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Review article

Impact of Parkinson's disease diagnosis validity on the association with cancer: A systematic review and meta-analysis

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ABSTRACT

Background: Meta-analyses have reported lower cancer incidence in patients with Parkinson's disease (PD) compared to the general population but with considerable data heterogeneity.
Objective: To explore how the validity of the PD diagnoses is related to the association with cancer.
Methods: We conducted a systematic review and meta-analysis in which studies were stratified into groups based on the diagnostic validity of Parkinson's disease. Studies investigating mortality data and those examining cancer risk within certain genetic subgroups of PD were excluded.
Results: Thirty-four articles encompassing 533,102 patients with PD from 11 countries met the inclusion criteria. Stratified analyses revealed no association between PD and overall cancer risk preceding or following the PD diagnosis in studies using validated PD data. Studies utilizing less robust PD identification methods, the majority of which were cohort studies, demonstrated a neutral or decreased cancer risk among PD patients. In the studies with the most rigorous PD validation organ-specific analyses showed an increased risk of cutaneous melanoma but no decreased risk in any type of cancer. The positive association between PD and melanoma was more pronounced in the studies with more robust PD diagnosis validity.
Conclusions: The reported associations between PD and cancer are substantially influenced by the quality of PD data. Future investigations should concentrate on organ-specific cancers, instead of pooling cancers together, and use only PD cohorts with validated diagnosis.

1. Introduction

Numerous epidemiological studies have reported associations between Parkinson's disease (PD) and cancer [1–5]. Most of these studies have reported that cancer occurs less often in persons with PD than in persons without PD. This negative overall association between cancer and PD can, to some extent, be anticipated given that smoking has been clearly associated with an increased risk of cancer and a decreased risk of PD [6–9]. Meta-analyses have revealed that after stratification by the strength of smoking associations in various cancer types, smoking does not entirely account for the observed link between cancer and PD [2].

There are some discrepancies in the existing literature, with some studies reporting no statistically significant differences in cancer risk between PD and non-PD populations [10,11]. The sole study to investigate PD risk in cancer patients also revealed no association between the incidence of overall cancer and subsequent PD development [12]. However, cutaneous melanoma seems to be more common among individuals diagnosed with PD [13–22]. In contrast to studies in Europe and the U.S., a Taiwanese cohort study with 60,023 patients reported that following PD diagnosis, an increased cancer risk was observed among patients, with the exception of breast, ovarian and thyroid cancers [18]. These results suggest that ethnicity and geographical factors may play an important role in the association between PD and cancer. Moreover, genetic data have revealed bidirectional links between the risk of PD and various cancer types, but the current body of evidence lacks consistency in supporting these genetic associations [23–25].

One potential reason for the inconsistent study outcomes may be limitations in the validity of PD diagnoses. This concern was previously

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highlighted in a systematic review published in 2010 [1]. However, the validation of PD diagnoses has been variably implemented or considered in subsequent research, and recent meta-analyses have generally overlooked this critical aspect [2,3,5].

Interestingly, inception studies have been shown to report lower standardized mortality ratios than non-inception studies for patients with PD with one probable reason for this being differences in diagnostic accuracy [26]. The issue of diagnostic code accuracy becomes particularly important when relying solely on administrative data without mechanisms for verification [27]. Therefore, we investigated the extent to which the validity of PD diagnosis influences the association with cancer incidence in previously published epidemiological studies.

2. Methods

2.1. Data sources and search strategy

PubMed, Web of Science and Google Scholar databases were searched from January 1, 1980 to March 1, 2022. Additionally, the reference lists of retrieved articles were searched. The keywords used for the search included "Parkinson's disease", "Parkinson", "cancer", and "neoplasm", and these keywords were connected via Boolean operators. Two reviewers (AM, JS) independently screened the abstracts to identify relevant articles, followed by a full-text review of the selected articles. Several additional relevant studies were found by searching the reference lists of the published articles that were initially identified through the database search. We conducted and reported this analysis in accordance with PRISMA guidelines for meta-analysis of observational studies in epidemiology [28]. This systematic review was registered at PROSPERO (CRD42023431783).

2.2. Study selection

Studies were eligible for inclusion if they were cohort or population-based case–control studies or cross-sectional studies of adults that reported original data. The search results were imported into Zotero software (version 6.0.30) to eliminate duplicates. Studies investigating the risk of PD in cancer patients, mortality data studies and studies limited to investigating cancer risk in only a certain genetic subgroup of PD patients were excluded. If a research article reported data on cancer risk both before and after PD, these data were included as separate studies.

2.3. Data extraction and quality assessment

The following variables were extracted: study design, the duration of the study, when the study was conducted, population characteristics (country, number of participants, cancer type), adjusted factors, number of cancer outcomes, year of publication and effect size.

The quality of studies was assessed using the Newcastle–Ottawa Scale (NOS) [28].

NOS evaluates studies based on three key domains. Selection (0–4 points)**:** evaluates representativeness, selection of controls, and exposure ascertainment. Comparability (0–2 points): assesses adjustments for key confounders. Outcome (cohort)/Exposure (case-control) (0–3 points)**:** considers follow-up length, assessment methods, and completeness of data. NOS scores were separately calculated for case-control, cohort studies and cross-sectional studies. The maximum total score was nine points.

In the primary analysis all studies were classified into two different categories (CAT A and CAT B) based on the validation of PD diagnoses. In CAT A studies, all PD diagnoses were prospectively or retrospectively verified by a neurologist using specified diagnostic criteria. In CAT B studies PD diagnoses were either partially or not validated at all. We also performed a sensitivity analysis, where we further classified CAT B studies into two groups CAT B1 and CAT B2. In CAT B1 studies PD diagnoses were only partially verified, e.g., by validating a subsample of the total cohort [29] or using an algorithm based on the prescription of PD medication and the absence of medical PD induced medication within 180 days before PD diagnosis [30].

In CAT B2 studies, there was no PD diagnosis verification. All cancer data in the included studies were extracted from reliable national cancer registries or prospective cancer databases, apart from one CAT B2 study, where cancer cases were self-reported and then confirmed by medical records and pathology review [31]. The duration of follow up between PD and cancer occurrence as well as between cancer and PD onset is shown in Table 1. Organ-specific cancer analyses were performed only for cancer types for which at least ten studies were available. When possible, cancer risk was stratified by sex, as several included studies reported cancer risk in men and women separately.

2.4. Statistical analysis

Under the assumption that the person-time of the unexposed group is vastly larger than that of the exposed group, we made no distinction between incidence rate ratios, hazard ratios and risk ratios and combined them in our pooled analyses. In consultation with our resident statistician and to enhance the robustness of our analysis, we performed a conversion of odds ratios (ORs) to risk ratios (RRs), thus enhancing the comparability individual studies. We converted odds ratios into risk ratios via the following equation: RR=OR/(1−Pref)+(Pref*OR), where RR = risk ratio; OR = odds ratio; Pref = prevalence of the outcome in the reference group. The distribution of categorical variables was assessed using Fisher's exact test.

Publication bias was assessed via Begg's rank test. Between-study heterogeneity was assessed with I^2 statistics. Due to the presence of substantial heterogeneity, a random effects model was used to calculate pooled RRs. We performed all the statistical analyses on Cochrane Review Manager 5.4.1. In some cases, this resulted in slightly, but not significantly different risk estimate figures compared to the original papers.

3. Results

Thirty-four articles met the eligibility criteria (supplementary material S1) and were included in the analysis, involving a total of 533,102 patients (9382 in CAT A studies and 523720 in CAT B studies) with PD from eleven countries (Table 1). Nine articles described cancer risk before PD diagnosis, 21 articles described cancer risk after PD diagnosis, and four articles reported cancer risk both before and after PD diagnosis, yielding 13 studies examining the risk of cancer before and 25 studies after the PD diagnosis. Regarding study quality, the median Newcastle–Ottawa Scale score was 7 for all studies as well as for both CAT A and CAT B. Begg's test revealed no significant publication bias (Kendall's tau $r = -0.032$, $p = 0.519$). Publication date was not associated with CAT A/B distribution B (separate analyses for before/after/all divided in two groups: $p > 0.09$ for all).

The majority (8/13) of the studies investigating the association between PD and cancer before PD involved clinical validation of PD by a neurologist. In contrast, the majority (17/25) of studies on cancer risk following PD were partially validated or not validated.

When stratifying all studies by study design, irrespective of whether they assessed cancer risk before or after Parkinson's disease, a notable difference in Category proportions was observed. Among case-control studies, 66.6 % were classified as CAT A, whereas this proportion was significantly lower in cohort studies (26 %) ($p = 0.018$). However, when accounting for the before/after PD status, this difference was no longer statistically significant ($p > 0.20$).

A pooled sensitivity analysis of all studies of overall cancer risk showed a negative association between PD and considerable heterogeneity (Fig. 1A).

Table 1
Characteristics of included studies

Before PD, N = 13

First author, year	Country	Study period	PD cases, N	Study design	Mean/median duration of follow up before outcome, years	NOS	CAT	Cancer outcomes, included in meta analysis	Adjustment factors	Overall cancer, N
Jansson, 1985[32]	USA	1978–1984	406	Retrospective cohort study	NR	7	A	Overall cancer	Age, sex	5
Rajput, 1987 [33]	USA	1967–1979	118	Case control study	NR	8	A	Overall cancer	Age, sex	19
Elbaz, 2002 [34]	USA	1976–1995	196	Case control study	Median 5.5	8	A	Overall, urinary tract, colorectal, lung, prostate, breast cancer, melanoma	Age, sex,	38
Amelio, 2022 [35]	Italy	2001–2002	222	Case-control study	NR	8	A	Overall cancer	Age, smoking Alcohol, coffee	15
Powers, 2006[36]	USA	1992–2005	352	Case control study	NR	9	A	Overall, breast cancer, melanoma	Age, smoking, ethnicity,education	74
Olsen, 2006 [37]	Denmark	1986–1998	8090	Case-control study	NR	6	B	Overall, lung, melanoma, breast, prostate, uterine cancer	Age, sex	74
Driver, 2007 [38]	USA	1982–2005	487	Nested case-control study	NR	7	A	Overall	Age, sex, Smoking, BMI, exercise	64
Fois, 2009 [39]	UK	1963–1999	4355	Record linkage cohort study	3.4	5	B	Overall, lung, melanoma, breast, prostate, colorectal, uterine cancer	Age, sex, region, year of hospitaladmission	926
Lo, 2010[10]	USA	1994–1995, 2000–2008	692	Nested case-control study	4.3	8	A	Overall, lung, melanoma, breast, urinary tract, colorectal cancer	Age, sex, smoking, alcohol,body mass index	56
Wirdefeldt, 2013[22]	Sweden	1964–2009	11786	Register-based matched cohort study	NR	8	B	Overall, lung, melanoma, breast, urinary tract, prostate, colorectal, uterine cancer	Age, sex, education	1.264
Tacik, 2016 [40]	USA	2003–2014	971	Retrospective case-control study	5	8	A	Overall, lung, melanoma, breast, prostate, colorectal, uterine cancer	Age, sex	202
Dalvin, 2017 [41]	USA	1976–2013	974	Case control	5	6	B	Melanoma	Age, sex	
Cui, 2019 [42]	Denmark	1996–2009	1813	Population-based case-control study	NR	8	A	Overall, melanoma, breast, prostate, urinary tract, colorectal cancer		175

After PD, N = 25

First author, year	Country	Study period	PD, patients, N	Study design	Duration of follow up before outcome, years	NOS	CAT	Cancer outcomes, included in meta analysis	Adjustment	Overall cancer, N
Jansson,1985 [32]	USA	1978–1984	406	Retrospective cohort study	8.6	6	A	Overall cancer	Age, sex	13
Moller,1995 [17]	Denmark	1977–1990	7046	Retrospective cohort study	4.6	4	B	Overall, melanoma, lung, breast, prostate, colorectal, uterine	Age	554
Minami,2000 [43]	Japan	1984–1992	228	Retrospective cohort study	8	6	B	Overall, lung, breast cancer	–	15
Olsen, 2005 [20]	Denmark	1977–1999	14088	Retrospective cohort study	5	5	B	Overall, lung, breast, urinary tract, colorectal, prostate cancer, melanoma	Age, sex	1.282
Elbaz,2005 [44]	USA	1976–2002	196	Cohort study	Median 8	8	A	Overall	Age, sex, smoking	71
Leibson, 2005 [11]	USA	1976–1995	197	Population based cohort study	NR	6	A	Overall		72
Driver, 2007 [31]	USA	1982–2005	487	Prospective cohort study	Median 5.2	6	B	Overall, lung, breast, colorectal, urinary tract,	Age, sex, smoking, BMI, exercise, alcohol	53

(*continued on next page*)

Table 1 (*continued*)

After PD, N = 25										
First author, year	Country	Study period	PD, patients, N	Study design	Duration of follow up before outcome, years	NOS	CAT	Cancer outcomes, included in meta analysis	Adjustment	Overall cancer, N
								prostate cancer, melanoma		
Fois, 2009[39]	UK	1963–1999	4355	Record linkage cohort study	3.4	5	B	Overall, lung, melanoma, breast, prostate, colorectal, uterine cancer	Age, sex, region, year of hospitaladmission	219
Bertoni, 2009 [13]	USA, Canada	1/2003–9/ 2003	2106	Cross sectional study	NR	NR	A	Melanoma	Sex, age	
Lo, 2010[10]	USA	1994–1995, 2000–2008	692	Nested case-control study	5	8	A	Overall, lung, melanoma, breast, urinary tract, colorectal cancer	Age, sex, smoking, alcohol,body mass index	90
Schwid, 2010 [15]	USA, Canada, Denmark	–	806	Cohort	1.8	3	A	Melanoma, breast, prostate cancer	–	
Becker, 2010 [29]	Israel	1994–2005	2993	Cohort with nested case control study	NR	8	B	Overall, lung, urinary tract, colorectal, breast cancer, melanoma	Age, sex, smoking, BMI	188
Sun, 2011[45]	Taiwan	2000–2005	4957	Population-based cohort study	NR	8	B	Overall cancer, melanoma	Age, sex, occupation, urbanization, comorbidity	NR
Inzelberg, 2011[14]	Israel	2002–2003	1395	Cross sectional study	NR	5	A	Melanoma	Sex, age, race	
Rugbjerg, 2012[46]	Denmark	1977–2008	20343	Population based cohort study	5.7	7	B	Overall, melanoma, lung, breast, urinary tract, uterine, prostate cancer	Age, sex,PD onset	2.218
Wirdefeldt, 2013[22]	Sweden	1964–2009	11,786	Register-based matched cohort study	NR	8	B	Overall, lung, melanoma, breast, urinary tract, prostate, colorectal, uterine cancer	Age, sex, level of education	562
Ong, 2014[19]	UK	1999–2011	219,194	National record-linkage cohort study	NR	7	B	Overall, lung, breast, urinary tract.prostate colorectal, uterine cancer	Age, sex, residence, Socioeconomic status, year of first hospital admission	17.524
Lin, 2015[18]	Taiwan	2004–2012	62023	Population based cohort study	8	7	B	Overall, melanoma, lung, breast, urinary tract, prostate, colorectal, uterine cancer	Age, sex	NR
Shalaby, 2016 [16]	USA	2009–2014	108	Case-control study	NR	7	A	Melanoma	Age, sex, race education	
Peretz,2016 [30]	Israel	2000–2012	7125	Population-based, retrospective cohort study	6	7	B	Overall, melanoma, lung, breast, prostate, colorectal cancer	Age	366
Lerman, 2018 [47]	Israel	2010–2018	7727	Population-based, retrospective cohort study	8	8	B	Melanoma	Age at index date sex, smoking, residence, birthplace	
Park, 2019 [48]	South Korea	2010–2015	52009	Population-based cohort study	6	8	B	Melanoma, breast, urinary tract, prostate, uterine, colorectal cancer	Age, sex, comorbidity, income	
Ording, 2019 [49]	Denmark	1980–2013	28835	Population-based cohort study	4.0	6	B	Melanoma, breast, urinary tract, lung cancer	Age, sex,CCI score	
Agaliu,2019 [50]	Israel, Spain, USA	–	712	Case control	NR	5	B	Melanoma, breast, urinary tract, prostate, colorectal cancer	Age, sex, ethnicity, BMI,smoking, alcohol	
Ryu, 2020[21]	South Korea	2010–2015	70730	Population-based cohort study	NR	8	B	Melanoma	Age, sex, income, comorbidity	

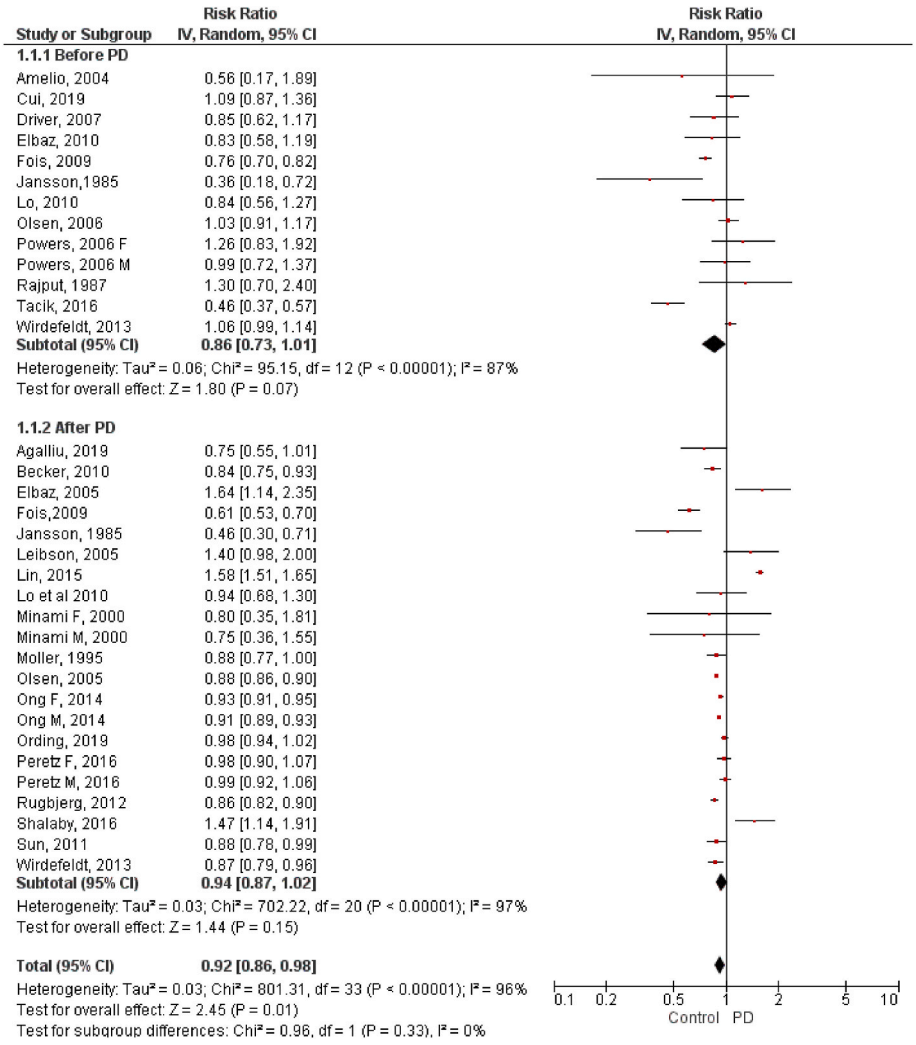

Fig. 1A. Pooled sensitivity analysis of all studies of overall cancer risk.

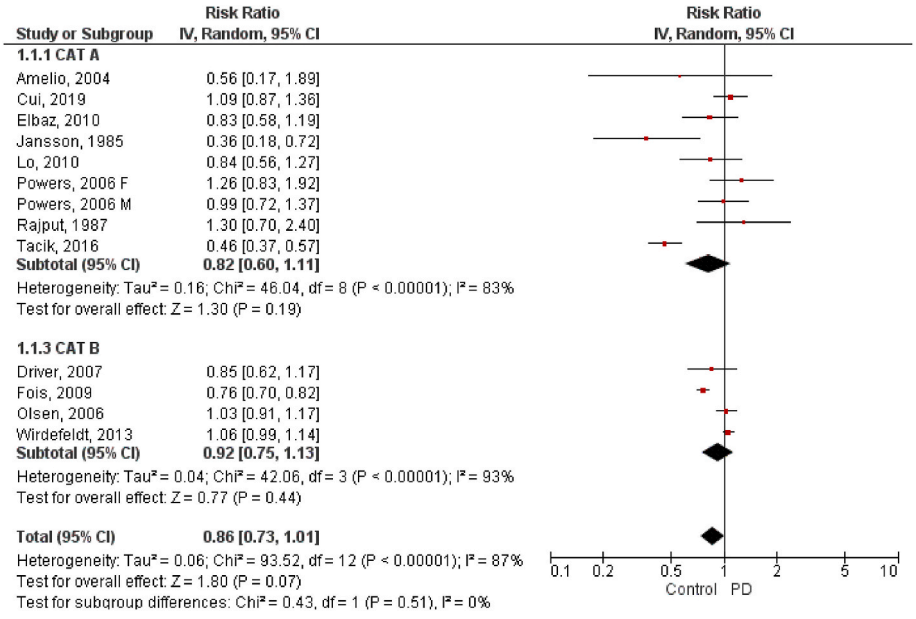

Fig. 1B. Overall cancer before PD.

3.1. Cancer risk before PD diagnosis

There was no association between overall cancer risk in patients with PD prior to the diagnosis of PD among CAT A and B studies (Fig. 1B). The same tendency was observed in the sensitivity analysis in any of the categories or in all the studies combined (Supplementary material S2). Only three studies (two CAT A study and one CAT B2 study) reported a decreased cancer risk in patients with PD, whereas none of the other studies reported an association between cancer and PD (S2). The risk of lung and uterine cancers was lower among PD patients only because of the presence of CAT B studies, but there was no association between PD and cancer in CAT A studies (Supplementary material S3). In organ-specific analyses there was no association between PD and bladder, breast, colorectal, prostate cancers or cutaneous melanoma in either CAT A or CAT B studies (S3).

3.2. Cancer risk after PD diagnosis

There was no association between PD and overall cancer risk in any of the categories or in the entire cohort (Fig. 1C). The risk of cutaneous melanoma was higher in PD patients than in non-PD patients, with considerably higher risk estimates in CAT A studies (Supplementary material, S4). The risks of lung, urinary tract and colorectal cancers were lower in patients with PD, but these associations were observed only in CAT B studies. Other organ-specific results consistently showed no association between PD and breast or prostate cancers among all studies. Additionally, uterine cancer, which was only examined in CAT B studies, was not found to be associated with PD.

3.3. Cancer risk in genetic PD subgroups

As previously stated, we excluded studies examining cancer risk in monogenic Parkinson's disease cohorts. Three out of the four studies in genetic subgroups *(LRKK2* gene), performed during the period found an increased risk of cancer, particularly in breast cancer risk in genetic carriers [51,52,53], whereas one study did not find any association between cancer risk and PD [54].

4. Discussion

In this meta-analysis, the impact of PD diagnosis validity on the associations between PD and cancer was explored across 34 research articles. In the CAT A studies, which are characterized by the highest diagnostic validity of PD, we did not observe any association between overall cancer risk and PD. Furthermore, CAT A studies showed that risk for cutaneous melanoma was increased among patients diagnosed with PD, a finding also reported in previous meta analyses [1–3]. Interestingly, following PD diagnosis, negative associations between PD and cancer were mostly found in the studies with unvalidated PD diagnosis (CAT B2), whereas only one study within the PD validated group (CAT A) showed a negative association. This was also clearly evident in the difference between CAT A and CAT B2 Risk Ratios estimates. This finding challenges the prevailing notion that PD is a "cancer-protective" condition. Consistent with existing evidence [23], these results underscore the limited meaningfulness of investigating overall cancer risk in PD patients while also demonstrating the crucial importance of diagnostic PD validity methods when evaluating the associations.

High heterogeneity has been recognized in earlier meta-analyses [1–3]. This is particularly pertinent considering that the outcome measure of these studies has been binary [55]. It may not be sensible to combine estimates when there is heterogeneity, and the potential sources of heterogeneity should be determined via methods such as subgroup analysis [56]. Our findings underscore the significant impact of variability in the correctness of PD case definitions on the validity of the results. Indeed, a similar finding seems to concern PD mortality data [26]. Importantly, studies with the most meticulous methods of PD validation comprise fewer patients than those that have used non-verified PD case definitions. Consequently, the outcomes of studies with

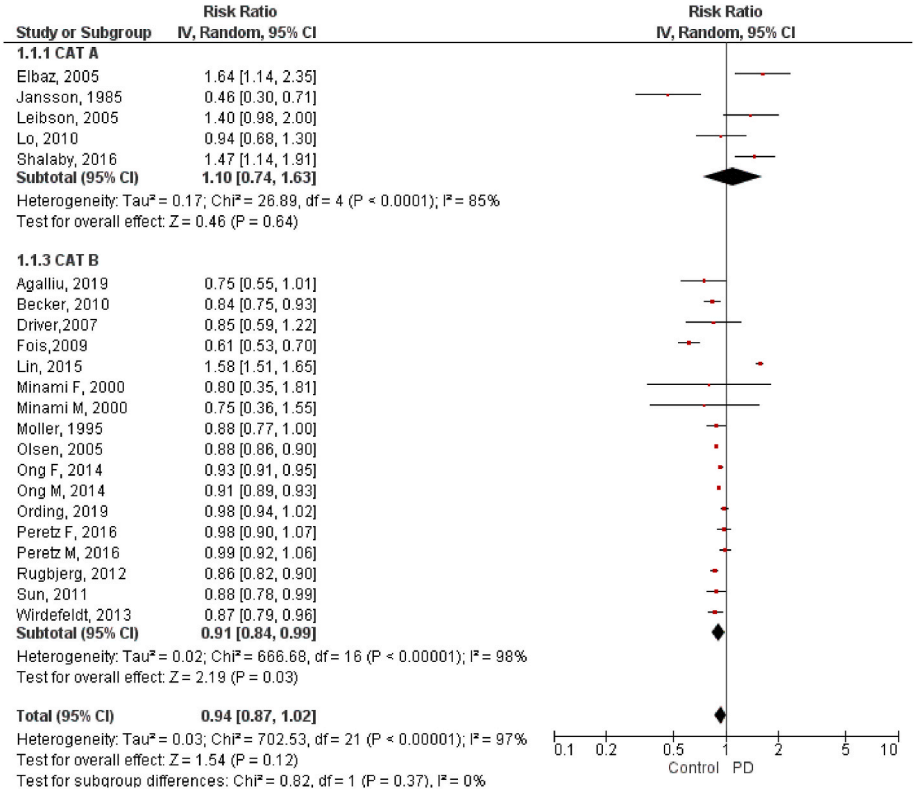

Fig. 1C. Overall cancer after PD.

less robust methodologies have disproportionately influenced the overall results, potentially introducing bias and leading to a perception of an inverse association between PD and cancer. Indeed, when pooling all studies investigating overall cancer risk in PD patients within the current dataset and omitting diagnostic validity categories and timing in relation to PD diagnosis, we observed a result similar to previous meta-analyses, due to the combined number of CAT B patients in the analysis (Fig. 2). This seemed to be driven by cohort studies, which also far more often lacked robust validation.

On average, the cohort studies included in our review featured approximately 24,000 patients with PD, in contrast to around 1470 cases in case-control studies. This disparity reflects a common methodological difference—cohort studies often rely on large-scale administrative datasets, which enable broader population coverage and statistical power. However, the use of such data typically comes at the cost of limited clinical validation. In practice, detailed confirmation of individual diagnoses in large datasets is often infeasible due to resource constraints.

As our sensitivity analysis demonstrated, even partial validation did not substantially improve the assessment of cancer outcomes. This may be attributed to limitations in outcome classification accuracy. Specifically, high specificity, while necessary, is insufficient alone to ensure high positive predictive value, particularly when the prevalence of the disease is low. In such contexts, even a small proportion of false positives can lead to a problematic number of misclassified individuals [57].

Moreover, the validity of administrative data for PD research is known to vary. Prior studies have reported substantial heterogeneity in the accuracy of PD case identification from routine healthcare records [58]. Additionally, recent findings from the U.S. Veterans Affairs database indicate ongoing challenges with diagnostic validity, including potential racial biases [59]. These issues underscore the need for caution and methodological rigor in interpreting results derived from administrative data sources.

Interestingly, none of the four studies in genetic PD subgroups reported a negative association between cancer and PD but the majority (3/4) found a positive association. The generalizability of these results

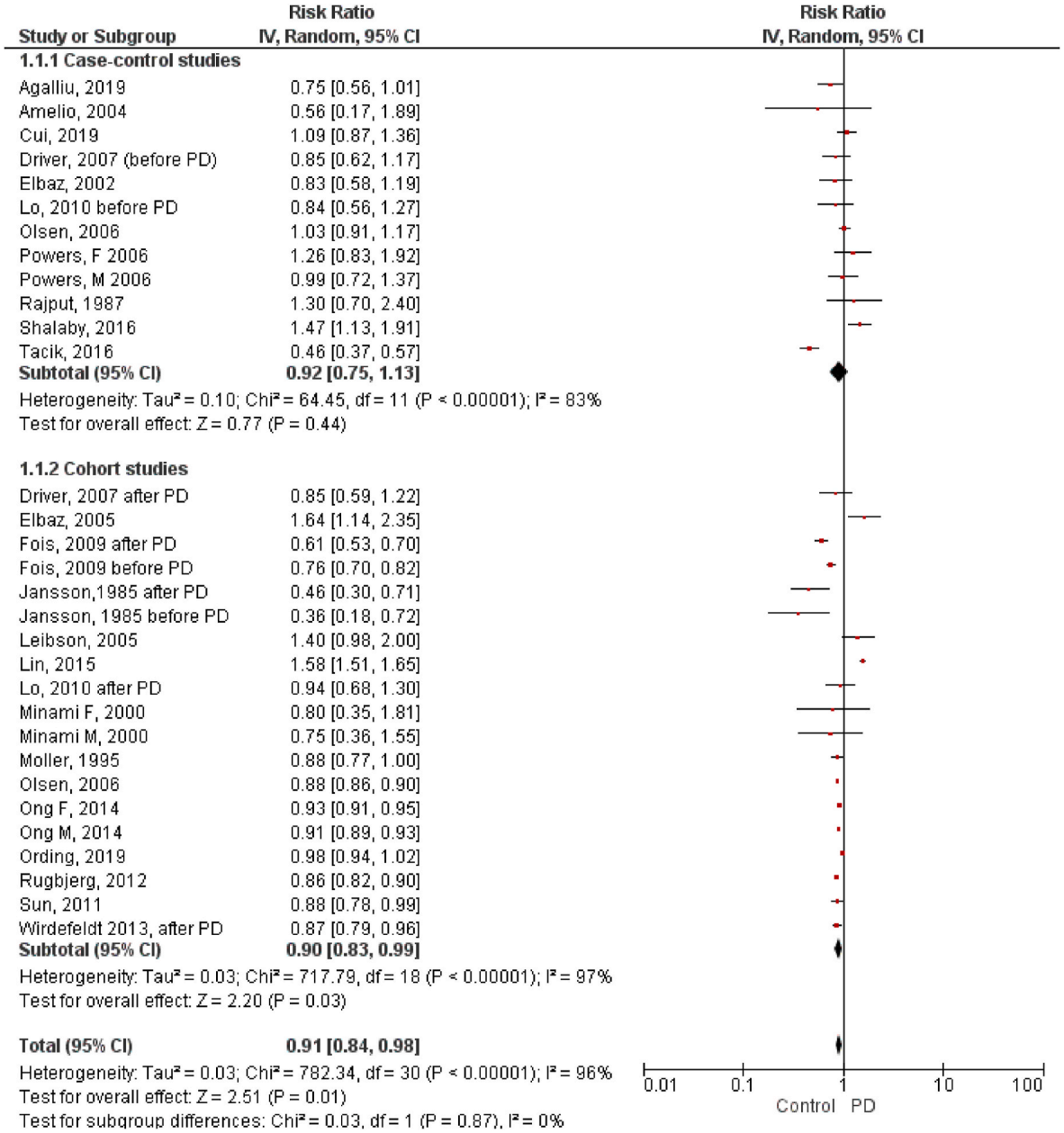

Fig. 2. Overall cancer risk in PD patients in combined analysis of case-control and cohort studies.

to the wider PD population is limited, but it should be noted that the validity of the PD diagnosis is naturally very high in these studies. It is unclear why studies with less robust PD case definitions more often find negative associations between PD and cancer. However, it has been reported that inception studies report lower standardized mortality ratios between PD patients and controls than non-inception studies, possibly because of differences in diagnostic accuracy [26]. It therefore seems possible that in the studies where PD data validity is lower the higher mortality of the assumed PD cohort leads to fewer cancer diagnoses since patients die from other causes before developing cancer. Our findings also illustrate that the studies without robust PD verification dilute the robust association between PD and melanoma. In five CAT A studies, the RR for melanoma after PD diagnosis was 5.78 (95 % CI 2.75–12.13), while in fourteen CAT B studies, it decreased to 1.37 (1.18–1.59). However, similar regression towards the mean observed in CAT B studies was not evident in CAT A studies that included cancer types that are negatively associated with PD. Methodological differences are important, as indicated by the conflicting results of two Taiwanese studies (both CAT B2 studies) investigating overall cancer risk after PD diagnosis [18,45]. The absence of associations between cancer and PD preceding PD diagnosis also remains somewhat unclear, but this phenomenon may be partially attributed to survival bias, which has been shown to exert a statistically significant impact on results when investigating PD risk following cancer [42]. It is also important to note that chronic, progressive disease may remain undiagnosed in individuals who have already been diagnosed with another such disorder [60,61]. The negative association may therefore partly result from possible underdiagnosis of cancer in PD patients.

The positive association between PD and melanoma, as observed in our data, is a well-established phenomenon, and several pathogenic mechanisms have been proposed to explain this relationship [62–64]. Conversely, the consistently lower risk of lung, bladder, and colorectal cancer in PD patients, as demonstrated in our analyses, warrants consideration. These cancers are strongly associated with smoking, and thus, their reduced incidence in PD patients could be attributed to the lower prevalence of smoking in this population. It is also possible that the biology of these cancers is different in PD patients than in the general population. Considering, that this reduced risk was observed in Category B studies, it is essential to conduct future organ-specific analyses utilizing validated PD data.

The strengths of this PRISMA-guided meta-analysis include the high quality of the majority of included studies according to the Newcastle–Ottawa Scale. To provide a consistent analysis of the association between PD and cancer, we included only studies that did not investigate a specific monogenic subgroup of PD, and we excluded the few studies investigating the prevalence of PD in cancer patients. Apart from previous meta-analysis we also excluded studies relying on mortality data due to their documented inaccuracies [65–68]. In contrast to the previous meta-analysis [2] we included four additional articles [11,32,34,38] on cancer incidence in PD patients and also included a study on cancer occurrence before PD only partially assessed earlier [22]. Additionally, several limitations of our analysis should be acknowledged. Our pooled estimates on organ-specific cancers are drawn from a modest number of CAT A studies, making it difficult to evaluate the association with PD. Moreover, organ-specific analyses were not feasible for many types of cancer because of the lack of studies fulfilling the inclusion criteria. The categorization of the included studies was based on the data provided in the articles; therefore, some studies with insufficient or lacking information on the validation of the diagnosis could have been misclassified. Nevertheless, it should be noted that our results are quite consistent with previous data if study categorization is disregarded, as shown by our sensitivity analysis [2–4]. We note that converting odds ratios (ORs) to risk ratios (RRs) may lead to overestimation when the outcome is not rare. Although we applied a standard conversion formula to adjust for this, the resulting RRs should be interpreted with caution. Our data also included a few studies (especially CAT A) conducted outside of the United States and Europe. Considering the differences in both cancer and PD epidemiology between populations, it would be very important to have more data of diverse ethnic and geographical origins [69].

Connections between PD and cancer are particularly intriguing because it is difficult to conceptualize two different diseases at the cellular level: the hallmark of PD is the degeneration of dopaminergic neurons in the substantia nigra, whereas uncontrolled cell growth is a key feature in all cancers. Furthermore, the identification of possible early triggering risk factors is highly valuable for the development of therapeutic strategies for both chronic and progressive disorders. Our results suggest that PD cannot be considered a fixed predisposing or protecting state in terms of cancer risk. It is essential to note the existence of subgroups within both PD and cancer populations. The examination of overall cancer risk across all PD patients may therefore be misguided, given the inherent heterogeneity in these conditions. Therefore, future analyses must strive for better precision to contribute meaningfully to the understanding of underlying mechanisms in various cancers and across the spectrum of Lewy body diseases.

CRediT authorship contribution statement

Ayla Mehdiyeva: Writing – original draft, Software, Methodology, Data curation. **Valtteri Kaasinen:** Writing – review & editing, Supervision, Formal analysis. **Eetu Heervä:** Writing – review & editing, Formal analysis. **Jussi O.T. Sipilä:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology, Formal analysis, Conceptualization.

Data availability

This manuscript is based on previous original research which is available from the publishers.

Financial disclosure related to research covered in this article

Nothing to declare.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Ayla Mehdiyeva reports financial support was provided by Maire Jokinen Foundation. Ayla Mehdiyeva reports financial support was provided by The Finnish Parkinson Foundation. Ayla Mehdiyeva reports a relationship with Sanofi that includes: travel reimbursement. Ayla Mehdiyeva reports a relationship with Abbvie that includes: travel reimbursement. Valtteri Kaasinen reports a relationship with Abbvie that includes: consulting or advisory, speaking and lecture fees, and travel reimbursement. Valtteri Kaasinen reports a relationship with Nordic Infucare AB that includes: consulting or advisory, speaking and lecture fees, and travel reimbursement. Valtteri Kaasinen reports a relationship with Eisai that includes: speaking and lecture fees. Valtteri Kaasinen reports a relationship with Teva that includes: speaking and lecture fees. Jussi Sipila reports a relationship with Terveystalo that includes: speaking and lecture fees. Jussi Sipila reports a relationship with Medaffcon that includes: consulting or advisory. Jussi Sipila reports

a relationship with Sandoz that includes: consulting or advisory. Jussi Sipila reports a relationship with Boerhringer Ingelheim that includes: consulting or advisory. Jussi Sipila reports a relationship with Lundbeck that includes: travel reimbursement. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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References

[1] A. Bajaj, J.A. Driver, E.S. Schernhammer, Parkinson's disease and cancer risk: a systematic review and meta-analysis, Cancer Causes Control 21 (5) (2010) 697–707, https://doi.org/10.1007/s10552-009-9497-6.
[2] Y.Q. Leong, S.W.H. Lee, K.Y. Ng, Cancer risk in Parkinson disease: an updated systematic review and meta-analysis, Eur. J. Neurol. 28 (12) (2021) 4219–4237, https://doi.org/10.1111/ene.15069.
[3] X. Zhang, D. Guarin, N. Mohammadzadehhonarvar, X. Chen, X. Gao, Parkinson's disease and cancer: a systematic review and meta-analysis of over 17 million participants [published correction appears in BMJ Open. 2021 Sep 22;11(9): e046329corr1], BMJ Open 11 (7) (2021) e046329, https://doi.org/10.1136/bmjopen-2020-046329. Published 2021 Jul 2.
[4] F. Catalá-López, M. Suárez-Pinilla, P. Suárez-Pinilla, et al., Inverse and direct cancer comorbidity in people with central nervous system disorders: a meta-analysis of cancer incidence in 577,013 participants of 50 observational studies, Psychother. Psychosom. 83 (2) (2014) 89–105, https://doi.org/10.1159/000356498.
[5] J.Y.S. Lee, J.H. Ng, S.E. Saffari, E.K. Tan, Parkinson's disease and cancer: a systematic review and meta-analysis on the influence of lifestyle habits, genetic variants, and gender, Aging (Albany NY) 14 (5) (2022) 2148–2173, https://doi.org/10.18632/aging.203932.
[6] V. Gallo, P. Vineis, M. Cancellieri, et al., Exploring causality of the association between smoking and Parkinson's disease, Int. J. Epidemiol. 48 (3) (2019) 912–925, https://doi.org/10.1093/ije/dyy230.
[7] B. Mappin-Kasirer, H. Pan, S. Lewington, et al., Tobacco smoking and the risk of Parkinson disease: a 65-year follow-up of 30,000 male British doctors, Neurology 94 (20) (2020) e2132–e2138, https://doi.org/10.1212/WNL.0000000000009437.
[8] K.N. Rose, M.A. Schwarzschild, S.N. Gomperts, Clearing the smoke: what protects smokers from Parkinson's disease? Mov. Disord. 39 (2) (2024) 267–272, https://doi.org/10.1002/mds.29707.
[9] A.J. Sasco, M.B. Secretan, K. Straif, Tobacco smoking and cancer: a brief review of recent epidemiological evidence, Lung Cancer 45 (Suppl 2) (2004) S3–S9, https://doi.org/10.1016/j.lungcan.2004.07.998.
[10] R.Y. Lo, C.M. Tanner, S.K. Van Den Eeden, K.B. Albers, A.D. Leimpeter, L. M. Nelson, Comorbid cancer in Parkinson's disease, Mov. Disord. 25 (12) (2010) 1809–1817, https://doi.org/10.1002/mds.23246.
[11] C.L. Leibson, D.M. Maraganore, J.H. Bower, J.E. Ransom, P.C. O'brien, W. A. Rocca, Comorbid conditions associated with Parkinson's disease: a population-based study, Mov. Disord. 21 (4) (2006) 446–455, https://doi.org/10.1002/mds.20685.
[12] D. Michal Freedman, Jincao Wu, Honglei Chen, et al., Associations between cancer and Parkinson's disease in U.S. elderly adults, Int. J. Epidemiol. 45 (3) (June 2016) 741–751, https://doi.org/10.1093/ije/dyw016.
[13] J.M. Bertoni, J.P. Arlette, H.H. Fernandez, et al., Increased melanoma risk in Parkinson disease: a prospective clinicopathological study, Arch. Neurol. 67 (3) (2010) 347–352, https://doi.org/10.1001/archneurol.2010.1.
[14] R. Inzelberg, J.M. Rabey, E. Melamed, et al., High prevalence of malignant melanoma in Israeli patients with Parkinson's disease, J. Neural Transm. 118 (8) (2011) 1199–1207, https://doi.org/10.1007/s00702-011-0580-2.
[15] S.R. Schwid, J. Bausch, D. Oakes, et al., Cancer incidence in a trial of an antiapoptotic agent for Parkinson's disease, Mov. Disord. 25 (12) (2010) 1801–1808, https://doi.org/10.1002/mds.23006.
[16] S.Y. Shalaby, E.D. Louis, Increased odds of melanoma: Parkinson's disease, essential tremor, dystonia versus controls, Neuroepidemiology 46 (2) (2016) 128–136, https://doi.org/10.1159/000443794.
[17] H. Møller, L. Mellemkjaer, J.K. McLaughlin, J.H. Olsen, Occurrence of different cancers in patients with Parkinson's disease, Br. Med. J. 310 (6993) (1995) 1500–1501, https://doi.org/10.1136/bmj.310.6993.1500.
[18] P.Y. Lin, S.N. Chang, T.H. Hsiao, B.T. Huang, C.H. Lin, P.C. Yang, Association between Parkinson disease and risk of cancer in taiwan, JAMA Oncol. 1 (5) (2015) 633–640, https://doi.org/10.1001/jamaoncol.2015.1752.
[19] E.L. Ong, R. Goldacre, M. Goldacre, Differential risks of cancer types in people with Parkinson's disease: a national record-linkage study, Eur. J. Cancer 50 (14) (2014) 2456–2462, https://doi.org/10.1016/j.ejca.2014.06.018.
[20] J.H. Olsen, S. Friis, K. Frederiksen, J.K. McLaughlin, L. Mellemkjaer, H. Møller, Atypical cancer pattern in patients with Parkinson's disease, Br. J. Cancer 92 (1) (2005) 201–205, https://doi.org/10.1038/sj.bjc.6602279.
[21] H.J. Ryu, J.H. Park, M. Choi, et al., Parkinson's disease and skin cancer risk: a nationwide population-based cohort study in Korea, J. Eur. Acad. Dermatol. Venereol. 34 (12) (2020) 2775–2780, https://doi.org/10.1111/jdv.16462.
[22] K. Wirdefeldt, C.E. Weibull, H. Chen, et al., Parkinson's disease and cancer: a register-based family study, Am. J. Epidemiol. 179 (1) (2014) 85–94, https://doi.org/10.1093/aje/kwt232.
[23] P.E. Sugier, E.A. Lucotte, C. Domenighetti, et al., Investigation of shared genetic risk factors between Parkinson's disease and cancers, Mov. Disord. 38 (4) (2023) 604–615, https://doi.org/10.1002/mds.29337.
[24] K. Senkevich, S. Bandres-Ciga, E. Yu, et al., No evidence for a causal relationship between cancers and Parkinson's disease, J. Parkinsons Dis. 11 (2) (2021) 801–809, https://doi.org/10.3233/JPD-202474.
[25] L. Wang, J.Y. Deng, X.Y. Fan, D. Yang, P.Y. Zhu, X.M. Wang, Absence of causal relationship between Parkinson's disease and subsequent prostate cancer: evidence from meta-analysis and Mendelian randomization studies, Front. Oncol. 13 (2024) 1323812, https://doi.org/10.3389/fonc.2023.1323812. Published 2024 Jan 4.
[26] A.D. Macleod, K.S. Taylor, C.E. Counsell, Mortality in Parkinson's disease: a systematic review and meta-analysis, Mov. Disord. 29 (13) (2014) 1615–1622, https://doi.org/10.1002/mds.25898.
[27] L. Wermuth, C.F. Lassen, L. Himmerslev, J. Olsen, B. Ritz, Validation of hospital register-based diagnosis of Parkinson's disease, Dan Med J 59 (3) (2012) A4391.
[28] M.J. Page, J.E. McKenzie, P.M. Bossuyt, et al., The PRISMA 2020 statement: an updated guideline for reporting systematic reviews, Br. Med. J. 372 (2021) n71, https://doi.org/10.1136/bmj.n71. (Accessed 29 March 2021).
[29] C. Becker, G.P. Brobert, S. Johansson, S.S. Jick, C.R. Meier, Cancer risk in association with Parkinson disease: a population-based study, Park. Relat. Disord. 16 (3) (2010) 186–190, https://doi.org/10.1016/j.parkreldis.2009.11.005.
[30] C. Peretz, R. Gurel, V. Rozani, et al., Cancer incidence among Parkinson's disease patients in a 10-yrs time-window around disease onset: a large-scale cohort study, Park. Relat. Disord. 28 (2016) 68–72, https://doi.org/10.1016/j.parkreldis.2016.04.028.
[31] J.A. Driver, G. Logroscino, J.E. Buring, J.M. Gaziano, T. Kurth, A prospective cohort study of cancer incidence following the diagnosis of Parkinson's disease, Cancer Epidemiol. Biomarkers Prev. 16 (6) (2007) 1260–1265, https://doi.org/10.1158/1055-9965.EPI-07-0038.
[32] B. Jansson, J. Jankovic, Low cancer rates among patients with Parkinson's disease, Ann. Neurol. 17 (5) (1985) 505–509, https://doi.org/10.1002/ana.410170514.
[33] A.H. Rajput, K.P. Offord, C.M. Beard, L.T. Kurland, A case-control study of smoking habits, dementia, and other illnesses in idiopathic Parkinson's disease, Neurology 37 (2) (1987) 226–232, https://doi.org/10.1212/wnl.37.2.226.
[34] A. Elbaz, B.J. Peterson, P. Yang, et al., Nonfatal cancer preceding Parkinson's disease: a case-control study, Epidemiology 13 (2) (2002) 157–164, https://doi.org/10.1097/00001648-200203000-00010.
[35] M. D'Amelio, P. Ragonese, L. Morgante, et al., Tumor diagnosis preceding Parkinson's disease: a case-control study, Mov. Disord. 19 (7) (2004) 807–811, https://doi.org/10.1002/mds.20123.
[36] K.M. Powers, T. Smith-Weller, G.M. Franklin, WT Jr Longstreth, P.D. Swanson, H. Checkoway, Diabetes, smoking, and other medical conditions in relation to Parkinson's disease risk, Park. Relat. Disord. 12 (3) (2006) 185–189, https://doi.org/10.1016/j.parkreldis.2005.09.004.
[37] J.H. Olsen, S. Friis, K. Frederiksen, Malignant melanoma and other types of cancer preceding Parkinson disease, Epidemiology 17 (5) (2006) 582–587, https://doi.org/10.1097/01.ede.0000229445.90471.5e.
[38] J.A. Driver, T. Kurth, J.E. Buring, J.M. Gaziano, G. Logroscino, Prospective case-control study of nonfatal cancer preceding the diagnosis of Parkinson's disease, Cancer Causes Control 18 (7) (2007 Sep) 705–711, https://doi.org/10.1007/s10552-007-9005-9. Epub 2007 Jun 12. PMID: 17562193.
[39] A.F. Fois, C.J. Wotton, D. Yeates, M.R. Turner, M.J. Goldacre, Cancer in patients with motor neuron disease, multiple sclerosis and Parkinson's disease: record linkage studies, J. Neurol. Neurosurg. Psychiatry 81 (2) (2010) 215–221, https://doi.org/10.1136/jnnp.2009.175463.
[40] P. Tacik, S. Curry, S. Fujioka, A. Strongosky, R.J. Uitti, J.A. van Gerpen, N.N. Diehl, M.G. Heckman, Z.K. Wszolek, Cancer in Parkinson's disease, Parkinson. Relat. Disord. 31 (2016) 28-33. doi: 10.1016/j.parkreldis.2016.06.014. Epub 2016 Jun 20. PMID: 27372241; PMCID: PMC5048511.
[41] L.A. Dalvin, G.M. Damento, B.P. Yawn, B.A. Abbott, D.O. Hodge, J.S. Pulido, Parkinson disease and melanoma: confirming and reexamining an association, Mayo Clin. Proc. 92 (7) (2017) 1070–1079, https://doi.org/10.1016/j.mayocp.2017.03.014.
[42] X. Cui, Z. Liew, J. Hansen, P.C. Lee, O.A. Arah, B. Ritz, Cancers preceding Parkinson's disease after adjustment for bias in a Danish population-based case-control study, Neuroepidemiology 52 (3–4) (2019) 136–143, https://doi.org/10.1159/000494292.
[43] Y. Minami, R. Yamamoto, M. Nishikouri, A. Fukao, S. Hisamichi, Mortality and cancer incidence in patients with Parkinson's disease, J. Neurol. 247 (6) (2000) 429–434.
[44] A. Elbaz, B.J. Peterson, J.H. Bower, et al., Risk of cancer after the diagnosis of Parkinson's disease: a historical cohort study, Mov. Disord. 20 (6) (2005) 719–725, https://doi.org/10.1002/mds.20401.

[45] L.M. Sun, J.A. Liang, S.N. Chang, F.C. Sung, C.H. Muo, C.H. Kao, Analysis of Parkinson's disease and subsequent cancer risk in Taiwan: a nationwide population-based cohort study, Neuroepidemiology 37 (2) (2011) 114–119, https://doi.org/10.1159/000331489.

[46] K. Rugbjerg, S. Friis, C.F. Lassen, B. Ritz, J.H. Olsen, Malignant melanoma, breast cancer and other cancers in patients with Parkinson's disease, Int. J. Cancer 131 (8) (2012) 1904–1911, https://doi.org/10.1002/ijc.27443.

[47] S. Lerman, B. Amichai, G. Weinstein, V. Shalev, G. Chodick, Parkinson's disease, melanoma, and keratinocyte carcinoma: a population-based study, Neuroepidemiology 50 (3–4) (2018) 168–173, https://doi.org/10.1159/000487855.

[48] J.H. Park, D.H. Kim, Y.G. Park, et al., Cancer risk in patients with Parkinson's disease in South Korea: a nationwide, population-based cohort study, Eur. J. Cancer 117 (2019) 5–13, https://doi.org/10.1016/j.ejca.2019.04.033.

[49] A.G. Ording, K. Veres, E. Horváth-Puhó, et al., Alzheimer's and Parkinson's diseases and the risk of cancer: a cohort study, J Alzheimers Dis 72 (4) (2019) 1269–1277, https://doi.org/10.3233/JAD-190867.

[50] I. Agalliu, M. San Luciano, A. Mirelman, et al., Higher frequency of certain cancers in LRRK2 G2019S mutation carriers with Parkinson disease: a pooled analysis, JAMA Neurol. 72 (1) (2015) 58–65.

[51] R. Saunders-Pullman, M.J. Barrett, K.M. Stanley, M.S. Luciano, V. Shanker, L. Severt, A. Hunt, D. Raymond, L.J. Ozelius, S.B. Bressman, LRRK2 G2019S mutations are associated with an increased cancer risk in Parkinson disease, Mov. Disord. 25 (15) (2010 Nov 15) 2536–2541, https://doi.org/10.1002/mds.23314. PMID: 20818610; PMCID: PMC2978749.

[52] R. Inzelberg, O.S. Cohen, J. Aharon-Peretz, I. Schlesinger, R. Gershoni-Baruch, R. Djaldetti, Z. Nitsan, L. Ephraty, O. Tunkel, E. Kozlova, L. Inzelberg, N. Kaplan, T. Fixler Mehr, A. Mory, E. Dagan, E. Schechtman, E. Friedman, S. Hassin-Baer, The LRRK2 G2019S mutation is associated with Parkinson disease and concomitant non-skin cancers, Neurology 78 (11) (2012 Mar 13) 781–786, https://doi.org/10.1212/WNL.0b013e318249f673. Epub 2012 Feb 8. PMID: 22323743.

[53] B.J. Warø, J.O. Aasly, Exploring cancer in *LRRK2* mutation carriers and idiopathic Parkinson's disease, Brain Behav 8 (1) (2017 Dec 7) e00858, https://doi.org/10.1002/brb3.858. PMID: 29568677; PMCID: PMC5853627.

[54] R. Allegra, S. Tunesi, R. Cilia, G. Pezzoli, S. Goldwurm, LRRK2-G2019S mutation is not associated with an increased cancer risk: a kin-cohort study, Mov. Disord. 29 (10) (2014 Sep) 1325–1326, https://doi.org/10.1002/mds.25969. Epub 2014 Jul 22. PMID: 25048644.

[55] A.C. Alba, P.E. Alexander, J. Chang, J. MacIsaac, S. DeFry, G.H. Guyatt, High statistical heterogeneity is more frequent in meta-analysis of continuous than binary outcomes, J. Clin. Epidemiol. 70 (2016) 129–135, https://doi.org/10.1016/j.jclinepi.2015.09.005.

[56] C.P. Cordero, A.L. Dans, Key concepts in clinical epidemiology: detecting and dealing with heterogeneity in meta-analyses, J. Clin. Epidemiol. 130 (2021) 149–151, https://doi.org/10.1016/j.jclinepi.2020.09.045.

[57] J. Chubak, G. Pocobelli, N.S. Weiss, Tradeoffs between accuracy measures for electronic health care data algorithms, J. Clin. Epidemiol. 65 (3) (2012 Mar) 343–349.e2, https://doi.org/10.1016/j.jclinepi.2011.09.002. Epub 2011 Dec 23. PMID: 22197520; PMCID: PMC3264740.

[58] Z. Harding, T. Wilkinson, A. Stevenson, S. Horrocks, A. Ly, C. Schnier, D.P. Breen, K. Rannikmäe, C.L.M. Sudlow, Identifying Parkinson's disease and parkinsonism cases using routinely collected healthcare data: a systematic review, PLoS One 14 (1) (2019 Jan 31) e0198736, https://doi.org/10.1371/journal.pone.0198736. PMID: 30703084; PMCID: PMC6354966.

[59] S.M. Goldman, F.M. Weaver, L. Cao, B. Gonzalez, K.T. Stroupe, K. Colletta, S. Jugnundan, E.G. Brown, C.M. Tanner, Validation of Parkinson's disease ascertainment in the veterans administration electronic medical record, Mov. Disord. 40 (2) (2025 Feb) 245–253, https://doi.org/10.1002/mds.30075. Epub 2024 Dec 4. PMID: 39629536; PMCID: PMC11832812.

[60] O. Kostopoulou, B.C. Delaney, C.W. Munro, Diagnostic difficulty and error in primary care–a systematic review, Fam. Pract. 25 (6) (2008) 400–413, https://doi.org/10.1093/fampra/cmn071.

[61] H. Singh, S. Sethi, M. Raber, L.A. Petersen, Errors in cancer diagnosis: current understanding and future directions, J. Clin. Oncol. 25 (31) (2007) 5009–5018, https://doi.org/10.1200/JCO.2007.13.2142.

[62] T. Pan, X. Li, J. Jankovic, The association between Parkinson's disease and melanoma, Int. J. Cancer 128 (10) (2011) 2251–2260, https://doi.org/10.1002/ijc.25912.

[63] T. Guttuso Jr., High lithium levels in tobacco may account for reduced incidences of both Parkinson's disease and melanoma in smokers through enhanced β-catenin-mediated activity, Med. Hypotheses 131 (2019) 109302, https://doi.org/10.1016/j.mehy.2019.109302.

[64] D.N. Dean, J.C. Lee, Linking Parkinson's disease and melanoma: interplay between α-synuclein and Pmel17 amyloid formation, Mov. Disord. 36 (7) (2021) 1489–1498, https://doi.org/10.1002/mds.28655.

[65] L. Kadastik-Eerme, N. Taba, T. Asser, P. Taba, Incidence and mortality of Parkinson's disease in Estonia, Neuroepidemiology 53 (2019) 63–72.

[66] H. Shi, C. Counsell, Accuracy of death certificates for recDa parkinsonian syndromes and associated dementia, J. Neurol. 268 (2021) 140–146.

[67] P. Hobson, J. Meara, Mortality and quality of death certification in a cohort of patients with Parkinson's disease and matched controls in North Wales, UK at 18 years: a community-based cohort study, BMJ Open 8 (2018) e018969.

[68] M. Moscovich, G. Boschetti, A. Moro, H.A.G. Teive, A. Hassan, R.P. Munhoz, Death certificate data and causes of death in patients with parkinsonism, Park. Relat. Disord. 41 (2017) 99–103, https://doi.org/10.1016/j.parkreldis.2017.05.022.

[69] Global Burden of Disease 2019 Cancer Collaboration, J.M. Kocarnik, K. Compton, Cancer incidence, mortality, years of life lost, years lived with disability, and disability-adjusted life years for 29 cancer groups from 2010 to 2019: a systematic analysis for the global burden of disease study 2019, JAMA Oncol. 8 (3) (2022) 420–444, https://doi.org/10.1001/jamaoncol.2021.6987.