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Technical Note

Magnetic resonance artifact induced by the electrode Activa 3389: an in vitro and in vivo study

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Summary

Background. The electrode Activa 3389 is widely implanted for deep brain stimulation (DBS) and MRI is often used to control the position of the electrode. However, induced distorsion artifacts may result in imprecise localization and may lead to misinterpretations of the clinical effects and mechanisms of DBS.

Methods. In vitro 3D MR study: the proximal and distal contacts of one electrode were spotted by two localizers. The maximal artifact height (MAH) and width (MAW: measured on distal contact), and the distances between the artifact and the localizers (proximal, distal and lateral) were measured on 2 transverse and sagittal MR sequences with 90 degrees rotation of frequency-encoded gradient and phase direction.

In vivo 3D MR study: coronal and sagittal reconstructions along the main axis of the electrode were performed on 10 postoperative MR (20 electrodes) to measure MAH and MAW.

A Student t test was used to compare *in vitro* and *in vivo* measurements.

Findings. In vitro study: A MAH of 10.35 mm (±0.23) and MAW of 3.6 mm (±0.2) were found. We measured symmetrical extensions of the artifact over the distal contact.

In vivo study: A MAH of 10.36 mm (±0.44) and MAW of 3.56 mm (±0.30) were obtained. No significant different artifact dimensions were measured between *in vitro* and *in vivo* studies ($p < 0.0001$).

Interpretation. Precise 3D localization of the electrode in implanted patients is provided by MR identification of the limits of the distal contact artifact. The position of the other contacts is deduced given the size of the contacts and the intercontact distance.

Keywords: Artifacts; electrodes; magnetic resonance imaging; subthalamic nucleus.

Introduction

The electrode Activa 3389 (Medtronic®, Minneapolis, MN, USA) is widely used to perform deep brain stimulation (DBS) for the treatment of movement disorders. Since accurate target localization is of major importance to obtain good clinical results, precise postoperative localization of the contacts is mandatory to improve our understanding of the clinical effects and the mechanisms of action of DBS. Magnetic resonance imaging (MRI) has gained a great interest in stereotactic procedures. However, the electrode induces a distortion artifact visible on MRI that may result in imprecise 3D localization. Therefore, the aim of this study is to provide quantitative (dimensions) and qualitative information on the artifact (position of the artifact related to the contact) in order to obtain a precise 3D localization of the electrode.

Methods and material

The electrode

The distal part of the electrode Activa 3389 bears 4 ring-shaped stimulating contacts (distal = contact 0 to proximal = contact 3) made of a platinum/iridium alloy. The dimensions of each contact, provided by the manufacturer, are: height 1.5 mm (measured along the main axis of the electrode) and width: 1.27 mm (measured orthogonal to the main axis of the electrode). Two adjacent contacts are separated by 0.5 mm. The proximal end of the electrode bears the four connecting contacts. Both ends are interconnected by thin cables also made of a platinum/iridium alloy.

In vitro MR study

The localizers

2 cylindric localizers (diameter 4 mm) made of plexiglas, located parallel to the electrode at a symmetrical distance of 4 mm were placed respectively at the distal limit of contact 0 and at the proximal limit of

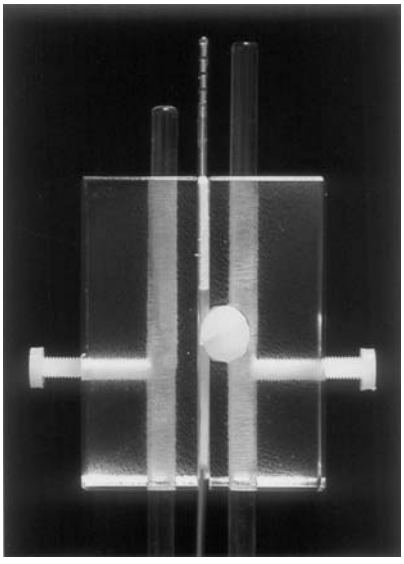

Fig. 1. Plexiglas referential receiving in the same plane the electrode between 2 parallel sliding cylindric localizers placed respectively at the distal limit of contact 0 and at the proximal limit of contact 3

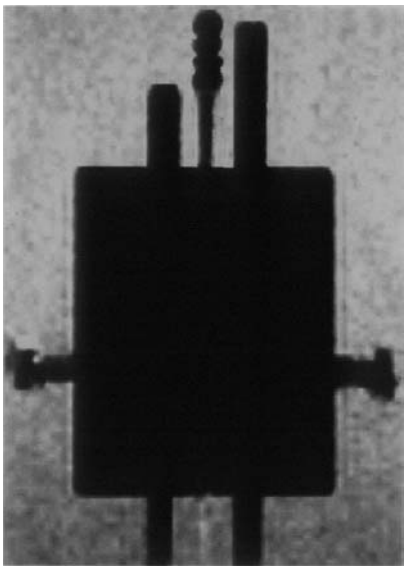

Fig. 2. MRI scan reconstruction of the electrode and the referential from a 3D T1 MPRAGE acquisition. An artifact is identifiable on each contact. The limits and the center of the distal artifact are more reliable for MR study

contact 3 (Fig. 1). Both electrode and localizers were immersed in an isotonic saline solution for the MR acquisition.

MR acquisition

3D T1-weighted magnetization prepared rapid acquisition gradient echo (MPRAGE) sequences (Siemens Vision® 1,5 Tesla, Erlangen, Germany) were acquired orthogonal (transverse) and parallel (sagittal) to the main axis of the electrode with 90 degrees rotation of the frequency-encoded gradients and phase directions. The following parameters were used: Repetition time 9.7 ms, Echo time 4 ms, Field of view 280*280; Matrix size 256*256. For each sequence, two series of 0.8 mm thickness slices with 0.4 mm overlapping were performed.

Measurements

The maximal artifact width (MAW) measured orthogonal to the main axis of the electrode at the level of contact 0, the maximal artifact height (MAH) measured along the main axis of the electrode and the distance between: a) the distal limit of the artifact and the distal localizer (DALD), b) the proximal limit of the artifact and the proximal localizer (PALD), c) the lateral limits of the artifact and the medial limit of the homolateral localizer (LALD) were measured on MRI slices reconstructed parallel to the main axis of the electrode (Fig. 2). Each measurement was performed by 2 investigators (first and last authors) on the 4 consecutive sequences.

In vivo study

MR acquisition

A 3D T1-weighted MPRAGE MR sequence was performed postoperatively in 10 implanted patients. The same parameters were used (see in vitro section). The acquisition consisted of one series of 1.25 mm thickness sagittal slices. Sagittal and coronal reconstructions were performed along the main axis of the electrode for the measurements (Fig. 3).

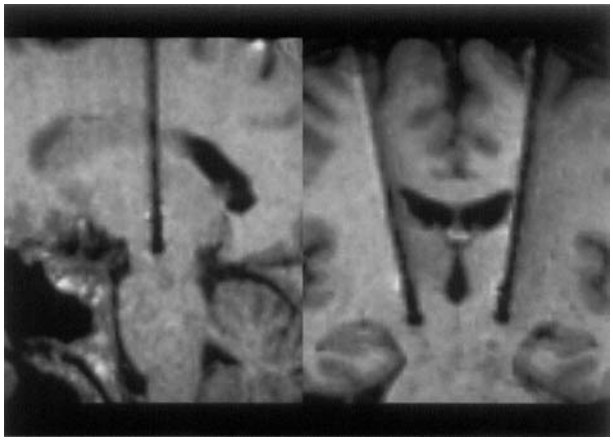

Fig. 3. Postoperative 3D T1-weighted gradient echo volumetric MRI showing the distorsion artifact induced by the stimulating contacts and the connecting cables along the main axis of the electrode

Measurements

MAW and MAH were measured on sagittal and coronal reconstructions. Each measurement was also performed by 2 investigators (first and last authors).

Statistical analysis

A Student t test was used to compare MAW and MAH results measured on coronal and sagittal reconstruction. A Student t test was also used to compare *in vitro* and *in vivo* values of MAW and MAH.

Results

In vitro study

8 values were obtained for each measurement. The MAW was 3.6 mm (±0.2). The MAH was 10.35 mm (±0.23). The DALD and PALD were measured at 1.4 mm (±0.18). The LALD was 2.2 mm (±0.2) bilaterally. The shape and dimensions of the artifact showed no significant modification according to the frequency-encoded gradient and phase directions.

In vivo study

40 values were obtained for each measurement. The MAW was 3.56 mm (±0.3 mm). The MAH was 10.25 mm (±0.44 mm).

Statistical analysis

No difference was observed between measurements performed on sagittal and coronal reconstructions ($p < 0.0001$). Similar values of MAW and MAH were obtained from the *in vivo* and *in vitro* measurements of the artifact induced by the electrode ($p < 0.0001$).

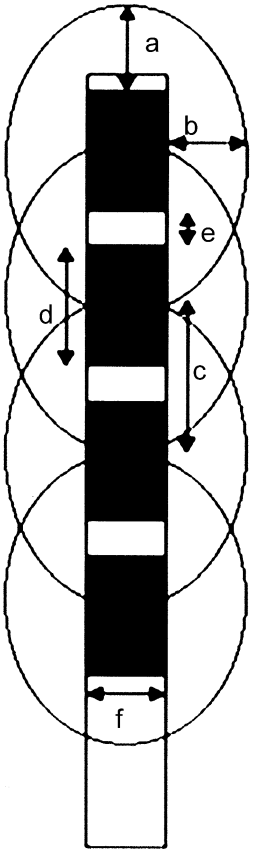

Fig. 4. Illustration of the dimensions and the overlapping of the artifacts induced by the stimulating contacts of the electrode Activa 3389 (Medtronic®, Minneapolis, MN, USA). *a* 1.4 mm, *b* 1.16 mm, *c* 2.3 mm, *d* 1.5 mm, *e* 0.5 mm, *f* 1.27 mm

Discussion

Deep brain stimulation (DBS) has shown to be efficient in the treatment of movement disorders such as Parkinson's disease (PD) [1, 5, 10], tremor [3] and dystonia [2, 9].

MRI has gained a great place in stereotactic procedures. This non-invasive procedure provides a visual targeting of anatomical structures implicated in the clinical effects of DBS and, despite image distorsion, can be used with confidence for target localization [1, 4, 7, 8].

Although MRI is widely used postoperatively in implanted patients, little is known in the literature about the accuracy of MRI to control the position of the electrodes. Meiners *et al.* [6] have shown that 3D fast spin-echo MRI sequence was useful to achieve a precise localization of stainless steel multicontact electrodes (Brain Electronics®) for epilepsy. The contacts were separated by 2.5 to 7.5 mm intervals. Regarding the electrode Activa 3389, MR distorsion artifact generated by the connecting cables is identifiable all along the main axis of the electrode (Fig. 3), followed distally by the artifact generated by each contact. As illustrated in Fig. 4, we can deduce from our study that each contact induces an ellipsoid-shaped artifact, extending symmetrically 1.4 mm over both proximal and distal limits of the contact and 1.16 mm over the lateral limit of the contact. These symmetrical measurements suggest that both artifact and relative contact have the same center.

Given the height of one artifact (4.3 mm) and the distance of 0.5 mm separating 2 adjacent contacts, we can deduce that a significant overlapping of 2.3 mm is present between 2 adjacent artifacts. For this reason, precise localization of the electrode can be better achieved through identification of the artefact of contact 0, whereas artifacts of contact 1 and 2 show a significant overlapping, and artifact of contact 3 is adjacent to the artifact of the connecting cables. *In vitro* and postoperative MR acquisitions confirm that contact 0 artifact is the most clearly identifiable (Figs. 2 and 3).

According to the pixel/voxel size and the multiplanar reconstructions of the volume of interest, the high 3D spatial resolution of the 3D MPRAGE sequence provides a suitable method for localizing the distal and

lateral limits of contact 0 artifact. Moreover, no significant difference in shape and dimensions of the artifact was observed *in vitro* according to the 90 degrees rotation of frequency-encoded gradient and phase directions. Similarly, compared to *in vitro* measurements, no significant modification of the artifact dimensions was observed on postoperative MR of implanted patients in spite of larger slice thickness.

Therefore, 3D T1-weighted MPRAGE MR sequence performed postoperatively in implanted patients provides a precise identification of the limits of contact 0 artifact and, given the size of the artifact, results in a precise 3D localization of the center of the contact itself. Position of contact 1, 2 and 3 can be deduced given the dimensions of the contacts and the distance between 2 adjacent contacts, provided by the manufacturer.

Precise 3D localization of the electrode in implanted patients will allow for study with an increased accuracy, the correlations between the preoperative targets, the electrode position and the clinical results, in order to have a better understanding of several aspects of DBS.

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Comments

Pollo *et al.* present a phantom study and in-vivo measurements of MR-imaging of the deep brain stimulation electrode commonly used in functional stereotactic treatment of movement disorders. The study was performed in order to make a judgement on the feasibility of performing post-implant MR to check the electrode position.

They found that the size of the MRI-artefact of the electrode contacts is larger than the actual dimensions of the electrode contacts in both the phantom-study and the in-vivo measurements. In the phantom study the position of the centre of the artefact corresponds well with the actual position of the centre of the electrode contact.

This study supports the use of post-operative MR for verification of correct electrode positioning. However, in order to show that the electrodes actually lie inside the target area, image-fusion with pre-operative MRI showing the target structure or some other way of relating the position of the target to the position of the electrode will remain necessary.

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The informational output of MRI especially with regard to anatomy is high. Stereotactic neurosurgeons therefore early recognized the potential of this diagnostic tool. In preoperative planning MRI has widely replaced the classical stereotactic atlas. For lesional stereotaxy MRI can also easily be used for postoperative therapy control. In neurostimulation however, the non negligible artefact, produced by the implanted material, has so far been an obstacle to a precise use of MRI. This is deplorable because MRI would not only explain therapy failures due to eccentric position of the lead but also side effects, resulting from co-stimulation of neighbouring structures. The present study has carefully analyzed the geometry of the artefact and describes a reliable technique to get rid of it. This is very useful and brings us forward in the use of MRI as a postoperative control. Unfortunately the paper does not address safety issues, which, according to the manufacturer of the implantable material have not been totally solved. The electrode acts as an antenna in the strong magnetic field of the MRI. Physicists anticipate induction of heat and electrical currents under these conditions, but clinicians have not confirmed this yet. The question remains if by absence of evidence of potential harm we can conclude there is evidence of absence.

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