Raba robotske kirurgije pri stimulaciji globokih možganskih jeder

Robot-assisted deep brain stimulation

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Izvleček

Stimulacija globokih možganskih jeder je prepoznana kot varna in učinkovita metoda zdravljenja različnih motenj gibanja, kot so esencialni tremor, Parkinsonova bolezen in distonija, kakor tudi za obsesivno-kompulzivne motnje in na terapijo neodzivne epilepsije. Glavna anatomska tarča stimulacije so bazalni ganglji. Sistem stimulacije globokih možganskih jeder sestavljajo kirurško vstavljene elektrode in generator električnih impulzov. Postavitev elektrod mora biti natančna, saj so učinki stimulacije globokih možganskih jeder odvisni od prostorske omejitve stimulacije. Nekateri nevrokirurški centri so pričeli z rabo robotsko asistirane stimulacije globokih možganskih jeder in dosedanji rezultati so bili

Abstract

Deep brain stimulation (DBS) is recognised as a safe and effective treatment for several movement disorders, namely essential tremor, Parkinson's disease, and dystonia, as well as for obsessive–compulsive disorder and refractory epilepsy. The main anatomical target of DBS is the basal ganglia. The DBS system comprises a pulse generator and surgically implanted electrodes. Lead placements must be accurate because the effects of DBS rely on the spatial restriction of the stimulation. Neurosurgical centres have started adopting robot-assisted DBS surgery. The results so far have been promising, with lead placement accuracy comparable to that of frame-based procedures.

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obetavni s primerljivo natančnostjo namestitve elektrode s klasičnimi postopki vstavitve, ki temeljijo na rabi stereotaktičnega okvirja. Prav tako so ugotovili, da so robotsko asistirani posegi krajši in manj zahtevni za bolnike. Stimulacija globokih možganskih jeder z uporabo robota je primerna za budne bolnike, bolnike v splošni anesteziji ter otroke.

Additionally, robot-assisted procedures are shorter and less demanding on patients. Robot-assisted DBS can be used on patients who are fully awake or under general anaesthesia, as well as on children.

INTRODUCTION

Deep brain stimulation (DBS) is recognised as an effective and safe treatment option for various illnesses (1,2). The American Food and Drug Administration (FDA) approved DBS treatment for essential tremor in 1997, for Parkinson's disease in 2002, for dystonia in 2003, and for severe obsessive–compulsive disorder (OCD) in 2009 (1). Similar indications for DBS are utilised in Europe, with the recent addition of refractory epilepsy in 2010 (1,3). Robot-assisted DBS surgery has developed recently, owing to its enhanced anatomical localisation, the ability to stabilise the surgeon's hand, and its help with anatomical planning for lead placement. Some of the robotic systems used include NeuroMate, Pathfinder, NeuroArm, ROSA, and Renaissance (4).

APPLICABLE ANATOMY FOR DBS

The basal ganglia and their related nuclei comprise subcortical cells engaged in motor control, motor learning, executive functions, behaviour, and emotions (5). The basal ganglia comprise four structures: the substantia nigra with its pars compacta and pars reticularis; the striatum, which consists of a caudate nucleus and putamen; the globus pallidus, which consists of its external and internal parts; and the subthalamic nucleus (STN) (1).

INDICATIONS FOR DBS

Essential tremor is a movement disorder defined as an isolated tremor syndrome of bilateral upper limb action tremor with or without tremor in other locations and lasting at least three years (6). The target for DBS is the ventral intermediate nucleus (Vim) of the thalamus (1).
Primary dystonia represents a group of hyperkinetic movement disorders characterised by sustained involuntary muscle spasms and postures. Primary dystonia represents the most common form, where dystonic movements are the only clinical feature and there is no evidence of neurodegeneration (7). With DBS, the internal segment of the pallidum (GPi) is targeted (1).
Parkinson's disease is the most common neurodegenerative movement disorder. The aetiology of the disease in most patients is unknown, but different genetic causes have been identified (8).
Parkinson's disease is characterised by the loss of dopaminergic neurons in the pars compacta of the substantia nigra and by the accumulation of misfolded α-synuclein, which is found in intra-cytoplasmic inclusions called Lewy bodies (8). Parkinson's disease is known for its classic triad of tremor, rigidity, and bradykinesia. The STN is the main target of DBS (1). After DBS of the STN, the dosage of levodopa can be reduced, although it can have slight negative effects on cognitive function. Another target is GPi, where stimulation using DBS has less pronounced negative cognitive effects (9).
OCD is characterised by the presence of obsessions (repetitive and persistent thoughts, images, impulses, or urges) or compulsions (repetitive behaviour or mental acts). OCD is an important mental disorder,

due to its high prevalence and disability (10). DBS is also approved for severe OCD, with the primary target being the anterior limb of the internal capsule and, recently, the nucleus accumbens in the ventral striatum (1).
Additionally, DBS can be used in severe cases of partial epilepsy, with targets in the medial temporal lobe, anterior nucleus of the thalamus, or posteromedial hypothalamus (1).

COMPONENTS OF THE DBS SYSTEM

The DBS system comprises a pulse generator connected to surgically implanted electrodes. The system is placed below the clavicle. The pulse generator induces current into the tissue, and the electric field generated by the flow of charge acts on the membrane ion channels of axons and leads to depolarisation (1). The safety and efficacy of DBS relies on the spatial restriction of the stimulation. Stimulation-induced side effects are a consequence of the electrical stimulation spreading to adjacent eloquent structures. Directional DBS leads are designed to reduce the risk of stimulation-induced side effects and improve the clinical benefits of DBS. A directional lead is a quadrupolar lead with the middle two electrodes segmented into three contacts, each spanning around 120° of the circumference. When all segments are activated, a ring electrode is created, but when only one or two segments are activated, the current can be injected in an angular direction. Directional DBS leads can compensate for small inaccuracies in lead placement (2). Closed-loop adaptive DBS, which is now entering the clinical stage, promises to deliver an individualised therapy with immense temporal precision. So far, pilot studies have shown promising results (11).

APPLICATION OF ROBOTICS IN NEUROSURGERY

The first application of robotics in neurosurgery was in a biopsy in 1988. However, the field of neurosurgery has still not adopted the extensive use of robotics in everyday practice, even though robotic systems can improve visualisation and dexterity, reduce tremors, and allow for greater precision from reduced fatigue (4,9). Modern robotic systems for cranial and spinal surgery are gaining in popularity in the United States and Europe. Neurosurgeons in

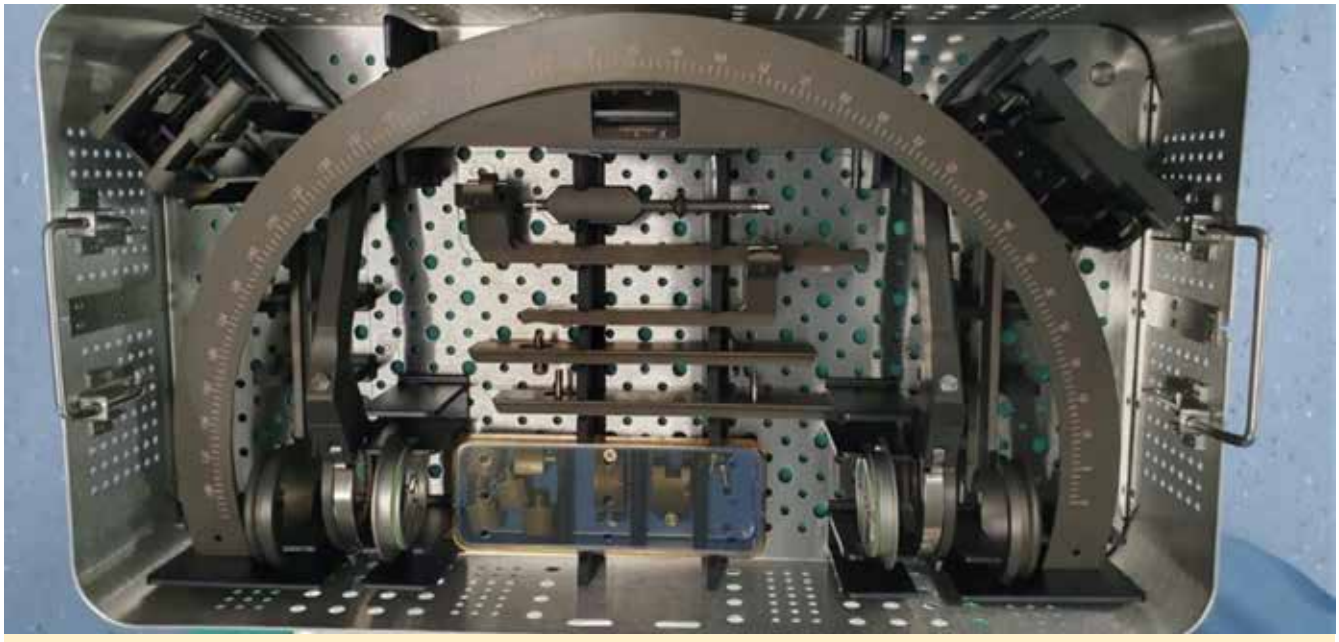

Figure 1. *Component of the stereotactic Leksell Vantage frame used for DBS implantation.*

Figure 2. *ROSA used for frameless implantation of DBS electrodes.*

Grenoble, France, have been using a stereotactic robot since 1989 and a microscope robot since 1995 (12). In DBS surgery, robotic frameless systems, such as NeuroMate, Renaissance, and ROSA, have been used for lead implantation, with accuracy comparable to that with frame-based stereotactic procedures (Figure 1) with microelectrode recordings (MERs) and awake macrostimulation testing that still represents the gold standard for lead implantation in DBS surgery (9). However, robot-assisted surgery for DBS remains an innovative technique, and data on its accuracy are limited (13).

EXAMPLES OF ROBOT-ASSISTED DBS SURGERY

Ma et al. conducted a retrospective review of patients with Parkinson's disease who were treated with DBS by the Remebot robotic system and compared them with others who received DBS using stereotactic frame surgery. They analysed 30 patients in each group. They found that the preoperative preparation of the robot was simplified, as the operation of coordinate adjustments was avoided. Also, the robot could simulate target corrections and reduce human error from manual coordinate adjustments. The robot arm had a 360° operating range with an automatic sensing device and with no surgical blind areas or dead angles. The accuracy of electrode placement was greater with robot-assisted implementation, but the difference was not statistically significant as the groups were relatively small. Robot-assisted DBS allows for small dural incisions and consequently minute cerebrospinal fluid loss, with minimal shift in brain tissue that affects the accuracy of electrode placement (9).

Mei et al. compared the accuracy of electrode placement between frameless robot-assisted DBS and frame-based techniques. They observed radial errors in a 2D scan (x and y axes) and vector errors in a 3D scan (x, y, and z axes). In their study, they used a frameless robot-assisted Sinovation SR1 DBS system. Eighteen patients with Parkinson's disease received DBS using a conventional frame-based technique and 17 by a frameless robot-assisted system. All patients were under local anaesthesia. The position of the electrodes was verified postoperatively by a 3D CT scan that was fused with a preoperative MRI. The mean values and standard deviations of the vector error and deviations of the coordinates were smaller in the frameless robot-assisted group, although, again, the differences were not statistically significant (13).

Faraji and colleagues studied the ROSA brain system (Figure 2) (14), which was FDA-approved in 2007 and gained approval for intracranial surgery and DBS in 2012. The researchers used ROSA to target Vim, STN, and GPi. They assessed the accuracy of radial errors using fused preoperative MRI and postoperative CT scans. They found that radial errors were comparable to errors with traditional frame-based DBS surgery. There was a statistically significant difference between radial errors in the first and second 10 patients, demonstrating a successful learning curve for the

surgeons. No complications (haemorrhage, infection, or lead misplacements) were noted using the ROSA system (12). Certain neurosurgical centres regard a 3-mm error as the threshold for lead reimplantation, and most consider an error of less than 2 mm ideal for lead placement. According to the literature, the vector error of ROSA was 1.6 mm for DBS, and frameless NeuroMate-assisted DBS had a vector error of 1.7 mm (13).

Ho and colleagues also conducted research on robotics in DBS surgery. They utilised the Mazor Renaissance platform and discovered that robot assistance significantly reduced operating times in a group of patients with Parkinson's disease (15).

Neudorfer et al. found that robot-assisted lead implantation was more accurate than conventional lead implantation. The duration of robot-assisted DBS surgery was significantly shorter than with conventional lead placement. Additionally, there was a statistically significant difference in lateral deviations between the two modalities. In the conventional group, 8.75% of implanted leads had a lateral deviation greater than 2 mm, whereas in the robot-assisted DBS group, the maximum lateral deviation was 1.52 mm. Neudorfer et al. concluded that robot-assisted DBS is superior to the conventional surgical technique and suggested that robot-assisted lead implantation should be considered a reliable alternative to purely mechanical devices (16).

Goia and colleagues also used the ROSA robot-assisted DBS platform and studied the accuracy of lead placements using the Euclidean 3D distance between the actual and intended location of contact 0. They discovered that the intended and actual locations of contact 0 were 0.81 mm on the right side and 1.12 mm on the left side. As such, they concluded that robot-assisted technology for DBS surgery is safe and accurate (17).

Neurosurgical centres have performed robot-assisted DBS surgery on both awake and sedated patients with Parkinson's disease. Awake surgery for DBS is popular because it allows for intraoperative test stimulations and correct electrode placements based on typical electrophysiological signals. In patients under general anaesthesia, an MRI or CT scan during surgery must be performed and merged with the preoperative MRI to assess the placement of leads. Jin et al. performed DBS surgery on patients awake and under general anaesthesia using a robot-assisted system. They discovered that operating times were significantly shorter in cases of general anaesthesia and that there were no differences between the clinical outcomes of the MER and non-MER groups (18).

DBS surgery is also used in children with dystonia, where the targeted anatomical structures are smaller and accuracy is even more important. Furlanetti and colleagues conducted research on 45 children who underwent robot-assisted DBS implantation under general anaesthesia. They concluded that robot-assisted stereotactic implantation of DBS electrodes in the paediatric age group is a safe and accurate surgical method, and more accurate than conventional stereotactic frame-based techniques (19).

PROS AND CONS OF ROBOT-ASSISTED DBS SURGERY

Robot-assisted DBS surgery can lead to a better clinical outcomes, due to more precision and consistency in instrumentation handling (20). The advantages of frameless robot-assisted DBS lead implantation are numerous: patients are more comfortable because they do not need to wear a heavy frame; the operation time is shorter; trajectory adjustments are easier; coordinates do not need to be set manually; and when selecting the entry points, targets, and fiducial registration, the robot arm can move easily between various entry points to decrease mechanical and human errors and find the optimal electrode position (13). The robot-assisted system is a simple, intuitive, portable, and cost-effective solution (21). However, it is limited by high costs, slow acceptance by surgeons, and a steep learning curve, as well as the fact that it requires many team members (13).

CONCLUSION

DBS represents an effective and safe treatment option for various movement disorders, as well as for refractory epilepsy and OCD. DBS relies on accurately placed leads and spatially restricted stimulation so that patients do not experience troubling side effects. Therefore, lead position is crucial in DBS surgery. Robot-assisted DBS surgery offers accuracy comparable to that with the frame-based procedure. The latter remains the gold standard, despite its high costs and steep learning curve.

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