Automatic Analysis and Visualization of Microelectrode Recording Trajectories to the Subthalamic Nucleus: Preliminary Results

Jon Haakon Falkenberg, James McNames, Jacques Favre, Kim J. Burchiel

Biomedical Signal Processing Laboratory, Electrical and Computer Engineering Department, Portland State University, and Department of Neurological Surgery, Oregon Health and Science University, Portland, Oreg., USA

Key Words
Parkinson’s disease • Stereotactic surgery • Microelectrode recording

Abstract
Although microelectrode recordings (MER) are commonly used to confirm stereotactic targets during surgery for movement disorders, there is no consensus on whether the additional risks and cost of MER are worth the benefits. This may be due, in part, to the inconsistency and inefficiency of subjective interpretation of MER data that is currently used in practice. We describe several fully automatic visualization methods for MER that efficiently and clearly indicate segments of the microelectrode trajectories with homogeneous neural activity that correspond to expected deep brain nuclei. Specifically we demonstrate that these visualization methods can help identify the subthalamic nucleus in Parkinson’s disease patients. These methods have the potential to significantly improve patient outcome by helping neurosurgeons objectively identify target structures more quickly and accurately.

Introduction
Chronic high-frequency stimulation of the subthalamic nucleus (STN) has been shown to improve symptoms of Parkinson’s disease (PD) in appropriately selected patients [1–13]. Despite confirmed clinical benefits reported by multiple centers, the ideal target for deep brain stimulating (DBS) electrode placement in the human STN has yet to be established. Recent advancements in microelectrode recording (MER) have shown promise in determining general target areas that are clinically effective [8, 12, 14]. Unfortunately, these MER analysis techniques are not uniform or objective. Currently, there exists debate regarding the reliability, accuracy and safety of using MER for stereotactic target localization [3, 4, 13, 15–18]. Hariz and Fodstad [4] have suggested that MER techniques may increase the risk of complications during movement disorder surgery without an attendant improvement in the accuracy of DBS electrode placement. While no significant difference of morbidity related to MER was observed in a large series comparing functional and morphological stereotactic procedures [19], concerns regarding the safety and necessity for MER in these procedures remain. Further research in MER analysis is needed to determine if MER can improve precision and consistency in DBS electrode placement. Clinical outcome data will ultimately establish whether MER is worthy of use in determining clinically effective target areas or, alternatively, if it can at least provide insights into the prognosis of the disease in individual cases.

Traditionally, neuronal structures have been classified electrophysiologically by three parameters: phasic activity (spike pattern), kinesthetic activity (response to movement) and tonic activity (firing rate) [20]. Phasic activity (spike pattern) analysis has depended largely on observer
interpretation and description, which has introduced an element of subjectivity. On the other hand, kinesthetic and tonic activity can be evaluated based on objective characteristics of the spike train (e.g. firing rate and interspike intervals). Despite this apparent objectivity of analysis, the literature does not describe uniform or quantitative characteristics of MER from the STN [5, 21]. It is likely that the differences between patients and disease stage account for some variability. Nevertheless, the lack of defining characteristics of the target described in the literature may also be due to inconsistent data analysis methods. Specifically, the current use of single-unit recording analysis introduces variability since investigators are required to make individual choices in selecting which spikes to include in the analysis. Despite the fact that spike counts are objective, the selection of data segments to be included for analysis is dependent on subjective observer judgment.

Typically, neurosurgeons use additional clues to help identify structure boundaries that cannot be obtained from single-unit analysis. For example, an abrupt increase in background noise is commonly observed as a microelectrode is transitioned from the zona incerta (ZI) and fields of Forel to the STN [5, 21]. This increase in background noise in the STN is due to the high density of cells in the STN region relative to the ZI [22]. Despite being a well-known distinguishing feature, quantitative measures of this transition in MER and assessment of its ability to distinguish between these two structures have not been accomplished in a quantitative fashion.

This study investigates methods to define the boundaries of the STN and surrounding structures, while not requiring single-unit analysis during the surgery. The methods were designed to be practical during surgery and to improve consistency, reproducibility and ease of target localization.

**Patients and Methods**

Fourteen consecutive PD patients (9 males, 5 females) who underwent bilateral implantation of DBS electrodes in the STN under local anesthesia at the Oregon Health and Science University and Portland Veterans Administration Medical Center were included in this study (2001–2003). The clinical criteria used to select candidates for bilateral STN implants are described in table 1.

**Surgical Technique**

All procedures were performed with patients in the ‘off’ state, with no levodopa or other medications administered for their PD after midnight prior to the surgery. A Leksell frame (Elekta Inc., Norcross, Ga., USA) was used for all procedures and was placed such that the anterior commissure/posterior commissure plane was approximately parallel to the base plane of frame. Patients had a preoperative 1.5-tesla magnetic resonance image in the frame using axial T$_1$-weighted fast spin echo (FSE), axial FSE inversion recovery and 3-dimensional T$_2$-weighted sequences. Magnetic resonance image data were transferred to a Stealth Station utilizing Framelink software (Medtronic Inc., Minneapolis, Minn., USA), whereupon Leksell fiducial points and anatomic landmarks were identified. Anatomical location of the STN was best determined on the T$_1$-weighted FSE inversion recovery and 3-dimensional T$_2$-weighted sequences. Anatomical location of the anterior commissure, posterior commissure and midsagittal plane was determined on the T$_1$-weighted FSE inversion recovery and 3-dimensional T$_2$-weighted sequences. Anatomical location of the STN were obtained using a target derived from the Schaltenbrand atlas. If the STN was visible on imaging, target coordinates were adjusted, if necessary. If the STN could not be unequivocally identified on magnetic resonance imaging, a nominal atlas target (lateral = 12, anteroposterior = –4, vertical = –4) was used as the first MER trajectory. A burr hole was drilled just anterior to the coronal suture, 12 mm from the midline to produce a trajectory parallel to the midsagittal plane. The dura was cut in a cruciate fashion, and the burr hole was sealed with gelfoam to minimize cerebrospinal fluid leakage. When microrecording was completed, the DBS electrode was inserted and anchored with a Navigus cap (Image-Guided Neurologics, Melbourne, Fla., USA).

**Microrecording Technique**

A commercially available microrecording system (Neurotrek, Alpha Omega Engineering, Nazareth, Israel) was used to acquire and store data. Neurophysiological signals were sampled at 12 kHz. Tungsten microelectrodes with an impedance of between 0.11 and

<table>
<thead>
<tr>
<th>Patient identification</th>
<th>Sex</th>
<th>Age years</th>
<th>Disease duration, years</th>
<th>Inclusion criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>STN 100</td>
<td>F</td>
<td>75</td>
<td>22</td>
<td>IP, DID, OO</td>
</tr>
<tr>
<td>STN 101</td>
<td>F</td>
<td>57</td>
<td>21</td>
<td>IP, DID, OO</td>
</tr>
<tr>
<td>STN 103</td>
<td>F</td>
<td>65</td>
<td>18</td>
<td>IP, DID</td>
</tr>
<tr>
<td>STN 104</td>
<td>M</td>
<td>55</td>
<td>17</td>
<td>IP, DID, OO</td>
</tr>
<tr>
<td>STN 105</td>
<td>M</td>
<td>75</td>
<td>20</td>
<td>IP, BR, DID</td>
</tr>
<tr>
<td>STN 106</td>
<td>M</td>
<td>54</td>
<td>16</td>
<td>IP, DID, OO, BR</td>
</tr>
<tr>
<td>STN 107</td>
<td>M</td>
<td>66</td>
<td>13</td>
<td>IP, OO, DID</td>
</tr>
<tr>
<td>STN 108</td>
<td>M</td>
<td>61</td>
<td>15</td>
<td>IP, OO, BR</td>
</tr>
<tr>
<td>STN 109</td>
<td>M</td>
<td>66</td>
<td>20</td>
<td>IP, OO, DID</td>
</tr>
<tr>
<td>STN 110</td>
<td>M</td>
<td>65</td>
<td>6</td>
<td>IP, OO, DID, BR</td>
</tr>
<tr>
<td>STN 111</td>
<td>M</td>
<td>68</td>
<td>15</td>
<td>IP, BR, DID</td>
</tr>
<tr>
<td>STN 113</td>
<td>M</td>
<td>63</td>
<td>8</td>
<td>IP, DID</td>
</tr>
<tr>
<td>STN 114</td>
<td>F</td>
<td>66</td>
<td>15</td>
<td>IP, BR, DID</td>
</tr>
<tr>
<td>STN 115</td>
<td>F</td>
<td>66</td>
<td>12</td>
<td>IP, BR, TR</td>
</tr>
</tbody>
</table>

Average 65 16

IP = Idiopathic PD; DID = drug-induced kinesia; BR = bradykinesia; OO = on/off fluctuations; TR = tremor.
Automatic Microelectrode Recording – STN

0.43 MΩ (measured at 1,000 Hz) were used. The Neurotrek system contains a spike discriminator with various spike-discriminating analysis tools (i.e. firing rate histograms, interspike interval histograms); however, on-line visual and auditory analyses were the primary methods for distinguishing the different structures along the trajectory and in confirming the target location.

For reasons related to the proprietary dimensions of the Alpha Omega system, and the Leksell frame, the presurgery nominal target depth was, by definition, 27.5 mm beyond the tip of the microelectrode introduction cannula. The initial point of MER was typically within the white matter just superior and rostral to the thalamic reticular shell. No attempt was made to avoid the ventricular system. This initial point of each MER was related solely to the unique dimensions of the Alpha Omega microdrive system, as used in conjunction with the Leksell frame and the cannulae provided with this system.

The initial depth increment with each repositioning of the microdrive was 1.0 mm. During the first 5–10 mm of the trajectory, initial cells, most probably from the anterior thalamus and nucleus reticularis of the thalamus were recorded. Once the putative thalamic neurons were encountered, the depth increment with each microdrive movement was decreased to 500 μm. When the ZI was eventually entered below the thalamus, the movement increment was further reduced to 200 μm for the remainder of the MER trajectory.

Each depth position was recorded for at least 30 s and MER was continued until the STN was unequivocally identified, and its caudal extent was mapped. Thus, the total length of the trajectory from the end of the cannula to completion of the MER pass was typically 30–32 mm.

Data Analysis

For all analysis and visualization techniques, a 10-second sample of the recorded signal was used for each depth position. The segment was chosen automatically to have the smallest deviation from the mean signal value of the whole recording [23].

Energy/Rank Energy

The energy of the recorded segments was calculated by taking the standard deviations of the signal. The rank of the energy was calculated at percentiles 1–99, percentiles 5–95, quartiles 25–75 and median 50% energy, and displayed at each of the different recording depths.

Power Spectral Density

Welch’s method of nonparametric estimation of power spectral density (PSD) was applied to the segmented signal and the mean subtracted [24]. Window length was set to 0.0852 s. The signal was divided equally into segments with 50% overlap. Each section was windowed with a Hamming window, and the modified periodograms were computed and averaged. Different magnitudes of power were plotted as different colors. The color spectrum range was set between 0 and 99% of magnitude values.

Marginal Probability Density Function

The marginal probability density function (mPDF) was obtained using the following technique: the signal mean was first removed, and the voltage amplitudes of the MER data were calculated and distributed over 100 bins and normalized with respect to the number of elements in the data. Similar to the PSD plot, the mPDF color spectrum range was set to 0–99% of the different magnitudes and was displayed with different colors.

Time Series

The smoothed instantaneous power signals (cut-off at 4 Hz) were decimated to 200 samples and visualized in 10-second segments per electrode depth. The instantaneous power was calculated by squaring the signal. The time series color spectrum was set to 0–99% of the amplitude of the time series, and different amplitudes were displayed as different colors.

Autocorrelation Function

The coefficients calculated from the biased autocorrelation function (ACF) with a maximal lag of 0.012 s produced a vector of 144 coefficients for each recording depth [25, 26]. Different amplitudes of the coefficients were plotted as different colors. The color spectrum was set as a function of a hyperbolic tangent function bounded by limits –1 and 1. The ACF coefficients were input arguments for the hyperbolic tangent function.

Partial Autocorrelation Function

The partial ACF utilized the Durbin-Levinson algorithm to estimate the coefficient depth [25, 26]. The maximal lag was 0.005 s and produced 60 coefficients for each recording depth. Similar to the ACF, the different coefficients were plotted as different colors, and the color spectrum was set as a function of a hyperbolic tangent function bounded by limits –1 and 1.

Results

Extracellular MER data from 26 trajectories were recorded from 14 PD patients undergoing bilateral STN implantation. The median recording time for each of the trajectories was 51 min (range 24–80 min). Due to nonconclusive micorecording data obtained on the first track, 2 of the 14 patients (STN 114 and STN 115, table 1) received 2 MER passes on the same side. The final target position for placement of the DBS electrode was not based on the visualization method described in this study, since this analysis was performed off-line. In these 14 cases, target mapping using MER was based strictly on the surgeon’s subjective evaluation of the MER signals.

Representative cell discharges along an STN MER trajectory are shown in figure 1. The traces represent a sample of the raw microelectrode data collected from the left STN trajectory (patient STN 106L). Results of statistical signal processing and visualization methods that were performed with this MER track from this patient are shown in figure 2. One hundred and three different depths of MER data were collected along the stereotactic trajectory in this figure, of which some depths and structures are shown as raw data in figure 1. It appears that MER, PSD and mPDF are the visualization methods that most
clearly represent the distinct neuronal populations along the track. Visualizations of PSD and mPDF for all 26 trajectories included in this report are shown in figures 3 and 4, respectively. Despite the fact that these analyses were conducted off-line and after the completion of the DBS implant procedure, figures 3 and 4 demonstrate that in 19 instances, localization of the STN by the neurosurgeon at the time of the MER overlapped with the localization of the nucleus by the data visualization methods described in this paper.

An example of the transition from the ZI to the STN, which could not easily be discerned from PSD or mPDF, is shown in figure 5. The time series plot in figure 5 shows unique signal characteristics that allow for the distinction of these structures along the stereotactic trajectory, suggesting the usefulness of more than a single visualization method in determining target location.

**Thalamus**

Rigorous analysis of the various nuclei of the thalamus encountered by the MER was not performed because the main goal of this study was to determine when the electrode entered and exited the reticular shell of the thalamus. This was typically the initial gray matter encountered by the microelectrode. Recording of these thalamic cells, and microelectrode impedance measurements, allowed the surgeon to be confident that the MER system was functioning properly. In effect, exit from the thalamic base during the continuation of the MER pass set the expectation of encountering the STN within a further 5–7 mm of the trajectory.

As the recording electrode penetrated more deeply into the thalamus towards the STN, the energy, PSD and mPDF gradually increased overall signal energy, frequency and power distribution, and energy distribution, respectively (fig. 2). Neuronal firing amplitudes in the time domain also increased, as is represented in the time series plot.

**ZI/Fields of Forel**

A relatively quiet region was typically and fairly abruptly encountered after the electrode had passed the clearly identifiable thalamic base. Individual action potentials were less common in this region. Analysis and visualization techniques detected this quiet zone by a drop in the amplitudes of energy, PSD, mPDF and time series plots (fig. 2). The first region encountered was likely the thalamic fasciculus (H1 fields of Forel), with the ZI located below this fiber tract [24]. Ventral to the ZI was the lenticular fasciculus (H2 fields of Forel), which typically showed a gradual increase in energy, PSD, mPDF and time series amplitude as the microelectrode approached the STN.

**Subthalamic Nucleus**

A steep increase in energy, PSD, mPDF and time series energy was detected as the microelectrode penetrated the STN as compared to recordings from the ZI and fields of Forel. It is well known that the transition from the ZI to the STN is physiologically characterized by an abrupt increase in background noise. However, previous reports have relied on empirical observations in the pallidum [27].
Fig. 2. MER data visualization example, from a patient with PD (STN 106L, target depth 28.5 mm). A Statistical properties of MER versus electrode depth. The top plot (Energy) represents annotations regarding the presumed location of the recording that were made during surgery based on the subjective observations of the surgeon. Based on atlas coordinates, the middle of the target structure (STN) was expected to be at a depth of 27.5 mm from the tip of the cannula (electrode depths from the cannula tip are listed at the top of the aligned plots). The next plot (PSD, Hz) shows the energy of the spontaneous neuronal discharge at different depths along the stereotactic trajectory, and the rank energy of the energy; from top to bottom 1–99th, 5–95th, 10–90th, 25–75th percentiles, respectively. The PSD, mPDF and time series (TS) plots show amplitude ranging from low (black) to high (white). The visualization clearly shows the boundaries of the target structure between 1.5 mm above (26 mm) and 2.5 mm below (30 mm) the expected target depth. Note that the ACF is highest in the region of the SNR. Cells in the vicinity of the SNR showed a high autocorrelation with a time lag of approximately 3 ms. This is likely due to the high-frequency tonic firing that typifies the SNR, in this case in the range of 250–300 Hz. B–D Different visualization angle of PSD, mPDF and the signal time series, respectively. RT = Reticular nucleus of thalamus; SNR = substantia nigra reticulata; PACF = partial autocorrelation function.
and STN [5, 16, 18], based on audiovisual feedback of the raw microelectrode data. The energy, PSD and mPDF were nonuniform throughout the STN. Typically, the dorsal part of the STN showed a steeper initial increase in statistical signal properties compared to a less steep decline in the ventral part of the STN. In 6 patients there was a recording with quite an abrupt decrease in energy, PSD and mPDF in a part of the STN (fig. 3 and 4). Similar abrupt decreases were occasionally observed in the reticular thalamus.

The statistical properties of the ACF shown in figure 2 displayed distinctive repeating positive and negative autocorrelation coefficients. These repeated patterns were separated by approximately 3 ms. However, these similar patterns seemed to be irregular compared to the other trajectories. The partial ACF displays some partial autocorrelation at a lag of 0.2 ms in the STN region. Interestingly, these patterns were only seen in the trajectories that showed distinct energy, PSD and mPDF for the STN nucleus.

Substantia Nigra Reticulata
During surgery the substantia nigra reticulata (SNR) was characterized by less background activity than the STN, and by cells with a regular and higher firing frequen-
As shown in the ACF plot, cells in the vicinity of the SNR showed a high autocorrelation with a time lag of approximately 3 ms. This is likely due to the high-frequency tonic firing that typifies the SNR, in this case in the range of 250–300 Hz. The entire length of the SNR was not systematically recorded, because the goal was to reach and record from the SNR to confirm the trajectory path. Visualization of the SNR was best characterized by mPDF, which demonstrated that the signals of the SNR had a smaller amplitude variation than the STN. Additionally, the PSD visualization usually showed that the power at different frequencies in the SNR is less than that of the STN.

**Discussion**

MER analysis is employed for the confirmation and adjustment of subcortical stereotactic target locations during stereotactic movement disorder surgery. Since the introduction of STN as a stereotactic target for the treatment of PD a decade ago, the ideal means for anatomical and physiological location of the target within the STN has remained elusive [1, 9, 10, 28, 29]. However, recent evidence has initiated attempts to delineate clinically effective DBS electrode target areas [8, 12, 14]. The role of MER guidance for stereotactic targeting is debatable, in part because there are no universal or consistent MER
standards to compare target placement with anatomical accuracy or clinical outcome [9, 10, 13]. Furthermore, there are legitimate concerns regarding potential additional risks of MER during stereotactic movement disorder surgery [13]. Given these concerns, the development of more objective and consistent MER analytical techniques [20] that address quantitative MER analysis standards, target placement accuracy assessment and objective comparisons of clinical outcome from DBS placement with and without MER are certainly justified. While quantitative analysis of MER data requires more mathematically rigorous approaches than have been previously employed, the techniques must also become more accessible, and preferably more cost effective and faster than traditional methods. This is the challenge of modern MER, one that we have attempted to address in this study. In effect, it is not one problem, but a series of challenges that must be overcome.

Fig. 5. Off-line analysis of the MER trajectory in this case (STN 103R, target depth 25.0 mm) demonstrated that the transition from the ZI to the STN could not easily be discerned from the PSD or mPDF. However, the time series plot showed unique signal characteristics that allowed for the distinction of the STN along this trajectory, demonstrating the usefulness of using more than a single visualization method in determining the target location. The top plot represents annotations regarding the presumed location of the recording that were made during surgery based on the subjective observations of the surgeon. RT = Reticular nucleus of thalamus; SNR = substantia nigra reticulata.
Selection of the epoch of MER to be automatically analyzed is one important issue. Typically, the MER observer selects a ‘typical’ data period for review, mainly based on experience, since intraoperative MER consists of both useful data (signal) and non-useful data (noise). The length of the data epoch chosen for review is critical, since the longer the epoch analyzed, the more likely that it will be contaminated by ambient electrical interference, cell injury discharges, patient movement and other transients. Selected epochs that are too brief are subject to other artifacts and decreased accuracy of the estimated signal properties. For example, MER is affected by electrode ‘settling’, related to the resistance of the tissue to the movement of the MER electrode. For this reason, the epoch selected needs to have reached a point of ‘stability’ when the recording is consistent, and not subject to subtle change in the microelectrode location. Consequently, to automate MER analysis and visualization it is important to segment the section of the MER that best represents the characteristics of the neuronal structure it was recorded from. In contributing to this endeavor, we have developed a method to automatically locate the point in MER data when stability has been achieved [23] and the recording has reached a point where analysis of its components is most relevant to the structure from which the activity has been recorded. Further advancements in the segmentation of MER will be important to improve automatic analysis of MER, and consequently target localization.

Final target location in relation to the dorsal and ventral STN borders as defined by our analysis varied substantially from the nominal target predicted from atlas-derived coordinates (fig. 3 and 4). This variability supports the notion that there is a dual role for MER, one in refining the location of the STN target intraoperatively and another in the need for more consistent on-line methods for determining and visualizing the STN MER data with respect to each recording trajectory. This study also suggests that using several visualization and analysis methods concurrently may provide an improved and more complete picture of the neuronal structures (fig. 5).

One of the basic suppositions of our analytical strategy is that different subcortical nuclei have unique and distinguishable physiological characteristics. Certainly, the cumulative physiological observations of prior studies would suggest that MER of the STN should manifest high PSD and mPDF compared to surrounding structures that are of lesser cellular density [10, 22]. A major goal of our study was to advance the reproducibility and consistency of defining neuronal characteristics along the MER trajectory, resulting in more objective and reproducible target placement. Related to this goal, one aim was to develop more objective and reproducible methods for locating brain structures, ultimately contributing to improvements in how surgeons and clinics compare MER data. Future goals include comparing quantifiable target characteristics with clinical outcomes, which may in turn improve further refinement of target placement and enhanced clinical outcome.

This study illustrates that an automatic method for multiple analyses and visualization of distinguishing characteristics of neuronal structures in the MER trajectory to the STN target may be feasible. Our methods seem capable of characterizing structures and distinguishing the dorsal and ventral borders of the STN, even when single-cell recording is problematic. Using our analytical approach, the boundaries of the STN could be detected, despite the use of lower-impedance microelectrodes that could be characterized as ‘semimicroelectrodes’. In most cases, the visualization methods of these analyses appear to replicate the target localization of an experienced neurosurgeon’s subjective evaluation of the MER data. The methods show promise for intraoperative target detection, objective comparison of target characteristics and the possibility that these characteristics can eventually be correlated with clinical outcome and DBS therapy in PD patients.

Acknowledgments

The authors would like to express their appreciation to Drs. Tony Whitworth, Michael Sandquist and Joseph Christiano for participating in the surgeries. This research was funded in part by the Medical Research Foundation of Oregon (Award No. ANEUS0020 to K.J.B.) and the Department of Neurological Surgery at Oregon Health and Science University.
This is an interesting preliminary report of an automatic analysis and visualization method applied to microelectrode recording during stereotactic surgery for subthalamic nucleus stimulation. It comes from the intuitive need felt by neurosurgeons during the search for the optimal target where to put the electrode. Whether or not microelectrode recording is considered as mandatory, useful, useless or even deleterious, one needs to analyze the wealth of data which are recorded in a better way than just relying upon the team's experience, more or less biased by the knowledge of the depth, which strongly suggests where the tip of the electrode is supposed to be. Unfortunately, the expertise provided by experts such as Denise Albe-Fessard working with Gerard Guiot in the fifties

References


[1, 2] is not always available and practically not usable considering the extent of the need in functional neurosurgery nowadays. This was already perfectly understood by Ohye et al. [3] in the seventies, when they created the concept of the physiologically defined functional target, at that time the thalamic ventral intermedius nucleus. They designed a simple, useful and highly suggestive method by displaying the power of the signal recorded along the track, which they coined as the neuronal noise, which is close to the time series (or amplitude vs. time displayed in fig. 2D above). In this paper, the authors present a more sophisticated multiparametric processing of the data, displayed in neurosurgeon-friendly visual graphs. This may become, along the usual learning curve, one of the tools which will not replace but assist the usual surgeon’s evaluation made by watching the screen and hearing the loudspeaker. This is the current trend, already initiated by companies, as represented in the current version of the Alpha Omega system, or by research teams. In the same prospect but using different algorithms, we are developing other methods [4] to recognize and analyze the spikes which are recorded, not only to recognize the nucleus, where they come from (zona incerta, subthalamie nucleus, substantia nigra pars reticulata), but also to try to discern subparts of these nuclei and of their corresponding spikes, such as for instance the somatomotor part, the associative part and the limbic part in the subthalamic nucleus. In all circumstances, these approaches might be justified, besides their scientific basic research interests, by the true benefit which can be expected from them, namely the ability of these methods to help better position the electrode in a more precise, cheaper and faster way. Even the concept of best positioning, although it is subjectively accepted, must also be clinically validated, through the additional clinical benefit or increased efficiency of deep brain stimulation in the patient. This actually contributes to the debate concerning the validity of microelectrode recording, which still has to be clarified. However, approaches similar to the one presented in this paper may help implement the functional knowledge of the stereotactic space and help assess the probability of being in a given structure associated with specific functional properties, once we have coordinates of a point in the patient’s brain [5].

Alim Louis Benabid
Grenoble, France

References