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Original Investigation

Perioperative Technical Complications in Deep Brain Stimulation Surgeries

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ABSTRACT

AIM: Deep brain stimulation (DBS) surgeries are multi-faceted and the various steps are interconnected. Since its first implementation, the method of DBS surgery has undergone changes. We have encountered several expected and also non-expected perioperative technical complications in the past seventeen years. Here, we describe the stereotactic frame, stereotactic localizer and planning station related complications and how we have managed them as much as possible.

MATERIAL and METHODS: This study is a retrospective qualitative analysis of the documented technical events encountered during DBS surgeries from 1999 onwards. We have collected these events from a cohort of approximately 921 DBS electrodes implantations from the centers of the authors.

RESULTS: Stereotactic frame related complications included movement related fixation problems, head anatomy related problems, and lack of maintenance related issues. Localizer related complications were compatibility issues of the stereotactic localizer and planning station, field of view effect on fiducials, air bubbles in localizers using liquid solutions, and disengaged localizer effect. Planning station related complications included image fusion failures and cerebrospinal fluid signal effect on image fusion.

CONCLUSION: The road to success in DBS therapy passes through the ability to cope with surgical and technical complications. Each step is unconditionally connected to the other, and detection of the problems that can be encountered in advance and preparations for these negative conditions are the key to success for the group responsible for executing the therapy. We are still learning from these events and advance our surgical approaches.

KEYWORDS: Deep brain stimulation, Image fusion, Management, Perioperative technical complication, Planning station, Stereotactic frame, Stereotactic localizer

INTRODUCTION

Deep brain stimulation (DBS) has become a widely applied procedure to treat patients with severe neurological and psychiatric disorders. This treatment modality is multi-faceted, and consists of several steps including patient selection, surgical planning of the anatomical target, surgical procedure, postoperative management and programming of the DBS therapy (7). The short and long-term therapeutic effects of DBS for various disorders have been documented extensively (8,16). Although, the surgical (4), hardware (10) and target related complications of DBS surgery are better recognized and managed, technical complications of DBS related to surgical planning stations, surgical equipment, and implants are less well described.

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MATERIAL and METHODS

The authors have performed hundreds of cases (>900 DBS lead implants) in seventeen years. Since then, we have encountered many expected and unexpected, specific and general technical problems. Some of these technical problems were related to the stereotactic frame, stereotactic localizer and planning station. In this study, we describe the technical problems of DBS surgeries in detail and share our experience with these complications and their management for groups who are willing to start a DBS program or who have recently started. A detailed discussion of the surgery, and target related complications is beyond the scope of this article, and can be found elsewhere (2,14).

RESULTS

Stereotactic Frame Related Complications

In this section, we will discuss problems linked to the stereotactic frame, including movement related fixation problems, head-anatomy related problems and lack of maintenance related problems.

Movement-related Fixation Problems: Mounting the stereotactic frame in patients with severe hyperkinetic movement disorders is a well-known challenge (Figure 1A). There are methods which can be helpful in these cases. One method is to apply ear fixation (Elekta, Stockholm, Sweden) (Figure 1B). An ear plug fits into the holder through one of its three holes. The hole that yields the required frame height with respect to the skull is used. The highest frame position is achieved by inserting the plugs into the lowest holes. After applying the ear plugs, the screws are tightened with a screwdriver to fixate the system to the head of the patient in the desired position. However, a serious issue is that this procedure can be very painful and cause substantial discomfort. In animal studies, usually a local anesthetic is applied to the ear (13). Another and more recent method is the Stereotactic Position Aid device (Inomed, Emmendingen, Germany). The system enables the orientation of patient's head and frame before the frame screws are driven. This product can be used for the majority of the stereotactic frames and produces less discomfort as compared to ear fixation (Figure 1C). This complication has been seen in 7 out of 460 patients.

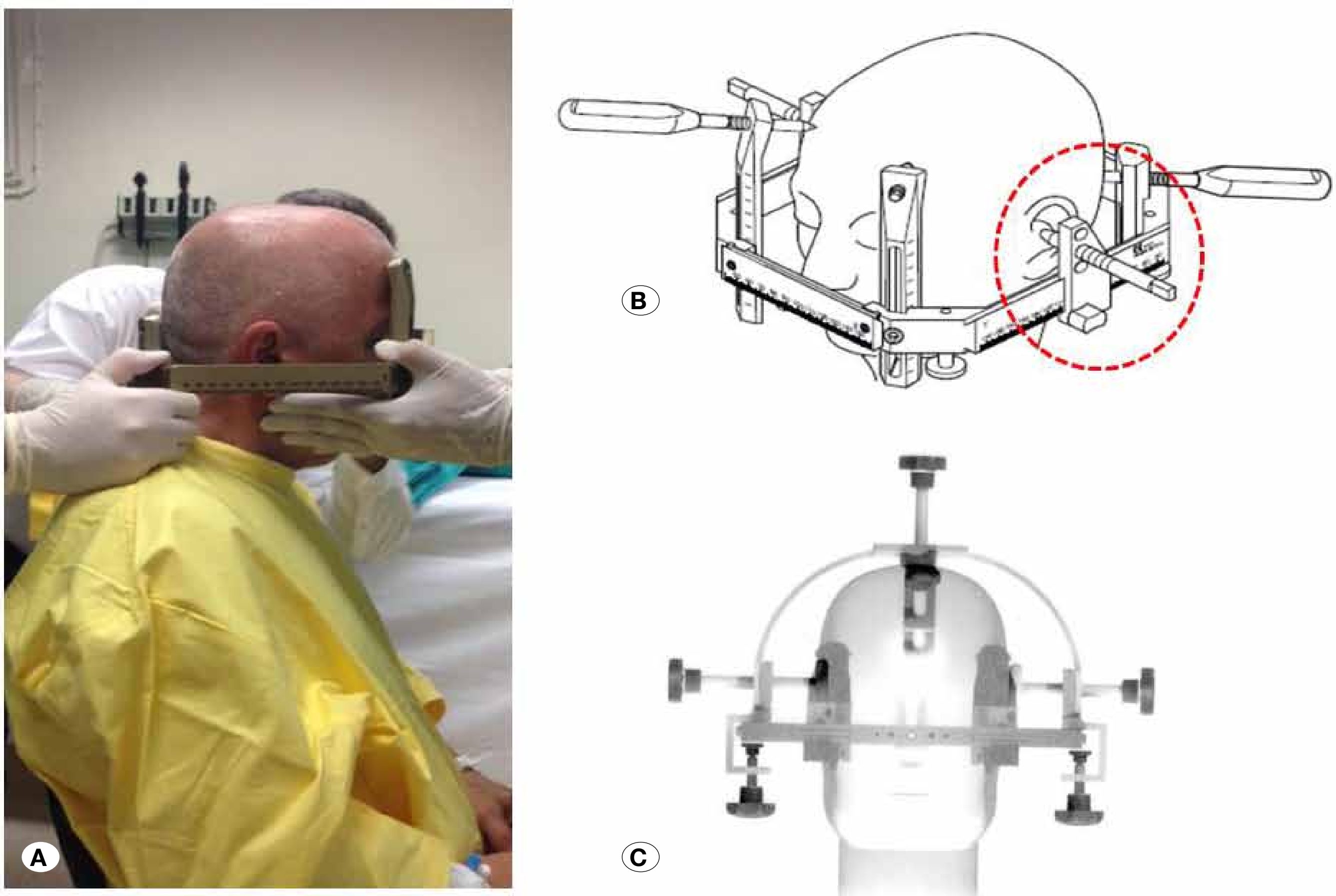

Figure 1: This figure shows the three methods of mounting the stereotactic frame on the head of the patient. **A)** The frame is fixated manually and mounted using the screws. **B)** An ear plug-assisted fixation method, **C)** A head-device supported fixation method is illustrated.

Head Anatomy Related Problems: Another problem can arise from the anatomy of the patient. The head anatomy is then not compatible with the shape of the frame. Especially the "arc support with slide parts" used in the Leksell Stereotactic G Frame and the Ark System (Elekta, Stockholm, Sweden) can be problematic in patients with a short-neck, even if the frame is placed as superiorly as possible (Figure 2A). These parts may apply serious physical pressure to the shoulder and may result in stopping the surgery. An alternative approach would be to change the orientation from "lateral right" or "lateral left" to "sagittal anterior" or "sagittal posterior" orientations (Figure 2B). We think that inspection of the neck length before frame fixation is an important action which is likely to avoid this complication. Another option to manage this complication is fixing the frame as inferior as possible on the patient's head. With this kind of inferior fixation, the parts which put pressure on the shoulder will show lower Z coordinate values. The parts causing pressure on the shoulder will also stay away from the skin. In 1 patient of our series we have experienced this complication.

Another head anatomy related problem can be related to the frontal sinuses. Therefore, the anatomy of the frontal sinuses should be evaluated carefully before driving the frontal screws. If the screws are positioned slightly more superiorly in patients with a large frontal sinus, the outer layer can be fractured (Figure 3). This is a complication which may require surgical repair of the frontal sinus. This complication has been observed in 1 case.

Problems Related to Lack of Maintenance: Another often seen complication can be the inaccuracy of the stereotactic equipment due to wearing. Adequate maintenance, including periodic phantom-based checks and necessary calibrations, is essential to achieve millimetric precision in DBS surgeries. A well-known reason for deformation of the stereotactic equipment is trying to use it differently or use force against it. Loss of screws and small parts due to high-pressure water applications is a frequently encountered drawback during the decontamination process of the stereotactic frames. A careful check of the integrity of the stereotactic equipment after the decontamination procedure is critical. In 14 cases of our series we experienced this complication.

MRI/CT Localizer Related Complications

In DBS surgeries, computed tomography (CT) and magnetic resonance imaging (MRI) technologies are used in order to transfer functional coordinates to the stereotactic coordinates.

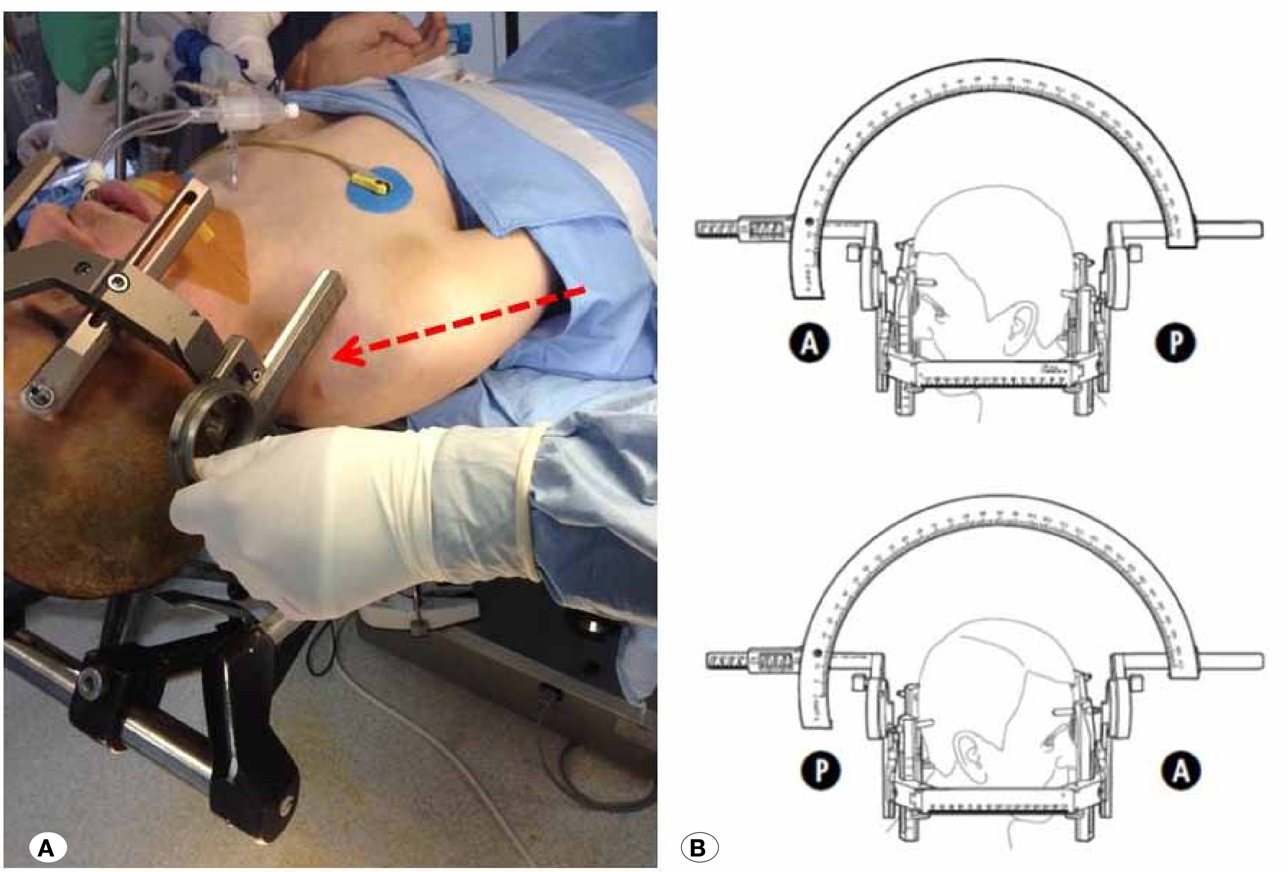

Figure 2: A) The complication occurring with the Leksell G frame's slide parts in a patient with dystonia with a short neck is illustrated. The red dashed arrow points towards this anatomical obstacle. **B)** Solution to this problem by using a sagittal approach instead of a lateral one is shown.

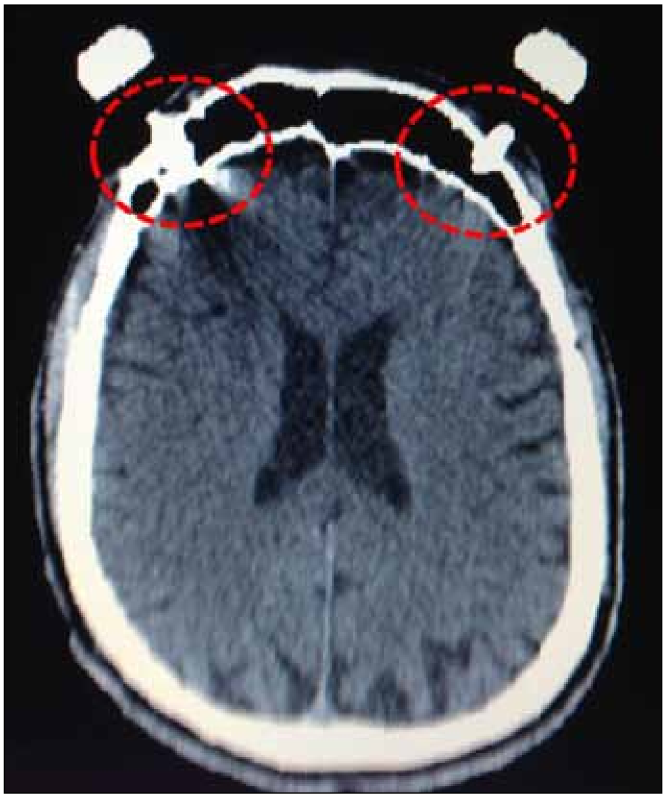

Figure 3: Here, the frontal screws have penetrated the outer layer of the frontal sinus due to the combination of a superior placement of the screws and a large frontal sinus.

Image fusion features of planning stations are used for this conversion process. Stereotactic software used for surgical planning requires registration points called fiducials to perform 3-dimensional measurements. These reference points, appearing in white and circular or elliptic shape on radiological images, should be defined or registered to the stereotactic software either manually or automatically. This section describes the complications linked to the stereotactic localizers used during DBS procedures.

Compatibility of Stereotactic Localizer and Planning Station: Stereotactic planning softwares require various numbers of fiducial marks to be identified for different frame systems. For example, while the Medtronic Framelink planning station (Medtronic, Minneapolis, USA) requires a minimum of 9 fiducials for the Leksell Stereotactic frame (Elekta, Stockholm, Sweden), 6 fiducial marks are sufficient for the Elekta SurgiPlan system (Elekta, Stockholm, Sweden). This means, if a surgical team has a localizer capable of providing 6 fiducial marks while they are working with a system requiring 9 fiducial points, it would be impossible to perform the targeting using these two systems. Although this point is logical, we have encountered problems, and therefore outline this problem here. In this sense, checking the compatibility of stereotactic localizer and stereotactic planning station before starting the measurement procedures is recommended. This complication has been seen in 1 case in our experience.

Field of View Effect on Fiducials: Another complication related to the MRI/CT localizer is missing fiducials which has to be viewed together with the patient's anatomy on radiological images. If the technical personnel who perform the stereotactic MRI or CT imaging are not informed, they may create images without paying particular attention to the fiducial marks around the head. Images not including the required fiducial marks due to insufficient field of view (FOV) undermine the capability of stereotactic planning systems to carry out the desired image processing. On the other hand, applying an unnecessarily large FOV value may result in images with a very low resolution. In this respect, axial test imaging by having 1 or 2 slices on the planned imaging area before total volume imaging will help to explore whether or not the FOV value is sufficient for the measurements. In 5 patients of our series, we have experienced this complication.

Air Bubbles in Localizers Using Liquid Solutions: In order to ensure fiducial marks are clearly noticed on MRI images, copper sulfate solution is recommended and used by some frame manufacturers. To obtain stereotactic MRI images for these systems, the localizer has to be filled with this solution. If the filling process is performed in an inadequate manner, air bubbles can remain in the copper sulfate solution filling localizer channels (Figure 4A). Performing the imaging with air bubbles will result in poorly detectable fiducial marks (Figure 4B). In this case, if MRI is preferred for stereotactic imaging, filling the localizer channels or checking the contents of pre-filled channels of localizer will be an effective way to prevent unwanted scenarios. This situation is not going to lead to any complications for the groups who are using CT localizers for stereotactic procedures. In 4 patients of our series, this complication was experienced.

Disengaged Localizer Effect: The engagement of the frame system and the localizer system is important to obtain accurate calculations before the DBS procedure. Independent of a CT or MRI localizer, it should be well attached and checked before the imaging process has been finalized. With images obtained with a disengaged or not fully engaged localizer, the fiducials are not going to show the right points on the radiological images which will result in miscalculated targets. To avoid this complication, junction points between the stereotactic frame and stereotactic localizer must be checked to see if they are completely engaged. Miscalculated targeting will also affect the recording and the permanent implant quality. In our experience, we also experienced 1 misplaced electrode during the postoperative imaging phase of the implant process because of this issue.

Planning Station Related Complications

The goal of image fusion is to integrate complementary multi-sensor, multi-temporal and/or multi-view information into one new image (5). Today, many different radiological image series are used for different purposes in the planning stages for DBS surgeries (3,7,12). Some image series are meant to provide information about the vascular structures on the trajectories. Such information can be obtained using MRI and CT-images enhanced with contrast-agents (6). Image fusion technology helps to integrate these two distinct pieces of information to serve an integrated purpose.

Image Fusion Failures: Although image fusion is often regarded as a computer-based software operation, the success and accuracy of the fusion depends on the imaging protocols. The way to make this process more precise is to ensure that imaging standards of the two images to be merged are as close as possible, including slice thicknesses and imaging angulations.

Today's stereotactic planning stations require some imaging standards to perform the best image fusion process with respect to their own image fusion algorithms. These detailed standards can be found in each manufacturer's instructions for use (IFU) booklets. For example, no gantry tilted images are required for Medtronic Framelink planning station (Medtronic, Minneapolis, USA). In this sense, angulation difference of two different image series of a patient could fail the image fusion process. If the imaging procedures are performed in relation to a reference plane, this problem will be eliminated to a great extent. The most important planes used for the frame fixation process are called Reid's baseline and the Glabella-Inion line (15). Performing the frame fixation process with respect to these planes and having all stereotactic and non-stereotactic images with respect to these planes will avoid angulation differences. In our series, we experienced image fusion failures in 85 procedures.

Cerebrospinal Fluid (CSF) Signal Effect Phenomenon on Image Fusion: One of the most important radiological image series used in the planning phase of DBS surgery is the axial T1 MR images with contrast enhancement to visualize vascular structures (1). The T2-weighed MR images are often used to directly visualize the target structures in DBS surgeries (9). Independent of the quality of the image fusion process performed for T1- and T2-weighed image series, the user may complain about the fusion quality of the images at the level of the lateral ventricles and the third ventricle. This perceived poor quality of fusion results from different signal characteristics of CSF in T2 and T1 images (11). CSF containing structures appear to have different volumes due to different signal responses of CSF to different sequences (Figure 5A). Such volumetric discrepancies noticed in the manual fusion quality checks may cause the user to perceive failed quality, even though the process has been completed successfully. At this point, we recommend using other anatomical structures instead of the ventricles to evaluate the quality of image fusion. Vascular structures, for instance, can be used for this purpose (Figure 5A-D). The pericranium is also a useful structure to evaluate the accuracy of image fusion. In 25 of 460 procedures, these volumetric discrepancies were experienced.

■ DISCUSSION

Here, we shared our experiences with stereotactic frame related complications. The first complication related to the stereotactic frame was described as movement related frame fixation problems. To solve this issue, the best solution was detailed as using a stereotactic positioning aid device. The second complication topic about stereotactic frames was head anatomy related complications. For the patients with a short neck, the sagittal anterior or sagittal posterior frame orientations and more inferior frame fixation methods were advised. Furthermore, oversized frontal sinus cavity related fixation problems were mentioned and anatomical checks before fixation were advised. Another complication related to the stereotactic frame was detailed as those related to a lack of maintenance. Performing the necessary checks after the decontamination processes and regular maintenances after each usage has become a standard operation procedure in our centers.

In the second part, our experiences with stereotactic localizer related complications were described. Firstly, the compatibility of stereotactic localizer and planning station was underlined and a compatibility check was suggested. Then, the missing fiducials on MR/CT scans due to the field

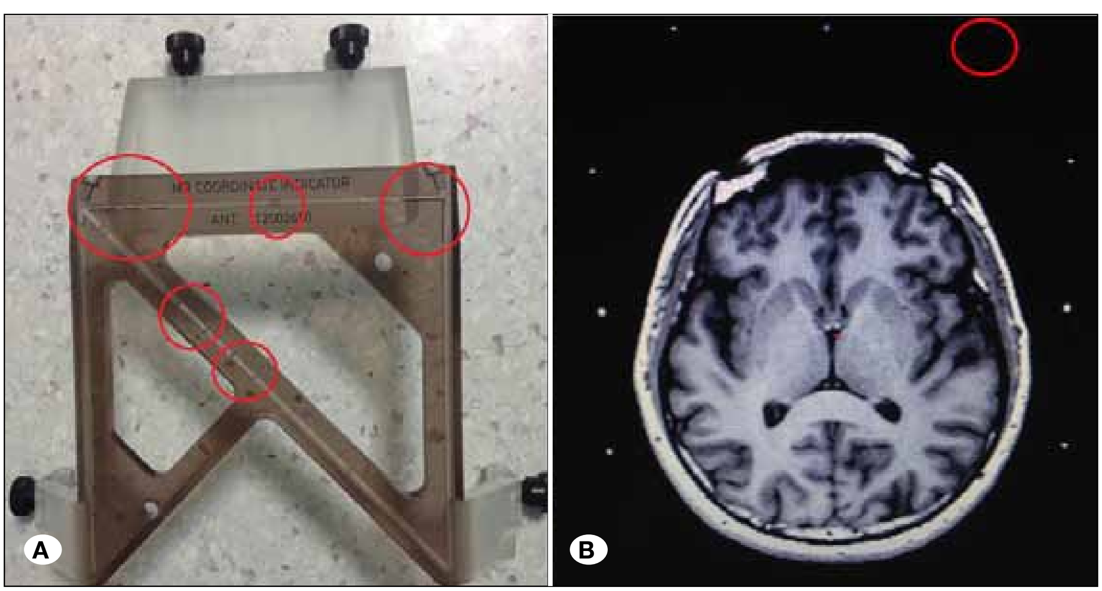

Figure 4: **A)** The anterior part of a localizer filled with copper-sulfate is shown. Red circles show the air bubbles in the channels of the localizer. **B)** A stereotactic T1 MR image is shown. The invisible fiducial is indicated with red circle on the radiological image.

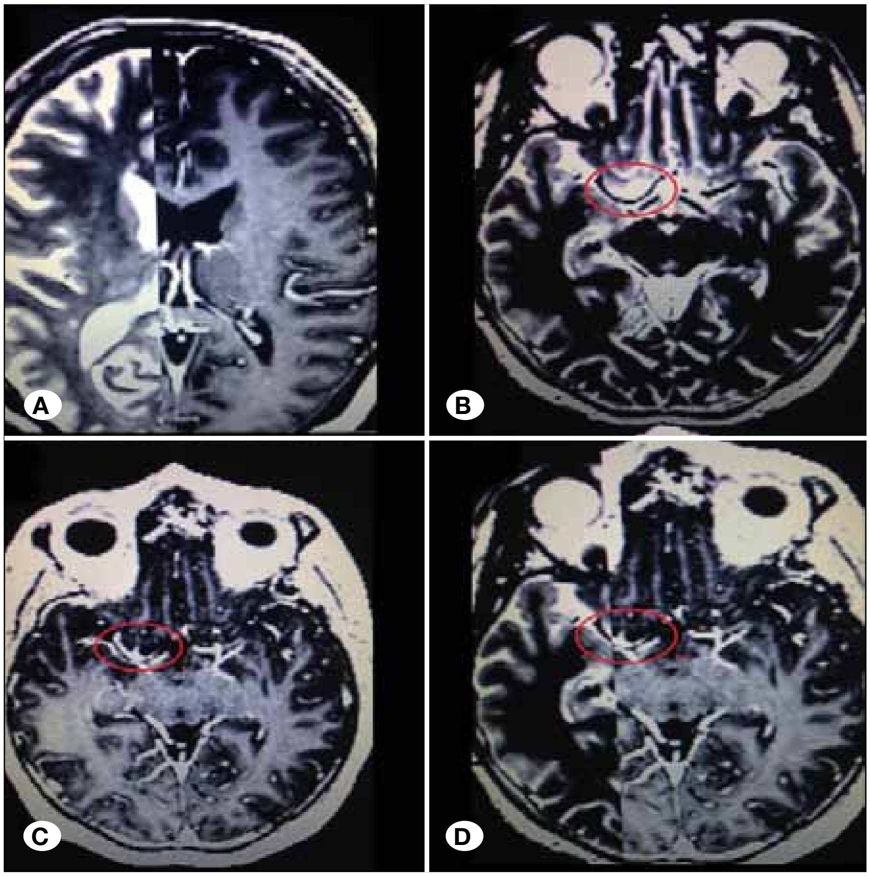

Figure 5: A) T1 and T2 axial slices merged at the level of lateral ventricles. CSF-containing structures have different volumes in T1 and T2 images. **B)** The red circle shows the blood flow signal in a T2 axial slice. **C)** The red circle shows the same vascular structure with a contrast agent in a T1 axial slice. **D)** The red circle shows the correlation between T1 and T2 images after the fusion process.

of view effect was described. To avoid this, setting the FOV to an optimum scanning area which will not cause invisible fiducials on scans and which will not cause low resolution scans was implemented. Also the problem of the presence of air bubbles in localizers using liquid solutions is mentioned to avoid a complication which may result in missing fiducial on radiological images. The last complication issue related to stereotactic localizers was imaging with disengaged or not fully engaged localizer. The junction points between the stereotactic frame and stereotactic localizer must be checked before the imaging process has been finalized.

In the third and the last part, planning station related complications were described. The first complication mentioned was the image fusion failures because of the imaging angulation differences between different series to be merged. Performing all the imaging with respect to one standard plane is advised for that issue. Secondly, the CSF signal on different MR series resulting in unsatisfactory image fusion perception is described. Checking the image fusion quality through the vascular structures is advised as well.

■ REFERENCES

1. Bériault S, Sadikot AF, Alsubaie F, Drouin S, Collins DL, Pike GB: Neuronavigation using susceptibility-weighted venography: Application to deep brain stimulation and comparison with gadolinium contrast: Technical note. J Neurosurg 121(1):131-141, 2014
2. Chan DT, Zhu XL, Yeung JH, Mok VC, Wong E, Lau C, Wong R, Lau C, Poon WS, Group TMD: Complications of deep brain stimulation: A collective review. Asian J Surg 32(4):258-263, 2009
3. Dormont D, Ricciardi KG, Tandé D, Parain K, Menuel C, Galanaud D, Navarro S, Cornu P, Agid Y, Yelnik J: Is the subthalamic nucleus hypointense on T2-weighted images? A correlation study using MR imaging and stereotactic atlas data. AJNR Am J Neuroradiol 25(9):1516-1523, 2004
4. Fenoy AJ, Simpson RK Jr: Risks of common complications in deep brain stimulation surgery: Management and avoidance: Clinical article. J Neurosurg 120(1):132-139, 2014
5. Flusser J, Sroubek F, Zitova B: Image fusion: Principles, methods, and applications. Tutorial Eusipco, 2007
6. Hertel F, Husch A, Dooms G, Bernard F, Gemmar P: Susceptibility-weighted MRI for deep brain stimulation: Potentials in trajectory planning. Stereotact Funct Neurosurg 93(5):303-308, 2015
7. Kocabicak E, Aygun D, Ozaydin I, Jahanshahi AKH, Tan S, Onar M, Boke O, Kurt M, Guz H, Terzi M, Alptekin O, Temel Y: Does Probe's Eye Subthalamic nucleus length on T2W MRI correspond with microelectrode recording in patients with deep brain stimulation for advanced Parkinson's Disease? Turk Neurosurg 23(5):658-665, 2013
8. Kocabicak E, Temel Y, Höllig A, Falkenburger B, Tan SK: Current perspectives on deep brain stimulation for severe neurological and psychiatric disorders. Neuropsychiatr Dis Treat 11:1051, 2015

9. O'Gorman RL, Shmueli K, Ashkan K, Samuel M, Lythgoe DJ, Shahidiani A, Wastling SJ, Footman M, Selway RP, Jarosz J: Optimal MRI methods for direct stereotactic targeting of the subthalamic nucleus and globus pallidus. Eur Radiol 21(1):130-136, 2011
10. Oh MY, Abosch A, Kim SH, Lang AE, Lozano AM: Long-term hardware-related complications of deep brain stimulation. Neurosurgery 50(6):1268-1276, 2002
11. Ortendahl DA, Posin JP, Hylton NM, Mills CM: Optimal visualization of cerebrospinal fluid on MRI. AJNR Am J Neuroradiol 7(3):403-407, 1986
12. Plantinga BR, Temel Y, Roebroeck A, Uludag K, Ivanov D, Kuijf ML, ter Haar Romenij BM: Ultra-high field magnetic resonance imaging of the basal ganglia and related structures. Front Hum Neurosci 8:876, 2014
13. Tan SK, Vlamings R, Lim L, Sesia T, Janssen ML, Steinbusch HW, Visser-Vandewalle V, Temel Y: Experimental deep brain stimulation in animal models. Neurosurgery 67(4):1073-1080, 2010
14. Temel Y, Visser-Vandewalle V: Targets for deep brain stimulation in Parkinson's disease. Expert Opin Ther Targets 10(3):355-362, 2006
15. Tokunaga A, Takase M, Otani K: The glabella-inion line as a baseline for CT scanning of the brain. Neuroradiology 14(2): 67-71, 1977
16. Wichmann T, DeLong MR: Deep-brain stimulation for basal ganglia disorders. Basal Ganglia 1(2):65-77, 2011