

Drug-use patterns and severe adverse events with disease-modifying drugs in patients with multiple sclerosis: a cohort study based on German claims data

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Purpose: To describe drug-use patterns in patients with multiple sclerosis (MS) using disease-modifying drugs (DMDs) and to estimate the incidence of severe adverse events (SAEs) of treatment.

Methods: We conducted a cohort study within the German Pharmacoepidemiological Research Database between January 1, 2006 and December 31, 2013. MS patients on DMDs were described in terms of clinical characteristics and drug-use patterns. Next, we assessed the incidence of AEs in new users of fingolimod, natalizumab, glatiramer acetate, and IFN β_{1a} .

Results: Among approximately 11 million insured members of German Statutory Health Insurance, the DMD-user cohort comprised 15,377 patients with MS, with a mean age of 39.6 years and 68% females. Nearly half of all DMD users had a diagnosis of depression, with prevalence ranging from 40.1% for IFN β_{1a} to 62.3% for immunoglobulins. The overall rate of MS relapses per patient and year was 0.34 (95% CI 0.33–0.34). During an average follow-up of 1,650 days, the majority (42.4%) of MS patients were adherent to DMD treatment (“continuous single users”), followed by patients interrupting treatment (39.5%, “interrupters”). Switch of DMD treatment (11.9%) was less frequent, and only 5.6% discontinued treatment. Treatment discontinuation was most common in users of natalizumab (7.5%) and IFN β_{1b} (7.0%). The most frequent SAE was hospitalization for depression, followed by any infectious disease and any malignancy. The incidence rate of all adverse events did not significantly differ across different DMDs.

Conclusion: Treatment discontinuation with DMDs and treatment switch were rare. Causes of rather frequent DMD-treatment interruption have to be evaluated in further studies based on primary data collection. Active safety monitoring of new DMDs based on claims data requires large data sets to detect rare AEs and availability of up-to-date data.

Keywords: multiple sclerosis, drug-use patterns, adverse events, claims data, disease-modifying drugs

Introduction

Multiple sclerosis (MS) is a chronic inflammatory disease of the central nervous system associated with several comorbidities, contributing considerably to impairment and disability in early adulthood.¹

Increase has been reported for Europe and also for Germany, leading to a growing burden of health care-related costs for the German health-care system.^{2,3}

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No curative treatment for MS exists, and disease-modifying drugs (DMDs) are the standard treatment to reduce the number and severity of relapses and to decelerate disease progression. IFN β and glatiramer acetate were the first licensed DMDs, but several new drugs have been approved in the past decade.⁴ Interferons and glatiramer acetate are considered first-line treatment in patients with clinical isolated syndrome not fulfilling criteria for MS and patients with mild–moderate relapsing–remitting MS.⁵ Other DMDs, such as natalizumab, fingolimod, and alemtuzumab, are recommended for patients with insufficient response to first-line treatments or those with high disease activity.^{6–10}

Although the newer drugs are highly efficacious, use of these DMDs requires careful patient monitoring, due to a higher risk of severe adverse events.^{4,5} For instance, natalizumab and fingolimod have been associated with progressive multifocal leukoencephalopathy (PML),^{11,12} a demyelinating and potentially fatal disease of the central nervous system.¹³ Data from disease registries are crucial to monitor drug use and safety profiles of novel treatments in MS in the real-world setting.¹⁴ Since the implementation of registries is very cost-intensive and time-consuming, claims data represent another valuable data source to complement data from disease registries.^{15,16}

Data on drug-use patterns of DMDs in clinical practice and the incidence of serious adverse events from Germany is scarce. Available evidence is mostly restricted to studies of individual drugs^{17–23} or is almost outdated and does not cover newer drugs, such as natalizumab or fingolimod.²⁴ Therefore, the objective of this study was to describe the clinical characteristics and drug-use patterns of MS patients using DMDs and to estimate the incidence of severe adverse events in DMD users.

Methods

Data source

The data source for this study was the German Pharmacoepidemiological Research Database (GePaRD), which has been described in detail elsewhere.^{25,26} GePaRD is based on claims data from four statutory health-insurance providers in Germany, and currently includes information on more than 20 million persons who have been insured with one of the participating providers since 2004 or later. Per data year, there is information on approximately 17% of the general population, and all geographical regions of Germany are represented. For this study, we used a subsample of three German statutory health insurances (SHI), including data of

approximately 11 million individuals to analyze clinical characteristics and drug-use patterns of DMDs among those with MS. Adverse events were investigated based on the complete database.

In brief, GePaRD contains demographic characteristics, including age and sex of the insured persons, data on hospitalizations, ambulatory care, and outpatient drug prescriptions. Via linkage to a pharmaceutical reference database, further information on Anatomical Therapeutic Chemical classification code, defined daily dose (DDD), and packing size can be obtained for each drug prescription. Drugs purchased over the counter and in-hospital medications are not included, with a few exceptions of expensive drug treatments administered in hospital (eg, alemtuzumab, rituximab, and natalizumab). All diagnoses in hospital and ambulatory care are coded according to the German Modification of the ICD10 (ICD10-GM).

Study population

We conducted a cohort study to investigate the clinical characteristics and drug-use patterns of DMDs in patients with MS and to estimate the incidence rate of severe adverse events in new users of fingolimod, natalizumab, glatiramer acetate, and IFN β_{1a} . The study period started on January 1, 2006 and ended on December 31, 2013 (depending on the availability of data of the individual SHI). Data from January 1, 2004 through December 31, 2005 were used only for assessment of exclusion criteria, comorbidity, and comedications.

In the first step, we selected a cohort to investigate clinical characteristics and drug-use patterns of DMD users with MS (DMD-user cohort). Individuals were eligible for the DMD-user cohort, if they had had at least one outpatient dispensation or in-hospital administration of a DMD, continuous insurance of at least 2 years during the study period (baseline period), at least one main hospital-discharge diagnosis or one confirmed outpatient diagnosis of MS (ICD10-GM G35) within the 365 days preceding the DMD dispensation, and valid information on age and sex. Cohort entry was defined as the date of the first outpatient DMD dispensation or in-hospital administration, if all inclusion criteria were fulfilled. Patients were then followed until SHI disenrollment, death, or December 31, 2013, whichever occurred first.

For assessment of adverse events, a subgroup of new users of fingolimod, natalizumab, glatiramer acetate, and

IFN β_{1a} (new-user subcohort) was selected from the DMD cohort and enriched with additional data from a fourth SHI. Patients were eligible for analysis only if they had not had an outpatient dispensation or in-hospital administration of a DMD in the baseline period. Follow-up accrued from the date of the first outpatient DMD dispensation or in-hospital administration until SHI disenrollment, death, treatment discontinuation of the DMD, the end of the study period, or occurrence of an adverse event, whichever occurred first.

Exposure definition

As exposure, outpatient dispensations of glatiramer acetate (L03AX13), IFN β_{1a} (L03AB07), IFN β_{1b} (L03AB08), alemtuzumab (L01XC04, L04AA34), fingolimod (L04AA27), natalizumab (L04AA23), azathioprine (L04AX01), immunoglobulins (J06BA01, J06BA02, L04AA03, L04AA04), mitoxantrone (L01DB07), methotrexate (L01BA01, L04AX03), rituximab (L01XC02), and cyclophosphamide (L01AA01) and in-hospital administration of alemtuzumab, rituximab, and natalizumab were assessed. Alemtuzumab, methotrexate, and rituximab were not approved for MS during the study period, but were assessed as potential rescue therapy. As data were available only until 2013, drugs approved later, such as teriflunomide, dimethyl fumarate, and cladribine, could not be examined. All patients in the DMD-user cohort and the new-user subcohort were classified as users of a specific DMD based on the prescription leading to cohort entry (index DMD). Patients receiving two or more drugs at the date of cohort entry were considered a separate group. All patients in the DMD-user cohort were also categorized as prevalent or new users.

Since GePaRD does not provide the prescribed duration of each drug dispensation, the supply had to be estimated to construct DMD-treatment episodes. This was done based on the DDD for each outpatient dispensation. For in-hospital administrations, we estimated a supply of 365 days for alemtuzumab, 30 days for natalizumab, and 182 days for rituximab. Additional supply of 100% was added to calculate the end of supply for each dispensation and account for dosing variations and poor adherence. To be considered for the same drug-specific treatment episode, the calculated end of supply (\times DDDs + 100%) of a previous prescription had to overlap the dispensation date of the following prescription of the index DMD. Otherwise, the calculated end of supply of the last dispensation was considered the end of treatment.

Clinical characteristics

At baseline, comorbidities and comedications were assessed based on main hospital-discharge diagnoses and confirmed outpatient diagnoses. Detailed definitions of all variables are available in Table S1 and S2. In addition to drugs used for chronic diseases and to treat symptoms of MS, comedication also included outpatient dispensations or in-hospital administration of DMDs and treatment of relapses with parenterally administered methylprednisolone. For the latter, we calculated the number of prescribed DDDs per day during follow-up as a proxy for the severity of a relapse. In addition, MS patients receiving in-hospital therapeutic plasmapheresis and immunoadsorption for treatment-refractory relapses were identified.

The number of relapses per person-year of follow-up under treatment with each DMD was calculated based on an outpatient dispensation of parenteral methylprednisolone, hospitalization with a main discharge diagnosis of MS with relapse (ICD10-GM codes G35.01, G35.11, G35.21, and G35.31), or hospitalization with a claim for in-hospital therapeutic plasmapheresis. To be considered a new relapse, a minimum gap of at least 30 days was required between all these events described. The number of hospitalizations and the number of different dispensed drugs were assessed as indicators of overall health status within the 2 years prior to cohort entry.

Data analysis

The DMD cohort was categorized with respect to sex, age at cohort entry, follow-up time, comorbidities, and comedication. In addition, the percentage of new users was calculated.

After construction of DMD-specific treatment episodes, the number of different individual DMDs used during cohort times and all DMD users were categorized into one of the following mutually exclusive groups regarding their drug-use patterns: 1) discontinuation of any DMD, ie, no outpatient dispensation or in-hospital administration of any DMD for 182 days after the end of the index treatment episode; 2) switch to another DMD, ie, if a treatment episode with another DMD started within the dispensation date of the last dispensation of the index DMD and 182 days after the end of the index treatment episode; 3) multiple use of two or more DMDs, ie, if the patient received a dispensation of another DMD before or on the same day of the last dispensation within the index

treatment episode or if the patient received a dispensation of two or more DMDs at cohort entry; 4) interruption of treatment with the index DMD, ie, if the start date of a new treatment episode with the index DMD was within 182 days after the index treatment episode; and 5) continuous single use of the index DMD, ie, if the index DMD was used continuously until the end of follow-up.

In the new-user subcohort, the crude incidence rate of each adverse event per 100,000 person-years was calculated with corresponding 95% CIs. Adverse events were ascertained based on main hospital-discharge diagnoses after cohort entry, and included cardiac arrhythmias and conduction disorders (excluding atrial fibrillation), myocardial infarction, stroke, eye disorders, PML, any infectious disease, lymphoma, any malignancy, anxiety disorders, depression, and all-cause mortality (Tables S1). Patients with a previous outpatient or inpatient diagnosis of the outcome in the baseline period were excluded. For eye disorders, PML, any infectious disease, anxiety disorders, and depression-only patients with hospitalization for the event in the baseline period were excluded. In a sensitivity analysis, patients were not censored at treatment discontinuation of the DMD for the calculation of incidence rates to account for possible latency periods and delayed occurrence of some outcomes (eg, PML and malignancies).

Ethics

In Germany, the utilization of health-insurance data for scientific research is regulated by the Code of Social Law. All health-insurance providers involved and the German Federal (Social) Insurance Office and Senator for Science, Health, and Consumer Protection in Bremen approved the use of GePaRD data for this study. Informed consent for studies based on GePaRD is not required by law, and according to the Ethics Committee of the University of Bremen, these studies are exempt from institutional review-board review.

Results

The DMD-user cohort comprised 15,377 patients with MS. The most frequent index drug was IFN β_{1a} (41.4%) followed by glatiramer acetate (26.6%), IFN β_{1b} (18.8%), azathioprine (6.3%), natalizumab (2.9%), immunoglobulins (1.7%), and fingolimod (1.4%) (Table 1). Results for users of methotrexate (n=52), rituximab (n=47), mitoxantrone (n=35),

cyclophosphamide (n=15), alemtuzumab (n=0), and patients with more than one DMD at cohort entry are not further displayed, due to the low number of events. The mean follow-up was 1,650 days (SD 996 days), and 1.7% of all DMD users died during follow-up. Mean follow-up duration differed among the different DMD users, with the longest for azathioprine (1993.3 days) and the shortest for fingolimod (510.6 days; Table S3).

Demographic and clinical characteristics

Table 1 displays demographic and clinical characteristics of DMD users with MS. More information is available in Table S3. The mean age of the DMD-user cohort was 39.6 years (SD 10.5 years) and did not substantially differ among the different DMD groups: it ranged from 36.3 years (SD 9.5 years) for natalizumab to 40.6 years (SD 10.7) for immunoglobulins. Only MS patients treated with azathioprine were substantially older, with a mean age of 48.2 years (SD 11.3 years). In total, 68% were female, and the female:male ratio was approximately 2:1, except for immunoglobulins and fingolimod: 84.8% and 74.5% for females, respectively.

With regard to comorbidities, other autoimmune disorders, such as rheumatic arthritis/collagen vascular disease (5.8%) and inflammatory bowel diseases (10.7%) were frequently observed. Inflammatory bowel diseases were most common in users of azathioprine (14.8%), followed by natalizumab users (12.4%). Nearly half of all included patients with MS had a diagnosis of depression, with a prevalence range of 40.1% in IFN β_{1a} users to 62.3% in those receiving immunoglobulin treatment. Complications of MS, such as muscle spasticity, fatigue, and bladder dysfunction, were most often observed in MS patients treated with fingolimod, followed by azathioprine and natalizumab. The mean rate of MS relapses per patient per year was 0.34 (95% CI 0.33–0.34) and was similar for all DMDs, except for patients receiving natalizumab, with 0.50 (95% CI 0.46–0.53) and immunoglobulins, with 0.46 (95% CI 0.42–0.50).

With regard to comedication, opioids were most prescribed in users of immunoglobulins (14.0%) and those on azathioprine (13.7%). In contrast, nonsteroidal anti-inflammatory drug (NSAID) use was most often seen in users of fingolimod (50.5%). MS-specific treatment with fampridin, as well as plasmapheresis and immunoadsorption, was rarely used overall and most common in users of natalizumab and fingolimod. Similarly, the proportion of DMD users previously treated with methylprednisolone

Table 1 Demographic and clinical characteristics of DMD users with MS

	Total	IFN β_{1a}	Glatiramer acetate	IFN β_{1b}	Azathioprine	Natalizumab	Immunoglobulins	Fingolimod
Number of MS patients	15,377	6372	4088	2885	966	442	257	208
Mean age at cohort entry (SD)	39.6 (10.5)	38.4 (10.1)	38.9 (9.4)	40.3 (10.7)	48.2 (11.3)	36.3 (9.5)	40.6 (11.5)	38.9 (10.2)
Sex (%)								
Male	31.6	31.8	29.1	34.2	35.8	33.7	15.2	25.5
Female	68.4	68.2	70.9	65.8	64.2	66.3	84.8	74.5
Comorbidities and complications (%)								
Myocardial infarction	0.3	0.2	0.2	0.3	0.5	0.5	0.4	0.0
Cardiac arrhythmias or conduction disorders	6.4	6.1	6.2	7.0	7.9	5.2	8.2	6.7
Stroke	1.2	1.0	0.9	1.8	2.0	2.0	1.2	1.0
Rheumatic arthritis/collagen vascular disease	5.8	5.1	5.7	4.5	11.9	3.6	9.3	3.4
Inflammatory bowel disease	10.7	10.2	11.1	9.8	14.8	12.4	11.3	9.6
Depression	44.1	40.1	48.7	40.9	48.7	51.4	62.3	54.3
Anxiety disorder	11.0	9.9	13.6	9.9	9.5	11.1	17.1	10.6
Hyperthyroidism/hypothyroidism	10.5	10.2	11.3	9.8	11.0	10.0	11.7	7.2
Cancer (except non-melanoma skin cancer)	4.1	3.4	4.1	3.9	8.2	2.3	8.2	3.4
Eye disorders	15.3	14.9	14.7	15.3	20.6	13.1	15.6	12.5
Alopecia	3.6	3.6	3.8	3.3	3.5	3.8	5.1	3.4
Athralgia	7.0	6.6	7.6	6.7	6.9	7.5	7.4	9.1
Muscle spasticity	10.6	9.3	9.7	11.0	15.7	15.4	10.5	23.1
Fatigue	13.9	13.3	15.2	13.7	11.4	15.6	15.6	18.3
Bladder dysfunction	16.1	13.2	14.8	16.3	29.0	20.8	22.2	31.7
Sexual dysfunction	2.7	2.3	2.8	2.8	4.5	4.1	1.6	2.4
Bowel dysfunction	4.2	3.6	3.7	3.8	8.3	5.9	8.6	8.2
Relapses per patient year (95%-CI)	0.34 (0.33–0.34)	0.32 (0.31–0.33)	0.33 (0.32–0.34)	0.35 (0.34–0.36)	0.34 (0.33–0.36)	0.50 (0.46–0.53)	0.46 (0.42–0.50)	0.38 (0.31–0.46)
Comedications and other treatments (%)								
Opioids	8.5	7.5	8.0	8.0	13.7	11.8	14.0	10.6
Antiepileptic drugs	10.4	8.5	10.1	9.3	18.5	17.0	16.7	16.8
Anti-dementia drugs	0.8	0.5	0.6	0.8	2.2	0.5	1.2	0.00
Nonsteroidal anti-inflammatory drugs	43.6	46.3	38.6	46.5	38.3	43.4	35.8	50.5
Muscle relaxants	16.3	13.5	14.9	17.9	28.7	24.2	16.0	23.1
Antidepressants	23.5	19.3	27.5	22.1	30.7	33.5	27.6	29.8
Anxiolytics	6.7	5.8	7.7	5.8	9.1	8.1	9.7	7.7

(Continued)

Table 1 (Continued).

	Total	IFN β_{1a}	Glatiramer acetate	IFN β_{1b}	Azathioprine	Natalizumab	Immunoglobulins	Fingolimod
Hypnotics and sedatives	10.5	9.5	11.5	8.6	11.8	18.3	13.2	16.8
Drugs for urinary frequency or incontinence	7.0	5.5	6.4	7.1	13.8	10.6	7.8	13.0
Fampridin	0.8	0.5	0.7	0.5	0.8	3.6	1.6	9.6
Plasmapheresis	0.9	0.7	0.5	0.8	0.8	5.0	0.4	5.3
Immunadsorption	0.2	0.1	0.1	0.3	0.4	0.9	0.8	1.9
Methylprednisolone	27.1	27.5	26.8	26.0	19.0	42.1	30.7	37.0
Median dispensed DDDs of methylprednisolone per day (Q1; Q3)	0.21 (0.10; 0.42)	0.21 (0.10; 0.42)	0.19 (0.10; 0.39)	0.21 (0.10; 0.42)	0.17 (0.09; 0.38)	0.28 (0.13; 0.57)	0.21 (0.10; 0.53)	0.42 (0.30; 1.05)

Abbreviations: CI, confidence interval; DDD, defined daily dose; DMD, disease-modifying drug; MS, multiple sclerosis; Q1, 1st quartile; Q3, 3rd quartile; SD, standard deviation.

and the median number of DDDs dispensed during follow-up was substantially higher for users of natalizumab and fingolimod compared to other DMDs.

DMD-use patterns

Nearly half of all DMD users with MS were new users, ie, they had not received any DMD prescription in the 2 years before cohort entry (Table 2). The highest proportion of new users was found for glatiramer acetate (52.3%) and the lowest for immunoglobulins (32.3%) and azathioprine (29.2%); 41% of natalizumab and 51.3% of fingolimod users did not receive any DMD prescription in the 2 years before treatment initiation. Overall, only 5.0% were treated with two or more DMDs before cohort entry, while this was more often seen in users of fingolimod (22.6%) and natalizumab (20.6%).

A large proportion of MS patients was adherent to DMD treatment during follow-up (continuous single users, 42.4%), followed by the patient group interrupting treatment with the index DMD for >182 days (interrupters). Switch of DMD treatment was less frequent (11.9%), and only 5.6% of all DMD users discontinued treatment. For individual DMDs, treatment discontinuation was most common in users of natalizumab (7.5%) and IFN β_{1b} (7.0%). Similarly, treatment switch was most often observed in users of natalizumab and IFN β_{1b} (15.4% and 18.3%, respectively). Most MS patients switched to glatiramer acetate (2.9%), followed by IFN β_{1a} (2.8%) and natalizumab (2.6%).

Incidence of adverse events

The cohort for analysis of adverse events comprised 9,045 new users, of whom 5,124 were new users of IFN β_{1a} (56.7%), 3,467 of glatiramer acetate (38.3%), 324 of natalizumab (3.6%), and 130 of fingolimod (1.4%). In general, the number of observed adverse events under current treatment was low for all DMDs, especially for natalizumab and fingolimod (Table 3). The most frequent adverse event among new users all four DMDs combined was hospitalization for depression, with 54 cases (0.6%), followed by any infectious disease, with 41 cases (0.5%) and any malignancy, with 28 cases (0.3%). The incidence rate of all adverse events did not significantly differ across different DMDs. In the sensitivity analysis without censoring at treatment discontinuation or switch, the number of adverse events was slightly higher. The incidence of hospitalization for any infectious disease was more than tripled for natalizumab, with 1,541.5 per 100,000 person-years (95%

Table 2 DMD-use patterns in patients with MS

	Total	IFN β_{1a}	Glatiramer acetate	IFN β_{1b}	Azathioprine	Natalizumab	Immunoglobulins	Fingolimod
Number of MS patients	15,377	6372	4088	2885	966	442	257	208
Different DMD used before cohort entry (%)								
0 ("new user")	48.1	49.5	52.3	47.5	29.2	41.2	32.3	51.0
1	46.8	47.1	42.5	48.6	65.4	38.2	57.6	26.0
2	4.7	3.2	4.9	3.7	5.1	18.3	8.6	22.1
3	0.3	0.2	0.3	0.2	0.3	2.3	1.6	0.5
4+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Different DMDs used during follow-up (%)								
1	76.0	77.3	76.6	70.9	82.1	68.6	63.4	91.3
2	18.7	17.5	18.4	22.5	13.3	26.0	26.8	7.7
3	4.5	4.4	4.2	5.3	3.7	4.5	7.0	0.5
4+	0.9	0.8	0.8	1.2	0.9	0.9	2.7	0.5
DMD user status during follow-up (%)								
Discontinuation	5.6	4.2	6.3	7.0	6.2	7.5	5.1	1.4
Continuous single users	42.4	37.0	47.7	51.2	28.2	43.7	13.2	76.4
Multiple users	0.6	0.5	0.6	0.7	1.0	0.2	0.0	0.0
Interrupters	39.5	48.6	32.3	22.9	59.5	33.3	76.7	15.4
Switchers	11.9	9.7	13.1	18.3	5.1	15.4	5.1	6.7
Switch to (%)								
Glatiramer acetate	2.9	3.5	0.0	6.5	1.0	3.4	0.8	1.0
IFN β_{1a}	2.8	0.0	5.6	5.6	1.9	3.2	1.6	0.5
IFN β_{1b}	1.0	0.9	2.1	0.0	0.6	0.7	0.8	0.5
Fingolimod	1.9	1.9	2.1	2.0	0.2	6.8	0.0	0.0
Natalizumab	2.6	2.8	2.7	3.4	0.5	0.0	0.0	3.8
Azathioprine	0.3	0.3	0.3	0.4	0.0	0.2	0.0	0.5
Immunoglobulins	0.2	0.2	0.2	0.2	0.2	0.7	0.0	0.0
Other	0.2	0.1	0.1	0.1	0.6	0.5	0.2	0.5

Abbreviations: DMD, disease-modifying drug; MS, multiple sclerosis.

Table 3 Incidence rate of severe adverse events in new users of selected DMDs

Outcome	Overall								Sensitivity analysis							
	n cohort	n cases	Person time	IR	IR Lower 95% CI	IR Upper 95% CI	n cases	Person time	IR	IR Lower 95% CI	IR Upper 95% CI	n cases	Person time	IR	IR Lower 95% CI	IR Upper 95% CI
All-cause mortality																
IFN β_{1a}	5124	3	5535.4	54.2	11.2	158.4	25	16,547	151.1	97.8	223.0					
Glatiramer acetate	3467	4	5916.0	67.6	18.4	173.1	19	11,247	168.9	101.71	263.8					
Natalizumab	324	0	534.1				5	1237	404.2	131.25	943.3					
Fingolimod	130	1	113.7	879.5	22.3	4900.1	1	169	592.5	15.00	3300.1					
Stroke																
IFN β_{1a}	5049	5	5471.8	91.4	29.7	213.3	17	16,264	104.5	60.89	167.4					
Glatiramer acetate	3417	3	5837.3	51.4	10.6	150.2	7	11,101	63.1	25.35	129.9					
Natalizumab	314	0	525.0				2	1204	166.2	20.13	600.3					
Fingolimod	128	0	112.3				0	164								
PML																
IFN β_{1a}	5124	0	5535.4				2	16,546	12.1	1.5	43.7					
Glatiramer acetate	3467	0	5916.0				0	11,247								
Natalizumab	324	1	534.0	187.3	4.7	1043.4	2	1234	162.0	19.6	585.3					
Fingolimod	130	0	113.7				0	169								
Any infectious disease																
IFN β_{1a}	5071	14	5498.0	254.7	139.2	427.3	54	16,305	331.2	248.8	432.1					
Glatiramer acetate	3429	22	5857.0	375.6	235.4	568.7	45	11,051	407.2	297.0	544.8					
Natalizumab	317	5	519.2	963.1	312.7	2247.6	18	1168	1541.5	913.6	2436.2					
Fingolimod	128	0	111.0				0	166								
Myocardial infarction																
IFN β_{1a}	5116	3	5530.0	54.3	11.2	158.5	10	16,495	60.6	29.1	111.5					
Glatiramer acetate	3463	2	5904.7	33.9	4.1	122.4	6	11,230	53.4	19.6	116.3					
Natalizumab	324	0	534.1				1	1236	80.9	2.1	450.8					
Fingolimod	130	0	113.7				0	169								
Lymphoma																
IFN β_{1a}	5113	2	5519.6	36.2	4.4	130.9	4	16,499	24.2	6.6	62.1					
Glatiramer acetate	3458	0	5896.2				0	11,208								
Natalizumab	323	0	532.2				1	1234	81.1	2.1	451.6					
Fingolimod	130	0	113.7				0	169								

(Continued)

Table 3 (Continued).

Outcome	Overall					Sensitivity analysis					
	n cohort	n cases	Person time	IR	IR Lower 95% CI	IR Upper 95% CI	n cases	Person time	IR	IR Lower 95% CI	IR Upper 95% CI
Eye disorders											
IFN β _{1a}	5109	7	5501.6	127.2	51.2	262.2	19	16,448	115.5	69.6	180.4
Glatiramer acetate	3452	2	5896.4	33.9	4.1	122.5	7	11,187	62.6	25.2	128.9
Natalizumab	322	0	532.4				2	1228	162.8	19.7	588.2
Fingolimod	130	0	113.7				0	168.79			
Depression											
IFN β _{1a}	5080	15	5490.1	273.2	152.9	450.6	76	16,213	468.8	369.3	586.7
Glatiramer acetate	3369	36	5758.4	625.2	437.9	865.5	89	10,748	828.0	665.0	1019.0
Natalizumab	323	3	531.3	564.7	116.4	1650.1	7	1217	575.1	231.2	1184.9
Fingolimod	129	0	113.5				0	169			
Cardiac arrhythmias											
IFN β _{1a}	4775	3	5202.6	57.7	11.9	168.5	16	15,432	103.7	59.3	168.4
Glatiramer acetate	3209	3	5513.9	54.4	11.2	159.0	8	10,457	76.5	33.0	150.8
Natalizumab	303	0	497.4				0	1154			
Fingolimod	121	0	103.2				0	155			
Any malignancy											
IFN β _{1a}	4935	16	5302.3	301.8	172.5	490.0	44	15,840	277.8	201.8	372.9
Glatiramer acetate	3310	9	5621.9	160.1	73.2	303.9	30	10,638	282.0	190.3	402.6
Natalizumab	316	2	526.6	379.8	46.0	1371.9	5	1195	418.5	135.9	976.6
Fingolimod	126	1	111.6	895.9	22.7	4991.5	1	161	619.9	15.7	3453.6
Anxiety disorders											
IFN β _{1a}	5119	0	5530.7				12	16,489	72.8	37.6	127.1
Glatiramer acetate	3456	2	5904.8	33.9	4.1	122.6	3	11,203	26.8	5.5	78.3
Natalizumab	323	1	530.8	188.4	4.8	1049.7	3	1228	244.3	50.4	713.9
Fingolimod	130	0	113.7				0	169			

Abbreviations: CI, confidence interval; DMD, disease-modifying drug; IR, incidence rate; MS, multiple sclerosis; PML, progressive multifocal leukoencephalopathy.

CI 913.6–2,436.2) compared to IFN β_{1a} , with 331.2 (95% CI 248.8–432.1) and glatiramer acetate, with 407.2 (95% CI 297.0–544.8). In addition, the incidence of depression was nearly doubled for glatiramer acetate, with 828.0 (95% CI 665.0–1,019.0) compared to IFN β_{1a} , with 468.8 (95% CI 369.3–586.7).

Discussion

In this large cohort study based on German claims data, we have described the clinical characteristics and drug-use patterns of 15,377 MS patients using DMDs and estimated the incidence of severe adverse events in new DMD users.

Among the most frequently observed comorbidities were two psychiatric conditions: depression and anxiety disorders. Variations for some comorbidities, eg, bladder dysfunction or muscle spasticity, indicated that natalizumab, fingolimod, and immunoglobulins were used primarily as second-line treatment in patients with higher disease activity. Users of azathioprine with MS had the highest prevalence of comorbidities. Although this may at least partly be attributed to a higher mean age, our results show that azathioprine is still frequently used as an alternative drug in patients with higher disease activity or in cases of nonresponse to other DMDs. In addition, the high prevalence of inflammatory bowel disease and rheumatic arthritis/collagen vascular disease indicates frequent use of azathioprine in MS patients with coexisting autoimmune disease.^{27,28} In comparison to other studies, most comorbidities in our study had higher prevalence than the aggregated results of a meta-analysis by Marrie et al.²⁹ However, the results varied widely in that study depending on region, study population, and study design, and none assessed comorbidities based on drug level.

The overall rate of MS relapses per patient per year in our study was similar for all DMD users, with the exception of patients receiving natalizumab or immunoglobulins. The overall rate in our study is consistent with the results Tremlett et al,³⁰ who followed relapsing–remitting MS patients and found that slightly lower overall annual relapse rates depended strongly on age and sex. For MS patients treated with natalizumab and fingolimod, lower annual rates^{31–33} than in our study have been reported. However, these studies differed from ours in terms of follow-up duration and the proportion of new DMD users.

The most frequently prescribed comedications were NSAIDs and antidepressants, which is similar to findings of a Dutch health care claim-data study.³⁴ In our study, NSAIDs were most often coprescribed in patients using fingolimod or interferons. The use of NSAIDs in these

patients may be indicated for symptomatic treatment of common side effects, such as headache and back pain,^{35–37} or for mitigation of flulike side effects associated with the use of interferons.^{38,39} Users of natalizumab and fingolimod more frequently receive plasmapheresis, immunoadsorption, methylprednisolone, and fampridine, again emphasizing their use in patients with higher disease activity.

Drug-use patterns for DMDs

Almost half of all DMD users with MS were new users without any DMD prescription in the 2 years before cohort entry. Although natalizumab and fingolimod are considered second-line treatment, roughly half of all users for the two did not receive any DMD prescription in the 2 years before treatment initiation. It remains unclear if these patients were treated first-line due to high disease activity or if pharmacological treatment was interrupted for more than 2 years, eg, due to nonresponse or remission of MS, and then restarted on a more efficacious DMD. Natalizumab and fingolimod revealed the highest proportion of patients previously treated with two or more DMDs, ie, second- or third-line treatment.

In general, the number of MS patients with treatment discontinuation was low, despite the long maximum observation period of 8 years. Nevertheless, we observed that <50% of the MS patients were treated continuously with the same DMD over time. In another German study based on claims data between 2001 and 2009, similar results were found, with only 30%–40% of MS patients adherent to DMDs within 2 years after initiation.²⁴ Interestingly, we found that nearly 40% of MS patients interrupted treatment with that drug for >6 months. Potential reasons for treatment interruptions may include adverse events or the wish for children/pregnancies, and should be evaluated in further studies. The proportion of switchers to other DMDs was relatively low, and highest for IFN β_{1b} and natalizumab. Again, reasons for DMD switch, eg, adverse events or nonresponse, should be investigated in further studies.

Incidence rate of adverse events

The primary analysis of severe adverse events in new users of fingolimod, natalizumab, glatiramer acetate, and IFN β_{1a} did not reveal significant differences in incidence rates among individual DMDs. In general, the observed absolute number of adverse events was low, especially for those with low background incidence in the overall population, such as lymphoma, stroke or PML, as well as for natalizumab and

fingolimod, as newer DMDs with small samples. This finding is of particular clinical relevance, since discontinuation of the latter drugs due to safety concerns has been associated with severe rebound effects that have to be balanced against the possible risk of severe adverse events.^{40,41} In the sensitivity analysis without censoring at treatment discontinuation or switch, the absolute number of adverse events was slightly higher. We found a more than tripled increased incidence of hospitalization for any infectious disease in users of natalizumab compared to users of IFN β_{1a} and glatiramer acetate. Increased risk for infection-related physician claims under natalizumab treatment has also been reported in a study based on administrative data from Canada, in which no increased risk was observed for first-line therapies, such as interferons or glatiramer acetate.⁴² The hospitalization rate for depression was nearly doubled for glatiramer acetate compared to IFN β_{1a} . Although the prevalence of depression in users of glatiramer acetate was slightly higher in the baseline period and our risk estimates were unadjusted, this observation requires evaluation. In previous studies, only IFN β has been associated with depression in patients with MS.^{43,44}

Strengths and limitations

The main strength of this study is the size and representativeness of GePaRD, which covers approximately 20 million insured members of SHI throughout Germany per data year. Determination of exposure based on pharmacy dispensing data is considered the gold standard, as recall bias can be ruled out, even for patients suffering from severe diseases, such as MS and information is regarded as precise in time, product (including brand), and dose.⁴⁵ As the DMDs examined are available on prescription only, ascertainment of exposure is assumed to be complete for most of the drugs.

A limitation of this study is that inpatient treatment with DMDs in GePaRD can be assessed only for natalizumab, rituximab, and alemtuzumab. If patients are hospitalized for longer periods receiving in-hospital DMD treatment, this might result in underestimation of exposure and biased drug-use patterns. Another limitation is that rituximab, alemtuzumab, cyclophosphamide, and mitoxantrone are compounding drugs that were partially reimbursed via a generic central pharmaceutical number during the study period. This did not allow a distinction among individual drugs, ie, exposure to these drugs will additionally have been underestimated. Further, GePaRD contains information on all outpatient drug dispensations; however, information on prescribed

daily doses cannot be directly ascertained. Therefore, we used an algorithm to estimate the duration of treatment to allow for dosage variation and possible nonadherence. As our study did not include a review of individual patient files to confirm the occurrence of outcomes, which is generally not feasible in GePaRD for data-protection reasons, case validation was not possible and misclassification of MS and adverse events cannot be ruled out. For this reason, only-mainhospital-discharge diagnoses were used for outcome definitions, which were assumed to provide the most valid information. Misclassification of MS cases is assumed to be rare, since our case definition required a diagnosis accompanied by an MS-specific treatment. As a general limitation, data were available only until 2013, ie, the number of users and severe adverse events of novel DMDs, such as natalizumab, and fingolimod was low and recently approved drugs, such as teriflunomide, dimethyl fumarate, and cladribine could not be examined.

Conclusion

Our study suggests a high burden of comorbidities in MS patients using DMDs, especially with respect to psychiatric and autoimmune diseases. Treatment discontinuation with DMDs and treatment switch were rare, but only 42% received continuous DMD treatment. Reasons for the unexpected high frequency of DMD-treatment interruption have to be evaluated in further studies. Active safety monitoring of new DMDs based on claims data requires large data sets to detect rare adverse events, such as PML, and availability of up-to-date data.

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Disclosure

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Supplementary materials

Table S1 Definition of comorbidities and outcomes

Entity of Disease	Diagnoses (ICD-10-GM)
Myocardial infarction	I21x, I22x
Other coronary heart disease	I20x, I23x-I25x
Congestive heart failure and cardiomyopathy	I099, I110, I130, I132, I255, I42x, I43x, I50x, I97I
Hemophagocytic syndrome	D76I
Arterioventricular block/bradycardia	I440-I443, R00I
Cardiac arrhythmias and conduction disorders	I44x, I45x, I48x, I460, I469, I47x-I49x, R000, R00I, R008, T82I, Z450, Z950
Hypertension	I10x-I13x, I15x
Stroke	I60x-I64
Cerebrovascular disease	G45x, G46x, H340, I65x-I69x
Chronic pulmonary disease	J40x-J47x, J60x-J67x, J684, J70I, J703
Rheumatic arthritis/collagen vascular disease	L940, L94I, L942, M05x, M06x, M08x, MI20, MI23, M30x, M310-M313, M32x-M35x, M45x, M46I, M468, M469
Inflammatory bowel disease	K50x-K52x
Mild liver disease	K700, K70I-K703, K709, K713-K715, K717, K73x, K74x, K760, K762-K764, K768, K769, Z944
Moderate/severe liver disease	I850, I864, I982, K704, K71I, K72I, K729, K765-K767
Renal disease	I120, I13I, N032, N033, N034, N035, N036, N037, N052, N053, N054, N055, N056, N057, N18x, N19x, N250, Z49x, Z940, Z992
Epilepsy	G40x, G41x,
Migraine	G43x
Depression	F204, F313-F315, F32x, F33x, F34I, F412, F432
Anxiety disorders	F41x
Diabetes	E10x-E14x
Hyperthyroidism/Hypothyroidism	E00x-E03x, E05x, E890
Lymphoma	C81x-C85x
Any malignancy	C00x-C97x
Blood dyscrasias	D59x, D60x-D64x, D693-D696, D70x, D72x
Weight loss or weight gain	R634, R635
Alcohol abuse	F10x, G62I, I426, K292, K70x, T51x, Z502
Drug abuse	F11x-F16x, F18x, F19x,
Eye disorders	H25x, H26x, H35x, H40x, H42x, H532
Alopecia	L63x-L65x
Arthralgia, muscle spasticity	M255
Muscle spasticity other neurological symptoms	R25x-R27x
Urinary tract infection	N390
HIV/AIDS	B20-B24x
Hepatitis B or C	B16x, B17I, B180-B182

(Continued)

Table S1 (Continued).

Entity of Disease	Diagnoses (ICD-10-GM)
Herpetic infections	B00x, B02x
Progressive multifocal leukoencephalopathy	A812
Mycoses	B35x-B49x
Pneumonia	J100, J110, J12x-J16x, J18x, J851
Tuberculosis	A15x-A19x
Other infectious diseases	A00x-B99x
Pancreatitis	K85x, K860, K861
Fatigue	F480, R53
Bladder dysfunction	N31x, N328, N393, N394, R32, R33, R391
Sexual dysfunction	F522, N484
Bowel dysfunction	K590-K592, R15

Table S2 Definition of comedication

Drug class	ATC Code	OPS Code
Insulin	A10A	
Antidiabetic drugs	A10B	
Antithrombotic drugs	B01A	
Anti-arrhythmic drugs	C01B	
Antihypertensive drugs	C02	
Glucocorticoids	H02AB (excl. H02AB04)	
Methylprednisolone (parenteral)	H02AB04	
Opioids	N02A	
Antiepileptic drugs	N03	
Anti-dementia drugs	N06D	
Nonsteroidal anti-inflammatory drugs	M01A	
Muscle relaxants	M03	
Antidepressants	N06A	
Anxiolytics	N05B	
Hypnotics and sedatives	N05C	
Drugs for urinary frequency and incontinence	G04BD	
Drugs used in erectile dysfunction	G04BE	
Fampridin	N07XX07	
Other interventions	ATC Code	OPS Code
Plasmapheresis		8820x
Immunoadsorption		8821x

Table S3 Demographic and clinical characteristics of DMD users with MS

	Total	IFNβ _{1a}	Glatiramer acetate	IFNβ _{1b}	Azathioprine	Natalizumab	Immunoglobulins	Fingolimod
Number of MS patients	15,377	6372	4088	2885	966	442	257	208
Mean cohort time in days (SD)	1650.5 (995.8)	1641.2 (998.9)	1624.0 (980.3)	1719.1 (993.1)	1993.3 (961.2)	1259.5 (796.0)	1882.0 (1029.3)	510.6 (327.2)
Type of cohort entry (%)								
Outpatient	99.4	100	100	100	100	88.0	100	100
Inpatient	0.6	0	0	0	0	12.0	0	0
Year of cohort exit (%)								
2006	0.7	0.8	0.5	0.9	0.8	0.00	0.8	0
2007	1.7	1.7	1.2	1.6	4.6	0.00	1.6	0
2008	1.5	1.6	1.2	2.1	2.3	0.9	0.8	0
2009	1.8	1.7	1.6	1.8	2.5	2.0	2.3	0
2010	0.7	0.5	0.9	0.8	1.3	0.5	1.2	0
2011	1.8	2.0	1.6	1.5	1.9	1.6	2.7	0.5
2012	2.4	2.5	1.7	2.2	6.2	2.0	2.3	1.0
2013	89.4	89.2	91.3	89.3	80.4	93.0	88.3	98.6
Type of cohort exit (%)								
Death	1.7	1.1	0.7	1.6	8.4	1.1	4.7	0.5
Interruption of insurance	7.1	7.5	6.8	7.8	5.1	6.6	6.2	1.0
End of study period	91.2	91.3	92.5	90.6	86.5	92.3	89.1	98.6
Mean number of hospitalizations before cohort entry (SD)	2.0 (1.7)	1.7 (1.3)	2.0 (1.6)	1.9 (1.5)	2.8 (2.5)	3.2 (3.3)	2.3 (2.0)	2.7 (2.5)
Comorbidities and complications (%)								
Coronary heart disease	2.1	1.7	1.5	2.5	5.1	2.3	4.3	1.4
Heart failure/cardiomyopathy	1.0	0.7	0.8	0.9	2.8	0.9	2.3	2.4
Hemophagocytic syndrome	0	0	0	0	0	0	0	0
Arterioventricular block/bradycardia	0.4	0.4	0.4	0.3	0.4	0	0.4	0.5

(Continued)

Table S3 (Continued).

	Total	IFNβ _{1a}	Glatiramer acetate	IFNβ _{1b}	Azathioprine	Natalizumab	Immunoglobulins	Fingolimod
Hypertension	14.1	13.4	12.4	15.2	23.5	7.7	16.3	19.2
Cerebrovascular disease	2.7	2.6	2.0	2.7	6.6	1.4	3.9	1.4
Chronic pulmonary diseases	20.9	20.7	21.5	20.9	18.2	20.8	24.9	22.6
Mild liver disease	5.1	4.8	4.2	5.9	8.7	5.0	2.7	6.3
Moderate/severe liver disease	0.1	0	0	0.0	0.1	0.2	1.2	0
Renal disease	0.8	0.5	0.9	0.8	1.8	0	0	2.4
Epilepsy	2.4	1.9	2.7	2.2	4.1	2.7	1.6	5.8
Migraine	9.6	9.8	10.4	9.1	6.7	8.8	8.2	12.0
Diabetes	3.9	3.2	3.4	4.4	7.6	3.8	4.3	2.4
Lymphoma	0.2	0.1	0.2	0.1	0.2	0.5	1.2	0
Blood dyscrasias	5.3	4.7	5.0	5.2	8.7	6.3	10.5	5.8
Weight loss or weight gain	1.5	1.4	1.7	1.5	1.6	1.4	2.3	1.9
Alcohol abuse	1.0	0.8	1.3	1.0	0.9	0.5	1.6	1.4
Drug abuse	0.7	0.5	0.7	0.6	1.3	1.1	1.6	0.5
Urinary tract infection	12.2	10.9	11.0	12.2	18.2	15.6	19.8	16.3
AIDS/HIV	0.2	0.2	0.2	0.1	0.3	0	0.8	0
Hepatitis B or C	0.2	0.2	0.3	0.1	0.2	0	0.4	0.5
Herpetic infections	3.8	3.5	3.4	4.1	6.1	2.9	7.4	4.3
Progressive multifocal leukoencephalopathy	0	0	0	0	0	0	0.4	0
Mycoses	15.7	14.8	16.5	14.7	17.8	16.7	24.1	13.0
Pneumonia	1.6	1.5	1.3	1.4	2.5	1.4	5.1	1.9
Tuberculosis	0.2	0.2	0.1	0.2	0.2	0	0.4	0.5
Other infectious diseases	40.6	39.6	41.7	39.4	40.8	41.9	52.9	44.2
Pancreatitis	0.3	0.2	0.2	0.4	1.1	0.5	0.4	0
Median number of different drugs used (Q1;Q3)	6 (4;10)	6 (4;9)	6 (4;10)	6 (4;10)	9 (5;14)	8 (5;12)	8 (5;14)	8 (5;11)
Median number of different DM used before cohort entry (Q1;Q3)	1 (1;1)	1 (1;1)	1 (1;1)	1 (1;1)	1 (1;1)	1 (1;2)	1 (1;1)	1 (1;2)

(Continued)

Table S3 (Continued).

	Total	IFN β_{1a}	Glatiramer acetate	IFN β_{1b}	Azathioprine	Natalizumab	Immunoglobulins	Fingolimod
Comedications and other treatments (%)								
Insulin	1.2	0.9	1.2	1.3	2.1	2.7	0.4	0
Antidiabetic drugs	1.1	0.8	1.0	1.5	2.9	1.4	0.4	1.4
Antithrombotic drug	8.4	7.9	7.7	7.2	13.5	12.4	14.8	12.0
Anti-arrhythmic drug	0.1	0.1	0.1	0.2	0.1	0.2	0.4	0
Antihypertensive drug	0.6	0.5	0.3	0.8	1.3	0	0.8	1.0
Glucocorticoids	35.2	34.4	35.4	33.7	41.8	38.2	31.5	34.6

Abbreviations: DMD, disease modifying drug; MS, multiple sclerosis.

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