

Methotrexate and relative risk of dementia amongst patients with Rheumatoid Arthritis: a multi-national multi-database case-control study

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Abstract

Inflammatory processes have been shown to play a role in dementia. To understand this role we selected two anti-inflammatory drugs (methotrexate and sulfasalazine) to study their association with dementia risk. **METHODS** A retrospective matched case-control study, of patients over 50 with rheumatoid arthritis (486 dementia cases and 641 controls) were identified from electronic health records in the United Kingdom, Spain, Denmark and the Netherlands. Conditional logistic regression models were fitted to estimate risk of dementia. **RESULTS** Prior methotrexate use was associated with dementia (OR: 0.71 95% CI 0.52-0.98). Methotrexate use was strongest with therapy longer than 4 years (odds ratio: 0.37 95% CI 0.17-0.79). Sulfasalazine use was not associated with dementia (odds ratio: 0.88 95% CI 0.57-1.37). **CONCLUSIONS** Further studies are still required to clarify the relationship between prior methotrexate use and duration as well as biological treatments with dementia risk.

Background

Dementia is one of the largest unmet medical needs, and with growing numbers of older people in a majority of countries worldwide, it is set to become an increasing burden on health services and economies [1]. Despite considerable progress in the understanding of the pathological lesions associated with the diseases causing the commonest forms of dementia – Alzheimer’s disease (AD), vascular dementia, dementia with Lewy bodies and fronto-temporal dementia - this has not resulted in therapeutic progress, with multiple trials of compounds designed for disease modification failing, often at great cost [2]. Whilst part of the failure of such trials might be that they have largely been conducted in patients with established disease, possibly too late for therapeutic benefit, there is an increasing realization that it is likely forms of dementia are part of a complex set of pathological processes [3]. Understanding these causal pathways, and in particular understanding their timing in relation to the onset of dementia, has become a pressing task in order to progress a novel approach to therapeutic development.

One of the processes that has come under intensive investigation in recent years has been that of inflammation [4–6]. In the analysis of large scale genome wide association studies, inflammatory pathways such as complement signalling were consistently identified as altering susceptibility to disease [7,8]. Post-mortem studies reflect this association with inflammation, as microglial and astrocyte numbers are increased and associated with pathological lesions in disease [9]. However, such genetic and pathological studies are unable to distinguish between cause and effect, and it might be that an inflammatory reaction is part of the defence mechanism or is contributing to disease progression [10].

An alternative approach to understanding the direction and timing of effect of inflammation in relation to dementia is to utilise existing observational clinical data where individuals have received anti-inflammatory drugs. It was such an approach that first highlighted the role of inflammation in neurodegeneration when it became apparent that non-steroidal anti-inflammatory compounds were associated with reduced dementia risk [11–14].

Many subsequent studies have reproduced this finding, although trials of such compounds have not been successful to date, perhaps because the association is only seen in those taking medication for extended periods of time before the onset of dementia [15]. In line with this, we recently found non-steroidal anti-inflammatory drugs (NSAIDs) were associated with higher cognitive function in participants in the UK Biobank cohort study of largely healthy individuals [16]. Rather than being cognitive enhancers, a potential explanation of this finding is that NSAIDs are reducing the decline in cognitive function in pre-clinical dementia states. Together, these real-world observational clinical data studies, therefore, have made a significant contribution in: first, adding support to the association with inflammation in disease; second, in adding support suggesting a direction of that effect; and third, in providing evidence for timing in relation to disease and therefore informing the design of clinical studies.

In recent years, more specific anti-inflammatory drugs have become part of the pharmacotherapy of disorders such as rheumatoid arthritis, providing an opportunity to begin to explore the effects of different mechanisms of inflammation in relation to neurodegeneration [17,18]. Recognizing this, we recently used Clinical Practice Research Datalink (CPRD), a large dataset derived from primary care in the UK, to explore the relationship between different anti-inflammatory compounds and showed that Disease-Modifying Antirheumatic Drugs (DMARDs), and especially methotrexate, are associated with a reduction in risk of incident AD [19]. However, although a relatively large study, the data was from a single source and in a single health care context and thus vulnerable to unanticipated confounding. Here we set out to replicate and extend this study across multiple real-world observational datasets across Europe.

Methods

2.1 Study design, setting and source of data

We used a nested retrospective case control study design, to investigate the association between the use of disease-modifying anti-rheumatic drug/s (methotrexate and sulfasalazine) and the incidence of dementia diagnosis in routine healthcare data. We used electronic health records (EHRs) available via the European Medical Information Framework (EMIF; www.emif.eu), a public-private partnership under the EU Innovative Medicines Initiative [20]. Methotrexate and sulfasalazine were selected as: 1) both drugs are first line treatments for rheumatoid arthritis; 2) there is not a universally accepted prescribing preference for these drugs when clinicians are faced with the same symptoms 3) each drug has a different mechanism of anti-inflammatory action [21,22].

We selected the four databases with primary care, hospital and pharmacy dispensing data sources from across Europe including: Integrated Primary Care Information (IPCI, 1.8 million) [23], Aarhus University Prescription Database (AUH, 1.8 million) [24], The Health Information Network (THIN, 3.8 million) [25,26] and Information System for Research in Primary Care (SIDIAP, 5.5 million) [27,28]. Data collection in IPCI, AUH, THIN and SIDIAP and was initiated in 1995, 2000, 2002 and 2006 respectively. Further information regarding the databases utilised is provided in the supplementary information (Table S1).

2.2 Participants and study size

The case population is formed by those individuals who were identified with a first-ever clinical or referral record of dementia. Further information regarding dementia definitions and mapping to the different databases in this study can be found in Perera et al (2018)[29]. The clinical codes for dementia and other disease variables can be found in the supporting information (Table S2).

The date at which a patient received the first diagnosis of dementia was defined as the index date. Up to 25 controls from the initial study population per case were matched on age (+/- 2 years), gender and GP practice. Up to 25 controls were utilised as it was anticipated that when only including those people with a previous history of RA for analysis the number of controls would decrease. For the AUH database, information on GP practice was not available; therefore controls were matched to cases on age and gender only. All individuals included in the analysis had been registered in their respective database for at least one year before the index date. The index date for controls (with no dementia diagnosis at their index date or before) was chosen as the date of dementia diagnosis of their matched dementia case. From this initial population of cases and controls only those people who were 50 years or older at index date were included in the study. Furthermore, for each case, matched controls who had a shorter period before index date were removed. Finally, only those people with a diagnosis of rheumatoid arthritis (RA) before the index date were included in this study. Any cases with no remaining controls after applying exclusion criteria were excluded. A population flowchart showing the individual numbers of cases and controls per dataset is shown below (Figure 1).

2.3 Outcome and Exposures

The outcome variable was defined as presence or absence of a diagnosis of a dementia as a binary variable. The diagnosis of dementia was identified in each database as a first-ever clinical or referral record of dementia from 1 January 1990 to the 31 December 2016. The exposure variables in this study were: first prescription of methotrexate, if any; first prescription of sulfasalazine, if any; number of days using methotrexate before index date; number of days using sulfasalazine before index date. The number of days of drug use was calculated from the first date of drug use to the last date of drug use followed by a 12 month gap all before the index date. Days of use for these drugs was converted to years by dividing by 365.25 for consistency. ATC Drug codes for the two anti-inflammatory medications were L01BA01 and L04AX03 for methotrexate and A07EC01 for sulfasalazine. All databases utilised ATC codes for methotrexate and sulfasalazine apart from THIN, which utilises ATC and Read coding.

2.4 Potential confounders and model adjustments

Factors considered potential confounders were identified including age at index date, highest body mass index measurement (BMI) 2-12 years before index date (either BMI or calculated from height and weight measurements), and comorbidities at or before index date (stroke and acute myocardial infarction (AMI)). Age was included as a confounder in all models due to the two year time window used for matching. The highest BMI 2-12 years from the index date was used when available, but calculated from weight and

highest height recorded in adulthood otherwise. The highest BMI was utilised as dementia patients are more likely to lose weight leading up to diagnosis [30]. Any BMI value less than 15 kg/m² or greater than 60 kg/m², any weight measurement less than 30kg or greater than 150kg and any height measurement less than 1 metre or greater than 2.5 metres were considered measurement errors and not considered. Cardiovascular disease, including stroke, has been hypothesised as lying on the causal pathway between RA and dementia, where people with RA are more at risk of developing cardiovascular disease such as stroke, which is then a risk factor for dementia [31,32], therefore models were used with and without this previous history of stroke.

We initially performed an unadjusted model and then we adjusted for age at index date (years), diagnosis of stroke before index date (yes or no), diagnosis of AMI (yes or no), BMI; and finally in fully adjusted models with all confounders but without the previous stroke diagnosis were performed.

2.5 Missing data

The only confounding variable with missing data was highest BMI (2-12 years) with a missingness of 39.57%. BMI was imputed to avoid the exclusion of patients and to reduce selection bias. An imputed dataset was generated using 10 multiple imputations by chained equations to replace these missing values. We included all confounders, diagnosis of hypertension, dementia diagnosis and both drug exposures in the imputation process.

2.6 Statistical methods

A descriptive summary table of the dataset utilised is presented in Table 1. For the descriptive summary statistics used in this study an unpaired t test was applied for normally distributed numerical demographics, a Wilcoxon unpaired t test was applied for non-normally distributed numerical demographics and a chi-square test for categorical demographics was applied.

Conditional logistic regression was used to estimate the association between drug use and dementia diagnosis using R version 3.4.3 and the “survival” package [33]. The data from each database was combined into one dataset and a variable indicating which database the data had originated from was created. We first calculated odds ratios (ORs) with 95% confidence intervals (CI) from crude models with no adjustment (model 0). Secondly, we adjusted for all confounders listed in section 2.4: age at index date (years), diagnosis of stroke before index date (yes or no), diagnosis of AMI (yes or no) (model 1) and database (multi-level variable). Finally, we calculated models with all confounders but without the previous stroke diagnosis (model 2).

To test the impact of days of use of anti-inflammatory medications before dementia diagnosis, a new variable was created based on the days of use of either methotrexate or sulfasalazine. For each medication, days of use before the index date were converted into tertiles for those taking medication. This created a multilevel variable of the different tertiles based on days of use of the medication. Those not taking the medication were as the reference level in the analysis. The four groups created for

methotrexate days of use variable were as follows: Group A (reference level n = 740), not taking methotrexate; Group B (n=52), more than 0 years but less than or equal to 1.18 years (432.33 days) of methotrexate use before index date; Group C (n=51), those with greater than 1.18 years but less than or equal to 4.11 years (1500.8 days) of use of methotrexate before index date; and finally Group D (n =51), those taking methotrexate for more than 4.11 years. The four groups created for sulfasalazine days of use variable were as follows: Group A (reference level), not taking sulfasalazine; Group B, more than 0 days but less than or equal to 0.49 years (177.5 days) of sulfasalazine use before index date; Group C, those with greater than 0.49 years but less than or equal to 2.21 years (808 days) of use of sulfasalazine before index date; and finally Group D, those taking sulfasalazine for more than 2.21 years. This multilevel variable, containing the different tertiles based on days of use for either methotrexate or sulfasalazine was then included into the models (instead of the binary variable indicated if drug was taken by patient) and models 0-2 were calculated using this multilevel variable.

Results

3.1 Descriptive data

A total of 486 subjects with RA who developed dementia (cases) and 641 matched controls were included. A study participant flow chart is provided showing the impact of each exclusion criterion (Figure 1). Characteristics of individuals included in the study are shown in table 1. IPCI had 433 patients (37% cases), SIDIAP 454 (47% cases), THIN 153 (47% cases) and AUH 87 (48% cases).

TABLE 1: Characteristics of individuals used in analysis

	Case	Control	P value
n	486	641	-
Age at index date (years)	79.8 (\pm 6.89)	79.5 (\pm 7.02)	0.522
Gender	86.4 %F	87.4 %F	0.707
Time since rheumatoid arthritis diagnosis before index date (years)	6.87 (\pm 6.29)	7.06 (\pm 5.92)	0.232
Prescribed with sulfasalazine	40 (8.23%)	57 (8.89%)	0.776
Years of sulfasalazine use before index date	2.72 (\pm 3.57)	2.57 (\pm 3.96)	0.457
Prescribed with methotrexate	123 (25.31%)	178 (27.77%)	0.392
Years of methotrexate use before index date	2.69 (\pm 3.06)	3.80 (\pm 2.44)	0.002
Diagnosed with AMI	26 (5.35%)	34 (5.30%)	1.000
Diagnosed with Stroke	37 (7.60%)	64 (10.00%)	0.202
Highest BMI before index date	28.1 (\pm 4.99)	28.8 (\pm 4.90)	0.061
BMI missingness	178 (36.62%)	211 (32.92%)	0.217
Total Time in Database (years)	7.64 (\pm 7.82)	7.77 (\pm 7.66)	0.301
Time in Database before Index date (years)	5.16 (\pm 7.47)	4.62 (\pm 7.01)	0.027

Cases and controls were balanced in terms of most of the measured variables (Table 1). Additionally, although the total time in the database between cases and controls did not differ, controls had slightly shorter time in the databases compared with the cases with time in the database before index date at 5.16 years for cases and 4.62 years for controls, respectively. However, this difference is not present in three databases (AUH, SIDIAP and THIN) when considering the individual databases. The difference is due to the IPCI dataset having more cases with a higher number of controls who have a shorter time before index date. Other covariates did not differ between cases and controls to a statistically significant extent.

3.2 Association between DMARDs use and dementia diagnosis

For the unadjusted model, there was a trend, although not statistically significant, towards reduced risk of dementia with methotrexate use (OR 0.76, 95% CI 0.56-1.03). Using adjusted models, we found a statistically significant association with methotrexate but no association with sulfasalazine in relation to dementia diagnosis. For models 1 and 2, similar ORs were obtained for methotrexate (0.71, 95% CI 0.52-0.98 and 0.71, 95% CI 0.52-0.98) both achieving statistical significance (Table 2). As models 1 and 2 show similar results, we conclude that there is no significant effect of stroke on the relationship between

drug exposure and dementia onset. A forest plot showing the results of Table 2 can be found in the supplementary information (Figure S1).

TABLE 2: Association between methotrexate and sulfasalazine treatment and dementia diagnosis in people with rheumatoid arthritis

Drug	Model 0		Model 1		Model 2	
	Unadjusted OR (95% CI)	p value	Adjusted OR (95% CI)	p value	Adjusted OR (95% CI)	p value
Methotrexate	0.76 (0.56-1.03)	0.076	0.72 (0.52-0.98)	0.036	0.71 (0.52-0.98)	0.034
Sulfasalazine	0.88 (0.57-1.36)	0.56	0.89 (0.57-1.38)	0.60	0.88 (0.57-1.37)	0.57

Model 0: no adjustment; Model 1 adjustment for age, BMI, stroke and AMI; Model 2: same as model 1 but not including diagnosis of stroke.

We then investigated the number of days of use of methotrexate and sulfasalazine before dementia diagnosis. The results showing the number of days of use of methotrexate in tertiles with dementia diagnosis are shown in Figure 2.

We found a clear treatment time effect (even though tertiles 1 and 2 were not significant) with those taking methotrexate for the longest period (greater than 4.11 years) prior to the index date having the greatest effect on dementia risk for all models (Figure 2). The results indicate that the association is only significant for those who took methotrexate for just over 4 years of treatment. For the unadjusted model those who took methotrexate for 4.11 years, achieved an odds ratio of 0.39 (95% CI 0.18-0.84, p value 0.015) with similar odds ratios obtained for models 1 and 2 of 0.38 (95% CI 0.18-0.84, p value 0.016) and 0.37 (95% CI 0.17-0.79, p value 0.011) respectively.

The full table of results can be found in the supplementary information (Table S3). We then repeated this analysis for sulfasalazine finding no significant association between duration of prescription and risk of dementia (Table 3)

TABLE 3: Association between of days of use of sulfasalazine treatment and dementia diagnosis in people with rheumatoid arthritis

Variable group	Model 0		Model 1		Model 2	
	Unadjusted OR (95% CI)	p value	Adjusted OR (95% CI)	p value	Adjusted OR (95% CI)	p value
No Sulfasalazine use	REF		REF		REF	
Sulfasalazine use for 0.49 years (first tertile)	0.60 (0.28-1.31)	0.20	0.65 (0.30- 1.41)	0.28	0.65 (0.30- 1.41)	0.28
Sulfasalazine use for 0.49 to 2.21 years (second tertile)	0.93 (0.45-1.93)	0.85	0.94 (0.45- 1.95)	0.86	0.89 (0.43- 1.85)	0.76
Sulfasalazine use for >2.21 years (third tertile)	1.21 (0.58-2.51)	0.62	1.16 (0.55- 2.44)	0.69	1.19 (0.57- 2.48)	0.65

Model 0: no adjustment; Model 1 adjustment for age, BMI, stroke and AMI; Model 2: same as model 1 but not including stroke variable

Discussion

In this uniquely large and geographically diverse sample using four European harmonized electronic health record datasets using the EMIF platform, we found evidence that in adults older than 50 years of age with rheumatoid arthritis, taking methotrexate was associated with a lower risk of a subsequent dementia diagnosis, specifically recorded methotrexate use for more than 4 years. We also investigated sulfasalazine use but found no such association. Although the exact mechanism of action of methotrexate or sulfasalazine is not well understood both appear to be involved in adenosine signalling [34–36]. However there is evidence to suggest that these drugs also are involved in different mechanisms [22] and this could explain why we did not see an association between sulfasalazine and dementia risk.

Investigations of anti-inflammatory DMARDs on dementia risk have reported conflicting results. Judge *et al.* (2017) showed a decreased risk of dementia with methotrexate use [19]. Using the UK Clinical Practice Research Datalink, Judge *et al.* found that DMARD users were at reduced risk of dementia (hazard ratio: 0.60; 95% confidence interval: 0.42–0.85) and the effect was strongest in methotrexate users (hazard ratio: 0.52; 95% confidence interval; 0.34–0.82). Our study extends these findings by utilising datasets across multiple countries as well as highlighting the stronger associations of longer methotrexate use with reduced dementia risk.

Judge *et al.* (2017) contradicts the study carried out by Chou *et al.* (2017). In this study using the Taiwan National Health Insurance Research Database, people taking non-biologic DMARDs had a higher risk of any dementia type (AD, vascular) compared with people who did not take DMARDs or used biologic DMARDs [37]. This study used a cut-off age of people equal or older than 20 years; however, the majority

of people used in the analysis were older than 65 (>80%). Furthermore, this study also showed that numbers of days of use of either methotrexate or sulfasalazine increased dementia risk. The contradictory results from this study could be for a number of reasons firstly differences in geographic locations (European versus Asian). Further studies are still required to clarify the relationship between prior methotrexate use and duration as well as dementia risk with use of other DMARDs, particularly biological therapies. Future experimental studies are warranted to determine the specific mechanisms for the protective association between prior methotrexate treatment and dementia.

Our study has several strengths. First, the use of multiple routine EHR databases under the EMIF platform, has allowed for aggregation and harmonization of huge volumes of suitable data to investigate the association between dementia and inflammatory exposures. The access to large amounts of data has meant that we have been able to select people with a relatively rare condition such as RA, and have sufficient numbers of incident cases of dementia. By only including people who had RA in this study we have increased the likelihood of cases and controls being comparable rather than just comparing medication use or not within the total samples and therefore could consider the effect of medications and dementia risk. In this study we used a matched population, which minimizes bias due to confounding by indication but also limits the generalizability of the findings. In particular we only utilised those people with RA also limiting our generalizability. In this study, four EHR databases, primary care and hospital based, from four European countries, were utilised, giving a general applicability across multiple European countries. Second, we followed an EMIF harmonization process where a single protocol was utilised for the study, single format of data extracts, semantic harmonization process ensuring comparability of clinical code lists, a Statistical Analysis Plan with the same statistical analysis steps applied on the extracted data ensuring consistency in results.

Our study also had limitations. We only investigated the effect of two anti-inflammatory drugs, methotrexate and sulfasalazine, without considering the impact of other drug treatments potentially administered such as biologics. Therefore, indication bias could exist as the severity of RA may impact the choice of medication where methotrexate and sulfasalazine are usually first line treatments for RA. However, Judge et al (2017) used propensity score matching to account for confounding by indication and showed similar results to our regarding a reduced risk of dementia with methotrexate use [19]. Furthermore, drug adherence could affect the results with drugs side effects which could affect the compliance of taking the medications utilized in this study. In addition, owing to the observational nature of the study, there remains the potential for residual confounding that could attenuate or explain the observed associations, due to unmeasured variables such as arthritis disease severity, health, and lifestyle effects. However in spite of this the data used for this study does reflect the wider rheumatoid arthritis patient population in terms of gender distribution [38].

In summary, this case-control study across multiple EHR databases found that prior methotrexate use, but not sulfasalazine use, was associated with dementia diagnosis even after adjusting for patients' demographics and comorbidities. Furthermore, we showed that there is a gradual decrease against dementia risk the longer the use of methotrexate before the index date. These findings are relevant from a

public health perspective since they highlight the potential of methotrexate to protect against dementia however the mechanism behind this remains to be elucidated.

Abbreviations

AD: Alzheimer's disease

MTX: methotrexate

SUL: sulfasalazine

DMARDs: Disease-Modifying Antirheumatic Drugs

NSAIDs: Non-steroidal anti-inflammatory drugs

EMIF: European Medical Information Framework

ATC: Anatomical Therapeutic Chemical

THIN: The Health Information Network

AUH: Aarhus University Prescription Database

IPCI: Integrated Primary Care Information

SIDIAP: Information System for Research in Primary Care

ICD-9/10: International Classification of Diseases

ICPC: International Classification of Primary Care

RA: rheumatoid arthritis

BMI: body mass index

AMI: Acute myocardial infarction

Declarations

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AVAILABILITY OF DATA AND MATERIALS: The datasets analysed during the current study are not publicly available due to confidentiality of patients but are available via application to individual data custodians under the EMIF platform (<http://www.emif.eu/>).

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Additional File Legend

File name Supporting Information.xlsx

Description of data: Excel document containing 1) Table S1 of characteristics of databases utilised in this study 2) Table S2 of clinical diagnosis codes for disease variables 3) Table S3 showing the association between of days of use of methotrexate treatment and dementia diagnosis in people with rheumatoid arthritis and 4) Figure S1 showing the association between methotrexate and sulfasalazine treatment with dementia diagnosis in people with rheumatoid arthritis

Figures

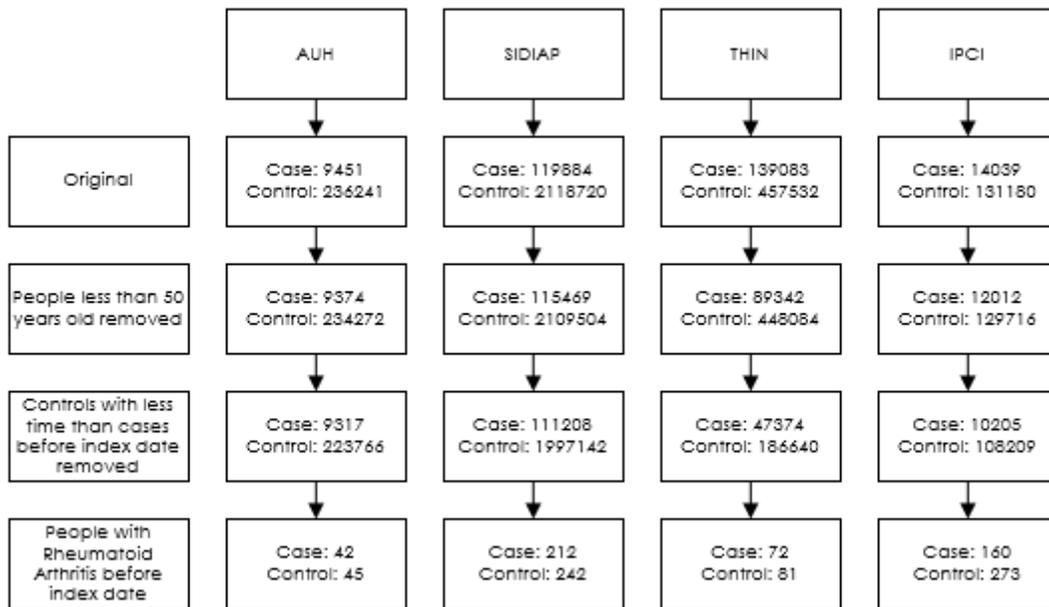


Figure 1

Number of individuals initially included in the study and number of individuals utilised for analysis

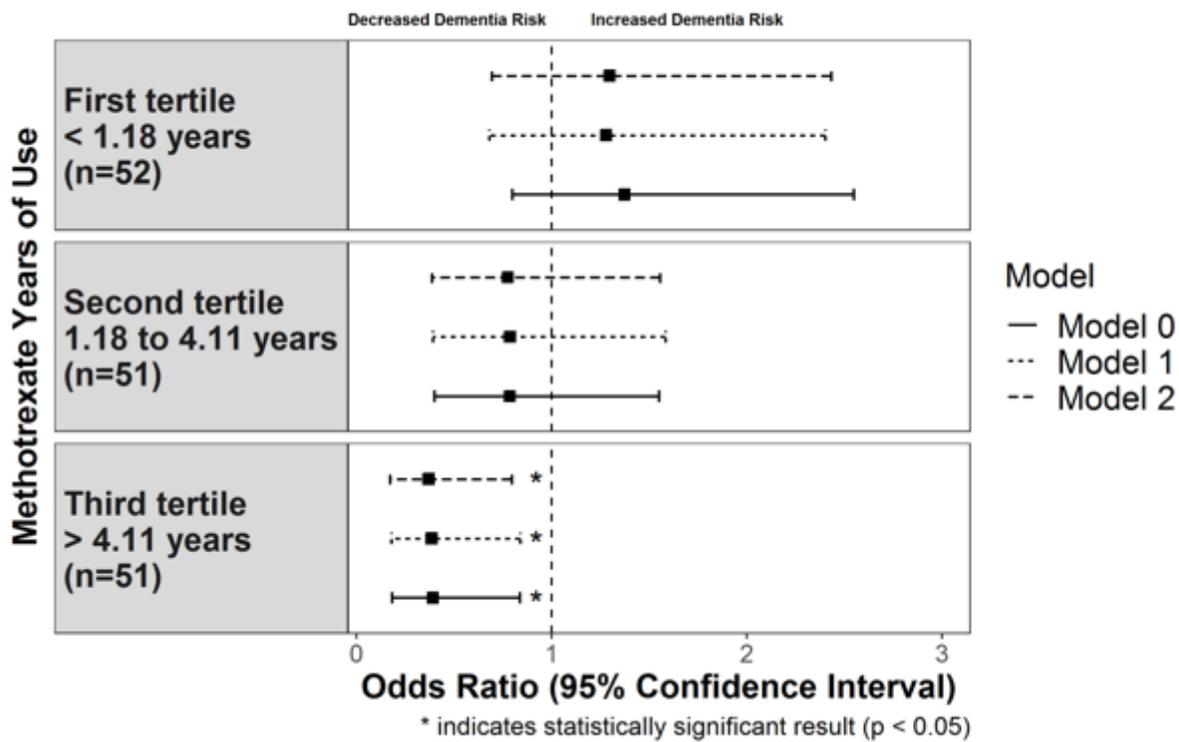


Figure 2

Association between methotrexate years of use and dementia diagnosis in people with rheumatoid arthritis

Supplementary Files

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