How to find, analyze, localize, and image epileptiform activities in the scalp EEG?

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This presentation was given as an introductory talk at the first BESA Epilepsy workshop in Lund, Sweden, November 25-26, 2010.

The first purpose of this workshop was an introduction into the new BESA Epilepsy program for fast clustering and reporting on interictal spikes in LTM EEG.

The second purpose was a training of new tools available in BESA Research for the averaging, analysis and imaging of interictal spikes and spectral analysis of seizure onsets.

For a better understanding of 3D mapping we suggest that you consult our new BESA Quick Guide on 3D maps.
Overviews of advanced methods of digital EEG review and source analysis can be found in:


Further papers on source analysis of interictal epileptic activity:


Papers can be obtained as PDF files from the author (mscherg@besa.de).
As a first example, we will use the EEG data of a patient with temporal lobe epilepsy to understand how improved montages and filter settings can enhance the perception of interictal spikes in the EEG. We will inspect a 10-sec page of EEG with different standard montages and filter settings.

Pressing F2, we obtain a standard EEG display with a longitudinal bipolar montage that is extended to inferior and has an additional transverse FT9-FT10 channel (Lueders montage). A standard EEG review filter is set: time constant of 0.3 sec, i.e. a low forward filter of 0.53 Hz; no high filter.

Polarity reversal can be seen over the left hemisphere between F7-P7 showing 4 spikes (marked by tags 1 & 2) and on the right between F8-P8 showing 2 spikes (tags 3 & 4).

The tags have been set by pattern search using the temporal lobe source montage described below.

Instead of using the recorded channels, the montage uses virtual channels, i.e. the EEG signals are interpolated at standard 10-20 and 10-10 locations on the scalp. This reduces local muscle artifact and allows for interpolation of missing or bad channels and to extrapolate to more inferior sites, e.g. FT9 / FT10 in cases where only the standard 10-20 electrodes are used. Thus, the EEG display always shows a consistent set of channels that makes reviewing more easy and reliable.
Pressing **F4**, we obtain the virtual average reference montage AV33 with inferior electrodes F9/10, T9/10, P9/10. These electrodes allow for some differentiation of spikes with tag 1/3 (spike signal largest at T9/10, present also at P9/P10) from spikes tag with tag 2/4 (spike signal largest at F9/10, not present at P9/P10).

Spikes, including inferior-temporal patterns, are better visible by using

1) a **virtual montage** that covers the whole head by extrapolating to intermediate and inferior sites even in the absence of deep electrodes,

2) the **grouping of channels** in three longitudinal rows (e.g. the denser Fp1, F7, FC5, T7, CP5, P7, O1 row), and

3) an **optimized filter band (2 – 35 Hz)** that suppresses slow EEG activities and renders spikes riding on slow EEG activity more visible. At the same time, the high filter removes a sufficient amount of EMG activity to enhance the visibility of spikes.
Pressing F11, we obtain the temporal-region source montage that estimates the activity at 4 different aspects of the temporal lobe. The EEG activity is projected onto the various brain regions using the potential distribution of all scalp electrodes in an inverse model. Thus, the left (upper 4 traces, blue) and right (next 4 traces, red) temporal lobe activities can be separated to a large degree from each other and from the activities in other brain regions (below).

The 4 temporal lobe aspects from top to bottom in each of the left and right groups are:

- temporal-basal
- temporal-polar
- temporal-anterior lateral
- temporal-posterior lateral

Spikes with tags 1/3 show the largest and earliest activity at the temporal base, while spikes with tags 2/4 show a leading temporal-polar activity.

Based on this distinction, obvious only in this specific source montage, we were able to search for similar spikes of these basal and polar types in the left (tags 1 & 2) and in the right temporal lobe (tags 3 & 4). The displayed EEG page shows typical detections that were found using a clear template for each spike type in the appropriate source channel.
We page through the EEG and look for a prominent spike that has a flat, undisturbed onset epoch (marked yellow block). This presents an ideal template for pattern search.

The largest spike signal is seen at the left temporal basal channel (top) and precedes the spike activity at the left temporal pole and anterior-lateral region (= left mesial basal spike).

Click on the spike and adjust to the spike maximum in the map using the arrow keys.

**Note:** the 3D map is automatically rotated to set the viewpoint to the center of the activity (between negative and positive poles in a dipolar topography).
In most cases, the 3D maps at the onset-peak interval are sufficient to localize the origin visually. You will learn the basics on how to do this in the following slides. We also suggest you consult our new BESA Quick Guide on 3D maps.

Another recommendation is to use the DipoleSimulator program (download the free software from www.besa.de) and place a dipole into the left sensorimotor region. Leave the dipole at the same location, change orientation by dragging on the current dipole arrow.

You will see all kinds of different maps with the negativity roll over the scalp. But, if you use the rules taught in the following, you will be able to see that all maps have exactly the same origin:

All these changes are only due to the complex 3-dimensional folding of the cortex resulting in different orientations of the source current.

Try out variations of the current orientation at other locations, export into ASCII files, and load into BESA for 3D mapping.

You will then understand that characterizing the location of spike using the electrode name closest to the negative peak (e.g. spike at F3, F7, P3 …) is insufficient, inaccurate and sometimes misleading.
3D mapping can substantially improve spike review and understanding of the origin of spikes. Let us learn how to interpret dipolar voltage topographies:

First, consider a line connecting the negative and positive maxima on the scalp (thin arrows). This line follows the shortest route having the highest voltage gradient (~ narrowest distance between equipotential lines).

Second, find the region of highest gradients (near thick arrows).

Third, consider the relative strength of the negative and positive poles.

In a close-to-tangential map (left, origin only in sulcus), the equivalent location is approximately below the area of maximum gradient (thick arrow).

In a perfectly radial map (middle, origin only on cortical convexity or deep), the center location coincides with the peak of the negativity. Since all scalp fields are dipolar (by physics) there is a positive pole on the opposite side of the head (cf. upper 2D map). It is weaker since the posivity is widespread.

A typical EEG spike map has one stronger and one weaker pole. The origin lies below the region of largest gradient along the line connecting both poles, but may be shifted slightly towards the stronger pole if this is dominant (thick arrow).

In the presented simulation, the location of all 3 sources is identical. This illustrates the predominant influence of source current orientation.

Download the free dipole simulator program from www.besa.de to gain a better understanding of the effects of orientation on EEG scalp topography.
How can we estimate the 'approximate source location' from these real temporal lobe spike maps? We follow the same principles as before:

First, consider a line connecting the negative and positive maxima on the scalp (thin arrows). This line follows the shortest route having the highest voltage gradient (~ narrowest distance between equipotential lines).

Second, find the region of highest gradients (near thick arrows).

Third, consider the relative strength of the negative and positive poles.

The left 3D map is a close-to-tangential map. The equivalent location is approximately below the area of maximum gradient (thick arrow). The vertical orientation is related to a current flow into the left temporal basal cortex (spike current flows into the cortex and, thus, produces cortex negativity).

The middle 3D map is also a close-to-tangential map. The negativity has rotated towards the left eye; the positivity is over the (left) posterior head. The center is more anterior, the current orientation points backward and upward. The only candidate for such a pattern can be a spike source current at the left temporal polar cortical surface. Here, the basal surface is still somewhat active. If not, the negativity would have shifted more towards the left eye.

The right map shows the typical radial pattern of a left temporal-anterior spike originating at the lateral cortical convexity. Only this pattern leads to the typical polarity reversal in the longitudinal bipolar montage.

Without inferior electrodes or the whole head virtual montages and 3D mapping, such temporal-basal and polar spikes can be easily overlooked.
The single spikes of this patient show a polarity reversal between F7-T7 and T7-P7 similar to typical temporal lobe spikes. The corresponding radial map at the spike peak has a maximum negativity over the temporal lobe.

Spike onset is unclear and varies between the single spikes. The single spike map during onset reflects mostly EEG background activity.

After averaging, the tangential topography during spike onset becomes apparent. The onset pattern shows a negativity over the frontal cortex and a more superior horizontally oriented, oblique dipolar pattern.

But, when just considering the spike peak, this seems to reflect a left temporal lobe spike. Is this correct?
Is this radial spike coming from the lateral surface of the left temporal lobe?
How can we estimate the 'approximate source location' from the maps?
Again, consider a line connecting the negative and positive maxima on the scalp (red arrows). This line follows the shortest connection having the highest voltage gradient (~ narrowest distance between equipotential lines).
Then, find the region of highest gradients and consider the relative strengths of the positive and negative poles.
The onset map is close-to-tangential (upper row), the equivalent location is approximately below the area of maximum gradient (green arrow).
The peak map appear radial (lower row), but the center location is shifted slightly from the negative peak towards the positive pole along the region of largest gradient. The positive pole is not on the other side of the head, but superior!
The equivalent centers of both maps are similar and point to a circumscribed region of origin in the rolandic cortex above the Sylvian fissure. Polarity indicates that the tangential rolandic spike is likely to arise from the anterior wall of the post-central gyrus (~face area) with ensuing propagation to the surface of the gyrus (radial map), since the tangential onset current is flowing backwards into the posterior wall of the central sulcus.

Exercise: DipoleSimulator
The origin of the spike onset zone can often be different from the apparent origin of the peak due to rapid propagation (in about 20-25% of cases!). A peak can arise from the overlap of activities in several regions involved in the propagation. But, spike onset is hidden in the EEG background signals. Thus, we need to find similar spikes and average to increase the onset signal over the background. This can be done by spatio-temporal pattern search in BESA Research and will become available in BESA Epilepsy 2.0.

The averaged spike signals can be used to compare onset and peak using 3D mapping and more elaborate localization and imaging strategies.
We now illustrate how spike templates are used during the review process to detect similar spikes and obtain an averaged signal allowing for the evaluation of the spike onset topography in comparison to the peak.

Pressing F4, we obtain an optimized montage for detecting spikes in the on-going EEG. This sets the virtual average reference montage AV33 including the inferior electrodes F9/10, T9/10, P9/10, and intermediate electrodes, e.g. FC1, FC5, CP1, CP5...

Spikes, including inferior-temporal patterns, are better visible by using

1) this **virtual montage** with 33 electrodes that covers the whole head by extrapolating to intermediate and inferior sites even in the absence of such electrodes,

2) the **grouping of channels** in three longitudinal rows (e.g. the denser Fp1, F7, FC5, T7, CP5, P7, O1 row), and

3) an **optimized filter band (2 – 35 Hz)** that suppresses slow EEG activities and renders spikes riding on slow EEG activity more visible. At the same time, the high filter removes a sufficient amount of EMG activity to enhance the visibility of spikes.

We **page through the EEG** and look for a prominent spike that has a flat, undisturbed onset epoch (marked yellow block). This presents an ideal template for pattern search

**Click on the spike and adjust** to the spike maximum in the map using the arrow keys.

**Press button SAV** to obtain the search-average-view dialog box.
The SAV-box provides preset optimized values and the option to modify these for the pattern search that starts when pressing OK.

The largest spike channel is identified and marked automatically, and one may choose either this channel, manually selected channel(s), or all displayed channel for template search. When using the average reference montage and a clear spike pattern, it is recommended to use the All channels template. With a source montage, the largest spike channel can be used as proposed automatically.

Optionally, several channels showing a clear spike pattern can be marked for template search (e.g. F9, T9, F7, FC5, T7) prior to pressing SAV.

If only one channel is selected, the marked pattern of this channel is shifted along the whole on-going EEG and correlation is assessed at peaks.

If the selected threshold is exceeded, a detection marker will be created. Thus, spikes are aligned optimally in time.

If several or all channels are selected, a spatio-temporal template is calculated and aligned with all selected traces.
After the pattern search is completed, the detected patterns are displayed automatically. We inspect these patterns using the paging functions and delete detected events where the spike is blurred by background noise or artifact. Simply **click** onto a noisy spike segment and **press** the **D** or **Del** key.

Thus, you may control the events that are included in the final average. The preliminary average can be viewed (menu: View / Average Buffers) and used as an improved template if desired.
After inspection of the detected spike epochs, we press **button F6** to obtain the averaged signals for all marked tags (up to 5 different pattern types).

The underlying batch process converts the tags 1-5 into triggers 41-45, saves these events into an ASCII file, reads and averages the segments from the original EEG file, and creates an averaged file that is displayed automatically.

Next, filters are set optimally for the analysis of the spike onset (5 Hz low filter, forward characteristic corresponding to a time constant of 30 ms; 35 Hz high filter). This creates an optimal baseline for the analysis of spike onset.

We may click onto the spike and inspect the 3D maps to localize onset and peak visually.
In cases, where 3D maps are hard to interpret or ambiguous, dipole localization and imaging methods can lead us to a better understanding of the onset, peak, and propagation from onset to peak of an interictal spike.

Using new batch functions this process has been made more safe in BESA Research by automatically setting appropriate filters and combining regional dipole fitting techniques with a new iterated LORETA approach.

The goal is to find a consistent answer from the two independent methods and to assess whether spike onset and peak arise from the same sublobar region.
After averaging is completed, the first averaged spike segments (Sp1) can be analyzed immediately by pressing the **F7 button**. A list of the automated settings and analysis steps is shown above in blue.

After the source analysis window opens, the user (marked in red) only needs to select the head model for the EEG to match the age of the subject. Then, the batch control proposes to the user to mark the onset interval. This step is helped by a visual comparison of the automatically calculated principal components analysis (PCA – displayed on the left) with the butterfly overplot showing all recorded channels in average reference (displayed above).

The onset interval is defined by finding the initial interval that exhibits one dominant principal component (accounting for a data variance of more than 90-95%). Its prominent waveform (here: 98.8%) is compared to the wings in the butterfly plot to assess, whether it comprises the peak (here: yes) or an earlier activity. Inspection of the following PCA components shows no significant other activities in the onset interval of case 2.

Next, the batch fits a regional source into the onset epoch and rotates the 3 underlying orthogonal dipoles such that the first dipole is oriented to explain all the activity at the maximum of the onset interval. If available, the individual MRI is loaded and a LORETA / CLARA image is computed for comparison.

If the image and the source localization coincide, the center of the region of onset has been defined. Note that neither method displays the extent of the activated zone – this information is not available from the scalp EEG. The extent of the image indicates the intrinsic smoothing of the method and the low resolution of the scalp EEG (here: 33 channels).
The EEG source analysis presents the onset source (fit interval -25 : -9.4 ms, red) and compares it with the peak source (fit interval -20 : 0 ms, blue). Both sources almost coincide in location and exhibit only a small difference in orientation. Their source waveforms (left) share the activity and are similar.

On the left, a comparison with a LORETA image at the onset maximum (-9.4 ms) is depicted. The tradeoff between resolution and smoothing has been optimized such that a mirror source in the other hemisphere can be separated in the LORETA image (the result above shows that there was no such mirror source on the right).

Separation and resolution can be enhanced by iterating LORETA twice with regularization constants appropriate for EEG and MEG, respectively, as seen on the right. The 2 iterations are especially useful for MEG to suppress the common ghost mirror foci around the source in the first LORETA image.

As shown before, the PCA over the onset interval (starting at the lowest point in the butterfly and global field power plots - GFP, top middle) exhibited one major component from a latency of -25 ms up to -9.4 ms before the spike peak. The maximum spike activity in the onset interval was at -9.4 ms.

A later peak can be seen in the 2nd dipole waveform of the red regional source that is overplotted over the 1st onset dipole waveform. The onset of this later activity with orthogonal orientation to dipole 1 indicates that the scalp topography starts rotating around -9.5 ms due to the increasing overlap of dipole 2. The related source was located in the same left frontal region. This indicates that only the relative contributions of sulcal and cortical surfaces in this region began to change just before the spike peak.
Next, we want to analyze spike onsets and peaks in the EEG/MEG of the patient with temporal lobe epilepsy presented initially (case 1).

Pressing F6, we obtained the averaged different spike types as displayed above. The F6 batch has also set the filters to 5 – 35 Hz, the low filter using a forward characteristic to enhance the spike onset and remove the baseline. This allows for excellent 3D mapping of onset and peak.

Here, only the peak maps are shown to characterize the different detected spike types:

- **Sp1**: left basal - EEG vertical map, MEG corresponding horizontal map, same center in left temporal lobe (92 averages)
- **Sp2**: left polar - EEG oblique map with negative maximum over the eye, MEG map with reduced inferior negativity, pointing to the same more anterior center (49 averages)
- **Sp3**: right basal - EEG vertical map, MEG corresponding horizontal map, same center in right temporal lobe (44 averages)
- **Sp4**: right polar - EEG oblique map with negative maximum over the eye, corresponding orthogonal MEG map, pointing to the same more anterior center (49 averages)

The leading signal at the temporal base can be seen in the basal source channels (traces 1 & 4) in the averages Sp1 & Sp3; the leading signal at the temporal pole can be seen in the polar channels in the averages Sp2 & Sp4 below the basal channels (traces 2 & 5).
Pressing F7, we started the EEG source analysis and defined the onset interval of Sp1, i.e. the average of the 91 left spikes with basal onset. The red onset and blue peak sources were then fitted automatically and overlayed with a CLARA image. The peak source was removed in order to show when the EEG signal starts deviating from the onset signal (onset of 2nd dipole source waveform of the red regional source). Then, using a separate batch, the MEG solution at the maximum of the onset interval was computed.

Both the EEG and MEG source localizations and the CLARA focus in the MEG point to the left basal temporal lobe as origin. In the EEG, the vertical orientation of the onset source supports this interpretation while the CLARA image simply highlights the anterior left temporal lobe without certainty about which surface is involved. This can only be assessed by the orientation of the EEG dipole. MEG source orientation is tangential to the spherical head model and, therefore, appears oblique in the coronal plane since the model sphere center is on the AC-PC line 16 mm behind AC. Thus, MEG dipole localizations and orientations should not be misinterpreted as pointing to the hippocampal region or showing the true current orientation. In fact, at least a major portion of the anterior parahippocampal gyrus has to be active to produce the clear basal onset signals in the scalp EEG and in MEG.

The extent of the basal activation cannot be estimated from EEG or MEG. Furthermore, depth should be interpreted with caution, because the equivalent vertical dipole can easily be shifted 1-2 cm deeper or laterally and still explain the data very well. Hence, orientation is the main cue to identify which surface is involved. In MEG, however, one must consider that only the tangential projection of the surface normal of the activated surface is seen.
The average of the 49 spikes with left temporal polar onset in the source montage was analyzed using the corresponding batch for spike type 2 (Sp2). To better illustrate the evolution at the onset, the onset source was separated into 2 dipoles (red = onset dipole 1, blue = onset dipole 2 of the regional source).

The red onset source is oriented backwards in EEG and MEG and points to the left polar surface as origin. This is supported by the MEG CLARA image while the EEG – as in the basal spikes – is unspecific with respect to which cortical surface is involved. However, since EEG represents the true current vector orientations as opposed to the tangential projection of the MEG dipoles, it can be seen from the orientation of the 2nd onset dipole (blue) that a rapid propagation occurred to the lateral polar part that was not visible in MEG due to the radial orientation of this activity. The 2nd EEG dipole could even be localized at an equivalent location within the polar region with the location again being unspecific with respect to which surfaces were involved.

The key information on the spreading involvement of the different surfaces of the anterior temporal lobe is provided by the orientations and source waveforms of both EEG dipoles. They show that the initial tangential polar spikes (red) are rapidly getting overlapped by propagation to the lateral-anterior convexity - as seen in the delayed onset of the near-to-radial 2nd EEG dipole (blue). Since the MEG cannot see this radial activity, the 2nd MEG dipole does not show a large activity during this later part of the onset interval (-12 : 0 ms).
In the following we will look at several examples with different origin of spike onset and peak.

We will use different fitting strategies that have been implemented in the batch functions. Thus, we take into account that the onset can be bilateral (needs to be tested!) and that the activity of the onset zone extends into the peak interval and overlaps with the propagated activities at the peak. Therefore, we need to fit one regional source to model the onset epoch and at least one more to model the propagated areas.

In BESA Research 5.3 three hypotheses are tested:

1. Location of onset and peak are different. Independent sources are used for the onset and peak epoch and their localization is compared.

2. Activity is propagated, if sources in 1 are different. Then, keep onset source fixed and fit additional source to estimate the direction of propagation.

3. Final check on onset: Use a bilateral symmetric pair of regional sources to assess if onset is in both hemispheres or close to the midline.
Onset and peak maps in case 3 were quite different. Looking at the negative peak in the EEG over O2, one might get the impression that the spike onset is in the right hemisphere. However, this is a typical case of the so-called 'paradoxical lateralization'. Again, just follow the rules of interpreting an EEG map by considering the corresponding positivity and the steepest gradients. You can observe immediately that the map center of the EEG spike onset is in the left mesial occipital cortex, consistent with the left MEG center.

At the spike peak, a clear lateralization to the left posterior temporal region can be seen with a relatively similar center between T7 and P7 in both EEG and MEG while the EEG negativity appears lower and more posterior (between P7 and P9). In addition, the MEG map is not a simple dipolar map but exhibits a 2nd, weaker dipolar pattern that seems to reflect the polarity reversal of the onset pattern. In the next slide, this will be confirmed by the dipole source waveforms showing the opposite polarity of the onset spike waveform overlapping with the crest of the peak source.

Thus, localizing a single dipole into the peak pattern of a spike may shift its localization in a hard-to-predict manner, if the overlap of the preceding and continuing onset activity from a remote onset region is not considered.

Localizing simply by selecting the regions of maximum positivity and negativity in MEG in a map that clearly has more that one underlying dipole pattern (or high background activity) is prone to intrinsic localization errors!
The onset activity (left, red, PCA: 98.7%) localizes to the mesial occipital cortex in
the left hemisphere that exhibits a widespread lesion and ventricular enlargement.

The interpretation of a left-sided origin is supported by the orientation of the first
EEG source shown on the left. The source current points from the interhemispheric
cleft into the left occipital cortex. This is in agreement with the negative polarity of
spikes at the cortical surface.

At the peak (right), a small discrepancy between the dipole localization and the
CLARA image can be seen. This is partly due to the limitation in inferior electrode
coverage and the smoothing properties of LORETA images leading to a deeper
localization in the cerebellum. Again the orientation provides the cue to identify the
inferior-lateral surface of the temporo-occipital cortex as the center of source
current.
In contrast to the previous case 1, the PCA of the averaged spikes in case 3 (for details see below) showed an onset activity different from the peak. In the onset interval of -62 : -37 ms, the first PCA waveform explained 98% of the variance and was orthogonal to the peak waveform. The latter was beginning to rise at the end of this interval and, hence, had only a variance of 0.8% in the onset interval.

Using the batch F7, several hypotheses were tested automatically to confirm the observed difference between the equivalent onset and peak sources:

**Strategy 1 (On-Peak):** Regional sources are fitted independently in the user / PCA defined onset interval (-62 : -37 ms) and in the peak interval (-20 : 0 ms).

**Strategy 2 (Peak+On):** The regional peak source is kept in the model and an additional source is fitted in the onset interval (2-source model). This source is oriented and the first dipole kept. Thus, the additional activity of the peak source region that may already start in the onset interval is modeled, and the remaining onset activity can be taken care of by the first dipole (red). This confirmed the ipsilateral onset activity remote from the peak. Note: this strategy is no longer used in BESA Research 5.3).

**Strategy 3 (On+Peak):** The independent regional onset source (red) is kept in the model and an additional source is fitted in the peak interval. This is the physiologically most plausible and preferred solution assuming focal onset and overlap of the later part of the onset activity with the rising peak activity. Strategy 3 takes this overlap into account and corrects for the resulting shift in the location of a single peak source – as in strategy 1 - that is due to not modeling the overlap.

**Strategy 4 (On-Bilateral):** A pair of symmetric regional sources is fitted in the onset interval to test whether a near midline activity is indeed coming from the cortical areas near the interhemispheric cleft (here: yes), or whether the onset occurs synchronously in both hemispheres. This test is important, especially for source activity oriented along the interhemispheric cleft, since such activity can be modeled very accurately by one midline source although coming from both sides.
This example of a right temporal spike (case 3) demonstrates the activation of yet another surface in the polar temporal region and a considerable propagation. Here, we analyzed the 4 spikes averaged from a sharp transient in the MEG.

Note that the initial EEG dipole map at -30 ms shows a frontal negativity. When considering the accompanying inferior positivity and the gradients of the equipotential lines, it becomes evident that the underlying center is more inferior and corresponds to an oblique equivalent dipole pointing down and inwards.

The initial downward component is confirmed by the MEG map at -30 ms.

15 ms before the peak we observe a typical right temporal polar pattern, while superficial lateral activity with partly posterior orientation dominates at the peak (0 ms). Again, the polar current is confirmed by the MEG maps.

Thus, we might conclude that the spikes are initiated at the superior and lateral surface of the right temporal pole within the Sylvian fissure. This interpretation is supported by the small downward spike in the right temporal basal source waveform. This signal is constructed using a vertical dipole in the right basal temporal region within a multiple source model covering the other aspects of the right temporal brain region, the corresponding regions on the left and all other brain regions by regional sources. Thus, the basal source waveform will pick up spikes in the supratemporal plane as well, but with inverse, downward polarity.

After this short initial superior spike, the typical propagation to the polar and further on to lateral regions was seen in the right temporal polar and lateral source waveforms. Averaging based on EEG led to a smoothing out of the initial sharp transients seen best in the MEG (upper left, 12 averages). Thus, based on EEG alone, spike onset
would have been interpreted as anterior-polar.
Source analysis of the right temporal polar spikes in case 3:
Again, we have separated the regional onset source into the initial 2 dipole components (red and blue) and used only a single dipole for the peak activity (green). Both EEG and MEG are best modeled by an initial, downward oriented dipole at the superior surface of the right temporal pole.
A strong polar activity follows immediately in EEG and MEG (blue) with the radial part only visible in EEG.
This slide illustrates that the 3D EEG and MEG maps already contained the key information for the correct interpretation of onset and propagation:

Based on the rules of finding an equivalent center in a (predominantly) dipolar map, the downward activity at -30 ms was identifiable in both the EEG and MEG maps. Considering the fact that epileptic spikes are cortical surface negative, the only candidate for the origin of a downward-posterior current can be the upper surface of the temporal lobe within the Sylvian fissure. The anterior location and the subsequent propagation to the inferior and lateral part of the temporal pole suggest the upper surface of the temporal pole as origin.

The polar maps at -15 ms are quite typical for temporal-polar spikes and easy to interpret. The stronger negativity and oblique, backward orientation of the EEG polar map indicates anterior, inferior and lateral involvement of the polar region. In contrast, the MEG is dominated by the polar and basal activity and blind to the radial part.

This is also the case at the peak where the MEG map is more complicated and not clearly dipolar. Where the MEG localizes, will strongly depend on which fissural aspects generate the predominant signals within a relatively widespread spiking zone involving the lateral and inferior cortical convexity.
Seizure onset can be difficult to assess in scalp EEG. However, some tools can be used to increase the seizure onset activity over the EEG background:

Filtering (3-20 Hz) and regional source montages (e.g. Temporal Region, Frontal, Central and Parietal Regions) render seizure onset activity better visible.

If a rhythmic pattern is seen at or before EEG or clinical seizure onset, spectral analysis with 3D phase maps can help to identify the sublobar origin of this rhythmic activity.
DSA (digital spectral arrays) can be used to identify periodic discharges with changing frequency that typically occur at seizure onset. These so-called spectral chirps can be well recognized using particular normalizations in the DSA time frequency diagrams depicting 15, 20, or 30 minutes of EEG.

In BESA, the activities of the right and left hemispheres are separated using regional sources. This helps to identify oscillatory activities occurring on one side only. The DSA display can be used to page through the EEG and jump to the onset of a seizure characterized by a spectral chirp (usually an oscillatory burst with the base frequency going down).

The traditional EEG review settings with an extended longitudinal montage and widely open filters are not optimal to analyze seizure onset. Typically, the onset oscillation is buried in EMG activity as seen above.
Pressing F3, optimized seizure detection settings are provided: the temporal lobe source montage is set, a band filter is activated with relatively steep cutoffs at 3 and 20 Hz to remove both slow EEG as well as EMG artifacts, and the default block epoch is set to ± 1 sec.

Thus, after clicking on a periodic EEG activity at seizure onset, a 2 sec epoch is set around the cursor, and a spectral FFT analysis can be performed on the marked epoch by pressing key ‘F’.

To change to a different montage quickly, you may use function keys F12 (frontal region source montage), F9 (AV33), F10 (Lbip+Sp), or the montage buttons Src and Usr.
After pressing 'F', the amplitude spectrum over the marked block is calculated and displayed. The largest spectral peak is seen at the right temporal basal source channel. Click onto the peak frequency value next to the spectrum to obtain amplitude maps. Then, right click into the map window on the best viewpoint to select phase mapping at the peak frequency.

Phase mapping intrinsically uses an average of the seizure onset cycles over the marked block to show the voltage topography at different phases through one cycle. The displayed serial 3D maps in right lateral view show an initial basal pattern with a subsequent rotation to polar and lateral. Thus, the propagation from basal to polar-lateral appears to be preserved within the seizure onset cycles.

For a more convenient interpretation of the time lags between the source activities at the different aspects of the temporal lobe, the serial phase maps are plotted at subsequent phase angles that correspond to a time shift of 5 ms between maps. This interval between maps can be conveniently decreased for higher frequencies or increased for lower frequencies.

The interpretation of these phase maps is the same as shown above for the voltage maps in time.
Conclusions

1. Spike analysis improves non-invasive EEG diagnosis.
2. Most often, interpretation of 3D maps is sufficient.
3. Spike hyperclusters are useful to identify and quantify multiple foci (BESA Epilepsy is now available as CE certified software).
4. In some cases, more careful analysis is required using averaging and imaging techniques.
5. To identify spike onset and propagation averaging is needed.
6. A good equidistant electrode coverage is important (then EEG is equivalent to MEG – MEG adds only in rare cases <5%).

Where to get more information?

www.besa.de

• download this talk
• download free DipoleSimulator program to understand the effect of source orientation and overlap on EEG mapping
• download tutorial on ‘Advanced EEG Review and Imaging in Epilepsy’
• get list of publications
• get recommendations for optimized electrode placement (FAQ)
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More lectures and tutorials showing the analysis of epileptic spikes and seizures can be found along with recommended electrode settings on:

www.besa.de