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The combination of stereo-EEG and radiofrequency ablation

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ABSTRACT

SEEG-guided radiofrequency thermocoagulation (SEEG-guided RFTC), a combination of Stereo-electroencephalography (SEEG) and radiofrequency thermocoagulation (RFTC), has been performed since 2001 in drug resistant epilepsy. The interest of this procedure is to aim at total or partial destruction of the epileptogenic zone, as tailored in each individual patient by the SEEG exploration. These multiple SEEG-guided RFTC lesions of epileptic foci are produced by using a radiofrequency generator connected to the electrode contacts. This review summarizes the results of SEEG-guided RFTC reported in 251 patients. This procedure appears to be safe since complications are rare, minor and usually reversible, which is explained by the use of functional electrical stimulations before RFTC. It makes it also possible to produce RF lesions located very close to cortical areas having a high functional value or being poorly accessible to a conventional surgical procedure. Even if seizure outcome is not as good as results of surgery, 41% of the patients are responders at 12 months with several seizure free patients. The benefit-risk ratio of the SEEG-guided RFTC procedure proved to be particularly favorable for the patients presenting with epileptogenic cortical malformation of development (nodular heterotopy as well as focal cortical dysplasia) and for those in whom surgery is not feasible or risky. For the patients in whom surgery is feasible, SEEG-guided RFTC could be used as a first step, as a predictive therapeutic test before resective surgery.

1. Introduction

SEEG-guided radiofrequency thermocoagulation (SEEG-guided RFTC) is a minimally invasive technique of epilepsy surgery, like stereotactic radiosurgery, laser-induced thermal therapy or MRI-guided focused ultrasound lesioning (Quigg and Harden, 2014). Developed from the 60′s onwards in the treatment of some behavioral disorders (Narabayashi et al., 1963), stereotactic radiofrequency thermocoagulation lesioning, using monopolar coagulation, was proposed more than 30 years ago to treat drug-resistant temporal lobe epilepsies by producing lesions in the amygdalo-hippocampal structures (Flanigin and Nashold, 1976). This technique proved to be remarkably well tolerated. However, the outcome of stereotactic RFTC proved definitively to be less favorable than that of standard surgery (Patil et al., 1995; Parrent and Lozano, 2000). Since 15 years, this procedure has been enriched by the possibility to be guided by Stereo-electroencephalography (SEEG), in order to improve its efficiency by creating lesions not targeted “a priori” on a selected structure, but aiming at a total or partial destruction of the epileptogenic zone, as tailored in each individual patient by the SEEG exploration. The SEEG method (Munari et al., 1994; Guenot et al., 2001a,b) consists of stereotactic implantation of depth electrodes in the brain to identify the exact location of the epileptogenic zone (EZ), as well as the pathways of seizure propagation. In addition to passive recording, these electrodes also can be employed to generate focal lesions of the epileptogenic zone and of seizures propagation pathways. These multiple bipolar SEEG-guided RFTC lesions of epileptic foci can be produced by using a radiofrequency generator connected to the electrode contacts. This procedure does not require passage of electrodes through brain beyond the passages required by diagnostic depth electrodes.

This focused review summarizes studies published until June 2017 (Guenot et al., 2004; Catenoix et al., 2008; Guenot et al., 2011; Cossu et al., 2014; Catenoix et al., 2015; Cossu et al., 2015; Bourdillon et al., 2016; Bourdillon et al., 2017) on SEEG-guided RFTC, reporting data on its safety and efficiency, in order to better assess which patients are likely to benefit from SEEG-guided RFTC.

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2. Methodology of SEEG-guided RFTC

2.1. Patients

RFTC was reported in the literature in patients having benefited from SEEG exploration for drug resistant epilepsy. All patients had previously benefited from a complete course of presurgical non-invasive investigation, but data obtained were not sufficiently congruent for a reliable localization of the epileptogenic zone. Intracerebral recordings of spontaneous seizures were therefore undertaken before any surgical decision. Patients were informed of the aims and risks of SEEG recordings, of the functional mapping by cortical stimulation and of RFTC, and signed a written consent.

2.2. Methodology of SEEG-guided RFTC

Intracerebral exploration was conducted according to the technique described by Talairach and Bancaud (1973), and reported in detail in previous publications (Cardinale et al., 2013; Guenot et al., 2001a,b).

2.2.1. Choice of targets

The patients benefited from a post-implantation MRI on which all electrodes and their contacts are visible. Targets were located in cortical sites showing either a low amplitude fast pattern or spike-wave discharges at the onset of the seizures (Fig. 1), in intralesional location, and/or in contacts where electrical stimulation induced usual seizures. Interictal paroxysmal activities were not considered for planning thermo-coagulation sites (excepted in focal cortical dysplasias, where interictal spikes are very congruent with the lesion). Before SEEG-guided RFTC, a functional mapping was systematically performed using high-frequency cortical bipolar stimulations (50 Hz, 0.5 ms pulse duration, 1–3 mA during 3 s) between two contiguous contacts. Sites where stimulation induced motor symptoms or language disorders were not coagulated. No coagulation was performed in close proximity of major vascular structures (i.e. less than 2 mm).

2.2.2. SEEG-guided RFTC procedure

SEEG-guided RFTC was performed at the end of the recording period and before electrode removal, without anesthesia, which enables clinical monitoring of the patient during the procedure. A control of SEEG activity was performed immediately after the RFTC. SEEG monitoring was sometimes continued for a few days after the coagulations, in particular in patients having very frequent seizures before RFTC. In those cases, it was thus possible to perform a second RFTC procedure in the following days when seizures persisted after the first SEEG-guided RFTC procedure. Ablation of the electrodes was performed after the end of the RFTC procedure, and patients were discharged after 1–2 days of clinical follow up. Post SEEG-guided RFTC MRI was not systematic (Fig. 2).

Lesions were made by using a radiofrequency lesion generator system (COSMAN G4, Cosman Medical, Burlington, MA, USA), connected to the SEEG electrodes (Microdeep, Dixi Medical, Besancon, France). The electrodes are CE mark certified for the thermocoagulations (class III, CE mark certified by the notified body LNE/G-MED 0459). Each electrode had a diameter of 0.8 mm, and included 5–18 recording contacts of 2 mm length, separated by 1.5 mm. Usually the lesions were produced between two contiguous contacts of the selected electrodes using a 50-V, 120-mA current known to increase in vitro the local temperature up to 78–82 °C within a few seconds, thus producing a lesion around the electrode contact in 10–30 s. A recent paper (Bourdillon et al., 2016) reported optimal parameters of SEEG-guided RFTC on the basis of in vivo animal data: 1) to reach the optimal lesional volume, the delivered power was increased until the impedance rapidly increased. This rapid modification corresponds to the occurrence of the coagulation. Intensity and voltage, which determine the delivered power, are not fixed parameters and can vary from a patient to an other; 2) to always select adjacent electrode contacts to create a dipole.

3. Results

3.1. Patients

RFTC were performed in a total of 251 patients, 139 males and 112 females, having benefited from SEEG exploration for drug resistant epilepsy between 2004 and 2013. The mean age was 27.5 ± 11.7 years (Standard Deviation (SD)) (range: 2–59); the mean disease duration was 20.8 ± 10.6 years (SD) (range: 1–58). Preoperative brain MRI was negative in 99 patients and showed structural lesion in 152 patients (Table 1). 1–72 RFTC were performed with an average of 11.6 ± 8.6 (SD) (range: 1–72) (Cossu et al., 2015; Bourdillon et al., 2017).

3.2. Safety

The procedure was completely painless. In 12.3% patients a typical seizure occurred during the SEEG-guided RFTC (Cossu et al., 2015). 3.3%, 9/275 (3/89 in Cossu et al., 2015 and 6/186 in Bourdillon et al., 2017), of the procedures led to side effects, most often transient motor deficit. In majority of the cases (6/275), side effects were transient (2.2%) and predictable by the functional mapping (Bourdillon et al., 2017). In only one patient out of 251 severe and unexpected permanent neurological morbidity occurred (Cossu et al., 2015).

3.3. Efficiency

In the majority of the studies, patients were classified as seizure-free or responders (i.e., patients with > 50% improvement of epilepsy) (Guenot et al., 2004; Catenoix et al., 2008; Guenot et al., 2011; Catenoix et al., 2015; Bourdillon et al., 2016; Bourdillon et al., 2017). In Cossu et al. (2015), the patients were assigned to one of the following categories: seizure free, sustained worthwhile improvement, transient benefit or no benefit. In this review, for more clarity, patients were classified as seizure free, responders or no responders. No patient shows any increase of seizure frequency. At two months in Bourdillon et al. (2017), 108/162 patients (67%) were responders with 41 (25%) of patients seizure-free. At 12 months, 78/162 (48%) were responders in Bourdillon et al. (2017) and 25/89 (28%) in Cossu et al. (2015). So103/251 patients (41%) exhibited a persistent significant improvement in their seizures, including 11% of seizure free patients (27/246). 58% of responders maintained their status during the long-term follow-up (mean 5.4 years) (Bourdillon et al., 2017).

3.4. Etiology of the epilepsy

In a sub-group of 31 patients with epilepsy symptomatic of cortical development 21 patients (67%) were responders (Catenoix et al., 2008). In this group, 9/14 of those with a malformation poorly accessible to surgical resection were responders and 6/14 (43%) were long-lasting seizure free (Catenoix et al., 2015). Cossu et al. have underlined the interest of this procedure in heterotopia with 8/12 seizure free patients (67%) (Cossu et al., 2014; Cossu et al., 2015). The results were less favorable in case of non lesional epilepsy with 22% and 33% of improvement reported (Catenoix et al., 2008; Cossu et al., 2015). No characteristic of the disease (age of onset, duration, sex of the patient, lobar localization of the epileptogenic zone) was linked to the outcome (Catenoix et al., 2008).

3.5. Predictive value of SEEG-guided RFTC outcome on post-operative seizure outcome

In Bourdillon et al. (2017), 91 patients underwent conventional epilepsy surgery after SEEG-guided RFTC. Because all of surgical