinencia pigmenti and gliosis of right hemisphere (a). Responses over the contralateral limbs to DCS over the lesioned hemisphere (b left) and TCS over the unaffected hemisphere (b right) indicating a preserved crossed corticospinal projection (c). DCS direct cortical stimulation, TCS transcranial stimulation, PH parietic hand

mapping, had to be removed due to spikes recorded by ECoG at that particular site so as to achieve better control of the seizures. He experienced worsened weakness of the parietic leg, which resolved several months later, after rehabilitation therapy. In terms of seizure control, except for one patient, the remaining nine have been seizure free under medical control after their operations.

Small sample size is the major limitation of the present study and further research to study the agreement between the findings of intraoperative brain mapping and preoperative fMRI in this patient population is necessary before any definite conclusion can be reached regarding the role of this technique in resective epilepsy surgery.

Conclusion

Using IONM to define the corticospinal projection pattern is a valuable technique that can potentially replace preoperative fMRI and transcranial magnetic stimulation in resective epilepsy surgery, particularly for younger patients. Not only can it improve the safety of surgical procedures, it also helps to predict the functional outcome.

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