

## Deep Brain Stimulation in Adult and Pediatric Movement Disorders

Laura CIF<sup>1</sup>, Simone HEMM<sup>1</sup>, Nathalie VAYSSIERE<sup>1</sup>, Philippe COUBES<sup>1</sup>

<sup>1</sup>Research Group on Movement Disorders, Department of Neurosurgery (Professor Philippe Coubes, Montpellier University Hospital, 34295 MONTPELLIER, CEDEX 5, FRANCE)

Correspondence should be addressed to Philippe COUBES

Tel/Fax: +33 (0) 4.67.33.74.64

[p-coubes@chu-montpellier.fr](mailto:p-coubes@chu-montpellier.fr)

[urmae@chu-montpellier.fr](mailto:urmae@chu-montpellier.fr)

### Background and purpose

In a wide range of medical conditions, a movement disorder can be the only symptom or it can be associated with other neurological deficits. Most of them are of unknown origin. Dystonia, dyskinesia, myoclonus, tremor, athetosis are abnormal movements susceptible to the influence of high frequency modulation of the basal ganglia. Nevertheless, the control of these symptoms is highly dependent on the etiology. Movement disorders (primary dystonia, myoclonus dystonia, tardive dyskinesia), which are not associated with other neurological deficits are more likely to be controlled by high frequency stimulation.

The first validated medical condition successfully treated by Deep Brain Stimulation (DBS) was Parkinson's disease (1). Gradually, the indications of this therapy were enlarged to include other diseases associating movement disorders as dystonia and dyskinesia of various etiologies. Based on the experience of our group (2) with brain lesioning surgery (pallidotomy) in a young patient with idiopathic generalized dystonia (3) and deep brain stimulation in Parkinson's disease dyskinesias (1; 4), we reported, in 1996 the efficacy of DBS in a young lady presenting with severe life threatening primary generalized dystonia after chronic bilateral stimulation of the GPi (5). Since then, 105 dystonic patients have been treated for bilateral stimulation of the Internal Globus Pallidus (GPi) in the department of Neurosurgery in Montpellier.

The originality of our method consists of the use of stereotactic MR imaging for the target determination, without microelectrode recordings. This considerably reduces the procedure's duration, which is important especially in children, as well as for the risk of haemorrhage (0 cases). Furthermore, the surgery is performed under general anesthesia which is better for patients with permanent involuntary movements.

We will present the population, the surgical procedure, the clinical management of the patients and the results obtained by DBS. In order to discuss the criteria for selecting the patients with dystonia - dyskinesia, we will briefly consider this medical condition. Whatever, other movement disorders being influenced by the DBS are sometimes associated with dystonia in patients to be operated.

Dystonia has been defined as a neurological syndrome characterized by involuntary, sustained muscle contractions, causing twisting and repetitive movements or abnormal postures. (6)

Its classification is a difficult task and can be done in several ways: according to the spread of the symptoms to different body parts, to the age of onset or to aetiology.

According to distribution, dystonia is classified into one of the following categories: focal, segmental, multifocal, hemidystonia and generalized dystonia.

The age of onset is another important criterion for characterizing a patient. In case of early onset, the disease is more likely to generalize and severely worsen than for adult-onset dystonias.

Dystonia can also be classified by aetiology. In primary dystonia, dystonia is the only symptom and can be sporadic or inherited (DYT1 dystonia (7)). Dystonia-plus is a group of syndromes where dystonia is usually associated with another neurological condition such as Parkinsonism or myoclonus (Dopa responsive dystonia, myoclonus-dystonia syndrome). The group of hereditodegenerative dystonias includes numerous diseases and in this group, dystonia is typically not pure. Amino acid disorders, lipid disorders, Lesch-Nyhan disease, pantothenate kinase-associated neurodegeneration (PKAN), mitochondrial diseases, Wilson's disease, Huntington's disease, Juvenile Parkinsonism-dystonia (8; 9) and many others are hereditodegenerative dystonias. Secondary dystonias are generated by insults such as drugs, strokes, tumours, infections (6) and this subgroup includes also dystonia-dyskinesia secondary to cerebral palsy (CP).

In 40% of the patients with early-onset dystonia a specific cause can be found. The aetiological diagnosis is established by clinical evaluation, neuroimaging and molecular analysis in primary dystonias. When the history of the disease, the clinical examination and the brain MRI suggest a hereditodegenerative dystonia, further investigations are performed such as blood work-up, urine sample analysis, CSF testing, electrophysiological studies, muscle, skin, liver biopsies, PET, eye slit-lamp examination.

The identification of the aetiology is very important for the prognosis of the disease and because of the existence of very few medical conditions having a specific treatment such as Dopa-Responsive dystonia, creatine deficiency or Wilson's disease.

Several drugs are available to treat dystonic symptoms but their efficacy is often limited, transient and difficult to assess (often because of the fluctuation of the symptoms). The most important drugs to be used are Levodopa (also as a diagnosis trial in Dopa responsive dystonia), anticholinergics, benzodiazepines, baclofen (10) and Botulinum toxin

injections especially for the treatment of focal dystonias (11)

Because of the poor efficacy of the pharmaceutical treatment in cases of very severe forms of movement disorders (especially generalized dystonias with onset in childhood) we were led to propose deep brain stimulation as another therapeutic strategy in order to control the symptoms generating life-threatening complications.

### Patients (Population)

In the following report, we will present the results of 82 patients presenting with segmentary or generalized dystonia treated by bilateral chronic electrical stimulation of the GPi. The population was divided in subgroups separating, for each of them, children from adults. Group 1 included patients with primary generalized DYT1 dystonia, group 2 primary generalized dystonia without DYT1 mutation, group 3 primary segmentary dystonia (cervical-axial dystonia), group 4 generalized dystonia-dyskinesia due to postanoxic cerebral palsy, group 5 generalized dystonia secondary to PKAN and group 6 one generalized dystonia secondary to mitochondrial disease. For the reported patients, the follow-up was at least of 6 months.

### Clinical evaluation

Dystonic movements and abnormal postures were evaluated using the Burke-Fahn-Marsden-Dystonia-Rating scale (BFMDRS, motor and disability part) (12) before the surgical procedure, several times during the post-operative hospital stay, every month during the first year and every three months afterwards .

### Surgical procedure

Bilateral electrode implantation was performed in a single surgical session under general anesthesia (13-15). The MR-compatible Leksell stereotactic frame was applied and a 3D-SPGR (spoiled gradient recall) acquisition was performed. The postero-ventral part of the GPi was located through axial, sagittal and coronal MRI studies (Figure 1A). The target coordinates (x, y, z) and the trajectory angles ( $\alpha, \beta$ ) were calculated using a dedicated software.

Two four contact electrodes (DBS 3389, Medtronic, Minneapolis) were implanted under strict profile radioscopic control. Immediate postoperative control MRI (Figure 1B) was obtained with the stereotactic frame on. Electrodes were connected to a pulse generator five days later (Itrel II or III, Kinetra and Soletra Medtronic, Minneapolis, USA), which was subcutaneously introduced in the abdominal area. In each patient final placement of the implanted devices and their connections were checked by a radiographic control during the postoperative hospital stay (Figure 2).

### Electric parameter settings

After implantation, stimulators were switched on. Electrical variables were set at high frequency (130Hz), 450  $\mu$ sec for the pulse width with one contact negatively activated. Intensity was progressively increased according to the needs of each patient (16) and the clinical evolution. Usually the first levels for the voltage were between 0.5V-0.8V. Over the time, we modified the electric parameters in several patients, by increasing the voltage or activating a second contact when requested. The mean steady state value of the voltage was  $1.6 \pm 0.3$ V. (17)

### Clinical results

Motor and disability scores' evolution (BMFDRS) for primary and secondary dystonia is presented in *table I and II*. Within each group, the improvement was progressive over time. With more than 3 years of follow-up, the clinical improvement was comparable for the two groups of primary dystonia (82% of improvement on the motor scale). The results obtained in the group of secondary dystonia and hereditodegenerative diseases are less important but yet around 40% with 3 years of follow-up. After three years, the disability score improvement was superior in the group of primary DYT1 dystonia (80%) compared to non-DYT1 primary dystonia (56%) and to secondary dystonia (19%). The group of secondary dystonia and hereditodegenerative diseases is a very heterogeneous group. This is why results for all etiologies should be presented separately.

### Discussion

We report here our experience with bilateral chronic electrical stimulation of the GPi in the treatment of primary DYT1 positive and DYT1 negative generalized dystonia (5; 18-21), generalized dystonia – dyskinesia secondary to post-anoxic cerebral palsy, generalized dystonia secondary to PKAN syndrome and to mitochondrial diseases. We also report the results obtained by DBS in primary segmentary dystonia. Since the first child has been operated, 126 other patients underwent surgery for DBS in our department (Dystonia + Parkinson).

While at the beginning DBS was proposed in children with primary generalized dystonia (with or without DYT1 mutation), selection criteria were revisited and enlarged for including now other types of dystonia in children and adults. Several patients with generalized dystonia associating myoclonus underwent surgery for chronic electrical stimulation of the GPi and we could see an early and complete control of myoclonus. These findings led us to propose this treatment in a child with genetically proven myoclonus-dystonia syndrome (20)(MDS, DYT11, mutation in the epsilon-amino sarcoglycan gene (22; 23)) and we obtained a very satisfactory improvement of his symptoms. We confirmed in a second patient with MDS the efficiency of GPi stimulation.

Being confronted with very severe clinical conditions in patients with secondary dystonia and hereditodegenerative diseases, in which the efficacy of the medical treatment was poor and in which dystonic movements and postures were comparable with those met in primary dystonia, we proposed DBS in several selected patients of these groups.

The criteria for patient selection in this group were clinical, electrophysiological and based on brain imaging as well as on etiology.

We performed surgery for DBS in patients in whom dystonia and dyskinesia were prominent compared to other neurological deficits (especially motor deficit and spasticity), the motor pattern was preserved and in patients presenting with severe or life threatening symptoms due to dystonia - dyskinesia (swallowing difficulties, permanent opisthotonos, painful muscle spasms).

Electroencephalogram, electroretinogram, visual and brainstem, somatosensory evoked responses were obtained. Motor evoked potentials were performed in elder children to identify pyramidal tract impairment. In order to exclude brain abnormalities contraindicating surgery (major cortical atrophy, severe periventricular leucomalacia especially met in cerebral palsy, basal ganglia and thalamic lesions), brain MR under general anesthesia was performed in all patients.

As shown in tables I and II, best results were obtained within the group of patients with DYT1 mutation (5; 18; 21; 24). The surgery of abnormal movements should intervene before the occurrence of skeletal deformities, which always diminish the outcome. Within the population of non-DYT1 dystonia and especially in secondary and hereditary dystonias, results are not so predictable. The improvement of dysarthria is variable and often very few influenced by DBS.

Stimulation's switch-off systematically causes the recurrence of symptoms within some hours or days. Whatever, in several patients we could see a long lasting preservation of the clinical improvement for several weeks without stimulation.

In the secondary dystonia group, the efficacy of stimulation is far more limited. We were led to propose it for very handicapped patients for whom other therapeutic strategies failed to improve dystonia, as already mentioned. The clinical and etiological heterogeneity among this group almost prevents any global interpretation of these results. In this group, a frequently associated hypertonia of pyramidal origin influences the dystonic component.

An important negative prognostic factor under stimulation is the existence of a permanent hypertonia at rest, whatever may be its origin. Although we are not yet able to predict the long-term prognosis, we observed an interesting improvement with dyskinesia-dystonia secondary to a perinatal anoxia (dyskinetic forms of cerebral palsy accounting for less than 10% of all forms CP) (25), PKAN and mitochondrial diseases treated by GPi stimulation. A constant control of pain associated with muscle spasms was obtained in patients suffering from secondary dystonia.

The progression of the causal disease is of critical importance for patient's prognosis.

Using this surgical method based on MRI alone (13-15), the associated morbidity is low. We didn't observe hemorrhage due to the intracerebral tracts as reported before in other series (our experience reaches 236 electrodes) (26). Secondary infection of the stimulation system remains the major complication of this technique and was observed in 4 patients. We summarize the complications observed in our population in table III.

The remarkable tolerance of the internal pulse generator must be also emphasized in children. We never observed any complication due to displacement with growth (loss of efficacy linked to the displacement of the electrode). As shown in figure 2 and 3, a residual length was enrolled around the battery and the electrode in order to compensate for growth in children and to provide some flexibility with movements in the system (Figure 2). Furthermore, it appears that growth does not interfere with stimulation, and the implantation of a single 90 cm extension compensates adequately for the growth of the child. We observed in two patients (1 child, 1 adult) an extension fracture due to adherences fixing the extension and limiting its mobility and flexibility.

The children's physical development (height, body weight) was followed as well as hormonal levels (Insulin-like Growth Factor-IGF1, Insulin-like Growth Factor Binding Protein 3-IGF-BP3, Estradiol, Testosterone, Folliculine Stimulating Hormone-FSH and Luteinizing Hormone-LH) in order to check puberty development.

## Conclusion

Despite cost and complexity of the follow-up, bilateral chronic electrical stimulation can be proposed as first line treatment for early onset primary generalized dystonia when pharmacologically intractable and also early considered in segmentary dystonia in adults and in well-selected cases of secondary dystonia. It is conservative, adaptable, reversible and well tolerated by the whole population. It must be applied soon, especially in primary dystonia before neuro-orthopaedic sequels occur. The complication rate remains low.

For secondary dystonia, pallidal stimulation can partially improve dystonic syndromes with important control of pain and swallowing difficulties.

## Bibliography

1. **Benabid AL, Pollak P, Louveau A, Henry S and de Rougemont J.** Combined (thalamotomy and stimulation) stereotactic surgery of the VIM thalamic nucleus for bilateral Parkinson disease. *Appl Neurophysiol* 50: 344-346, 1987.
2. **Gros C, Frerebeau P, Perez-Dominguez E, Bazin M and Privat JM.** Long term results of stereotaxic surgery for infantile dystonia and dyskinesia. *Neurochirurgia (Stuttg)* 19: 171-178., 1976.
3. **Iacono RP, Kuniyoshi SM, Lonser RR, Maeda G, Inae AM and Ashwal S.** Simultaneous bilateral pallidotomy for idiopathic dystonia musculorum deformans. *Pediatr Neurol* 14: 145-148., 1996.
4. **Benabid AL, Pollak P, Seigneuret E, Hoffmann D, Gay E and Perret J.** Chronic VIM thalamic stimulation in Parkinson's disease, essential tremor and extra-pyramidal dyskinesias. *Acta Neurochir Suppl (Wien)* 58: 39-44, 1993.
5. **Coubes P, Echenne B, Roubertie A, Vayssiere N, Tuffery S, Humbertclaude V, Cambonie G, Claustres M and**

- Frerebeau P.** [Treatment of early-onset generalized dystonia by chronic bilateral stimulation of the internal globus pallidus. Apropos of a case]. *Neurochirurgie* 45: 139-144., 1999.
6. **Fahn S.** Concept and classification of dystonia. *Adv Neurol* 50: 1-8, 1988.
  7. **Ozelius LJ, Hewett JW, Page CE, Bressman SB, Kramer PL, Shalish C, de Leon D, Brin MF, Raymond D, Corey DP, Fahn S, Risch NJ, Buckler AJ, Gusella JF and Breakefield XO.** The early-onset torsion dystonia gene (DYT1) encodes an ATP-binding protein. *Nat Genet* 17: 40-48., 1997.
  8. **Dwork AJ, Balmaceda C, Fazzini EA, MacCollin M, Cote L and Fahn S.** Dominantly inherited, early-onset parkinsonism: neuropathology of a new form. *Neurology* 43: 69-74, 1993.
  9. **Ishikawa A and Takahashi H.** Clinical and neuropathological aspects of autosomal recessive juvenile parkinsonism. *J Neurol* 245: P4-9, 1998.
  10. **Ford B, Greene PE, Louis ED, Bressman SB, Goodman RR, Brin MF, Sadiq S and Fahn S.** Intrathecal baclofen in the treatment of dystonia. *Adv Neurol* 78: 199-210, 1998.
  11. **Tsui JK, Fross RD, Calne S and Calne DB.** Local treatment of spasmodic torticollis with botulinum toxin. *Can J Neurol Sci* 14: 533-535, 1987.
  12. **Burke RE, Fahn S, Marsden CD, Bressman SB, Moskowitz C and Friedman J.** Validity and reliability of a rating scale for the primary torsion dystonias. *Neurology* 35: 73-77., 1985.
  13. **Vayssiere N, Hemm S, Zanca M, Picot MC, Bonafe A, Cif L, Frerebeau P and Coubes P.** Magnetic resonance imaging stereotactic target localization for deep brain stimulation in dystonic children. *J Neurosurg* 93: 784-790., 2000.
  14. **Vayssiere N, Hemm S, Cif L, Picot MC, Diakonova N, El Fertit H, Frerebeau P and Coubes P.** Comparison of atlas- and magnetic resonance imaging-based stereotactic targeting of the globus pallidus internus in the performance of deep brain stimulation for treatment of dystonia. *J Neurosurg* 96: 673-679., 2002.
  15. **Coubes P, Vayssiere N, El Fertit H, Hemm S, Cif L, Kienlen J, Bonafe A and Frerebeau P.** Deep brain stimulation for dystonia : surgical technique. *Stereotactic and Functional Neurosurgery* 78: 183-191, 2002.
  16. **Hemm S, Vayssiere N, Mennessier G, Cif L, Zanca M, Ravel P, Frerebeau P and Coubes P.** Evolution of brain impedance in dystonic patients treated by GPi electrical stimulation. *Neuromodulation* 7: 67-75, 2004.
  17. **Hemm S, Diakonova N, Mennessier G, Vayssiere N, Cif L and Coubes P.** Stimulated volume and energy consumption in improved dystonic patients treated by high frequency GPi stimulation. *Movement Disorders* 17: S302., 2002.
  18. **Coubes P, Roubertie A, Vayssiere N, Hemm S and Echenne B.** Treatment of DYT1-generalised dystonia by stimulation of the internal globus pallidus. *Lancet* 355: 2220-2221., 2000.
  19. **Coubes P, Cif L, Azais M, Roubertie A, Hemm S, Diakonova N, Vayssiere N, Monnier C, Hardouin E, Ganau A, Tuffery S, Claustre M and Echenne B.** Traitement des syndromes dystoniques par stimulation électrique chronique du globus pallidus interne. *Arch Pediatr* 9 Suppl 2: 84s-86s., 2002.
  20. **Cif L, Valente EM, Hemm S, Coubes C, Vayssiere N, Serrat S, Di Giorigio A and Coubes P.** Deep Brain Stimulation in Myoclonus-Dystonia Syndrome. *Mov Disord* 19: 724-727, 2004.
  21. **Coubes P, Cif L, Hemm S, Vayssiere N, Serrat S, Picot MC, Tuffery S, Claustres M, Echenne B and Frerebeau P.** Electrical stimulation of the internal globus pallidus in advanced primary generalized dystonia. *J Neurosurg* 101: 189-194, 2004.
  22. **Gasser T.** Inherited myoclonus-dystonia syndrome. *Adv Neurol* 78: 325-334, 1998.
  23. **Zimprich A, Grabowski M, Asmus F, Naumann M, Berg D, Bertram M, Scheidtmann K, Kern P, Winkelmann J, Muller-Myhsok B, Riedel L, Bauer M, Muller T, Castro M, Meitinger T, Strom TM and Gasser T.** Mutations in the gene encoding epsilon-sarcoglycan cause myoclonus-dystonia syndrome. *Nat Genet* 29: 66-69, 2001.
  24. **Roubertie A, Echenne B, Cif L, Vayssiere N, Hemm S and Coubes P.** Treatment of early-onset dystonia: update and a new perspective. *Childs Nerv Syst* 16: 334-340., 2000.
  25. **Lin JP.** The cerebral palsies: a physiological approach. *J Neurol Neurosurg Psychiatry* 74 Suppl 1: i23-29, 2003.
  26. **Starr PA, Vitek JL, DeLong M and Bakay RA.** Magnetic resonance imaging-based stereotactic localization of the globus pallidus and subthalamic nucleus. *Neurosurgery* 44: 303-314, 1999.

## FIGURE LEGENDS

Figure 1: Stereotactic MRI. A. Pre-operative planning. B. Post-operative MRI to control the final electrode position (black points = electrode artefacts).

Figure 2: Radiographic control of the implanted devices. A. Electrodes connected to the extensions. B. Neurostimulators with extension length reserve. Arrow indicates a extension fracture during sports.

| Motor score                         |          | 6 months after surgery             | 1 year after surgery               | 2 years after surgery              | >3 years after surgery             |
|-------------------------------------|----------|------------------------------------|------------------------------------|------------------------------------|------------------------------------|
|                                     |          | /120 (%) <sup>1</sup>              | /120 (%) <sup>1</sup>              | /120 (%) <sup>1</sup>              | /120 (%) <sup>1</sup>              |
| PGD <sup>2</sup> DYT1+ <sup>3</sup> | Children | 80±20<br><i>n</i> <sup>5</sup> =14 | 77±28<br><i>n</i> <sup>5</sup> =13 | 76±25<br><i>n</i> <sup>5</sup> =12 | 82±18<br><i>n</i> <sup>5</sup> =10 |
|                                     | Adults   | 75±17                              | 75±21                              | 70±16                              | 73±13                              |

|                            |          | $n^5=10$ | $n^5=8$  | $n^5=5$  | $n^5=2$ |
|----------------------------|----------|----------|----------|----------|---------|
| PGD <sup>2</sup> DYT1-     | Children | 72±15    | 74±15    | 66±26    | 72±21   |
|                            |          | $n^5=12$ | $n^5=12$ | $n^5=11$ | $n^5=9$ |
|                            | Adults   | 53±31    | 64±33    | 73±26    | 71±26   |
|                            |          | $n^5=19$ | $n^5=19$ | $n^5=16$ | $n^5=7$ |
| Cervico-axial dystonia     | Children | 77±0     | 93±0     | 93±12    | 100±10  |
|                            |          | $n^5=1$  | $n^5=1$  | $n^5=1$  | $n^5=1$ |
|                            | Adults   | 70±34    | 88±20    | 85±21    | 84±12   |
|                            |          | $n^5=7$  | $n^5=7$  | $n^5=7$  | $n^5=4$ |
| Post-anoxic cerebral palsy | Children | 31±8     | 37±6     | 45±0     | 51±0    |
|                            |          | $n^5=5$  | $n^5=2$  | $n^5=1$  | $n^5=1$ |
|                            | Adults   | 41±25    | 38±10    | 45±15    | 62±0    |
|                            |          | $n^5=5$  | $n^5=5$  | $n^5=3$  | $n^5=1$ |
| PKAN <sup>4</sup>          | Children | 51±29    | 59±25    | 22±5     | 33±13   |
|                            |          | $n^5=4$  | $n^5=4$  | $n^5=2$  | $n^5=2$ |
|                            | Adults   | 71±12    | 73±10    | 74±1     | 88±0    |
|                            |          | $n^5=2$  | $n^5=2$  | $n^5=2$  | $n^5=1$ |
| Mitochondrial disease      | Children | 27±17    | 46±30    | 25±10    | 42±6    |
|                            |          | $n^5=3$  | $n^5=2$  | $n^5=2$  | $n^5=2$ |

**Table II.** Motor scores (BMFDRS) of dystonic children treated by DBS.

Mean values ±SD. The values in brackets represent the mean improvement in percent. A reduction in the score indicates an improvement in function. BMFDRS denotes Burke-Marsden Fahn's Dystonia Rating Scale.

<sup>1</sup>The improvement in percent is calculated based on the maximal possible gain  $(\text{Score}_{\text{preop}} - \text{Score}_{\text{postop}}) / (\text{Score}_{\text{preop}})$ .

<sup>2</sup>Primary generalized dystonia

<sup>3</sup>DYT1 mutation

<sup>4</sup>Pantothenate kinase-associated neurodegeneration

<sup>5</sup>Number of patients

| Disability score                    |          | 6 months after surgery             | 1 year after surgery               | 2 years after surgery              | >3 years after surgery             |
|-------------------------------------|----------|------------------------------------|------------------------------------|------------------------------------|------------------------------------|
|                                     |          | /120 (%) <sup>1</sup>              | /120 (%) <sup>1</sup>              | /120 (%) <sup>1</sup>              | /120 (%) <sup>1</sup>              |
| PGD <sup>2</sup> DYT1+ <sup>3</sup> | Children | 58±39<br><i>n</i> <sup>5</sup> =14 | 62±39<br><i>n</i> <sup>5</sup> =13 | 63±27<br><i>n</i> <sup>5</sup> =12 | 80±14<br><i>n</i> <sup>5</sup> =10 |
|                                     | Adults   | 61±25<br><i>n</i> <sup>5</sup> =10 | 64±29<br><i>n</i> <sup>5</sup> =8  | 74±14<br><i>n</i> <sup>5</sup> =52 | 58±3<br><i>n</i> <sup>5</sup> =2   |
| PGD <sup>2</sup> DYT1-              | Children | 42±23<br><i>n</i> <sup>5</sup> =12 | 52±21<br><i>n</i> <sup>5</sup> =12 | 54±24<br><i>n</i> <sup>5</sup> =11 | 49±29<br><i>n</i> <sup>5</sup> =9  |
|                                     | Adults   | 35±34<br><i>n</i> <sup>5</sup> =19 | 52±31<br><i>n</i> <sup>5</sup> =19 | 67±30<br><i>n</i> <sup>5</sup> =16 | 58±36<br><i>n</i> <sup>5</sup> =7  |
| Cervico-axial dystonia              | Children | 100±0<br><i>n</i> <sup>5</sup> =1  | 92±0<br><i>n</i> <sup>5</sup> =1   | 92±0<br><i>n</i> <sup>5</sup> =1   | 100±0<br><i>n</i> <sup>5</sup> =1  |
|                                     | Adults   | 55±36<br><i>n</i> <sup>5</sup> =7  | 74±22<br><i>n</i> <sup>5</sup> =7  | 86±18<br><i>n</i> <sup>5</sup> =7  | 74±12<br><i>n</i> <sup>5</sup> =4  |
| Cerebral palsy                      | Children | 4±3<br><i>n</i> <sup>5</sup> =5    | 11±4<br><i>n</i> <sup>5</sup> =2   | 19±0<br><i>n</i> <sup>5</sup> =1   | 19±0<br><i>n</i> <sup>5</sup> =1   |
|                                     | Adults   | 21±22<br><i>n</i> <sup>5</sup> =5  | 28±21<br><i>n</i> <sup>5</sup> =5  | 17±12<br><i>n</i> <sup>5</sup> =3  | 27±0<br><i>n</i> <sup>5</sup> =1   |
| PKAN <sup>4</sup>                   | Children | 35±32<br><i>n</i> <sup>5</sup> =4  | 28±28<br><i>n</i> <sup>5</sup> =4  | 2±2<br><i>n</i> <sup>5</sup> =2    | 7±14<br><i>n</i> <sup>5</sup> =2   |
|                                     | Adults   | 31±20<br><i>n</i> <sup>5</sup> =2  | 43±10<br><i>n</i> <sup>5</sup> =2  | 62±7<br><i>n</i> <sup>5</sup> =2   | 65±0<br><i>n</i> <sup>5</sup> =1   |
| Mitochondrial disease               | Children | 8±5<br><i>n</i> <sup>5</sup> =3    | 10±3<br><i>n</i> <sup>5</sup> =2   | 11±3<br><i>n</i> <sup>5</sup> =2   | 8±1<br><i>n</i> <sup>5</sup> =2    |

**Table III.** Disability scores (BMFDRS) of dystonic children treated by DBS.

Mean values ±SD. The values in brackets represent the mean improvement in percent. A reduction in the score indicates an improvement in function. BMFDRS denotes Burke-Marsden Fahn's Dystonia Rating Scale.

<sup>1</sup>The improvement in percent is calculated based on the maximal possible gain (Score<sub>preop</sub>-Score<sub>postop</sub>)/(Score<sub>preop</sub>).

<sup>2</sup>Primary generalized dystonia

<sup>3</sup>DYT1 mutation

<sup>4</sup>Pantothenate kinase-associated neurodegeneration

<sup>5</sup>Number of patients

| Complications      | Number |
|--------------------|--------|
| Haemorrhage        | 0      |
| Infection          | 4      |
| Lead fracture      | 3      |
| Extension fracture | 3      |

**Table IV.**