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Perioperative considerations for elective surgery in patients with deep brain stimulation implantation

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In the more than 30 years that have passed since its introduction, deep brain stimulation (DBS) has been shown to be effective and safe for a growing number of diseases, such as depression and obsessive-compulsive disorder, as well as movement disorders such as Parkinson's disease, dystonia, and essential tremor. As a result of population aging due to the increase in life expectancy, the number of patients requiring DBS implantation is increasing. These patients often require surgery or treatment for diseases other than the original disease that required DBS. Most diagnostic tests or procedures can damage the DBS system by various mechanisms, so clinicians unfamiliar with DBS have difficulty treating these patients. The purpose of this review is to summarize the knowledge necessary for patient management that will be useful for clinicians treating patients with DBS implantation.

KEY WORDS: Deep brain stimulation, Surgery, Complications, Patients

BACKGROUND

Since the introduction of high-frequency unilateral thalamic stimulation by Benabid et al. [1] in 1987, the use of deep brain stimulation (DBS) has become the basis for the treatment of movement disorders refractory to medical management. The identification of the role of the subtahalamic nucleus (STN) and the introduction of the first stimulation of the STN in 1993 marked another milestone in the role of DBS in Parkinson's disease (PD) [2,3]. Over conventional ablative treatment such as thalamotomy and pallidotomy, DBS has advantages in reversibility, adjustability and safety profile. DBS has been considered as the primary surgical treatment for movement disorders as an alternative to ablative surgery. Long-term outcomes of DBS for PD demonstrated significant improvements in quality of life and activities of daily living, as well as in basic dopamine-responsive motor and nonmotor features [4-6]. The application of DBS continues to expand, and it was approved by the United States Food and Drug Administration for dystonia in 2003 and obsessive-compulsive disorder in 2005. Recent studies have also demonstrated the efficacy and safety of DBS for pain, epilepsy, and Tourette's syndrome [7,8]. Studies are ongoing into the role of DBS in a variety of

conditions, including major depression, anorexia nervosa, and Alzheimer's disease [9-11].

Over the past 30 years since its introduction, more than 150,000 patients worldwide have been treated with DBS [12]. Also, due to the aging of the population, by 2040, 25% of the world's population is expected to be 65 years or older. The number of patients who received DBS implantation will continue to increase due to the increase in the elderly population, the expansion of diseases that are indications for DBS, and the discovery of new targets. When these patients require treatment for other diseases, patient management can be complicated for clinicians unfamiliar with DBS [13].

Aim of this review

Patients with DBS implantation may require treatment for other diseases, but treatment may be limited because of the presence of the DBS system. DBS-related issues should be considered when considering treatment or surgery for other conditions. The purpose of this review is to summarize the knowledges necessary for patient management useful to clinicians treating patients with DBS implantation.

This article does not include any personal data. This article was exempt from IRB approval.

DEEP BRAIN STIMULATION SYSTEM

Current DBS systems consist of unilateral or bilateral intracranial electrodes, an implantable pulse generator (IPG) under the clavicle or axilla, and an extension wire connecting the electrodes to the IPG. The system delivers stimulation to the electrodes with an amplitude, pulse width, and frequency set by the clinician and the patient's programming device.

Although DBS systems may look similar to the well-known implantable cardiac electronic devices (CIEDs) such as pacemakers and implanted defibrillators, they differ in mechanism of action, stimulation parameter, and method of operation. The CIEDs are usually more complex to neurostimulation system including DBS. Whereas program parameters are adjusted based on electrical feedback from the leads in CIEDs, neurostimulator provides continuous stimulation on the target region. As for stimulation parameter, neurostimulation uses higher frequency above 100 Hz and higher current, CIEDs uses lower frequency and lower current. DBS system can be turned off, but CIEDs cannot be turned off. In both systems, the function may be impaired by electromagnetic interference, which may lead to patient morbidity.

Previous DBS systems delivered current in a voltage controlled method by electrochemically induced changes in electrode impedance at the brain-electrode interface [14]. Current systems provide a more clinically effective constant current stimulation by current-controlled method [15]. DBS systems provide either unipolar or bipolar stimulation. In unipolar mode, the active electrode is set to the cathode and the IPG case is set to the anode. In bipolar stimulation, one of the four electrodes of the electrode acts as the cathode and the other acts as the anode. Modern DBS systems provide a rechargeable IPG, which extends the life of the device and reduces the need for additional surgery to replace the IPG [16,17].

MEDICAL IMAGING

X-ray, diagnostic ultrasound and computed tomography

Patients who have DBS systems can safely undergo x-ray, diagnostic sonographic ultrasound, and computed tomography (CT) scans without additional management.

Magnetic resonance imaging

Magnetic resonance imaging (MRI) imaging of patients with DBS systems was previously absolutely contraindicated due to electromagnetic interactions. Problems caused by electromagnetic interactions include excessive heating of the DBS electrode tip due to the synthesis of the generated current, voltage induction proportional to the gradient pulse change over time, unintentional reprogramming of the IPG, image artifacts and distortion, and the functioning of the DBS system [18]. The amount of heat generated within a DBS system by electromagnetic interaction depends on several factors such as the electrical properties of the stimulator, the field strength of the MRI system, the location of the DBS component relative to the radiofrequency (RF) energy source, the RF coil used, the imaging site, and the specific absorption rate [19].

DBS manufacturers provide specific guidelines for the use of MRI in patients with DBS implantation. Boston Scientific has previously banned MRI scans after DBS, but states that the new system is only possible with a 1.5 T full body or head transmit/receive and RF quadrature only coil [20]. Medtronic also states that patients with DBS system can undergo MRI scans under specific conditions, and complete MRI guideline is available from their website (https://manuals.medtronic.com/manuals/mri/region) [21].

In situations where MRI cannot be replaced with CT or ultrasound, clinicians should always confirm with manufacture and check the following conditions prior to MRI scan (Table 1). Table 2 presents points to be noted before, during, and after MRI.

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INTRAOPERATIVE CONSIDERATION – MEDICAL DEVICE INTERACTIONS WITH THE DEEP BRAIN STIMULATION SYSTEM

Several medical devices used during surgery can interact with the DBS system, generating varying degrees of electromagnetic interference, potentially affecting the functioning of the neurostimulator. Even with the DBS system turned off, the conductivity of the metal case, leads and DBS device is maintained and current can pass through it.

Table 1. Specific conditions to check prior to MRI scans in patients with a DBS system

Checklists prior to MRI scans in patients with a DBS system
• Only 1.5-T horizontal-bore MRI
• Only a transmit/receive head coil
• Calculation of the head SAR using correct patient weight
• MRI parameters that allow an average head SAR ≤ 0.1 W/kg
• The gradient dB/dt ≤ 20 T/s [32]

MRI: magnetic resonance imaging, DBS: deep brain stimulation, SAR: specific absorption rate.

Diathermy

Diathermy refers to the treatment via heat, with the generation of heat within body tissues from high-frequency electromagnetic currents to promote healing or aid in healing (Fig. 1A). In principle, it is applied transdermally and electrically generates a short-wave diathermy with a power of up to 1,000 W. It is often used to relax muscle and treat joint disorders [22].

There have been case reports of serious brain damage due to heat generation at the tip of the DBS electrodes after using diathermy for dental treatment [23,24]. Manufacturers have since issued a product advisory advising caution against the use of all forms of diathermy in patients with neurostimulators [16,17].

Electrocautery

Electrocautery is a treatment in which heat is generated within a metal wire electrode by passing an electric current, typically used for tissue destruction to varying degrees, such as tissue hemostasis or removal of benign skin lesions (Fig. 1B). None of the manufacturer's safety reports state things with electrocautery, and the Medtronic guidelines group them together as "diathermy" and into

Table 2. Specific considerations before, during, and after MRI scans

Before MRI	Identify the implanted DBS system
	The model of the implanted DBS system
	The presence of an implanted pocket adaptor
	Implant status of the lead
	Integrity of the system in terms of any suspicious wire breaks
	Check for MRI contraindications
	Receiver-only coil applied to the head or a transmission coil extending above the chest
	Evidence of electrode or connecting wire breaks
	Use of non-compliant parameters
	Availability of safer diagnostic methods (e.g., computed tomography or sonography)
	Other implants or limiting factors for which MRI is prohibited or contraindicated
	Check the impedance of all electrodes and the battery voltage
	Record the stimulation values
	Turn off the neurostimulator
	Set the stimulation amplitude to 0 V
	Check the use of the appropriate MRI parameters
	Limit the active scan time
	Provide a sufficient explanation to the patient about possible complications and ask the patient to report any discomfort
	Properly position the patient
During MRI	Avoid sedation for constant communication with the patient to identify early complications
	Warming sensation, pain, unpleasant stimulation, unusual sensations
	Perform continuous patient monitoring
	Check consciousness between MRI sequences
After MRI	Confirm the patient's condition
	Have a DBS specialist check whether the stimulator is working
	Turn on the device and reprogram the stimulator to its original settings

MRI: magnetic resonance imaging, DBS: deep brain stimulation.

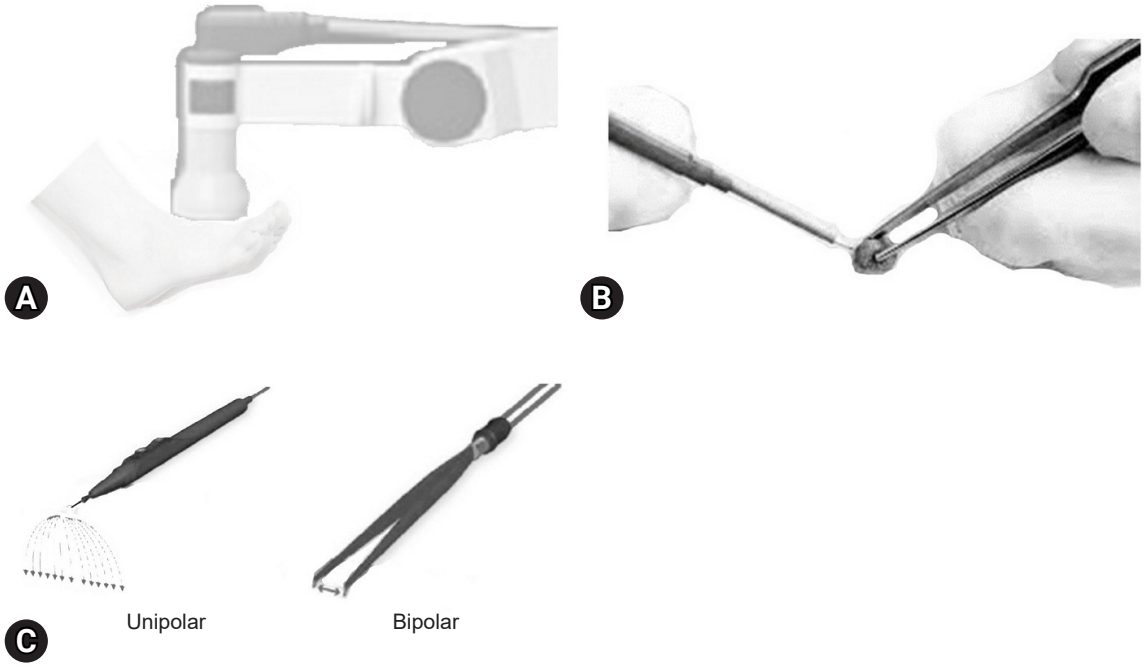

Fig. 1. Examples of medical devices that may affect the deep brain stimulation system. (A) Diathermy. (B) Electrocautery. (C) Electrosurgery.

a possible hazard category [25].

The effect of electrocautery on cardiac pacemaker has been widely reported, and the effect on DBS can be estimated based on it. Cases of pacemaker failure due to electrocautery in an asynchronous mode resulting in hemodynamic instability have been reported [26]. Unintended reprogramming can occur even in asynchronous mode when used very close to the IPG [27,28]. Caution is needed when used very close to the IPG, because unintended reprogramming can occur even in asynchronous mode.

Electrosurgery

Electrosurgery is generally used during surgery and includes various methods of cutting and coagulation as electrical energy flows from an active electrode to a distributed electrode (Fig. 1C) [22]. Electrosurgery affects the tissue immediately adjacent to the active electrode. There are two different electrode configurations: unipolar mode and bipolar mode.

Unipolar mode

In the unipolar mode, a current generated through an electrode enters the patient's body and reaches a grounding pad. The presence of a conductive material between the monopolar device and the dispersive pad can redirect the path, which may inadvertently heat the tissue outside the surgical target due to the conversion of current to heat as energy passes through the tissue. Unipolar electrosurgery can induce thermal brain injury in patients with DBS system, so its use is not recommended by all DBS manufacturers. However, unlike diathermy, there are no experimental works or clinical trials for the use of electrosurgery.

Sometimes the surgeon may inevitably have to use monopole cauterization. In such a situation, the ground plane may be placed on the shoulder or occiput opposite the IPG [29]. The DBS system should be switched off and used at the lowest possible energy level.

Bipolar mode

In bipolar mode, the current only passes through the tissue between the two electrodes of the electrosurgical device, so the current spread is small. The bipolar mode of electrosurgery can be safely used in patients with implanted neurostimulators [30].

Electrocardiogram

Electrical signals generated by the DBS system may affect the electrocardiogram (ECG) recording, so may need to be turned off to limit interference [31]. However, it should be kept in mind that turning off the DBS unit may result in recurrent motor symptoms, resulting in artifacts interfering with ECG recording.

Postoperative considerations

After the operation, the DBS system must be turned on again. In

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the case of general anesthesia, the recurrence of motor symptoms can be prevented by turning on the device before waking up from anesthesia [30,32]. Because the extrathalamic arousal system is involved in the human sleep-wake cycle, STN stimulation can result in cortical asrousal [32].

MEDICATIONS TO AVOID

The most frequent disease for which patients underwent DBS surgery is PD, and antidopaminergic drugs such as metoclopramide and dopamine depleting drugs should be avoided to avoid worsening symptoms [33]. Comprehensive drug adjustment is required so that the combination drug does not aggravate symptoms or cause serious side effects due to drug interactions in consideration of comorbidities. Tricyclic antidepressants for pain control can cause hypertensive crisis and dyskinesia when taken together with levodopa. Antipsychotic drugs, such as phenothiazine, should be avoided as they can worsen PD-related symptoms.

ADDITIONAL TREATMENT METHODS

Ultrasound

Although diagnostic ultrasound can be safely performed in patients with an implanted nerve stimulator, the manufacturer recommends not placing the transducer directly over the implanted device. Therapeutic ultrasound depends on the output. There have been case reports that phacoemulsification for cataract removal was safely performed in patients with DBS [34,35]. However, lithotripsy can damage the neurostimulator circuit due to high-power ultrasound frequencies. This does not mean that the use of lithotripsy is contraindicated in patients with DBS, but if it is unavoidable, the ultrasound beam should not be directed within 15 cm of the neurostimulator [36]. MRI-guided focused ultrasound, which has been widely used recently for essential tremor, is, in principle, a contraindicated treatment when metallic substances such as neurostimulators and pacemakers exist in the body [37].

Radiation therapy

The risk to the DBS system of radiation therapy can be assessed on the basis of reports of patients with CIED. In vivo and in vitro studies, ionizing radiation has been shown to affect voltage changes by causing permanent and/or potential damage due to ionization of semiconductors in circuits [38,39]. Radiation therapy should not be administered near DBS devices, as irradiation may induce the creation of abnormal electrical pathways. If radiation therapy is required, lead shielding should be used to limit exposure and to protect the device, and the device should be checked for defects after each session [36,40]. In such situations, guidance on the safe application of radiation therapy for patients using CIEDs may be consulted [41,42]. Table 3 represents the risk classification of patients with CIEDs according to the cumulative dose and pacing dependence [41]. Using energies greater than 10 Gy can damage the random access memory and semiconductors in the device due to secondary neutrons generated in the linear accelerator head [43].

Laser

Because there are limited data on the safety of the laser use in patients with DBS, caution should be exercised prior to use and the risks should be fully discussed with the patient. When performing laser treatment, the DBS system should be turned off and the laser should be placed as far away from the system as possible [36]. After treatment, the DBS unit should be checked.

External cardiac defibrillators

Since external cardiac defibrillation and cardioversion are required for lifesaving purpose in emergent situations, its use should not be withheld in patients with DBS. There has been case report that 300 J of external cardioversion did not affect the DBS system [44]. Medtronic recommends using the lowest possible power setting and placing the paddle perpendicular to the DBS system as far from the neurostimulator as possible [36].

Electroconvulsive therapy

When electroconvulsive therapy (ECT) is required in a patient implanted with DBS, safety concerns from heat generation at the DBS electrode due to induction of RF current by electric charge, functional disruption of the DBS system, and electrode displacement due to induced seizure activity should be considered. There have been case reports in which ECT was safely performed with

Table 3. Risk classification of patients with CIEDs according to the cumulative dose and pacing dependence

	< 2 Gy	2–10 Gy	> 10 Gy
Device-independent	Low risk	Intermediate risk	High risk
Device-dependent	Intermediate risk	High risk	High risk

CIED: implantable cardiac electronic device.

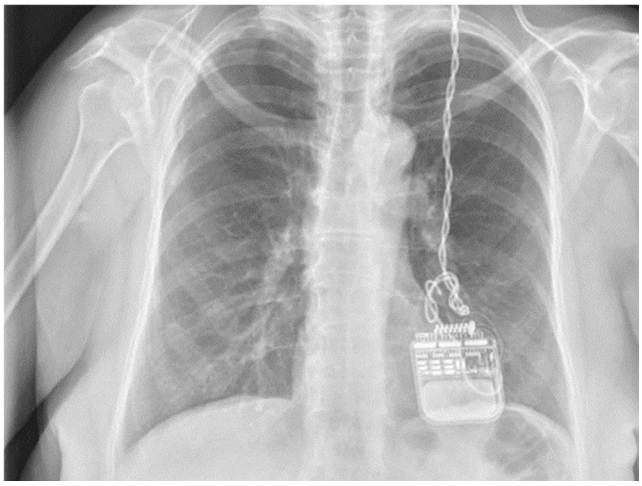

Fig. 2. Example of Twiddler syndrome, which is a malfunction of the device due to damage to the implantable pulse generator or lead.

the nerve stimulator turned off, the ECT electrode placed as far from the DBS electrode as possible, and using the lowest possible energy to induce seizures [45,46].

Cardiac pacemakers and implantable cardioverter defibrillators

The implantation of pacemakers and/or implantable cardioverter defibrillators (ICDs) in patients using neurostimulators is not contraindicated. However, it requires the approach of a multidisciplinary team (e.g., cardiologist, DBS specialist, anesthesiologist) to optimize the patient's clinical condition and adjust the settings of the underlying medical device as needed. Measures are needed to prevent potential interactions between devices. The pacemaker should be programmed for bipolar detection mode to avoid over-exaggeration and inappropriate response [47,48]. It is not recommended to insert the IPGs of the two systems in close proximity to reduce electromagnetic interference [47]. After the ICD delivers the shock, the function of the nerve stimulator should be checked. To ensure consistent functioning of the pacemaker device, detailed cardiac investigations such as Holter monitoring should be performed whenever DBS device settings are adjusted [49].

Physical therapy

One of the things to be aware of when doing physical therapy in patients with DBS is Twiddler syndrome, which is a malfunction of the device due to damage to the IPG or lead [50]. Lead dislodgment, diaphragmatic stimulation, and loss of capture may occur due to conscious or unconscious manipulation of the implantation site, leading to device malfunction. X-ray examination should be performed before treatment to confirm the position of the lead and IPG (Fig. 2), and caution is required as the wire may be damaged by neck manipulation at a large angle.

Mammography

Caution is required as overclocking may cause physical damage to the DBS device if the tissue is compressed too hard during mammography.

Summary

- X-rays, CT, and diagnostic ultrasound can be done relatively safely.
- If MRI cannot be substituted for other tests, it should be performed according to the recommendations by referring to the manufacturer's guideline.
- The DBS system can interact with other medical device used during surgery by electromagnetic interference.
- If electrosurgery is required during surgery for hemostasis, use bipolar mode instead of unipolar mode.
- High-power ultrasound for therapeutic purpose should be avoided as much as possible. If absolutely necessary, make sure that the beam does not enter within 15 cm of the system.
- Radiation therapy using energy of 10 Gy or more can damage the DBS system.

CONCLUSION

Clinicians who manage patients with DBS should always pay attention to the device, and keep in mind that device can be damaged during procedure or surgery. A multidisciplinary approach involving DBS experts is often required. The DBS system should be reassessed to confirm if it works well.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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