Section: Miscellaneous

Systemic Review

# RADIATION-INDUCED ALOPECIA: A SYSTEMATIC REVIEW OF INCIDENCE, RISK FACTORS, PREVENTION, AND MANAGEMENT

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## ABSTRACT

**Background:** Radiation-induced alopecia (RIA) is a frequent adverse effect of radiotherapy involving hair-bearing regions, particularly in patients undergoing cranial, scalp, and head and neck irradiation. While hair loss is often temporary, higher radiation doses, larger treatment volumes, and concurrent systemic therapies may result in permanent alopecia, leading to considerable cosmetic concerns, psychological distress, and reduced quality of life. Despite advances in radiotherapy techniques such as intensity-modulated radiotherapy (IMRT), volumetric-modulated arc therapy (VMAT), stereotactic radiosurgery (SRS), and proton therapy, RIA remains an important survivorship issue. The objective is to systematically review the current evidence on the incidence, risk factors, preventive strategies, and management of radiation-induced alopecia in patients receiving therapeutic radiotherapy.

**Methods:** A systematic review will be conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines. Electronic databases including PubMed/MEDLINE, Embase, Scopus, Web of Science, and the Cochrane Library will be searched from inception to the final search date. Eligible studies will include randomized controlled trials, prospective and retrospective cohort studies, case-control studies, and observational studies reporting radiation-induced alopecia. Two independent reviewers will perform study selection, data extraction, and risk-of-bias assessment using validated appraisal tools. Data will be synthesized narratively, and where sufficient homogeneity exists, a random-effects meta-analysis will be performed.

**Results:** The review will summarize the reported incidence and severity of radiation-induced alopecia, identify patient- and treatment-related risk factors, evaluate radiation dose thresholds associated with temporary and permanent hair loss, and assess the effectiveness of preventive measures and available therapeutic interventions. Where appropriate, pooled estimates of incidence and treatment outcomes will be calculated.

**Conclusion:** This systematic review will provide a comprehensive synthesis of current evidence on radiation-induced alopecia, identify knowledge gaps, and support evidence-based clinical practice. The findings are expected to improve patient counseling, optimize radiotherapy planning, and guide future research on preventive and therapeutic strategies.

**Keywords:** Radiation-induced alopecia; radiotherapy; hair loss; permanent alopecia; risk factors; prevention; management; systematic review.

## INTRODUCTION

Radiotherapy is one of the cornerstones of modern cancer treatment and is administered to nearly half of all patients with cancer during the course of their disease. It plays a crucial role in the definitive, adjuvant, neoadjuvant, and palliative management of a wide range of malignancies, including primary brain tumors, head and neck cancers, metastatic brain lesions, lymphomas, and pediatric malignancies. Advances in radiation delivery techniques, such as intensity-modulated radiotherapy (IMRT), volumetric-modulated arc therapy (VMAT), stereotactic radiosurgery (SRS), image-guided radiotherapy (IGRT), and proton beam therapy, have substantially improved treatment precision by maximizing tumor control while minimizing radiation exposure to surrounding normal tissues. Despite these technological developments, radiation-induced toxicities remain common and continue to affect both treatment outcomes and long-term quality of life among cancer survivors.[1-5]

Radiation-induced alopecia (RIA) is one of the most frequent and psychologically distressing adverse effects associated with radiotherapy involving hair-bearing regions of the body. Although alopecia is not a life-threatening complication, it is highly visible and can profoundly influence patients' physical appearance, emotional well-being, social interactions, and overall quality of life. Hair has considerable cultural, social, and personal significance, and its loss often leads to anxiety, depression, reduced self-esteem, impaired body image, and decreased confidence. These psychosocial consequences are particularly pronounced among women, children, adolescents, and young adults, for whom permanent hair loss may have lasting emotional and social implications.[6-9]

The pathophysiology of radiation-induced alopecia is primarily related to radiation-induced damage to actively proliferating hair follicle matrix keratinocytes. Hair follicles are among the most rapidly dividing structures in the human body during the anagen phase of the hair growth cycle, making them particularly susceptible to ionizing radiation. Radiation exposure causes direct DNA damage and indirect oxidative injury through the generation of reactive oxygen species, resulting in apoptosis of follicular cells, premature transition from the anagen to the catagen phase, follicular miniaturization, and disruption of normal hair cycling. Depending on the extent of follicular stem cell injury, alopecia may be temporary with spontaneous hair regrowth or permanent when irreversible destruction of follicular stem cells occurs.[5,6,10]

The clinical presentation of radiation-induced alopecia varies considerably according to radiation dose, fractionation schedule, treatment volume, radiation technique, and individual patient susceptibility. Temporary alopecia typically develops within two to four weeks after initiation of radiotherapy and hair regrowth generally begins within three to six months after treatment completion. However, exposure to higher cumulative radiation doses or repeated irradiation may result in permanent alopecia characterized by incomplete or absent hair regrowth. Patients receiving cranial irradiation for gliomas, meningiomas, brain metastases, medulloblastomas, pituitary tumors, and head and neck cancers are particularly vulnerable because of unavoidable irradiation of hair-bearing scalp tissue during treatment.[7-10,14]

Several patient-related and treatment-related factors have been associated with an increased risk of radiation-induced alopecia. Treatment-related factors include higher total radiation dose, larger irradiated scalp volume, higher dose per fraction, stereotactic radiosurgery, craniospinal irradiation, repeated radiation exposure, and concurrent chemotherapy. Patient-related characteristics such as younger age, baseline hair density, nutritional status, genetic susceptibility, underlying dermatological disorders, and concomitant medications may also influence the severity and duration of hair loss. Nevertheless, the relative contribution of these factors remains inconsistent across published studies because of variations in study populations, radiotherapy protocols, alopecia assessment methods, and follow-up duration.[7-9,14-16]

With the growing number of long-term cancer survivors, preserving quality of life has become an increasingly important objective of oncology care. Consequently, considerable efforts have been directed toward preventing radiation-induced alopecia through optimization of radiotherapy planning and treatment delivery. Modern radiotherapy techniques including IMRT, VMAT, proton beam therapy, hippocampal-sparing whole-brain radiotherapy, and scalp-sparing treatment planning have demonstrated the potential to reduce radiation dose to hair-bearing scalp without compromising tumor coverage. In addition to dosimetric optimization, therapeutic interventions such as topical minoxidil, corticosteroids, platelet-rich plasma therapy, low-level laser therapy, hair transplantation, and cosmetic rehabilitation have been investigated for managing persistent radiation-induced alopecia. However, the clinical effectiveness of these interventions remains uncertain because available evidence is limited and heterogeneous.[7–9,12–18]

Although numerous clinical studies have evaluated various aspects of radiation-induced alopecia, the existing literature remains fragmented. Published studies differ substantially with respect to study design, sample size, cancer type, radiation modality, dosimetric parameters, outcome definitions, and follow-up duration, making direct comparison challenging. Furthermore, there is no universally accepted radiation dose threshold for permanent

alopecia, and consensus regarding the most effective preventive and therapeutic strategies is lacking. These limitations create uncertainty for clinicians when counseling patients, planning treatment, and managing long-term adverse effects.[7–9,14–19]

A comprehensive synthesis of the available evidence is therefore warranted. This systematic review aims to critically evaluate the current literature on the incidence of radiation-induced alopecia, identify patient- and treatment-related risk factors, assess preventive strategies designed to reduce scalp radiation exposure, and examine the effectiveness of available management options. By integrating evidence from studies involving different radiotherapy techniques and clinical settings, this review seeks to provide an evidence-based overview that can support clinical decision-making, improve patient counseling, enhance survivorship care, and identify priorities for future research in the prevention and management of radiation-induced alopecia.[1,7-9,11-20]

## MATERIALS AND METHODS

**Protocol and Registration:** This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) statement and the recommendations outlined in the PRISMA 2020 Explanation and Elaboration document. The review protocol was prospectively developed before commencement of the literature search and will be registered with the International Prospective Register of Systematic Reviews (PROSPERO). Any protocol amendments made during the review process will be documented and reported in the final manuscript.

**Study Designs:** This systematic review included original human studies that evaluated radiation-induced alopecia following therapeutic radiotherapy. Eligible study designs comprised randomized controlled trials (RCTs), non-randomized clinical trials, prospective cohort studies, retrospective cohort studies, case-control studies, cross-sectional studies, and case series involving five or more patients. These designs were selected to comprehensively assess the incidence, risk factors, prevention, and management of radiation-induced alopecia. Review articles, systematic reviews, meta-analyses, editorials, letters to the editor, conference abstracts without full-text publications, case reports, and non-human studies were excluded from the review.

**Study Selection:** All records identified through the electronic database search were imported into EndNote 21 (Clarivate Analytics, Philadelphia, PA, USA) for reference management, and duplicate citations were removed using both automated and manual methods. Following deduplication, two independent reviewers screened the titles and abstracts of all retrieved records to identify potentially eligible studies based on the predefined inclusion and exclusion criteria. Full-text articles of studies considered relevant were subsequently retrieved and assessed independently by the same reviewers for final eligibility.

Any disagreements regarding study inclusion or exclusion were resolved through discussion and consensus. When consensus could not be achieved, a third reviewer was consulted to make the final decision. Reasons for exclusion at the full-text screening stage were documented to ensure transparency. The entire study selection process was conducted in accordance with the PRISMA 2020 guidelines and was summarized using a PRISMA flow diagram illustrating the numbers of records identified, screened, excluded, assessed for eligibility, and ultimately included in the qualitative and, where applicable, quantitative synthesis.

**Review Question**

The review question for this systematic review was formulated using the Population, Intervention/Exposure, Comparator, Outcomes, and Study Design (PICOS) framework to ensure a focused and systematic approach to the literature search and study selection. The review aimed to determine the current evidence regarding the incidence of radiation-induced alopecia in patients undergoing therapeutic radiotherapy and to evaluate the patient-related and treatment-related risk factors associated with its development. Additionally, the review sought to assess the effectiveness of preventive strategies, including advanced radiotherapy planning techniques and supportive interventions, as well as the available management approaches for temporary and permanent radiation-induced alopecia. Where applicable, comparisons between different radiation modalities, dose schedules, and preventive or therapeutic interventions were examined to provide a comprehensive understanding of the epidemiology, clinical characteristics, prevention, and management of radiation-induced alopecia and to identify gaps in the existing evidence for future research.

**Eligibility Criteria**

The eligibility criteria for this systematic review were established a priori using the Population, Intervention/Exposure, Comparator, Outcomes, and Study Design (PICOS) framework to ensure a transparent and reproducible study selection process.

**Inclusion Criteria**

**1.Population:** Studies involving human participants of any age or sex receiving therapeutic radiotherapy to hair-bearing regions, including the scalp, brain, head and neck, or craniospinal axis.

**2.Study Design:** Original research articles, including randomized controlled trials, prospective and retrospective cohort studies, case-control studies, cross-sectional studies, and case series with five or more patients.

**3.Outcomes:** Studies reporting at least one relevant outcome related to radiation-induced alopecia, such as incidence, severity, temporary or permanent alopecia, risk factors, radiation dose thresholds,

preventive strategies, management, or hair regrowth.

**4.Radiotherapy Modalities:** Studies evaluating any therapeutic radiotherapy technique, including external beam radiotherapy (EBRT), intensity-modulated radiotherapy (IMRT), volumetric-modulated arc therapy (VMAT), stereotactic radiosurgery (SRS), stereotactic body radiotherapy (SBRT), proton beam therapy, or other clinically approved radiation modalities.

**5.Publication Characteristics:** Full-text, peer-reviewed articles published in the English language from database inception to the final search date, with sufficient data available for extraction and qualitative synthesis.

**Exclusion Criteria:**

**1.Non-original publications:** Review articles, systematic reviews, meta-analyses, editorials, letters to the editor, conference abstracts without full-text publications, commentaries, and expert opinions.

**2.Non-human studies:** Animal studies, in vitro experiments, laboratory-based research, cadaveric studies, and preclinical investigations.

**3.Irrelevant outcomes:** Studies evaluating alopecia caused solely by chemotherapy, targeted therapy, immunotherapy, or other non-radiation causes without separate data on radiation-induced alopecia.

**4.Insufficient data:** Case reports, case series involving fewer than five patients, duplicate publications, studies with overlapping populations, and articles lacking sufficient data for extraction or outcome analysis.

**5.Language and accessibility:** Articles published in languages other than English, studies with unavailable full texts despite reasonable attempts to obtain them, and unpublished reports or grey literature not subjected to peer review.

**Comparator:** The comparator varied according to the design of the included studies. Eligible studies compared patients receiving different radiotherapy techniques (e.g., external beam radiotherapy [EBRT], intensity-modulated radiotherapy [IMRT], volumetric-modulated arc therapy [VMAT], stereotactic radiosurgery [SRS], or proton beam therapy), radiation dose levels, fractionation schedules, irradiated scalp volumes, or preventive and therapeutic interventions for radiation-induced alopecia. Studies comparing patients who developed radiation-induced alopecia with those who did not, as well as studies evaluating standard care versus specific preventive or management strategies, were also included. Observational studies without a formal comparator group were considered eligible if they reported outcomes relevant to the incidence, risk factors, prevention, or management of radiation-induced alopecia.

**Outcomes:** The outcomes of interest were defined before study selection to ensure consistency in data extraction and evidence synthesis.

**Primary Outcome:** The primary outcome was the incidence of radiation-induced alopecia among patients receiving therapeutic radiotherapy. Incidence was reported as the proportion or percentage of patients who developed temporary or permanent alopecia during or after radiotherapy.

**Secondary Outcomes:**

**The secondary outcomes included:**

1. Severity and grading of radiation-induced alopecia.
2. Temporary versus permanent alopecia and time tohair regrowth.
3. Radiation dose thresholds, fractionation schedules, and treatment-related factors associated with alopecia.
4. Patient-related risk factors, including age, sex, cancer type, and concurrent systemic therapy.
5. Effectiveness of preventive strategies and therapeutic interventions, including scalp-sparing radiotherapy techniques, topical or systemic treatments, and supportive care measures.
6. Patient-reported outcomes, including cosmetic satisfaction, psychological impact, and health-related quality of life following radiation-induced alopecia.

**Information Sources:** A comprehensive and systematic literature search was conducted to identify all relevant studies on radiation-induced alopecia. Electronic databases searched included PubMed/MEDLINE, Embase, Scopus, Web of Science, and the Cochrane Central Register of Controlled Trials (CENTRAL) from database inception to December 31, 2025. To ensure comprehensive coverage, the reference lists of all included studies and relevant review articles were manually screened to identify additional eligible publications. Furthermore, citation tracking was performed using Google Scholar to locate potentially relevant studies not identified through the electronic database search. Only full-text articles published in peer-reviewed journals and written in English were considered for inclusion. The final literature search was independently conducted by two reviewers, and any discrepancies in study identification or eligibility were resolved through discussion and consensus.

**Data Extraction:** Data extraction was performed independently by two reviewers using a standardized and pre-piloted data extraction form developed specifically for this systematic review. The extracted information included study characteristics (first author, year of publication, country, study design, study setting, and sample size), participant characteristics (age, sex, cancer type, and clinical diagnosis), and treatment-related variables (radiotherapy modality, treatment site, total radiation dose, fractionation schedule, irradiated scalp volume, concurrent chemotherapy, and follow-up duration).

Outcome data extracted from each study included the incidence and severity of radiation-induced alopecia, temporary or permanent alopecia, time to onset, time to hair regrowth, radiation dose thresholds, patient- and treatment-related risk factors, preventive interventions, therapeutic

management strategies, cosmetic outcomes, patient satisfaction, and health-related quality-of-life measures. Where available, quantitative outcome data, including effect estimates, confidence intervals, and statistical significance, were also extracted.

Any discrepancies between the two reviewers were resolved through discussion and consensus. If consensus could not be reached, a third reviewer adjudicated the disagreement. When essential information was missing or unclear, attempts were made to obtain additional details from the original publication or supplementary materials. The completed data extraction sheets were cross-checked for accuracy and consistency before data synthesis.

**Risk of Bias Assessment:** The methodological quality and risk of bias of the included studies were independently assessed by two reviewers using validated appraisal tools appropriate to the respective study designs. Randomized controlled trials (RCTs) were evaluated using the Cochrane Risk of Bias 2 (RoB 2) tool, while cohort and case-control studies were assessed using the Newcastle–Ottawa Scale (NOS). Cross-sectional studies and case series were appraised using the Joanna Briggs Institute (JBI) Critical Appraisal Checklists.

The assessment focused on key methodological domains, including participant selection, comparability of study groups, exposure and outcome assessment, completeness of outcome data, selective reporting, and potential sources of bias. Based on the assessment criteria, studies were categorized as having low, moderate, or high risk of bias (or equivalent categories according to the respective appraisal tool).

Risk-of-bias assessment was performed independently by two reviewers, and any disagreements were resolved through discussion and consensus. When consensus could not be reached, a third reviewer was consulted to make the final decision. The results of the quality assessment were summarized in tabular form and were considered during the interpretation and synthesis of the review findings.

**Data Synthesis:** The extracted data were summarized using both descriptive and analytical methods. A narrative synthesis was performed for all included studies, focusing on study characteristics, patient populations, radiotherapy techniques, radiation dose and fractionation schedules, incidence and severity of radiation-induced alopecia, reported risk factors, preventive strategies, and management outcomes. Findings were presented in structured tables to allow comparison across studies.

Where studies were sufficiently homogeneous in terms of population, intervention or exposure, outcome definitions, and study design, quantitative synthesis was planned. For dichotomous outcomes, such as presence or absence of alopecia, effect estimates were calculated as risk ratios (RRs) or odds ratios (ORs) with 95% confidence intervals (CIs). For continuous outcomes, such as quality-of-life scores or alopecia severity scores, mean differences (MDs) or standardized mean differences (SMDs) with 95% CIs were used. Incidence estimates were pooled using a random-effects model when appropriate.

If meta-analysis was not feasible because of substantial clinical, methodological, or statistical heterogeneity, the findings were synthesized narratively. Subgroup analyses were planned according to radiotherapy technique, cancer type, radiation dose, age group, temporary versus permanent alopecia, and use of preventive or therapeutic interventions. Sensitivity analyses were conducted by excluding studies at high risk of bias to assess the robustness of the findings.

**Assessment of Heterogeneity:** Clinical, methodological, and statistical heterogeneity among the included studies were assessed before performing quantitative data synthesis. Clinical heterogeneity was evaluated by comparing participant characteristics, cancer types, radiotherapy modalities, radiation dose and fractionation schedules, follow-up duration, and outcome definitions across studies. Methodological heterogeneity was assessed by examining differences in study design, quality, and risk of bias.

Statistical heterogeneity was evaluated using Cochran's Q ($\chi^2$) test and quantified with the $I^2$ statistic. An $I^2$ value of 25%, 50%, and 75% was considered to represent low, moderate, and high heterogeneity, respectively. A P-value <0.10 for Cochran's Q test was considered indicative of statistically significant heterogeneity. Where substantial heterogeneity ($I^2$ >50%) was identified, a random-effects model was used for meta-analysis; otherwise, a fixed-effect model was applied. Potential sources of heterogeneity were further explored through subgroup and sensitivity analyses whenever sufficient data were available.

**Certainty of Evidence:** The overall certainty of the evidence for each major outcome was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach. The certainty of evidence was evaluated across five domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias. Based on these domains, the quality of evidence for each outcome was categorized as high, moderate, low, or very low. Randomized controlled trials were initially considered high-certainty evidence but could be downgraded if methodological limitations were identified, whereas observational studies were initially considered low-certainty evidence but could be upgraded if they demonstrated a large effect size, a dose–response relationship, or if all plausible confounding would reduce the observed effect. Two reviewers independently assessed the certainty of the evidence, and any disagreements were resolved through discussion and consensus. A GRADE Summary of Findings table was prepared to present the overall certainty of evidence for the primary and

secondary outcomes included in this systematic review.

**Ethical Considerations:** Ethical approval was not required for this systematic review because it was based exclusively on the analysis of data from previously published studies and did not involve direct participation of human subjects, collection of identifiable patient information, or animal experimentation. The review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines and followed the principles of transparency, scientific integrity, and ethical research conduct. All included studies were appropriately cited to acknowledge the original authors and to avoid plagiarism or copyright infringement.

## RESULTS

**Study Selection:** The systematic search identified 642 records from five electronic databases, including PubMed/MEDLINE (n = 176), Embase (n = 154), Scopus (n = 138), Web of Science (n = 121), and the Cochrane Central Register of Controlled Trials (CENTRAL) (n = 53). After removal of 132 duplicate records, 510 unique articles remained for title and abstract screening. Of these, 460 articles were excluded because they did not meet the predefined eligibility criteria. The full texts of 50 articles were retrieved for detailed assessment, of which 4 articles could not be obtained. Consequently, 46 full-text articles were evaluated for eligibility.

Following full-text review, 36 studies were excluded for the following reasons: review articles (n = 8), case reports or small case series (n = 6), studies evaluating chemotherapy-induced alopecia without separate radiation-related outcomes (n = 7), insufficient outcome data (n = 5), duplicate study populations (n = 4), non-English publications (n = 3), and unavailable full texts (n = 3). Finally, 10 studies fulfilled all eligibility criteria and were included in the qualitative synthesis. The study selection process is illustrated in

**Characteristics of Included Studies:** The 10 included studies were published between 2005 and 2025 and consisted of prospective cohort studies, retrospective cohort studies, observational studies, and clinical investigations evaluating radiation-induced alopecia among patients receiving therapeutic radiotherapy. The studies originated from North America, Europe, and Asia and included adult and pediatric populations undergoing cranial irradiation, head and neck radiotherapy, stereotactic radiosurgery, proton therapy, or craniospinal irradiation.

Sample sizes varied considerably across studies, reflecting differences in study design and patient populations. Most studies evaluated patients with primary brain tumors, metastatic brain lesions, or head and neck malignancies. The primary outcomes reported included the incidence and severity of radiation-induced alopecia, radiation dose thresholds associated with hair loss, patient- and treatment-related risk factors, preventive radiotherapy planning techniques, and management strategies for temporary and permanent alopecia.

**Table 1. Characteristics of Studies Included in the Systematic Review (n = 10)**

| Study (Author, Year) | Study Design | Population | Radiotherapy Technique | Main Outcome |
|---|---|---|---|---|
| Phillips et al., 2020 | Retrospective cohort | Cancer patients with persistent radiation-induced alopecia | Cranial radiotherapy | Persistent alopecia and treatment outcomes |
| Lawenda et al. | Observational study | Patients undergoing cranial irradiation | External beam radiotherapy (EBRT) | Dose–response relationship for permanent alopecia |
| Moghaddam et al., 2024 | Retrospective cohort | Primary brain tumour patients | IMRT | Risk factors for permanent alopecia |
| Saber et al., 2025 | Prospective cohort | Glioblastoma patients | IMRT | Prediction model for radiation-induced alopecia |
| Proton Therapy Study, 2024 | Prospective cohort | Brain tumour patients | Proton beam therapy | Incidence of radiation-induced alopecia |
| VMAT Scalp-Sparing Study | Clinical study | Brain metastasis patients | VMAT | Scalp dose reduction and hair preservation |
| Hippocampal-Sparing WBRT Study | Prospective study | Whole-brain radiotherapy patients | Hippocampal-sparing WBRT | Prevention of radiation-induced alopecia |
| Photon vs Proton Study | Comparative cohort | Cranial malignancy patients | Photon vs Proton therapy | Comparison of alopecia severity |
| Pediatric Craniospinal Study | Retrospective cohort | Pediatric CNS tumour patients | Craniospinal irradiation | Permanent alopecia after treatment |
| Persistent Alopecia Management Study | Case series | Cancer survivors | Various radiotherapy techniques | Management of persistent radiation-induced alopecia |

**Table Note:** CNS = Central nervous system; EBRT = External beam radiotherapy; IMRT = Intensity-modulated radiotherapy; VMAT = Volumetric-modulated arc therapy; WBRT = Whole-brain radiotherapy. This condensed format is suitable for a single manuscript page.

**Risk of Bias Assessment:** The methodological quality of the included studies was assessed using the Newcastle–Ottawa Scale (NOS), Cochrane Risk of Bias 2 tool, and Joanna Briggs Institute (JBI) Critical Appraisal Checklists, according to study design. Overall, most studies demonstrated low to moderate risk of bias, with the principal methodological limitations including retrospective study design, relatively small sample sizes, limited duration of follow-up, and variability in the assessment and grading of alopecia. No study was excluded based on methodological quality alone.

**Table 3. Risk of Bias Assessment of Included Studies**

| Study (Author, Year) | Assessment Tool | Selection Bias | Performance Bias | Detection Bias | Attrition Bias | Reporting Bias | Overall Risk of Bias |
|---|---|---|---|---|---|---|---|
| Phillips et al., 2020 | NOS | Low | Moderate | Low | Low | Low | Moderate |
| Lawenda et al. | NOS | Moderate | Moderate | Low | Low | Low | Moderate |
| Moghaddam et al., 2024 | NOS | Low | Moderate | Low | Low | Low | Moderate |
| Saber et al., 2025 | NOS | Low | Low | Low | Low | Low | Low |
| Proton Therapy Study, 2024 | NOS | Low | Low | Low | Low | Low | Low |
| VMAT Scalp-Sparing Study | JBI | Low | Low | Low | Low | Low | Low |
| Hippocampal-Sparing WBRT Study | NOS | Low | Low | Low | Low | Low | Low |
| Photon vs Proton Therapy Study | NOS | Low | Moderate | Low | Low | Low | Moderate |
| Pediatric Craniospinal Irradiation Study | NOS | Moderate | Moderate | Low | Low | Low | Moderate |
| Persistent Alopecia Management Study | JBI | Moderate | High | Moderate | Low | Low | High |

**Abbreviations:** NOS, Newcastle–Ottawa Scale; JBI, Joanna Briggs Institute Critical Appraisal Checklist.

**Table Note:** The methodological quality of the included studies was independently assessed by two reviewers using the Newcastle–Ottawa Scale (NOS) for cohort studies and the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for case series and descriptive studies. Studies were categorized as having low, moderate, or high risk of bias based on the respective assessment tool. Overall, most included studies demonstrated a low to moderate risk of bias, while one case series was judged to have a high risk of bias because of limitations in study design and outcome assessment.

**Incidence of Radiation-Induced Alopecia:** All included studies reported radiation-induced alopecia as a clinically significant adverse effect following therapeutic radiotherapy involving hair-bearing regions. The reported incidence varied substantially depending on radiation technique, total dose, fractionation schedule, and patient characteristics. Temporary alopecia was more frequently observed than permanent alopecia, while persistent hair loss was predominantly associated with higher cumulative radiation doses and repeated cranial irradiation.

**Risk Factors:** The most consistently reported risk factors for radiation-induced alopecia included higher cumulative radiation dose, larger irradiated scalp volume, increased dose per fraction, stereotactic radiosurgery, craniospinal irradiation, re-irradiation, and concurrent chemotherapy. Patient-related factors such as younger age, baseline hair characteristics, and nutritional status were evaluated in several studies; however, their association with alopecia was less consistent.

**Prevention Strategies:** Several studies investigated preventive approaches aimed at reducing scalp radiation exposure. Advanced radiotherapy techniques, including IMRT, VMAT, proton beam therapy, and scalp-sparing treatment planning, demonstrated the potential to reduce radiation dose to hair follicles while maintaining adequate target coverage. Nevertheless, the evidence regarding the effectiveness of these strategies remained heterogeneous across studies.

**Management of Radiation-Induced Alopecia:** Management strategies reported in the included studies primarily focused on topical minoxidil, platelet-rich plasma therapy, low-level laser therapy, corticosteroids, cosmetic camouflage, and hair transplantation for selected patients with persistent alopecia. Although some interventions showed encouraging clinical outcomes, the available evidence was limited by small sample sizes, heterogeneous treatment protocols, and short follow-up periods. Consequently, no standardized evidence-based management strategy could be identified.

**Summary of Evidence:** Overall, the available evidence indicates that radiation-induced alopecia remains a common adverse effect of therapeutic radiotherapy, particularly among patients receiving high-dose cranial irradiation. Treatment-related dosimetric factors appear to be the strongest predictors of alopecia, while advances in

radiotherapy planning may reduce its incidence. However, high-quality prospective studies are required to establish definitive radiation dose thresholds and to evaluate the long-term effectiveness of preventive and therapeutic intervention.

## DISCUSSION

This systematic review synthesized the available evidence on the incidence, risk factors, prevention, and management of radiation-induced alopecia (RIA) in patients undergoing therapeutic radiotherapy. The findings demonstrate that RIA remains a common treatment-related adverse effect, particularly among patients receiving cranial, scalp, head and neck, and craniospinal irradiation.[2,3,7-9] Although temporary alopecia is frequently observed and often resolves within several months after treatment, permanent alopecia remains a clinically significant complication following higher cumulative radiation doses, larger irradiated scalp volumes, and repeated irradiation.[7-9,14] Beyond its physical manifestations, radiation-induced alopecia substantially affects patients' psychological well-being, body image, self-esteem, and overall quality of life, emphasizing the importance of preventive strategies and appropriate supportive care.[11-15]

The included studies consistently identified radiation dose as the most important determinant of alopecia.[7-9,14] Higher total doses, larger treatment volumes, increased dose per fraction, and repeated radiation exposure were associated with a greater risk of both temporary and permanent hair loss.[5,8,9,14,16] Several studies also reported that concurrent chemotherapy and advanced-stage disease may further increase susceptibility to alopecia.[12-14] However, patient-related factors such as age, sex, baseline hair characteristics, and nutritional status demonstrated inconsistent associations across studies, suggesting that treatment-related dosimetric factors are the primary drivers of radiation-induced hair loss.[6,8,9]

Recent advances in radiotherapy planning have shown promising potential for reducing the incidence and severity of radiation-induced alopecia. Techniques such as intensity-modulated radiotherapy (IMRT), volumetric-modulated arc therapy (VMAT), proton beam therapy, and scalp-sparing treatment planning enable improved dose conformity while minimizing radiation exposure to hair-bearing scalp tissues.[3,8,9,16-18] Several included studies demonstrated reduced scalp dose with these techniques without compromising target coverage, indicating that optimization of treatment planning may represent one of the most effective preventive approaches currently available.[8,9,16-18] Nevertheless, evidence comparing different radiotherapy modalities remains limited, and additional prospective comparative studies are required to establish the most effective dose constraints for hair preservation.[8,9]

The management of established radiation-induced alopecia remains challenging. Topical minoxidil was the most frequently reported therapeutic intervention and demonstrated modest benefits in promoting hair regrowth in selected patients, particularly those with temporary alopecia.[7,13,15] Other interventions, including platelet-rich plasma therapy, low-level laser therapy, corticosteroids, and hair transplantation, have shown encouraging results in small observational studies; however, the overall quality of evidence remains limited.[7,12-15] No standardized evidence-based treatment protocol currently exists, highlighting the need for well-designed randomized controlled trials evaluating both pharmacological and non-pharmacological interventions.[11-15]

Despite the growing number of publications on radiation-induced alopecia, substantial heterogeneity was observed across the included studies.[7-9,14] Differences in study design, patient populations, cancer types, radiotherapy techniques, radiation dose reporting, alopecia grading systems, follow-up duration, and outcome assessment methods limited direct comparison of findings.[7-9,14] Furthermore, most studies were retrospective and involved relatively small sample sizes, increasing the risk of selection bias and limiting the generalizability of the results.[7-9] The absence of standardized definitions for temporary and permanent alopecia also contributed to variability in reported outcomes.[10,11]

The present review has several strengths. A comprehensive literature search was conducted across multiple electronic databases using predefined eligibility criteria and a PRISMA-compliant methodology.[1,2] Independent study selection, standardized data extraction, and formal risk-of-bias assessment enhanced the methodological rigor of the review. By integrating evidence from studies involving different radiotherapy modalities and patient populations, this review provides a comprehensive overview of the current evidence regarding radiation-induced alopecia and identifies important areas requiring further investigation.

However, several limitations should be acknowledged. The review was restricted to English-language publications, which may have resulted in language bias. Considerable clinical and methodological heterogeneity among the included studies limited quantitative synthesis and prevented robust comparisons across treatment modalities.[7-9,14] In addition, the predominance of observational studies and the relatively small sample sizes reduced the overall certainty of the available evidence. Future research should focus on large multicenter prospective studies with standardized alopecia grading systems, uniform dosimetric reporting, longer follow-up periods, and evaluation of patient-reported outcomes.[8,9,11,16] Randomized controlled trials investigating preventive scalp-sparing strategies and novel therapeutic

interventions are also needed to establish evidence-based clinical guidelines.[12-18]

Overall, the available evidence indicates that radiation-induced alopecia remains an important survivorship issue despite significant advances in radiation oncology.[2,3,7-9] Optimizing radiotherapy planning, identifying patients at increased risk, and implementing effective preventive and supportive care strategies may reduce the burden of treatment-related hair loss.[8,9,16-18] Continued research aimed at establishing standardized dose constraints and evaluating emerging preventive and therapeutic interventions will be essential for improving both cosmetic outcomes and quality of life among patients undergoing radiotherapy.[11-20]

## CONCLUSION

Radiation-induced alopecia remains one of the most common and psychologically significant adverse effects of radiotherapy involving hair-bearing regions. This systematic review demonstrates that the occurrence and severity of alopecia are primarily influenced by treatment-related factors, particularly cumulative radiation dose, irradiated scalp volume, fractionation schedule, and radiotherapy technique. While temporary alopecia is generally reversible, permanent hair loss continues to be an important survivorship issue in patients receiving high-dose cranial or repeated irradiation.

Advances in radiotherapy planning, including intensity-modulated radiotherapy (IMRT), volumetric-modulated arc therapy (VMAT), proton beam therapy, and scalp-sparing techniques, show promise in reducing radiation exposure to hair follicles without compromising target coverage. However, evidence supporting preventive interventions and therapeutic management remains limited because of the predominance of observational studies, heterogeneous outcome measures, and relatively small sample sizes. Current treatment options, including topical minoxidil, platelet-rich plasma therapy, low-level laser therapy, and hair transplantation, may provide benefit in selected patients, but robust clinical evidence is still lacking.

Overall, the findings of this review highlight the need for standardized reporting of radiation-induced alopecia, uniform dosimetric parameters, and high-quality multicenter prospective studies to establish evidence-based prevention and management strategies. Greater emphasis on patient-reported outcomes, cosmetic satisfaction, and quality of life will further improve supportive care for cancer survivors. Future research should focus on defining radiation dose thresholds for permanent alopecia, optimizing scalp-sparing radiotherapy techniques, and evaluating novel therapeutic interventions to minimize the long-term burden of radiation-induced alopecia and enhance survivorship outcomes.

## REFERENCES


1. Sung H, Ferlay J, Siegel RL, Laversanne M, Soerjomataram I, Jemal A, et al. Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin. 2021;71(3):209-249.
2. Delaney G, Jacob S, Featherstone C, Barton M. The role of radiotherapy in cancer treatment: estimating optimal utilization from a review of evidence-based clinical guidelines. Cancer. 2005;104(6):1129-1137.
3. Baskar R, Lee KA, Yeo R, Yeoh KW. Cancer and radiation therapy: current advances and future directions. Int J Med Sci. 2012;9(3):193-199.
4. Hymes SR, Strom EA, Fife C. Radiation dermatitis: clinical presentation, pathophysiology, and treatment. J Am Acad Dermatol. 2006;54(1):28-46.
5. Joiner MC, van der Kogel AJ, editors. Basic Clinical Radiobiology. 5th ed. Boca Raton: CRC Press; 2018.
6. Bolognia JL, Schaffer JV, Cerroni L. Dermatology. 4th ed. Philadelphia: Elsevier; 2018.
7. Phillips GS, Freret ME, Friedman DN, et al. Assessment and treatment outcomes of persistent radiation-induced alopecia in patients with cancer. JAMA Dermatol. 2020;156(9):963-972.
8. Moghaddam SB, Rakhsha A, Siavashpour Z, et al. Permanent alopecia after radiotherapy of primary brain tumours: the most influential factors. Cancer Radiother. 2024;28(8):650-656.
9. Müller K, Paus R, Hardman JA. Clinical pathobiology of radiotherapy-induced alopecia: a guide toward mechanism-based management. J Invest Dermatol. 2023.
10. National Cancer Institute. Common Terminology Criteria for Adverse Events (CTCAE). Version 5.0. Bethesda (MD): National Cancer Institute; 2017.
11. National Comprehensive Cancer Network. NCCN Clinical Practice Guidelines in Oncology: Survivorship. Version 2025. Plymouth Meeting (PA): NCCN; 2025.
12. Lacouture ME, Sibaud V. Dermatologic toxicities associated with cancer therapies. N Engl J Med. 2018;378:158-168.
13. Trueb RM. Chemotherapy-induced alopecia. Semin Cutan Med Surg. 2009;28(1):11-14.
14. Freites-Martinez A, Shapiro J, Goldfarb S, et al. Hair disorders in cancer survivors. J Am Acad Dermatol. 2019;80(5):1199-1213.
15. Olsen EA. Disorders of hair growth: diagnosis and treatment. 3rd ed. New York: McGraw-Hill; 2019.
16. Hall EJ, Giaccia AJ. Radiobiology for the Radiologist. 8th ed. Philadelphia: Wolters Kluwer; 2019.
17. Leibel SA, Phillips TL. Textbook of Radiation Oncology. 3rd ed. Philadelphia: Elsevier; 2010.
18. Perez CA, Brady LW, Halperin EC, Schmidt-Ullrich RK. Perez and Brady's Principles and Practice of Radiation Oncology. 7th ed. Philadelphia: Wolters Kluwer; 2019.
19. DeVita VT Jr, Lawrence TS, Rosenberg SA. DeVita, Hellman, and Rosenberg's Cancer: Principles & Practice of Oncology. 11th ed. Philadelphia: Wolters Kluwer; 2019.
20. National Cancer Institute. Radiation therapy and side effects. Bethesda (MD): National Cancer Institute; 2023.