# Dopamine D2 Receptor Imaging with Iodine-123-Iodobenzamide SPECT in Idiopathic Rotational Torticollis

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The cause of idiopathic rotational torticollis (IRT) is not completely understood to date. However, basal ganglia are believed to be involved in the pathophysiology of IRT. To elucidate this disorder further, the value of iodobenzamide (IBZM) SPECT was studied for the evaluation of striatal dopamine D2 receptors in these patients. **Methods:** Striatal dopamine D2 receptor density was assessed in 10 patients with IRT using $^{123}$I-IBZM SPECT. The images were interpreted by a nuclear medicine physician initially to determine IBZM binding within the striatum and the cerebellum and, secondly, interstriatal IBZM binding. The results were correlated with the clinical parameters of the patients and compared with the results obtained from normal controls. **Results:** No difference was found in average, specific striatal IBZM binding (basal ganglia/cerebellum ratio) between patients and controls. However, interstriatal analysis of IBZM binding revealed a significantly higher binding in the striatum contralateral to the direction of the torticollis ($p = 0.026$, by chi-square test). **Conclusion:** It was concluded that the striatal dopamine D2 receptor status is altered in patients with IRT.

**Key Words:** iodobenzamide; dopamine receptor; dystonia; idiopathic rotational torticollis; IBZM SPECT

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Dystonia is a syndrome characterized by sustained muscle contractions which frequently cause twisting and repetitive movements of the relative part of the body or abnormal postures (*1*). Prolonged abnormal cocontractions of agonist and antagonist muscles with additional recruitment of distant muscles characterize dystonia neurophysiologically. This pattern distinguishes dystonia from other movement disorders. Most cases belong to the group of adult-onset idiopathic focal dystonia. Within this group, cervical dystonia (CD) is one of the most prevalent types. Depending on the type of head deviation, patients with CD may show rotational torticollis, laterocollis, retrocollis or combinations thereof (Table 1). According to the ad hoc committee of the Dystonia Medical Research Fondation, dystonia is classified by the age of onset, cause and body distribution of the abnormal movement (Table 1). The exclusion of symptomatic dystonia justifies the nomination of idiopathic focal dystonia (IFD) and, in case of head rotation, idiopathic rotational torticollis (IRT).

The precise pathophysiology underlying idiopathic adult-onset dystonia remains unclear. CT and MRI are unable to detect consistent structural changes in patients with IFD (*2*), and postmortem examinations have not demonstrated consistent abnormalities in these patients (*3*). Focal lesions within the basal ganglia produce typical dystonia in patients with symptomatic dystonia; therefore, dystonia is attributed to abnormal basal ganglia function (*4*). PET and SPECT provide the opportunity to assess functional abnormalities of the dopaminergic system of patients with idiopathic dystonia in vivo (*5,6*). Blin et al. (*7*) found a positive correlation between the striatal dopamine D2 receptor density and the severity of the movement disorder in patients with tardive dyskinesia in whom dystonia is believed to be due to neuroleptic medication. PET studies provide evidence of metabolic abnormalities in the basal ganglia in idiopathic dystonia. In IRT, a breakdown in the normal relationship of glucose metabolism between the thalamus and the basal ganglia was found (*2*). It was postulated that this uncoupling might be related to dysfunction in thalamostriate or pallidothalamic projections.

Crossman and Sambrock (*8*) induced torticollis spasmodicus in the monkey by injecting hydroxydopamine into the striatum. In this experiment, it was observed that the relatively hyperactive (normal) striatum drives the head to the weaker contralateral side. All these data support the hypothesis that the basal ganglia are involved in the pathophysiology of CD.

Few data on the postsynaptic dopamine D2 receptor system in patients with CD have been published (*9–11*). In a recent study, Leenders et al. (*12*) found an asymmetric binding of $^{11}$C-N-methylspiperone to striatal D2 receptors in a series of six patients with focal dystonia (predominant-

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**TABLE 1**
Classification of Dystonia (*1*)

| | |
|---|---|
| Cause | Idiopathic |
| | Sporadic |
| | Familial |
| | Symptomatic |
| Age of onset | Childhood (0–12 yr) |
| | Adolescent (13–20 yr) |
| | Adult (> 20 yr) |
| Distribution | Focal |
| | Segmental |
| | Multifocal |
| | Generalized |
| | Hemidystonia |
| Clinical variants of idiopathic form | Classic torsion |
| | Paradoxic |
| | Myoclonic |
| | Diurnal |
| | Dopa-responsive |

ly rotational torticollis). A trend was found of higher striatal tracer uptake in the hemisphere contralateral to the direction of head rotation.

Iodine-123-IBZM has been shown to bind to dopamine D2 receptors with high affinity and specificity (*5*) and has been used in several human studies to evaluate the regional cerebral dopamine D2 receptor density in men using SPECT (*13–19*).

To establish whether the postsynaptic dopaminergic function is involved in the pathophysiology of IRT, $^{123}$I-IBZM SPECT was performed in 10 patients with this dystonic disorder.

## MATERIALS AND METHODS

### Patients and Controls

Ten patients (seven male and three female) who presented to the Movement Disorder Clinic of the Department of Neurology, Universitätsklinikum Rudolf Virchow with IRT were included in this study. The ages ranged from 32 to 59 yr (mean 43.8 yr, s.d. 11.3 yr). Nine patients had isolated IRT. One patient (P5) had additional graphospasm ipsilateral to the IRT.

All patients underwent detailed neurologic examinations by a senior neurologist (L.S.). The diagnoses were made on the basis of clinical findings and polyelectromyographic results. None of the patients had any other neurologic disorder.

In all patients, structural lesions within the basal ganglia had been excluded by MRI. The details are given in Table 2.

Eight appropriate control subjects (five male and three female), age range from 42 to 91 yr (mean 57.6 yr, s.d. 18.0 yr) were studied. Statistically, the mean age of patients and controls was not significantly different ($p = 0.06$). None of the control subjects had neuropsychiatric abnormalities or a family history of movement disorders. One control (C1) had suffered a cortical infarction in the left parietal lobe 1 yr ago.

All patients and controls were not receiving pharmacologic therapy for at least 1 wk prior to SPECT.

The examination of patients and healthy volunteers was approved by the local institutional authorities of the Rudolf Virchow Medical Center. Informed consent was obtained from each subject.

### Radiotracer

Indium-123-IBZM (S-(−)-N-[(1-ethyl-2-pyrrolidinyl)methyl]-2-hydroxy-3-iodo-6-methoxybenzamide, Dupont/Cygne, Eindhoven, The Netherlands), was labeled by a kit procedure developed by Kung et al. (*20*). The chemical purity was more than 98%, and a concentration of $^{125}$I of less than 0.5% was found. The specific

**TABLE 2**
Patient and Control Data and Results

| Subject no. | Sex | Age | Symptoms | IBZM BG/CB | IBZM $BG_{right}/BG_{left}$ | MRI | Δ% (See Equation 1) |
|---|---|---|---|---|---|---|---|
| P1 | M | 32 | RT to the right | 1.62 | 0.93 | Unremarkable | 8.4 |
| P2 | M | 46 | RT to the right | 1.76 | 0.98 | Unremarkable | 2.6 |
| P3 | M | 54 | RT to the left | 1.54 | 0.91 | Unremarkable | 11.8 |
| P4 | M | 35 | RT to the right | 1.54 | 0.93 | Unremarkable | 9.2 |
| P5 | M | 33 | RT to the right graphospasm | 1.57 | 1.00 | Unremarkable | 0.8 |
| P6 | F | 59 | RT to the left | 1.67 | 1.06 | Periventricular WML | 8.1 |
| P7 | M | 56 | RT to the left | 1.66 | 1.01 | Unremarkable | 0.7 |
| P8 | F | 34 | RT to the right | 1.71 | 0.94 | Unremarkable | 6.8 |
| P9 | F | 34 | RT to the left | 1.73 | 1.01 | Unremarkable | 0.7 |
| p10 | M | 55 | RT to the left | 1.60 | 1.06 | Unremarkable | 7.8 |
| C1 | M | 55 | Acute vision loss | 1.65 | 1.02 | Cortical infarction | 2.2 |
| C2 | F | 91 | Lumbago | 1.63 | 1.02 | Periventricular WML | 3.0 |
| C3 | M | 42 | Cervical myelopathy | 1.58 | 1.01 | Unremarkable | 0.8 |
| C4 | M | 42 | LDH | 1.53 | 0.97 | Unremarkable | 3.4 |
| C5 | M | 80 | Lumbago | 1.59 | 1.03 | Periventricular WML, mild atrophy | 2.4 |
| C6 | F | 50 | Lumbago | 1.64 | 0.97 | Unremarkable | 3.0 |
| C7 | M | 51 | Lumbago | 1.58 | 0.97 | Unremarkable | 4.0 |
| C8 | M | 50 | LDH | 1.41 | 1.00 | Unremarkable | 0.0 |

BG/CB = index of specific striatal IBZM binding, RT = rotational torticollis, LDH = lumbar disk herniation, WML = white matter lesion.

activity of the radiotracer was 2.4 × $10^5$ Ci/mmole (*5*). Because of the high specificity to dopamine D2 receptors, the accumulation of the tracer in the striatum is dominated by D2 receptor binding and can be used to demonstrate the distribution of these receptors in vivo.

### SPECT Study

An oral dose (300 mg) of sodium perchlorate was given to each subject 1 hr prior to the study to protect the thyroid gland from the uptake of free iodine. After accurate positioning of the patient with the head in the center of rotation, the camera rotated around to reduce the radius of rotation to a minimum. Positioning of patients with rotating torticollis represented a special challenge; therefore a special effort was made to keep the head in a stable position. The head was fixed with a tape band during acquisition.

Correction for head tilting was possible by the reconstruction algorithm (discussed later). A dose of 111 to 185 MBq (3–5 mCi) of sterile, pyrogene-free $^{123}$I-IBZM was injected as a bolus into an antecubital vein. SPECT studies were conducted with a single-head gamma camera connected to a dedicated computer system and a low-energy, high-resolution, parallel-hole collimator (APC 3, Elscint). During 360° rotation, 60 frames were acquired on a 64 × 64 matrix over approximately 60 min. The timing for SPECT was determined from the in vivo kinetic data reported by this group, which showed that 120-min postinjection specific striatal binding of IBZM is on a high steady-state level (*18*). Therefore, the tomographic acquisition was started 120 min postinjection in all subjects. After normalization for inhomogeneity, the center of rotation and physical decay of the tracer, the data were rearranged as transverse slices through a standard filtered back projection algorithm. Attenuation correction was not applied to the data because no algorithm corrects adequately for heterogeneous tissue-bone-air absorption, especially at the level of the nasopharynx and the ears.

A four-step algorithm (MSCBREOB4X, Medisoft, Witten, Germany) was applied to correct for abnormal head position because head tilting is common in patients with torticollis. First, transverse slices (perpendicular to the detector ring) were reconstructed with the option to correct the slice orientation for rotation. Second, on the basis of these images, the reconstruction algorithm generates a coronal slice (thickness 4 pixels) that allows the viewer to correct the images in case of a tilted position of the patient's head and to establish a vertical (paraaxial) plane perpendicular to the long axis of the head. Third, on the basis of these 30 paraaxial slices, a midsagittal slice (thickness 4 pixels) was generated to define the orbitomeatal line (OM line) in visual comparison to the MRI scans. Fourth, finally, 15 slices (thickness 2 pixels = 8.4 mm) parallel to the OM line and, therefore, anatomically identically oriented to the MRI scans, were generated. From these 15 slices (thickness 2 pixels = 8.4 mm), two adjacent slices with the highest striatal uptake were selected in visual accordance with the identically oriented T1-weighted MRI scans.

Two slices within the cerebellum were selected and summed to one slice for quantitative analysis. The cerebellar slices were automatically selected by the computer program at 10 mm above and parallel to the OM line. Concomitantly, two irregular regions of interest (ROIs) were defined from SPECT images and further checked by comparison with T1-weighted MRI scans aided by the human brain atlas proposed by Talairach et al. (*21*). Considering the added slice thickness of 16.8 mm, the total volume of the striatal ROI selected for quantification was approximately 9 ml. This volume corresponds to the neuroanatomic volume of the striatum (*22*). The size and position of the ROIs was kept the same for all subjects; all areas were drawn by the same reader (J.H.). The reader was blinded to any clinical information concerning the subjects under investigation. For quantification, the concentration of the tracer uptake was calculated by dividing the mean tracer uptake in the striatum by the uptake in the cerebellum (basal ganglia/cerebellum ratio [BG/CB ratio]). Assuming that nonspecific binding, affinity and access to the receptor are stable, the BG/CB can be considered a reliable index of striatal D2 receptor density (*23,24*).

| | | IBZM-grading | | |
|---|---|---|---|---|
| | $\chi^2$ | - 1 | + 1 | 0 |
| Clinical-grading | - 1 | 2 | 1 | 2 |
| | + 1 | 0 | 3 | 2 |
| | 0 | 0 | 0 | 8 |

$\chi^2$-test, p=0.026

**FIGURE 1.** Correlation of interstriatal $^{123}$I-IBZM binding and direction of head rotation in patients with IRT and in controls. Chi-square test proves statistical significance (p = 0.026). Clinical grading: grade −1 = head rotation to the left, grade +1 = head rotation to the right, grade 0 = control subjects. Grading of IBZM SPECT: grade −1 = striatal IBZM binding right > left (> 4.8%), grade +1 = striatal IBZM binding left > right (> 4.8%), grade 0 = striatal IBZM binding right = left.

In addition, interstriatal ratios (Δ%) were calculated according to Equation 1 (*28*):

$$\Delta\% = \frac{(BG_{right}/CB - BG_{left}/CB) \times 200}{(BG_{right}/CB + BG_{left}/CB)}.$$

To transform numerical data into categorical data, a clinical and a scintigraphic grading was performed according to the following criteria: grade +1 was assigned to head rotation to the right, grade −1 to head rotation to the left and grade 0 to controls. On scintigraphic studies, grade −1 was assigned to subjects with a significantly higher IBZM binding in the right striatum compared with the left striatum. Grade +1 was assigned to a higher binding in the left striatum, and grade 0 was assigned to symmetric striatal IBZM binding (Fig. 1).

The results obtained were then correlated with clinical findings.

### MRI Study

In all patients, MRI of the brain was performed on a 1.5-T Siemens Magnetom, Erlangen, Germany; transverse spin-echo, T1-, T2- and proton-density-weighted images parallel to the OM line were acquired. Evaluation was done with regard to lesions within the basal ganglia and the cerebellum (reference region) and regional or global brain atrophy.

### Data Analysis

Two-tailed Student's t-test for unpaired samples was applied to compare the two groups under investigation and to evaluate asymmetric striatal IBZM binding in patients with IRT. Data were transformed into categorical gradings according to preestablished criteria; the chi-square test was performed to evaluate whether the

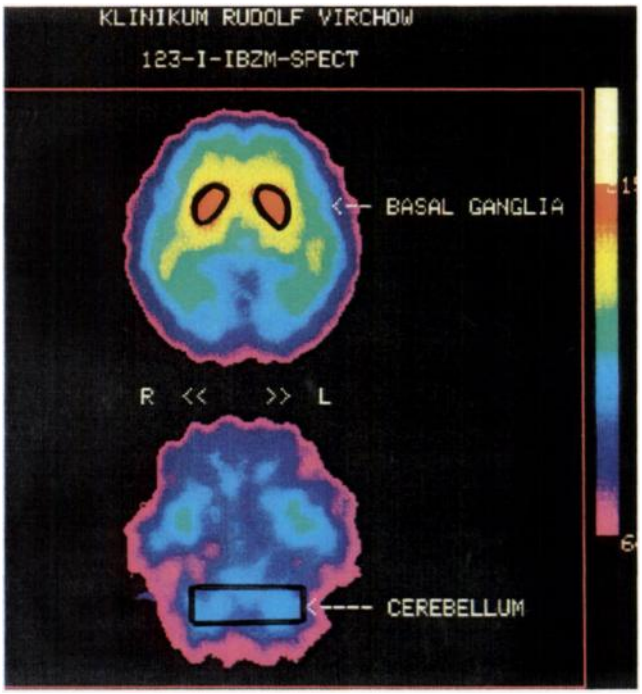


**FIGURE 2.** Results of $^{123}$I-IBZM SPECT in Control C6. Transverse slices with ROIs at the level of the basal ganglia (top) and at the level of the cerebellum (bottom). High symmetric binding of IBZM in the striatum. Low unspecific tracer binding in the cerebellum. BG/CB ratio = 1.64, Δ% = 3. Images are normalized to the total injected dose. The same color scale is applied as in Figure 4.

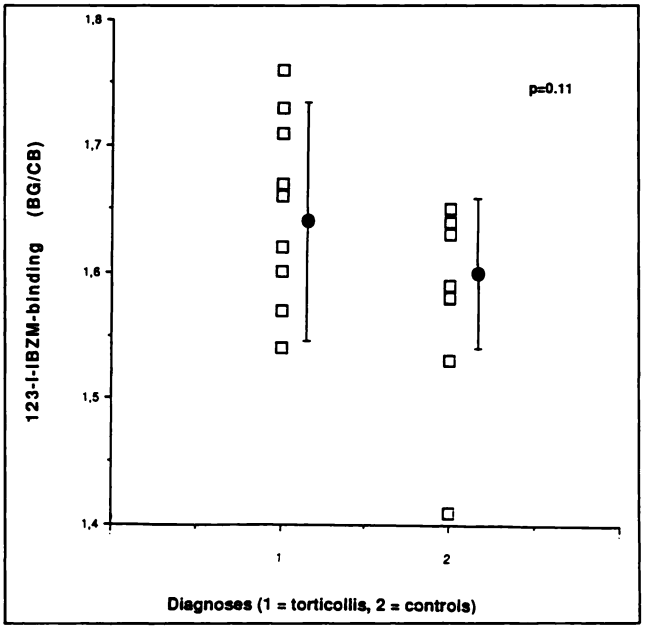


**FIGURE 3.** Specific striatal IBZM binding (mean BG/CB ratios) in patients with IRT and in controls (single results, □, and mean values, ●, ± s.d.).

two-parameter asymmetric binding and affected hemisphere were correlated. The correlation of the subject's age and the duration or severity of IRT and IBZM binding was tested by linear-regression analysis. For all tests, statistical significance was assumed at $p < 0.05$.

### Radiation Exposure

Whole-body radiation exposure at an injected dose of 111 to 185 MBq $^{123}$I-IBZM has been calculated to be 1.8 to 3.0 mSv, based on the biodistribution ascertained by Kung et al. (*20*) and the ICRP 26 (*38*).

## RESULTS

The specific dopamine D2 receptor binding of $^{123}$I-IBZM in the striatum compared with a reference region of non-dopaminergic brain tissue (cerebellum) is expressed as a ratio and is listed for each individual in Table 2.

### Control Subjects

In all control subjects, the highest uptake of $^{123}$I-IBZM was found within the basal ganglia. Frontal, temporal and cerebellar activity was significantly lower, reflecting predominantly nonspecific binding of the radiotracer (Fig. 2). The mean BG/CB ratio in controls was 1.59 (s.d. = 0.05).

No correlation of striatal IBZM binding with age was found ($r = 0.20$, $p = 0.64$). The mean interstriatal difference (see Equation 1) of IBZM binding Δ% in controls was 2.4% (s.d. = 1.4%). The range of normal interstriatal variation was defined as 0% to 4.8% (mean ± 2 s.d.).

### Patients

In patients with IRT, the highest dopamine D2 receptor binding of $^{123}$I-IBZM was found within the basal ganglia. The frontal, temporal and cerebellar activity were significantly lower, reflecting predominantly nonspecific fixation

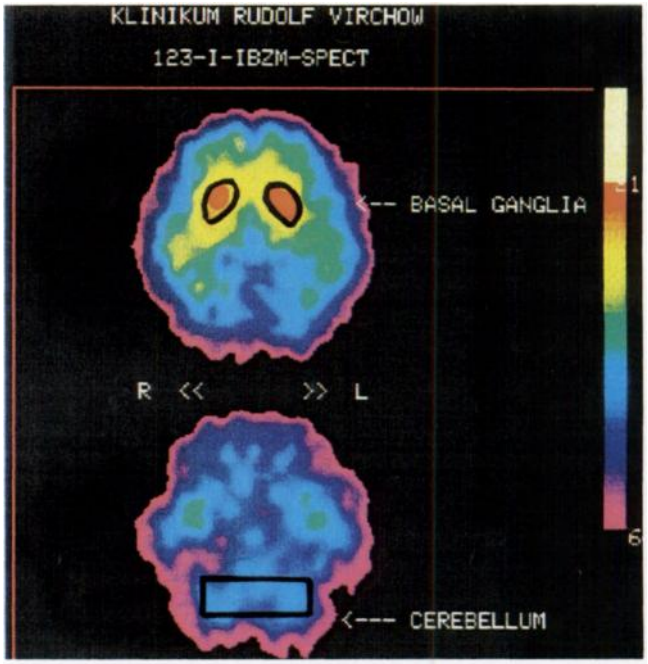


**FIGURE 4.** Results of $^{123}$I-IBZM SPECT in Patient P10, with the head rotated to the left. Transverse slices with ROIs at the level of the basal ganglia (top) and at the level of the cerebellum (bottom). Higher binding of IBZM in the right striatum compared with the left side. Low unspecific tracer binding in the cerebellum. BG/CB ratio = 1.60, Δ% = 7.8. Images are normalized to the total injected dose. The same color scale is applied as in Figure 2.

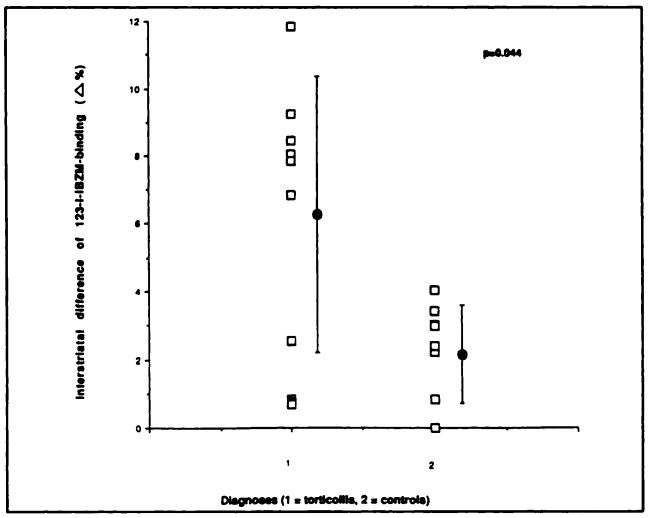


**FIGURE 5.** Interstriatal difference on $^{123}$I-IBZM binding and Δ% (see Equation 1) in patients with IRT and in controls (single results, □, and mean values, ●, ± s.d.).

of the radiotracer. The mean BG/CB ratio was 1.64 (s.d. = 0.08) and was not significantly different from that of the controls studied (p = 0.11, Fig. 3).

No correlation was found between the IBZM binding and age (r = 0.03, p = 0.95) or the duration of IRT (r = 0.37, p = 0.30). The mean interstriatal difference (see Equation 1) of IBZM binding Δ% was 5.7% (s.d. = 4.1%) and was significantly higher than in the controls (p = 0.044) (Figs. 4 and 5).

When the asymmetric striatal IBZM binding was correlated with the direction of heat rotation, according to the predefined clinical grading system, in 5 of 10 patients, a significantly higher binding was found in the striatum contralateral to the direction of the torticollis (p = 0.026, chi-square test, Figs. 1 and 4). In 4 of 10 patients, no significant interstriatal difference of IBZM binding was noted. In one patient (P3), lower binding was found in the striatum contralateral to the direction of the torticollis.

MRI of the brain did not reveal any focal lesions within the basal ganglia or the cerebellum in patients or controls. One patient (P6) and one control (C5) showed periventricular white matter lesions but not within the basal ganglia or the cerebellum. One control patient (C5) had mild brain atrophy. One control subject (C1) had focal atrophy within the right parietal lobe that was consistent with an old brain infarct.

## DISCUSSION

The mechanism underlying IRT is not completely understood to date. However, it is widely accepted that the basal ganglia are involved in the pathophysiology of IRT (*4–8*). Turning behavior and head rotation, in particular, have been studied in various animal models. Hassler and Dieckmann (*25*) suggested that the head rotates to a direction contralateral to the abnormal hemisphere because the affected putamen does not inhibit tonic contraversive pallidal activity. Foltz et al. (*26*) in the late 1950s produced ipsiversive head rotation by making large lesions in the mesencephalic tegmentum in nonhuman primates. Crossman and Sambrock (*8*) showed that selective lesions in the dopaminergic pathway induced ipsiversive rotation of the head in monkeys. This phenomenon is abolished by low-dose apomorphine and exacerbated by amphetamine; high-dose apomorphine produced contraversive turning. However, the significance and the validity of animal experiments has been questioned because an interspecies variation might be responsible for different brainstem control mechanisms of posture (*27*). PET studies of the regional glucose metabolism in IRT did not completely explain the complex pathophysiology in humans (*28*).

From recent work, there is some evidence that the dopaminergic system is involved in the pathophysiology of IRT (*3,12,28*). In this study, $^{123}$I-IBZM SPECT was used to evaluate the dopamine D2 receptor density in patients with IRT and in controls. It has been demonstrated that BG/CB ratios of the tracer binding positively correlates with the striatal D2 receptor density ($B_{max}$)(*23,29*). This index has been shown to be independent of blood flow under secular equilibrium, as demonstrated by previous PET studies using $^{11}$C-raclopride (*30*).

In this study, in patients with IRT the average specific striatal dopamine D2 receptor binding was not significantly different from the control group. However, patients exhibited a more asymmetric binding of the radioligand to the receptor compared with controls. In 5 of 10 patients, a higher receptor binding was found in the striatum contralateral to the direction of head rotation. In one patient, however, an inverse binding characteristic was found. In the remaining four patients, no significant asymmetry of striatal receptor binding was detected. This finding of a higher dopamine D2 receptor density in the striatum contralateral to the direction of head rotation was statistically significant for this patient group. These findings were consistent with recent investigations published by Leenders et al. (*12*) and Brücke et al. (*11*) who also found a tendency of a higher D2 receptor binding in the striatum contralateral to the direction of head rotation in a small group of patients with CD. Such a unilateral dopamine receptor deficit would be consistent with the animal data of Crossman and Sambrock (*8*) that show that the relatively hyperactive normal striatum drives the head to the contralateral side. The primary striatal abnormality leading to a D2 binding asymmetry remains, however, unclear. It could reflect presynaptic dopaminergic changes leading to secondary D2 upregulation or a primary postsynaptic deficit leading to reduced D2 receptor density. In one patient (P3), a higher receptor binding was found in the striatum ipsilateral to the direction of head rotation. This finding could explain the observation that, not infrequently, a bilateral affliction of muscle groups is observed in IRT, and the head rotation can be the result of complex bilateral muscle activity (*31*). In the remaining four patients, no significant asymmetry of the receptor binding was found. This phenomenon might

indicate different stages of IRT. However, no correlation was found between the duration of the disease and receptor binding.

PET studies that measured the presynaptic $^{18}$F-fluorodopa uptake in patients with dystonia indicated changes in dopa metabolism that lead to a reduced endogenous dopamine pool rather than diminished nerve terminals arising from the nigrostriatal projections (*10*). These presynaptic changes could be responsible for the postsynaptic phenomena observed in the present study. A similar mechanism was proposed in patients with untreated Parkinson's disease and with schizophrenia in whom a decrease of nigrostriatal dopaminergic neurons and a decreased endogenous dopamine concentration might lead to an upregulation of striatal dopamine receptor sensitivity (*32,33*). However, these results remain controversial (*18,34*). Because of the small number of patients, the results of the present study yield preliminary semiquantitative data on striatal dopaminergic function in IRT. These findings must be interpreted with caution, and several problems concerning the selection of the patients, the study design and the method have to be discussed.

First, the clinical spectrum of diseases with dystonic movement disorders is wide, and different underlying mechanisms could be responsible for the symptoms of the subjects described in this report. To select a clinically homogeneous group of patients with IRT, stringent diagnostic criteria were defined to exclude secondary dystonic states (*1,7*). Therefore, MRI of the brain was performed in all individuals. In all cases, the MRI study was unremarkable with regard to lesions within the basal ganglia or the cerebellum. However, some uncertainty remains whether or not secondary dystonia should have been considered in some patients.

Second, even though a designated algorithm was applied to the data to correct for mispositioning of the head, a minimal effect of tilting, which could influence the data, cannot be entirely excluded. In addition, the current spatial resolution of the imaging system is somewhat crude. Therefore, the authors were unable to discriminate between the putamen and head of the caudate nucleus. If the pathologic changes are localized in areas of the striatum that are smaller than the spatial resolution, SPECT might not detect them. However, IBZM SPECT has been useful in several clinical studies of movement disorders (*13–19*).

Third, several types of drugs are known to influence the IBZM binding. Therefore, medical treatment was discontinued for a certain period prior to SPECT. Long-term effects of several central nervous system active drugs on D2 receptor binding, however, can not be entirely excluded. Endogenous dopamine receptor ligands could also compete with IBZM for receptor binding. A unilateral low endogenous pool of dopamine could increase the number of free D2 receptors and thus mask the reduced IBZM binding (*23*). This phenomenon could explain the normal IBZM binding that was found in some patients with ITS. Furthermore, this might also explain why a correlation was not observed with age or duration of the disease in this study.

The age-dependent variation of D2 receptors has been studied with controversial results in healthy volunteers (*35–37*). The most severe decrease of D2 receptors with age has been shown to take place within the first 30 to 40 yr of age (*35,36*), although in elderly persons no further significant decrease has been described. This might be the reason why no correlation with age was found in this relatively older population of patients and controls.

## CONCLUSION

It was concluded from this study that the striatal dopaminergic system and, particularly, the postsynaptic striatal dopamine D2 receptors may be involved in idiopathic dystonic diseases, such as IRT. This finding provides further support for the hypothesis of an involvement of the basal ganglia in the pathophysiology of idiopathic dystonia.

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