Neurophysiologie Clinique/Clinical Neurophysiology (2017) xxx, xxx—xxx

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COMPREHENSIVE REVIEW

SEEG-guided radiofrequency thermocoagulation

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KEYWORDS
Epilepsy surgery;
Radiofrequency;
SEEG guided RF-TC;
Stereoencephalography;
Thermo-SEEG;
Thermocoagulation

Summary We propose expert recommendations on the use of SEEG-guided radiofrequency thermocoagulation (RF-TC) based on an exhaustive literature review. This technique consists in performing a RF-TC lesion using a SEEG depth electrode at the end of the recording. It is indicated when conventional surgical resection of the ictal onset zone is not possible. SEEG guided RF-TC can also be considered as a diagnostic tool since an improvement, even limited, has a high positive predictive value concerning the good outcome after surgery. It is possible to perform SEEG only in the purposes of performing RF-TC. An over-implantation of the presumed ictal onset zone is possible when such a procedure is planned. The RF-TC target should only be defined based on the ictal activity, except when a type II focal cortical dysplasia electrophysiological interictal signature is recorded. A single or multiple coagulations should always be performed between contiguous electrode contacts. The power delivered by the generator should be increased until the impedance suddenly changes, which indicates that the thermocoagulation has occurred. The procedure should be performed under clinical monitoring without

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https://doi.org/10.1016/j.neucli.2017.11.011
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Please cite this article in press as: Bourdillon P, et al. SEEG-guided radiofrequency thermocoagulation. Neurophysiologie Clinique/Clinical Neurophysiology (2017), https://doi.org/10.1016/j.neucli.2017.11.011

anesthesia and after systematically testing neurological functions by electric stimulation on each target. Multiple SEEG-guided RF-TC can be proposed in a single patient, for example, in cases of relapse after a previous effective procedure. Conventional resection surgery remains feasible after a RF-TC procedure.
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Introduction

The idea of using stereotactic surgery in humans to perform lesions by means of radiofrequency waves came in the second half of the 20th century [23]. The first paper reporting a positive effect in epilepsy was published in 1965 [22], but treating epilepsy was not initially the main purpose of this procedure, which aimed to reduce unmanageable behavioral disorders by selective amygdalotomy. Several lesioning techniques have been proposed, but the use of radiofrequency thermocoagulation (RF-TC) was the most popular due to its intrinsic advantages [5,25]. From the 1970s to the 1990s, stereotactic RF-TC as a surgical treatment of focal epilepsy was largely developed [18] mainly as an alternative to conventional surgery in mesial temporal lobe epilepsy (MTLE) [10,15,17]. However, due to the rather disappointing results of this technique in MTLE compared to those of conventional surgery, it has been almost totally abandoned. These early results have been obtained from single lesion procedures guided by non-invasive investigations.

Nevertheless, these approaches did not take into account another major aspect of stereotaxy: the use of the methodology as way to record rather than a way to lesion [26]. This major aspect was brought by Talairach et al. and their startling and revolutionary contribution in the comprehension of epilepsy. They proposed a new conceptual frame of the disease as dynamic process sustained by a pathological network rather than a focal abnormality. The concept of SEEG-guided radiofrequency thermocoagulation (SEEG-guided RF-TC) emerged from these two aspects of stereotaxy:

- recording;
- lesioning.

This new approach was introduced in 2004 by using stereoelectroencephalographic (SEEG) recordings of ictal activity to guide RF-TC [11,12]. This technique offers several advantages [4]:

- thermocoagulation can be targeted on the seizure onset zone delineated by SEEG recordings;
- multiple lesions can be performed between adjacent contacts of the SEEG electrodes;
- the electrodes used to perform the thermocoagulation are those implanted for the SEEG, so that carrying out thermo-SEEG does not increase the surgical risk related to electrodes implantation *per se*;
- thermo-SEEG can be preceded by functional mapping through cortical stimulation, thus preventing the occurrence of a postlesional neurological deficit;
- the procedure does not require anesthesia.

Principles

RF-TC has become popular for intracranial use since the second part of the 20th century, probably due to the possibility of producing well-circumscribed lesions, of performing stimulation and recording at the same time, of having impedance monitoring and to the easy adaptation of RF-TC to stereotactic and scopic systems [6]. In 2004, it was proposed to use SEEG electrodes to perform bipolar SEEG-guided radiofrequency thermocoagulation of the epileptogenic zone (EZ) [12] in drug-resistant epileptic patients who are ineligible for conventional surgical resection of the ictal onset zone because of the proximity of a functional area or an epileptic network that is too extensive. In other words, it is possible to perform an SEEG inpatient ineligible for respective surgery in order to perform a SEEG-guided RF-TC. Bipolar RF-TC is based on the spreading of a RF current between the two poles of a dipole. This creates an oscillation in each given point of the electric field (E-field) between these two poles which induces the nearby charged ions in the electrolyte to move back and forth in space at the same high frequency, creating an ionic oscillation current named j. RF-TC is the result of the frictional heating within the tissue resulting from J-field. The power deposition and the elevation of temperature are directly linked to the J-field [5,24]. Both in vitro and *in vivo* data in animals [1] and in humans in the literature [3,4,7,8], provide evidence that performing bipolar RF-TC using SEEG electrode is a safe procedure.

Settings

Which optimal settings are likely to create as large and reproducible RF-TC lesions as possible? Animal *in vivo* and in vitro experiments [1] showed in vitro that increasing the intensity and voltage of the delivered current until these parameters spontaneously collapse (which corresponds to a rapid modification of impedances) provides larger lesions than using fixed parameters, even for a longer spell. When direct monitoring of the impedance is available, an abrupt modification of its value indicates that coagulation has occurred. It is worth noting that the patient or the neurosurgeon may hear the coagulation before reaching its

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