

MANAGEMENT OF VITILIGO

Ph.D. Thesis

Translational Medicine Program

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1 LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BRAF	B-Raf Proto-Oncogene, Serine/Threonine Kinase
BSA	Body Surface Area
CI	Confidence Interval
CTLA-4	Cytotoxic T-Lymphocyte-Associated Protein 4
CTL	Cytotoxic T Lymphocyte
CXCL9/10	C-X-C Motif Chemokine Ligand 9/10
F-VASI	Facial Vitiligo Area Scoring Index
F-VASI75	75% Improvement in Facial-VASI Score
FDA	Food and Drug Administration
GRADE	Grading of Recommendations, Assessment, Development and Evaluation
HR	Hazard Ratio
IFN-γ	Interferon Gamma
JAK	Janus Kinase
NB-UVB	Narrowband Ultraviolet B
NK	Natural Killer Cell
NMSC	Non-Melanoma Skin Cancer
PICO	Population, Intervention, Comparator, Outcome
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO	International Prospective Register of Systematic Reviews
PUVA	Psoralen plus Ultraviolet A
RCT	Randomised Controlled Trial
RR	Risk Ratio
STAT	Signal Transducer and Activator of Transcription
T-VASI	Total Vitiligo Area Scoring Index
T-VASI50	50% Improvement in Total-VASI Score
TYR	Tyrosinase Gene
UV	Ultraviolet
VASI	Vitiligo Area Scoring Index
WHO	World Health Organization

2 STUDENT PROFILE

2.1 Vision, mission, and specific goals

My vision is to improve the clinical management of vitiligo through rigorous evidence synthesis and the translation of emerging immunological discoveries into practice-changing therapeutic strategies. My mission is to evaluate the efficacy and safety of novel JAK inhibitor therapies in vitiligo, and to clarify the association between vitiligo and malignancy risk, thereby supporting clinicians in making evidence-based decisions. My specific goals are to quantify the repigmentation efficacy of JAK inhibitors across clinical trial designs, and to determine whether vitiligo patients carry an elevated, reduced, or neutral risk of developing skin and systemic cancers compared to the general population.

2.2 Scientometrics

Metric	Value
Number of all publications	5
Cumulative IF	25.2
Publications related to the thesis	2
Number of citations on Google Scholar:	74
H-index:	3

The detailed bibliography of the student can be found in Section 16

2.3 Future plans

My future plan is to complete specialist training in dermatology, with a continued focus on inflammatory skin disease and immunology. I hope to contribute to clinical research in vitiligo, including participation in or initiation of prospective studies evaluating JAK inhibitor treatment strategies. I am also interested in contributing to ongoing post-authorisation safety work examining malignancy risk with JAK inhibitors in dermatological conditions. Alongside clinical and research commitments, I aim to

support junior researchers where possible and to incorporate patient-reported outcomes and quality of life measures into future trial work.

3 SUMMARY OF THE THESIS

This thesis presents two complementary systematic reviews and meta-analyses addressing critical knowledge gaps in the management of vitiligo, a chronic autoimmune depigmenting disorder affecting approximately 1–2% of the global population.

The first study evaluated the efficacy and safety of Janus kinase (JAK) inhibitors in patients with vitiligo, including both randomised controlled trials (RCTs) and open-label studies. Drawing on data from multiple trial populations, the analysis demonstrated that JAK inhibitors produce clinically meaningful and statistically significant repigmentation at the facial level, with a relative risk of 3.47 (95% CI: 0.98–12.22) for achieving $\geq 75\%$ improvement in Facial Vitiligo Area Scoring Index (F-VASI75) compared to placebo. Pooled VASI improvement reached a mean of 43.79% across included studies. Ruxolitinib cream (1.5%) emerged as the most evidence-supported topical JAK inhibitor, while oral formulations showed promising repigmentation in open-label cohorts (48.7–63.7%). Safety profiles were generally favourable; acneiform eruptions and nasopharyngitis were the most commonly reported adverse events, and serious systemic adverse events were rare.

The second study investigated the association between vitiligo and the risk of malignant neoplasms, using observational data from cohort and case-control studies involving hundreds of thousands of patients. The analysis revealed that vitiligo is associated with a significantly reduced risk of melanoma (HR: 0.80, 95% CI: 0.72–0.89) and non-melanoma skin cancer (NMSC) (HR: 0.38, 95% CI: 0.27–0.52), consistent with proposed immune surveillance mechanisms mediated by auto-reactive CD8⁺ T cells. In contrast, lymphoma risk was not significantly elevated (HR: 1.00, 95% CI: 0.87–1.14). These findings provide important context for the clinical use of JAK inhibitors in vitiligo, suggesting that the immunological environment of vitiligo may confer some inherent protection against cutaneous malignancy.

Together, these two studies provide a robust evidence base to support guideline-driven use of JAK inhibitors in vitiligo and to contextualise the oncological risk profile of this patient population.

4 GRAPHICAL ABSTRACT

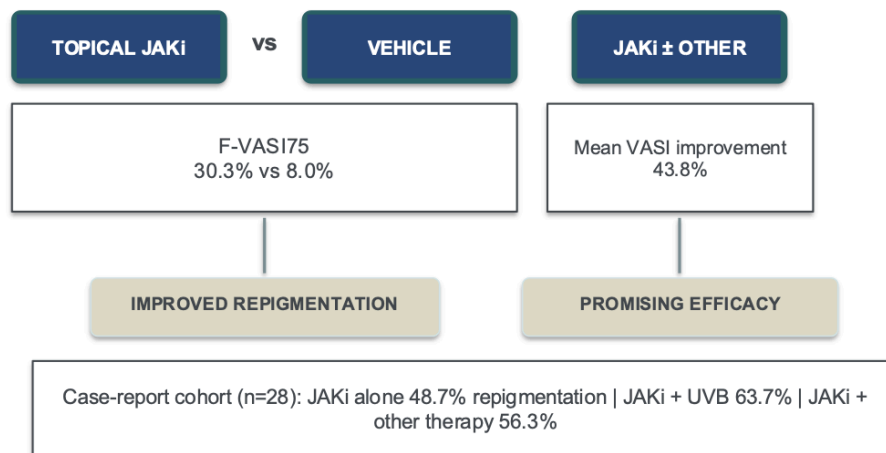
MANAGEMENT OF VITILIGO

Two systematic reviews and meta-analyses evaluating novel treatment efficacy and malignancy risk in vitiligo

CONTEXT: Vitiligo has a substantial disease burden; JAK inhibitors offer a targeted therapeutic approach, while the relationship between vitiligo and malignancy risk remains uncertain.

JAK inhibitors in vitiligo: efficacy and safety

Systematic review and meta-analysis



Cancer risk in patients with vitiligo

Systematic review and meta-analysis



IMPLICATION: Improving personalised patient care in vitiligo through effective targeted therapies and evidence-based assessment of long-term malignancy risk



CENTRE FOR TRANSLATIONAL MEDICINE

5 INTRODUCTION

5.1 Overview of the topic

5.1.1. What is the topic?

The topic of this thesis is the management of vitiligo, with a particular focus on evaluating emerging therapeutic strategies and addressing important long-term safety concerns. Specifically, this research investigates the efficacy and safety of JAK inhibitors for the treatment of vitiligo and examines the association between vitiligo and the risk of malignancy through two systematic reviews and meta-analyses. By synthesising the available evidence, this thesis aims to support evidence-based clinical decision-making and improve the management of patients with vitiligo.

5.1.2. What is the problem to solve?

Despite significant advances in the understanding and treatment of vitiligo, important clinical uncertainties remain. Although JAK inhibitors have emerged as a promising targeted therapy, evidence regarding their efficacy and safety has been fragmented and inconsistent. Furthermore, concerns regarding the long-term safety of these therapies, particularly their potential association with malignancy, persist. At the same time, the relationship between vitiligo itself and cancer risk remains unclear, with previous studies reporting conflicting results. Addressing these uncertainties is essential to support evidence-based treatment decisions, optimise patient management, and provide accurate counselling regarding both therapeutic outcomes and long-term safety.

5.1.3. What is the importance of the topic?

This thesis addresses two important areas of uncertainty in the management of vitiligo: the effectiveness of emerging targeted therapies and the long-term safety of patients with the disease. By systematically evaluating the efficacy and safety of JAK inhibitors alongside the association between vitiligo and malignancy, this research provides a comprehensive synthesis of the available evidence. The findings strengthen the evidence base for clinical practice, support informed treatment decisions and patient counselling, and identify areas where further research is needed to optimise the management of vitiligo.

5.1.4. What would be the impact of the research results?

The research presented in this thesis substantially advances the evidence base for the management of vitiligo by addressing important gaps in the current literature. To the

best of our knowledge, this is the first systematic review and meta-analysis to evaluate the efficacy of JAK inhibitors using evidence derived exclusively from randomised controlled trials, thereby providing the highest level of evidence for treatment effectiveness. Furthermore, this study is the first to generate an analytical cohort from published case reports and case series, allowing quantitative evaluation of outcomes in patients treated with JAK inhibitors outside controlled clinical trials. In addition, this thesis presents the first comprehensive systematic review and meta-analysis investigating the association between vitiligo and both cutaneous and non-cutaneous malignancies within a single study. Collectively, these findings provide novel evidence that informs clinical practice, establishes methodological foundations for future evidence synthesis, and identifies priorities for subsequent clinical and translational research in vitiligo.

5.2 Overview of vitiligo — epidemiology and pathogenesis

Vitiligo is a chronic, immune-mediated depigmenting disorder characterised by the selective destruction of melanocytes in the skin, mucous membranes, and occasionally hair follicles (1). It affects an estimated 1–2% of the global population regardless of sex or ethnicity, though its visibility and psychosocial impact are disproportionately felt in individuals with darker skin phototypes (2, 3). Despite its non-life-threatening nature, the disease imposes a disproportionate psychosocial burden. The psychosocial challenges of vitiligo are felt particularly acutely by individuals with darker skin tones, in whom lesion contrast is more conspicuous. Importantly, patients with vitiligo are likely to have concomitant anxiety, sleep disturbance, and depression (4-6).

Vitiligo is classified into segmental vitiligo (SV), which is unilateral and typically stable, and non-segmental vitiligo (NSV), the more common form, which is bilateral, progressive, and strongly associated with other autoimmune conditions including thyroid disease, type 1 diabetes mellitus, alopecia areata, and psoriasis (7). The autoimmune aetiology of NSV is now well established, with autoreactive CD8+ cytotoxic T lymphocytes playing a central role in the targeted destruction of melanocytes (8).

Central to the immunopathogenesis of vitiligo is the JAK/STAT signalling axis. Interferon-gamma (IFN- γ), produced primarily by CD8+ T cells and natural killer cells, signals through JAK1 and JAK2 to activate STAT1, which upregulates CXCL9 and CXCL10 (9). These chemokines recruit additional autoreactive T cells to the lesion, amplifying melanocyte destruction in a self-sustaining inflammatory loop (9). The recognition of this pathway as a central mediator of disease progression has provided a strong biological rationale for the development of targeted therapies aimed at inhibiting JAK/STAT signalling in vitiligo.

5.3 JAK inhibitors in vitiligo — background

JAK inhibitors are small molecules that competitively and reversibly inhibit one or more members of the Janus kinase family (JAK1, JAK2, JAK3, TYK2), thereby blocking cytokine-mediated activation of downstream STAT transcription factors (9). JAK inhibitors have transformed the management of several immune-mediated diseases including rheumatoid arthritis, psoriatic arthritis, atopic dermatitis, and alopecia areata (10). The biological plausibility of JAK inhibitors in vitiligo stems directly from the central role of IFN- γ /JAK/STAT in disease maintenance (9).

Several JAK inhibitors have been investigated in vitiligo. Ruxolitinib, a selective JAK1/JAK2 inhibitor, has been developed as a topical formulation (1.5% cream) and demonstrated efficacy in pivotal Phase 3 trials (TRuE-V1 and TRuE-V2) (11). Baricitinib (JAK1/JAK2), tofacitinib (JAK1/JAK3), and other agents have been studied in smaller trials and open-label studies (12-15). Currently, ruxolitinib cream is the only JAK inhibitor approved by the US Food and Drug Administration (FDA) for the treatment of non-segmental vitiligo in patients aged 12 years and over (16).

Despite the increasing body of evidence supporting the use of JAK inhibitors in vitiligo, important uncertainties remained at the time this study was initiated. Existing studies varied considerably in design, route of administration, outcome measures, and reporting practices, making it difficult to draw robust conclusions regarding overall efficacy and safety. Furthermore, no comprehensive quantitative synthesis had integrated evidence across the full spectrum of available study designs and JAK inhibitor formulations. Therefore, this study aimed to provide a comprehensive evaluation of the efficacy and safety of JAK inhibitors in vitiligo through a systematic review and meta-analysis,

while exploring differences according to formulation, study design, and outcome measures.

5.4 Vitiligo and cancer risk — background

The relationship between vitiligo and malignancy has attracted considerable scientific interest owing to the unique immunological mechanisms underlying the disease. The autoreactive CD8⁺ T-cell response responsible for melanocyte destruction may also enhance immune surveillance against melanoma cells, which share several melanocytic antigens with normal melanocytes. This hypothesis is supported by observations that vitiligo-like depigmentation in patients with melanoma is associated with improved clinical outcomes and survival (17). Furthermore, depigmentation is a recognised adverse effect of several anti-melanoma therapies, including immune checkpoint inhibitors and BRAF inhibitors, highlighting the close relationship between melanocyte autoimmunity and anti-tumour immunity (18, 19).

The association between vitiligo and cancer risk is further complicated by therapeutic and behavioural factors. Long-term NB-UVB phototherapy and the increasing use of immunomodulatory treatments, particularly JAK inhibitors, have raised questions regarding their potential impact on malignancy risk. In addition, differences in sun-exposure behaviour among patients with vitiligo may influence the incidence of skin cancers and contribute to variation in reported risk estimates (20).

Epidemiological studies investigating cancer risk in patients with vitiligo have reported inconsistent findings. While several studies suggest a reduced risk of melanoma and non-melanoma skin cancer, others have reported an increased risk of certain malignancies, including haematological cancers (21-23). Interpretation of these findings is limited by variations in study design, sample size, follow-up duration, and adjustment for confounding factors. Therefore, a comprehensive systematic review and meta-analysis was undertaken to provide a more robust assessment of the relationship between vitiligo and cancer risk.

6 OBJECTIVES

6.1 Study 1 — JAK inhibitors in vitiligo

This study aimed to comprehensively evaluate the efficacy and safety of JAK inhibitors in the treatment of vitiligo through a systematic review and meta-analysis. The specific objectives were to:

1. Quantify the efficacy of JAK inhibitors in vitiligo by pooling repigmentation outcomes, including F-VASI75 response rates and percentage improvement in VASI scores.
2. Explore differences in efficacy according to route of administration and study design.
3. Assess the safety profile of JAK inhibitors through pooled analyses of adverse events.

6.2 Study 2 — Cancer incidence in vitiligo

This study aimed to investigate the association between vitiligo and malignancy risk through a systematic review and meta-analysis of observational studies. The specific objectives were to:

1. Determine the pooled risk of melanoma, non-melanoma skin cancer, and haematological malignancies in patients with vitiligo compared with control populations.
2. Explore potential sources of heterogeneity through subgroup and sensitivity analyses.
3. Assess the methodological quality of the included studies using the ROBINS-E tool.

7 METHODS

7.1 Study 1

7.1.1 Study Design and Registration

This systematic review and meta-analysis investigating the efficacy and safety of JAK inhibitors in vitiligo was conducted in accordance with the Cochrane Handbook for Systematic Reviews of Interventions (24) and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (25). The review protocol was prospectively registered with the International Prospective Register of Systematic Reviews (PROSPERO; registration number: CRD42023445503).

7.1.2 Eligibility Criteria

Eligible studies were assessed using the Population, Intervention, Control, Outcome (PICO) format as follows: P- Patients with vitiligo, I- JAK inhibitor administered topically or orally, C- Placebo, vehicle cream, or conventional therapy, and O- Percentage change from baseline; patients who achieved a 75% improvement in their facial Vitiligo Area Scoring Index (VASI) score or total VASI score, as well as adverse events.

7.1.3 Search Strategy

A comprehensive and systematic literature search was performed across three electronic databases — MEDLINE, EMBASE, and the Cochrane Central Register of Controlled Trials — on 10 September 2023.

7.1.4 Study Selection and Data Management

Search results were exported to the EndNote 20 citation manager (Clarivate Analytics, Philadelphia, PA, USA). After automatic and manual duplicate removal, articles were selected using the Rayyan Intelligent Systematic Review program. Two independent review authors performed the selection based on title, abstract, and full text, following the inclusion criteria. Disagreements were resolved by a third reviewer, and Cohen's Kappa coefficient was calculated at each selection step to evaluate the level of agreement.

7.1.5 Data Extraction and Risk of Bias Assessment

Data from eligible articles were collected independently by three reviewers using a predesigned sheet. Disagreements were resolved by a fourth reviewer.

Risk-of-bias assessment was independently carried out by two authors using the Cochrane RoB-2 tool for randomised trials and the ROBINS-I tool for non-randomised intervention studies. Each study outcome was classified as having "low," "some concerns," or "high" risk of bias, with any discrepancies between reviewers resolved through adjudication by a third author. The certainty of evidence for primary outcome parameters was subsequently evaluated using the GRADEPro software, in accordance with the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) framework.

7.1.6 Statistical Analysis

Meta-analysis was performed where a minimum of three studies were available. To account for anticipated heterogeneity across studies, a random-effects model was adopted throughout. Effect sizes were expressed as proportions and Risk Ratios (RR), each accompanied by 95% confidence intervals (CI), and were derived from patient and event counts reported in the individual studies.

Pooled proportions were estimated via a random intercept logistic regression model, following the approach recommended by Schwarzer et al. and Stijnen et al (26, 27), with heterogeneity variance (τ^2) quantified using the maximum likelihood method. Pooled RRs were computed using the Mantel-Haenszel method, incorporating exact calculations to handle zero cell counts as outlined by Cooper, Hedges, and Valentine (2009) and Sweeting, Sutton, and Lambert (2004) (28-30). A Hartung-Knapp adjustment was applied to yield more conservative interval estimates, and heterogeneity variance (τ^2) was estimated using the Paule-Mandel method, with confidence intervals derived via the Q profile approach (31, 32).

Meta-analysis results were presented as forest plots, which additionally displayed prediction intervals to convey the expected range of effects in future studies. Statistical heterogeneity was quantified using the I^2 statistic as described by Higgins and Thompson (24), while outlier detection and model diagnostics were conducted in accordance with the guidance of Harrer et al. (33).

Publication bias was evaluated through visual inspection of funnel plots and Egger's test, with a significance threshold set at 10%. For cohort analyses, one-sample one-sided t-tests were used to assess mean percentage repigmentation, with Bonferroni-Holm correction applied for multiple comparisons, and intergroup differences were examined using ANOVA ($\alpha = 0.05$). All statistical analyses were conducted in R (v4.1.2), utilising the base R environment alongside the meta (v6.2-1) and dmetar (v0.0.9000) package (34, 35).

7.1.7 Ethical Considerations

This meta-analysis was conducted exclusively using previously published aggregate data pertaining to JAK inhibitor use in vitiligo. No new patient data were collected, generated, or directly handled during this study. Accordingly, ethical approval was not required.

7.2 Study 2

7.2.1 Study Design and Registration

This systematic review and meta-analysis investigating cancer risk in vitiligo was conducted in accordance with the Cochrane Handbook for Systematic Reviews of Interventions (24) and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (25). The review protocol was prospectively registered with the International Prospective Register of Systematic Reviews (PROSPERO; registration number: CRD42023483130).

7.2.2 Eligibility criteria

We included observational studies, including cohort and case-control studies, that evaluated the incidence or risk of malignancy in patients with vitiligo compared with a control population without vitiligo. Eligible studies were required to report quantitative risk estimates, including hazard ratios (HRs), with corresponding 95% confidence intervals. The primary outcomes of interest were melanoma, non-melanoma skin cancer (NMSC), and lymphoma. Case reports, case series, reviews, conference abstracts, and studies without a comparator group were excluded.

7.2.3 Search Strategy

A systematic literature search was conducted on 24 November 2023 in MEDLINE, Embase, and the Cochrane Library. The search strategy combined controlled vocabulary and free-text terms related to vitiligo and malignancy. No language restrictions or search filters were applied. Search results were exported to EndNote 20 (Clarivate Analytics, Philadelphia, PA, USA), where duplicate records were removed through automated and manual procedures. Study selection was performed independently by two reviewers using the Rayyan Intelligent Systematic Review platform, with disagreements resolved by a third reviewer.

7.2.4 Study Selection and Data Management

Search results were imported into EndNote 20 (Clarivate Analytics, Philadelphia, PA, USA), where duplicate records were removed both automatically and manually. Study selection was subsequently conducted using the Rayyan Intelligent Systematic Review platform. Two reviewers independently screened the records by title, abstract, and full text according to the predefined inclusion criteria. Any disagreements were resolved through consultation with a third reviewer. Inter-reviewer agreement was assessed at each stage of the selection process using Cohen's kappa coefficient.

7.2.5 Risk of bias assessment and quality of evidence

The methodological quality of the included studies was assessed independently by two reviewers using the Risk of Bias in Non-randomised Studies of Exposures (ROBINS-E) tool. The assessment considered bias arising from confounding, participant selection, exposure classification, deviations from intended exposures, missing data, outcome measurement, and selective reporting. Disagreements were resolved through discussion with a third reviewer. The overall certainty of evidence for each outcome was evaluated using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework (36).

7.2.6 Statistical synthesis

Hazard ratios (HRs) and their corresponding 95% confidence intervals were used as the primary effect measures. Pooled estimates were calculated directly from reported HRs and their standard errors. Statistical significance was assumed when the pooled confidence interval did not cross the null value. Meta-analysis results were presented using forest plots. Statistical heterogeneity was assessed using the I^2 statistic, and

publication bias was evaluated through visual inspection of funnel plots. All statistical analyses were performed in R (37) using the meta package (38) .

Pre-specified subgroup analyses were conducted using mixed-effects models. This approach assumed a common between-study variance across subgroups, which was considered appropriate given the limited number of studies within certain subgroups and the absence of a priori expectations regarding differences in heterogeneity (39). Differences between subgroups were assessed using an omnibus test, Cochran Q test (40). Statistical significance was defined as a two-sided p-value <0.05.

7.2.7 Ethical Considerations

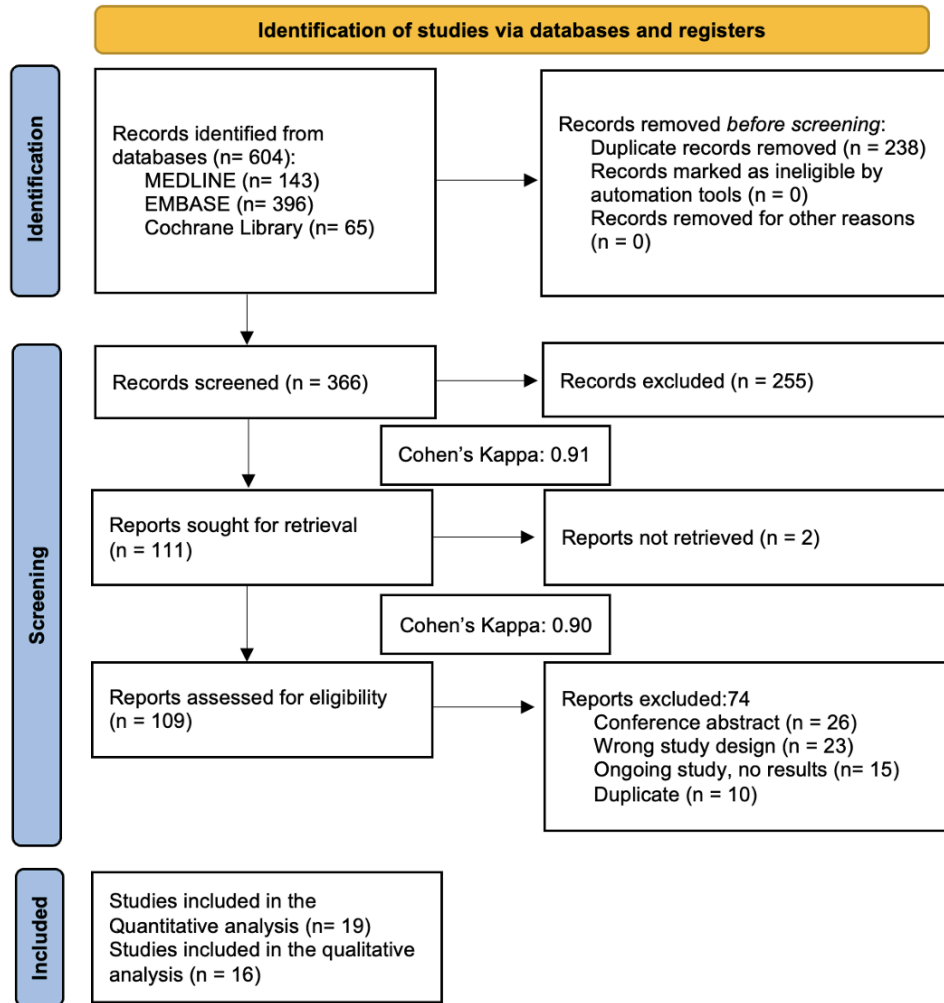
This meta-analysis was conducted exclusively using previously published aggregate data examining the association between vitiligo and malignancy risk. No new patient data were collected, generated, or directly handled during the study. Accordingly, ethical approval was not required.

8 RESULTS

8.1 Study 1

8.1.1 Systematic search, selection, and study characteristics

Altogether, 604 studies were identified through searches of Medline, Embase, and the Cochrane Library. Of these, 366 records remained for title and abstract screening after duplicate removal. In total, 36 studies were assessed for eligibility and included in the qualitative synthesis. Studies were excluded primarily because heterogeneous data reporting precluded meaningful aggregation of results. Altogether, 16 studies were included in the quantitative synthesis. Details of the search and selection process are illustrated in the PRISMA 2020 flow diagram (Figure 1).



**Reports not retrieved: Abstract only (n = 2)

Fig. 1. PRISMA 2020 flow diagram for the selection process for study 1.

8.1.2 Meta-analysis of Randomized Controlled Trials

Three randomized controlled trials (11, 41) comprising 726 patients were included in the meta-analysis. In total, 144 of 476 patients in the intervention group achieved a 75% improvement in the F-VASI75, compared with 20 of 250 patients in the control group. Patients receiving topical ruxolitinib were more likely to achieve F-VASI75 than those receiving vehicle cream (RR 3.47, 95% CI: 0.98–12.22; $p = 0.051$) (Figure 2).

Any adverse event occurred in 49.4% of patients receiving ruxolitinib and 42.4% of patients receiving vehicle cream, corresponding to a relative risk of 1.27 (95% CI: 0.88–1.82; $p = 0.107$) (Figure 3). Serious adverse events occurred in 1.9% of patients in the intervention group and 0.4% of patients in the control group (RR 2.83, 95% CI: 2.31–3.47; $p = 0.002$). Overall, treatment discontinuation due to adverse events was rare, with two cases reported in each treatment arm.

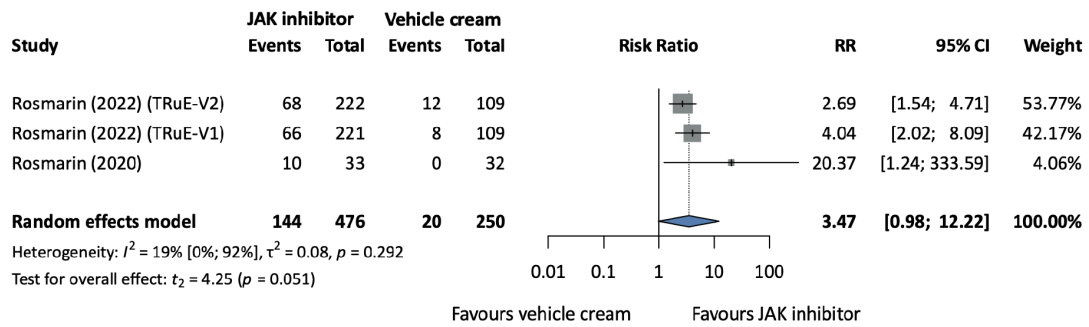


Fig. 2. Forest plot of the number of patients who achieved 75% improvement in their facial vitiligo area scoring index (F-VASI) score.

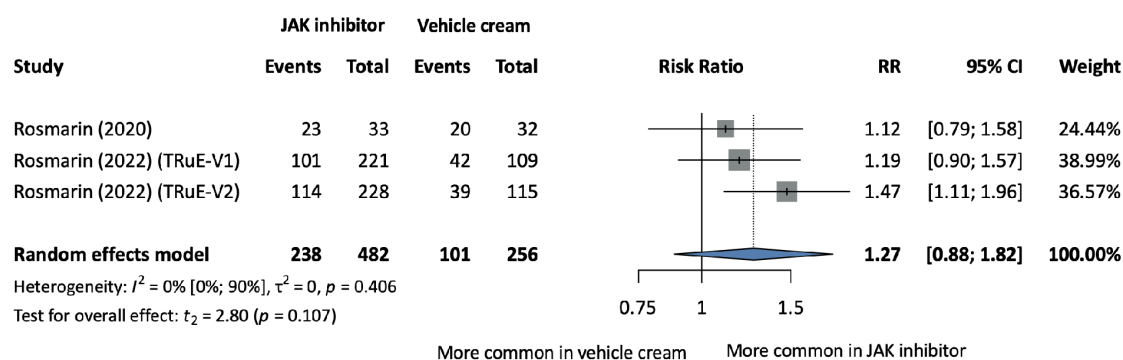


Fig. 3. Forest plot of the number of patients who experienced any adverse events throughout the trial.

8.1.3 Meta-analysis of Single-Arm Trials

Four single-arm trials evaluated the efficacy of JAK inhibitors administered either alone or in combination with conventional therapies (12, 14, 42) . Three studies investigated topical JAK inhibitors, whereas one study evaluated oral upadacitinib. The pooled analysis demonstrated a significant improvement in vitiligo lesions, with a mean percentage repigmentation of 43.79% (95% CI: 0.71–0.93; $p < 0.001$) (Figure 4).

Subgroup analysis restricted to studies utilising JAK inhibitors without adjunctive conventional treatment demonstrated a mean percentage repigmentation of 30.83% (95% CI: 5.14–56.50), indicating a clinically meaningful and statistically significant improvement.

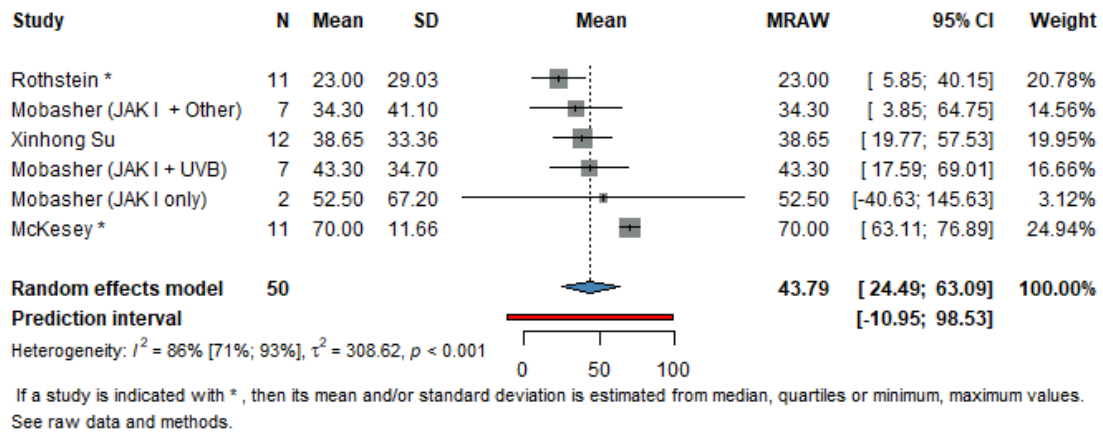


Fig. 4. Forest plot of the mean percentage repigmentation in vitiligo lesions of patients included in single-arm trials employing JAK inhibitors with or without conventional treatment.

8.1.4 Analysis of the Cohort Constructed from Case Reports and Case Series

A cohort of 28 patients was assembled from published case reports and case series evaluating oral JAK inhibitors in vitiligo. Patients were categorised into three groups according to treatment strategy: JAK inhibitor monotherapy (43-49), JAK inhibitor combined with UV-B phototherapy (15, 43-45, 50, 51) , and JAK inhibitor combined with other therapies (13, 52).

Patients receiving JAK inhibitor monotherapy demonstrated a mean repigmentation of 48.7% (95% CI: 28.0%–∞%; $p = 0.0018$). The greatest improvement was observed

among patients receiving JAK inhibitors combined with UV-B phototherapy, with a mean repigmentation of 63.7% (95% CI: 49.0%–∞%; $p < 0.0001$). Patients receiving JAK inhibitors in combination with treatments other than UV-B phototherapy demonstrated a mean repigmentation of 56.3% (95% CI: 18.0%–∞%; $p = 0.061$). When all patients were analysed together, the overall mean repigmentation was 55.68% (95% CI: 44.51%–∞%; $p < 0.0001$).

No significant differences were observed between treatment groups on ANOVA testing ($p = 0.456$). Similarly, Fisher's exact tests performed using repigmentation thresholds of 0% and 50% revealed no statistically significant differences between groups ($p = 0.32$ and $p = 0.35$, respectively).

ANOVA – 3-month follow-up time

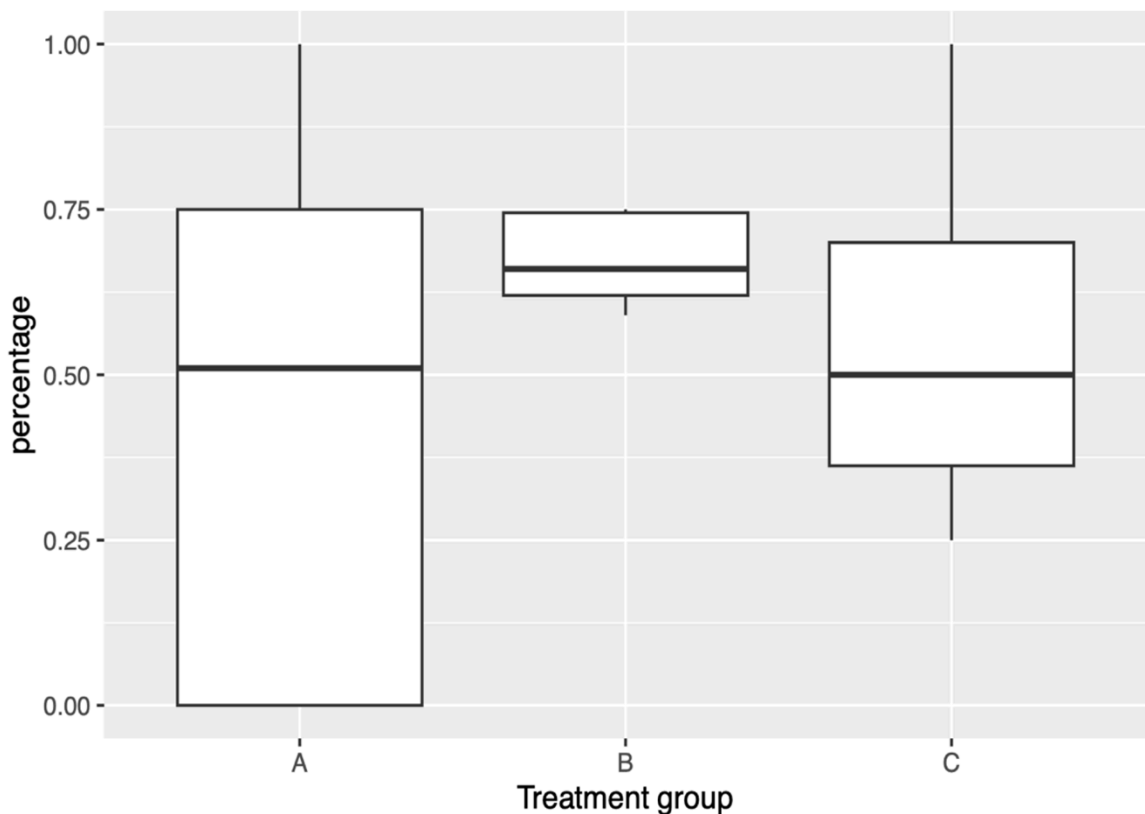


Fig. 5. Analysis of variance of the three groups assembled from the case reports. $N=28$, $p=0.456$, group A – JAK inhibitors alone, group B – JAK inhibitors and UVB, group C – JAK inhibitor and other treatments except UVB.

8.2 Study 2

8.2.1 Systematic search, selection, and study characteristics

Altogether, 7,753 studies were identified through searches of Medline, Embase, and the Cochrane Library. Following duplicate removal, 6,378 records remained for title and abstract screening. In total, 12 studies met the eligibility criteria and were included in the qualitative synthesis. Owing to heterogeneity in outcome reporting, six studies were eligible for quantitative synthesis and were included in the meta-analysis. Three separate meta-analyses were performed, evaluating the risk of non-melanoma skin cancer, melanoma, and lymphoma, respectively. Details of the search and selection process are illustrated in the PRISMA flow diagram (Figure 6).

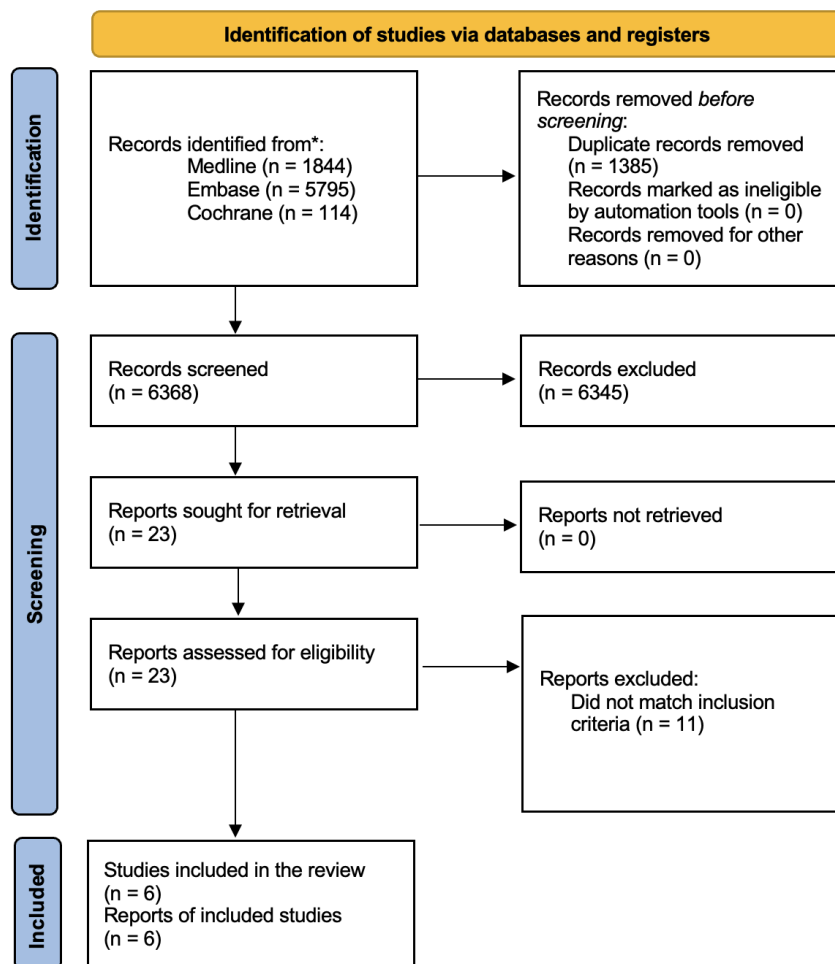


Fig. 6. PRISMA 2020 flow diagram for the selection process for study 2.

All included studies were observational in design and comprised cohort and case-control studies. Collectively, the studies included a large population of patients

with vitiligo and corresponding control populations. Studies were conducted across Europe, North America, and Asia, providing data from diverse healthcare settings and populations.

8.2.2 Risk of Lymphoma in Vitiligo Patients

The meta-analysis for lymphoma included three studies (53-55). The pooled hazard ratio was 1.00 (95% CI: 0.40–2.53), indicating no significant difference in lymphoma incidence between patients with vitiligo and non-vitiligo controls (Figure 7).

8.2.3 Risk of Melanoma in Patients with Vitiligo

Five studies (53, 55-58) were included in the melanoma subgroup analysis. The pooled hazard ratio for melanoma was 0.80 (95% CI: 0.27–2.34), indicating no significant association between vitiligo and melanoma risk (Figure X). Substantial heterogeneity was observed across studies ($I^2 = 80\%$; $p < 0.001$) (Figure 7).

8.2.4 Risk of Non-Melanoma Skin Cancer in Patients with Vitiligo

Two studies evaluated the risk of non-melanoma skin cancer (55, 58). The pooled hazard ratio was 0.38 (95% CI: 0.00–732.76), suggesting no significant association between vitiligo and non-melanoma skin cancer risk (Figure 7). However, the extremely wide confidence interval indicates considerable uncertainty surrounding this estimate.

8.2.5 Subgroup Comparison

No significant differences were observed between the lymphoma, melanoma, and non-melanoma skin cancer subgroups ($\chi^2 = 3.47$, $df = 2$, $p = 0.176$). Nevertheless, the substantial heterogeneity observed across studies warrants cautious interpretation of the pooled estimates.

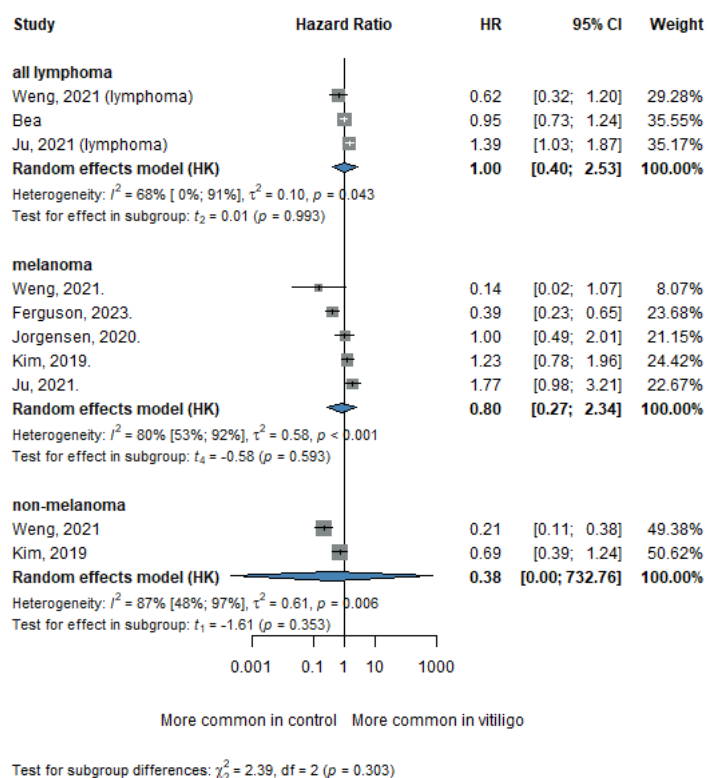


Fig. 7 Forest plot of the meta-analysis assessing the association between vitiligo and the risk of lymphoma, melanoma, and non-melanoma skin cancer.

9 DISCUSSION

9.1 Summary of findings

Our first study found that JAK inhibitors are effective treatment options for vitiligo and are associated with clinically meaningful repigmentation across multiple levels of evidence. In randomized controlled trials, approximately one-third of patients treated with topical ruxolitinib achieved F-VASI75, compared with fewer than one in ten patients receiving vehicle cream. Single-arm trials demonstrated a mean repigmentation of 43.8%, while the cohort assembled from case reports and case series showed an overall repigmentation rate of 55.7%.

The greatest degree of repigmentation was observed among patients receiving JAK inhibitors in combination with UV-B phototherapy, with a mean repigmentation of 63.7%. Patients treated with JAK inhibitor monotherapy also experienced substantial improvement, achieving a mean repigmentation of 48.7%. Although combination therapy appeared to provide superior outcomes, direct comparisons between treatment strategies did not demonstrate statistically significant differences, likely owing to the limited sample size and heterogeneity of the available evidence.

Our findings also suggest that JAK inhibitors are generally well tolerated. The overall incidence of adverse events did not differ significantly between patients receiving topical ruxolitinib and those receiving vehicle cream, and treatment discontinuation due to adverse events was uncommon. Taken together, these findings support the use of JAK inhibitors as a promising therapeutic option for vitiligo. However, the limited number of randomized controlled trials, the heterogeneity of outcome reporting, and the lack of direct comparative studies highlight the need for further high-quality research to determine the optimal route of administration and the role of combination therapies, particularly with phototherapy.

Our second study found no statistically significant association between vitiligo and the risk of lymphoma, melanoma, or non-melanoma skin cancer. Lymphoma incidence was comparable between patients with vitiligo and controls, while melanoma and non-melanoma skin cancer demonstrated non-significant trends towards a reduced risk.

Among the malignancies evaluated, the lowest pooled risk estimate was observed for non-melanoma skin cancer, followed by melanoma, whereas lymphoma risk remained

unchanged. However, substantial heterogeneity in the melanoma analysis and the imprecision of the non-melanoma skin cancer estimate limit the certainty of these findings.

Overall, our results do not support an increased risk of malignancy in patients with vitiligo. Although the observed trends may suggest a protective effect against skin cancers, further large-scale studies are required to clarify these associations.

9.2 Comparisons with other international publications

The findings of the first study are consistent with the growing body of evidence supporting the efficacy and safety of JAK inhibitors in the treatment of vitiligo. While previous reviews have examined this topic, our study provides a more comprehensive evaluation by synthesizing evidence from randomized controlled trials, single-arm studies, and case reports and case series (59). Across all analyses, JAK inhibitors were associated with clinically meaningful repigmentation and a favourable safety profile.

Our findings from randomized controlled trials are consistent with those of studies evaluating topical ruxolitinib, which demonstrated significant improvements in repigmentation outcomes compared with vehicle treatment (11, 41). Similarly, studies investigating oral JAK inhibitors, including ritlecitinib and upadacitinib, have reported substantial improvements in F-VASI scores with relatively few adverse events, supporting the therapeutic potential of this drug class in vitiligo (60, 61). However, the limited availability of comparative studies prevented direct assessment of the relative efficacy of oral and topical formulations.

The apparent benefit of combining JAK inhibitors with phototherapy observed in our cohort analysis is also supported by previous studies. Experimental and clinical evidence suggests that phototherapy may enhance the repigmenting effects of JAK inhibitors by promoting melanocyte stimulation (44). A previous meta-analysis similarly reported improved outcomes with concomitant UV-B phototherapy and JAK inhibitor treatment (62). Furthermore, a multicentre observational study demonstrated superior repigmentation among patients receiving tofacitinib in combination with NB-UVB compared with phototherapy alone, without an increase in adverse events (63). Although our findings align with these observations, the available evidence remains insufficient to establish the superiority of combination therapy over JAK

inhibitor monotherapy, highlighting the need for adequately powered randomized controlled trials.

Our findings are also consistent with reports demonstrating the efficacy and safety of JAK inhibitors in paediatric populations. Several case reports have documented successful repigmentation with topical JAK inhibitors in children, including infants, with few or no reported adverse events (63-65). These observations are particularly relevant given the limited therapeutic options available for younger patients and are reflected in recent recommendations advocating the use of topical JAK inhibitors as first- or second-line treatment options in paediatric and adolescent vitiligo patients (66).

Despite these encouraging findings, caution remains warranted, particularly with oral JAK inhibitors, given concerns regarding potential long-term adverse effects, including immunosuppression, cardiovascular events, and malignancy risk (67). Consequently, further studies with longer follow-up periods are required to better define the long-term safety profile of JAK inhibitors and establish their optimal role within vitiligo treatment algorithms.

Our findings in the second study are broadly consistent with the existing literature investigating the relationship between vitiligo and malignancy. While previous studies and meta-analyses have primarily focused on melanoma and NMSC (68, 69), our study is, to our knowledge, the first systematic review and meta-analysis to simultaneously evaluate the risk of lymphoma, a non-skin-related malignancy, alongside skin malignancies in patients with vitiligo. By extending the scope beyond cutaneous cancers, our study provides a more comprehensive assessment of malignancy risk in this population. Across all malignancy subtypes examined, we found no statistically significant association between vitiligo and cancer incidence.

For melanoma, we observed a non-significant trend towards a reduced risk among patients with vitiligo. This finding is consistent with previous reports demonstrating lower melanoma incidence in vitiligo populations, including studies by Teulings et al. (70) and Lindelöf et al. (71). A proposed explanation is the enhanced immune surveillance characteristic of vitiligo, whereby melanocyte-reactive CD8⁺ T cells may also recognise and eliminate malignant melanocytes (72, 73). Genetic studies have further suggested that polymorphisms affecting melanocyte biology, particularly within

the TYR gene, may contribute to both vitiligo susceptibility and protection against melanoma development (22, 74). Nevertheless, substantial heterogeneity across studies and evolving melanoma epidemiology may partly explain the variability in reported outcomes (75, 76).

Similarly, our analysis demonstrated a trend towards a lower incidence of NMSC, although the estimate was imprecise. Previous observational studies have reported reduced rates of photodamage and NMSC in patients with vitiligo despite comparable ultraviolet exposure (77, 78). This apparent paradox has been attributed to heightened immune activity, including increased natural killer cell activity and enhanced surveillance against atypical keratinocytes and melanocytes (79). However, conflicting findings have also been reported, with some studies observing higher rates of NMSC that did not reach statistical significance (20).

In contrast to several autoimmune diseases, including rheumatoid arthritis, Sjögren's syndrome, and coeliac disease, which are associated with an increased risk of lymphoma (80-82), our analysis found no evidence of an altered lymphoma risk in patients with vitiligo. Although this may reflect differences in the underlying immune mechanisms of vitiligo, the limited number of available studies warrants cautious interpretation. Notably, isolated reports have suggested an increased lymphoma risk, highlighting the need for further investigation (83).

Beyond melanoma, NMSC, and lymphoma, several studies have reported associations between vitiligo and other malignancies, including thyroid, breast, and prostate cancers (84, 85). However, the evidence remains inconsistent, and the biological mechanisms underlying these observations are incompletely understood. Consequently, larger prospective studies are required to clarify whether vitiligo influences the risk of specific malignancies and to further elucidate the complex interplay between autoimmunity, immune surveillance, and carcinogenesis.

9.3 Strengths

9.3.1 Study 1

Our study has several strengths. First, it was conducted in accordance with Cochrane Collaboration and PRISMA recommendations, ensuring methodological rigor, transparency, and reproducibility. Second, we incorporated evidence from multiple

study designs, including randomized controlled trials, single-arm studies, and case reports and case series. The consistency of findings across these independent analyses strengthens confidence in the observed efficacy of JAK inhibitors in vitiligo. Finally, to maximize the use of the available literature, we constructed a cohort from case reports and case series, enabling a more comprehensive evaluation of treatment outcomes and allowing inclusion of data that would otherwise have been excluded from quantitative synthesis.

9.3.2 Study 2

This study has several strengths. The inclusion of large population-based observational studies from multiple geographic regions enhanced the generalisability of the findings and enabled the evaluation of malignancy risk across diverse populations. Furthermore, to our knowledge, this is the first systematic review and meta-analysis to evaluate lymphoma risk in patients with vitiligo alongside melanoma and non-melanoma skin cancer, providing a broader assessment of malignancy risk than previous reviews.

9.4 Limitations

9.4.1 Study 1

Several limitations should be acknowledged. The number of available randomized controlled trials was limited, restricting the strength of the evidence base. In addition, substantial heterogeneity in outcome reporting, particularly among single-arm studies and case reports, limited the inclusion of eligible studies in the quantitative analyses. The additional cohort derived from case reports and case series provided complementary evidence on treatment outcomes; however, its findings should be interpreted cautiously because of the potential for publication and selection bias, as well as clinical heterogeneity between patients. Although F-VASI75 and T-VASI50 have been proposed as clinically meaningful endpoints, these outcomes were not consistently reported across studies, hindering data synthesis and comparison. The lack of direct comparative studies between oral and topical JAK inhibitors, as well as between monotherapy and combination treatment approaches, precluded definitive conclusions regarding optimal treatment strategies. Finally, the relatively short follow-up periods of the included studies limited the assessment of long-term efficacy and the occurrence of uncommon or delayed adverse events.

9.4.2 Study 2

Several limitations should be acknowledged. First, the relatively small number of studies eligible for quantitative synthesis limited the precision of the pooled estimates, particularly for lymphoma and non-melanoma skin cancer. Second, substantial heterogeneity was observed across studies, reflecting differences in study populations, outcome definitions, and methodological approaches. Furthermore, our analyses were restricted to studies reporting hazard ratios, resulting in the exclusion of several potentially relevant studies. Finally, important confounding factors, including phototherapy exposure, sun-exposure behaviours, and regional differences in cancer incidence, were not consistently accounted for, which may have influenced the observed associations.

10 CONCLUSIONS

10.1 Study 1

This study demonstrates that JAK inhibitors represent a promising therapeutic option for the management of vitiligo. Across randomized controlled trials, single-arm studies, and case reports and case series, treatment with JAK inhibitors was consistently associated with clinically meaningful repigmentation and an acceptable safety profile. The findings also suggest that combination therapy with UV-B phototherapy may further enhance treatment outcomes, although the current evidence remains insufficient to draw definitive conclusions regarding its superiority over monotherapy.

Despite these encouraging results, important knowledge gaps remain. The limited number of randomized controlled trials, the heterogeneity of outcome reporting, and the lack of direct comparisons between oral and topical formulations restrict the strength of current recommendations. Future research should focus on well-designed comparative studies, standardized outcome measures, and long-term follow-up to establish the optimal use of JAK inhibitors in vitiligo management.

Overall, the evidence presented in this study supports the growing role of JAK inhibitors in the treatment of vitiligo and highlights their potential to improve outcomes for patients with this often challenging and psychologically burdensome condition.

10.2 Study 2

This study found no significant association between vitiligo and the risk of melanoma, non-melanoma skin cancer, or lymphoma. Although trends towards a reduced incidence of skin malignancies were observed, the available evidence was insufficient to confirm a protective effect. The findings nevertheless suggest that vitiligo is not associated with an increased overall risk of the malignancies evaluated and support the hypothesis that the immune dysregulation underlying vitiligo may influence cancer susceptibility.

Despite these findings, important uncertainties remain. The limited number of eligible studies, substantial heterogeneity between cohorts, and inconsistent adjustment for important confounding factors restrict the strength of current conclusions. Future research should focus on large prospective studies with standardized reporting and

long-term follow-up to further clarify the relationship between vitiligo and both cutaneous and non-cutaneous malignancies.

Overall, this study provides the most comprehensive assessment to date of melanoma, non-melanoma skin cancer, and lymphoma risk in patients with vitiligo. The findings indicate that an increased risk of these malignancies has not been demonstrated; however, they should not be interpreted as evidence that vitiligo is protective against cancer. While enhanced immune surveillance has been proposed as a potential mechanism underlying the observed associations, this remains hypothetical and requires further investigation. These findings contribute to the growing understanding of the complex interplay between autoimmunity, immune surveillance, and cancer development.

11 IMPLEMENTATIONS FOR PRACTICE

11.1 Study 1

The findings of this study support the integration of JAK inhibitors into the management of vitiligo, given their demonstrated efficacy and favourable safety profile. While current evidence suggests that JAK inhibitors may be effective both as monotherapy and in combination with phototherapy, further evidence is required to define their optimal clinical use. The incorporation of JAK inhibitors into treatment algorithms may expand therapeutic options for patients with vitiligo and improve clinical outcomes.

11.2 Study 2

The findings of this study suggest that vitiligo is not associated with an increased risk of melanoma, non-melanoma skin cancer, or lymphoma. These results may provide reassurance to both clinicians and patients regarding the long-term malignancy risk associated with vitiligo. While routine cancer surveillance should continue in accordance with standard clinical practice, the available evidence does not support the need for additional monitoring solely based on a vitiligo diagnosis.

12 IMPLEMENTATION FOR RESEARCH

12.1 Study 1

Future studies should directly compare topical and oral JAK inhibitors and evaluate the efficacy of combination therapies, particularly with phototherapy. Greater standardisation of outcome reporting is needed to improve comparability across studies and facilitate evidence synthesis. In addition, long-term studies incorporating patient-reported outcomes and quality-of-life measures are required to determine the durability, cost-effectiveness, and overall clinical value of JAK inhibitors in vitiligo management.

12.2 Study 2

Further research is required to clarify the relationship between vitiligo and malignancy risk. Large, prospective, multicentre studies with standardized outcome reporting are needed, particularly for lymphoma, where the current evidence base remains limited. Future investigations should also evaluate the long-term impact of phototherapy and immunomodulatory treatments on cancer risk and explore associations with non-cutaneous malignancies, including thyroid, breast, and prostate cancers. Such studies will improve understanding of the interplay between autoimmunity, immune surveillance, and carcinogenesis, and help inform evidence-based surveillance strategies for patients with vitiligo.

14 IMPLEMENTATION FOR POLICYMAKERS

14.1 Study 1

The findings may provide an evidence base to inform policymakers and guideline developers when considering the potential integration of JAK inhibitors into vitiligo treatment pathways. While the available evidence suggests therapeutic efficacy, the relatively small number of randomised trials, together with the more limited evidence for oral JAK inhibitors and combination therapy, means that definitive recommendations regarding their position within existing treatment algorithms may be premature. As the evidence base develops, clearer recommendations regarding appropriate patient selection and eligibility criteria may help support equitable access and efficient allocation of healthcare resources, particularly given the substantial cost associated with these therapies. Further high-quality evidence, particularly from larger randomised trials and studies evaluating long-term effectiveness and safety, will be important to inform future policy and guideline development.

14.2 Study 2

The findings may contribute to evidence-based recommendations regarding malignancy surveillance in patients with vitiligo. The absence of a statistically significant association between vitiligo and melanoma, non-melanoma skin cancer, or lymphoma may inform proportionate surveillance strategies and patient counselling, while acknowledging the limitations of the available evidence. Further large-scale, high-quality studies are warranted to establish more precise estimates of malignancy risk and inform future surveillance recommendations.

15 FUTURE PERSPECTIVES

Future research should focus on establishing standardised and validated outcome measures for vitiligo clinical trials, incorporating both objective assessments of repigmentation and patient-reported quality-of-life outcomes. In addition, adequately powered randomised controlled trials comparing oral and topical JAK inhibitors, as well as monotherapy and combination treatment strategies, are needed to define the optimal therapeutic approach and inform evidence-based treatment algorithms. Longer follow-up periods will also be essential to evaluate the durability of treatment response and long-term safety.

Further investigation into the relationship between vitiligo and malignancy is warranted. Large prospective cohort studies and international registries linking vitiligo diagnoses, treatment exposures, and long-term cancer outcomes would provide more robust evidence regarding the risk of both cutaneous and non-cutaneous malignancies. Moreover, mechanistic studies exploring the shared immunological pathways underlying vitiligo and anti-tumour immunity may improve understanding of the complex interplay between autoimmunity, immune surveillance, and carcinogenesis. Such research has the potential to inform both dermatological practice and future therapeutic strategies.

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14.1 Publications related to the thesis

Efficacy and Safety of JAK Inhibitors in the Management of Vitiligo: A Systematic Review and Meta-analysis

A. A. Mohammed, A. S. Lengyel, F. A. Meznerics, I. Szondy, A. Walter, B. Szabó, D. Pál, A. Bojtor, A. Bánvölgyi, N. Kiss, et al.

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Cancer Risk in Vitiligo: No Evidence of Increased Prevalence—A Systematic Review and Meta-analysis

A. A. Mohammed, A. S. Lengyel, F. A. Meznerics, I. Szondy, A. Walter, B. Nagy, Z. Csabi, A. Bánvölgyi, N. Kiss, P. Hegyi, et al.

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14.2 Publications not related to the thesis

Evaluating Cross-Protection: Meningococcal Vaccines Show Effectiveness in Gonorrhoea Prevention — A Systematic Review and Meta-analysis

I. Szondy, K. Lőrincz, A. Walter, A. A. Mohammed, P. Hegyi, N. Kiss, F. A. Meznerics, A. Bánvölgyi

Vaccine, 2025 Vol. 56 Article 127188

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Doxycycline Prophylaxis for the Prevention of Sexually Transmitted Infections: A Systematic Review and Meta-analysis of Randomised Controlled Trials

I. Szondy, F. A. Meznerics, K. Lőrincz, L. V. Kemény, A. Walter, A. A. Mohammed, P. Hegyi, N. Kiss, A. Bánvölgyi

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International Journal of Molecular Sciences, 2024 Vol. 25 Issue 23 Pages 12821

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EZH2 Overexpression Is Associated with Aggressive Behaviour and Promotes Cell Proliferation in CNS WHO Grade 3 Meningiomas

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