



Dental Implant Rehabilitation in Patients Receiving Head and Neck Radiotherapy: Clinical Outcomes, Site-Specific Dose, and Treatment Timing

Efsun Somay^{1*}, Erkan Topkan² and Ugur Selek³

¹Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Baskent University, Ankara, Türkiye

²Department of Radiation Oncology, Faculty of Medicine, Baskent University, Adana, Türkiye

³Department of Radiation Oncology, School of Medicine, Koc University, Istanbul, Türkiye

***Corresponding Author:** Efsun Somay, Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Baskent University, Ankara, Türkiye.

Received: October 08, 2026

Published: October 19, 2026

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DOI: 10.31080/ASDS.2026.10.2157

Abstract

Dental implant rehabilitation can improve oral function and quality of life in patients treated for head and neck cancer. However, reported implant outcomes vary considerably across studies because of differences in radiation exposure, anatomical location, reconstruction methods, treatment sequencing, outcome definitions, and follow-up protocols. This narrative review synthesizes current evidence regarding implant survival and clinical success, site-specific radiation dose, osteoradionecrosis of the jaw (ORNJ), and practical considerations for implant-based rehabilitation. Particular attention is given to distinguishing implant retention from clinical and prosthetic success, recognizing that the mere presence of an implant does not necessarily indicate sustained functional benefit. Assess radiation exposure at the intended implant site rather than inferring it from the prescribed tumor dose or whole-jaw exposure. The 2024 ISOO-MASCC-ASCO guideline identifies jaw regions receiving at least 50 Gy as being at risk for ORNJ and recommends avoiding implant placement in these regions when suitable alternatives exist. However, this recommendation should not be interpreted as a universal threshold for implant failure. Implant placement before radiotherapy, during oncologic reconstruction, and after radiotherapy represent distinct clinical scenarios that require consideration of treatment chronology, tissue condition, and potential complications. When interpreting published outcomes, account for differences between implant-level and patient-level measures, as well as definitions and timing of adverse events. Individualized multidisciplinary assessment remains essential for balancing anticipated rehabilitation benefits against treatment-related risks.

Keywords: Dental Implant; Head and Neck Cancer; Radiotherapy; Osteoradionecrosis; Radiation Dose; Implant Survival; Competing Risks; Oral Rehabilitation

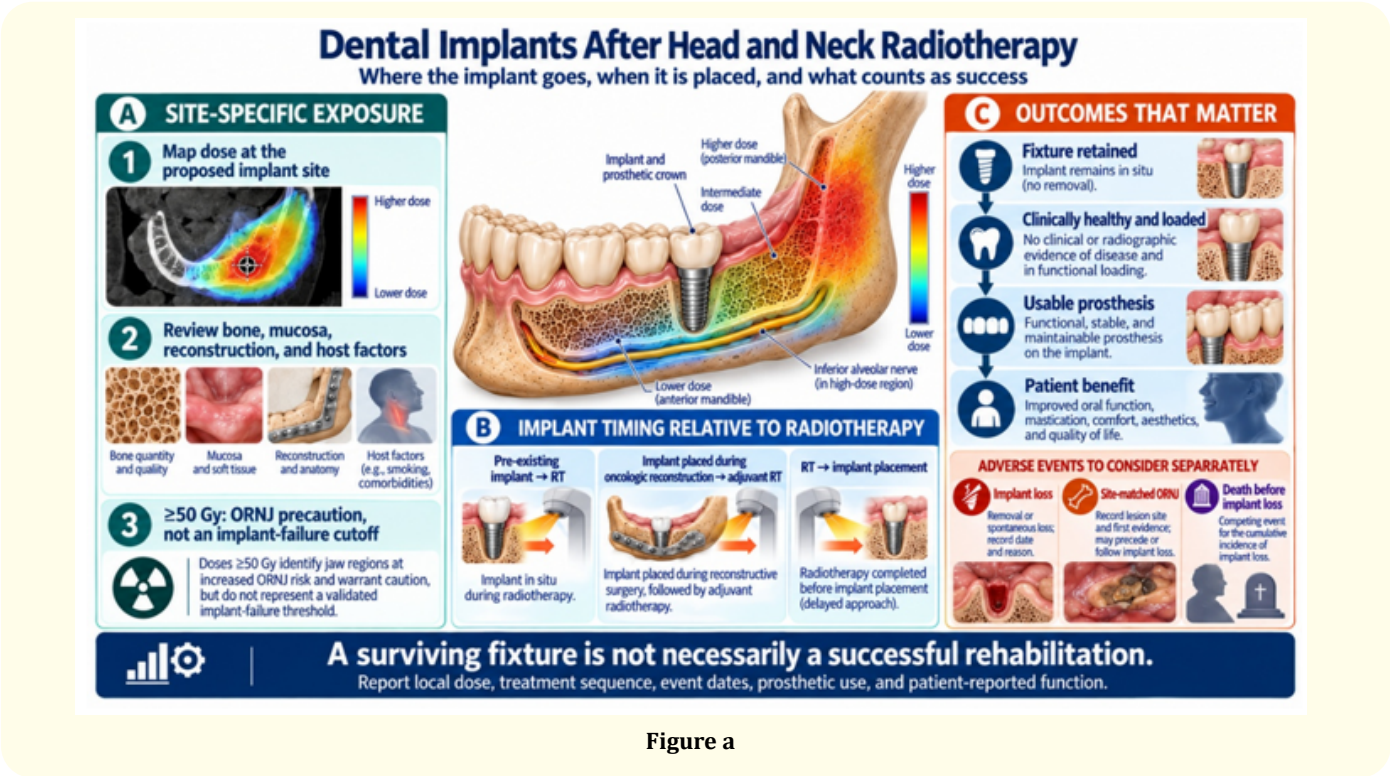


Figure a

Abbreviations

ASCO: American Society of Clinical Oncology; CT: Computed Tomography; Gy: Gray; ISOO: International Society of Oral Oncology; MASCC: Multinational Association of Supportive Care in Cancer; MEDLINE: Medical Literature Analysis and Retrieval System Online; MRI: Magnetic Resonance Imaging; OR: Odds Ratio; ORNJ: Osteoradionecrosis of the Jaw; PET/CT: Positron Emission Tomography/Computed Tomography; RT: Radiotherapy.

Introduction

Rehabilitation after head and neck cancer treatment aims to restore eating, speech, comfort, and social participation as well as dentition. Surgical resection may alter jaw continuity and prosthetic support, while radiotherapy can produce fibrosis, xerostomia, mucosal changes, and reduced mouth opening. These effects may make conventional removable prostheses difficult to retain or tolerate. Implant-supported rehabilitation can offer meaningful benefits to selected patients, particularly when anatomical changes limit other options. However, its potential benefit must be considered alongside the condition of the bone and soft tissues at the proposed implant site, the demands of surgery,

and the patient’s capacity for long-term prosthetic maintenance [1].

The published evidence supports a cautious, individualized approach. Systematic reviews generally report lower implant survival in irradiated than in nonirradiated bone, although many implants remain in situ over extended follow-up [2-5]. Estimates vary across studies because cohorts differ in cancer site, resection and reconstruction, radiation technique, implant location, follow-up duration, and outcome definitions [6,7]. An implant that remains in situ may be unloaded, show progressive peri-implant bone loss, or fail to support a prosthesis that the patient can use comfortably. Consequently, fixture retention, clinical implant success, prosthetic performance, and patient-reported benefit should be evaluated as related but distinct outcomes [8-10].

Radiation exposure requires similar precision. The prescribed tumor dose does not necessarily represent the dose received by an implant bed: modern treatment plans create spatially heterogeneous distributions across the mandible, maxilla, and reconstructed tissues [8,11-14]. Evidence linking local dose to implant outcomes and osteoradionecrosis of the jaw (ORNJ)

therefore makes site-specific dosimetry more informative than a general statement that the patient received head and neck radiotherapy [8,11,15,16]. The 2024 ISOO-MASCC-ASCO guideline identifies jaw regions receiving at least 50 Gy as being at risk for ORNJ and advises avoiding implant placement in such regions when other restorative options are available [17]. This recommendation guides risk assessment; it does not establish a universal implant-failure threshold or assure safety at lower doses.

The order and timing of events further affect interpretation. An implant may be placed before radiotherapy, during cancer reconstruction before adjuvant treatment, or after the jaw has been irradiated. These sequences expose the implant and surrounding tissues to different clinical conditions. Likewise, ORNJ detected after implant placement may have followed unrecognized bone injury, been triggered by surgery, been complicated by infection, or developed later within a high-dose region. Establishing an association requires considering the dates and anatomical locations of radiotherapy, implantation, ORNJ, and implant loss together; sequence alone does not establish causation [13,16,18]. Outcome analyses must also account for multiple implants within individual patients and for death before implant failure, which affects estimates of the probability of failure over time [8,19].

This narrative review summarizes current evidence on dental implant rehabilitation in patients receiving head and neck radiotherapy, with particular attention to implant survival and clinical success, radiation exposure at the implant site, treatment sequencing, and osteoradionecrosis of the jaw (ORNJ). It also considers anatomical and reconstructive factors, the interpretation of implant- and patient-level outcomes, time-to-event and competing-risk considerations, and practical considerations for multidisciplinary treatment planning. The aim is to provide a clinically oriented synthesis of the available evidence, clarify important limitations in interpreting reported outcomes, and identify areas warranting further investigation.

Review Methodology

This narrative review was informed by targeted searches of PubMed/MEDLINE and examination of the reference lists of relevant publications through September 2026. The reviewed literature included original clinical studies, systematic reviews and meta-analyses, consensus statements, and clinical practice guidelines

addressing dental implant rehabilitation in patients receiving head and neck radiotherapy. The synthesis focused on implant survival and clinical success, site-specific radiation exposure, treatment sequencing, ORNJ, and functional rehabilitation outcomes. Publications were selected based on clinical relevance and their contribution to understanding these domains, with particular attention to differences in outcome definitions, anatomical and treatment characteristics, and follow-up duration. No formal risk-of-bias assessment or quantitative meta-analysis was performed. We synthesized findings descriptively, with attention to methodological limitations and clinical applicability.

Interpreting implant survival and clinical success

Evaluating dental implant rehabilitation after head and neck radiotherapy requires distinguishing physical implant retention from clinical performance and functional rehabilitation. Although implant survival is a frequently reported endpoint, it does not necessarily indicate satisfactory peri-implant health, successful prosthetic restoration, or meaningful patient benefit [8-10]. Moreover, implant- and patient-level outcomes address different clinical questions and are not directly interchangeable. Recognizing these distinctions is essential for interpreting published findings and assessing the clinical value of implant-supported rehabilitation.

Implant survival, clinical success, and functional rehabilitation

Implant survival generally means a fixture remains in situ, although some studies also require functional loading. Clinical success may include broader criteria, such as implant stability, acceptable peri-implant bone levels, absence of persistent symptoms or infection, and satisfactory function. Prosthetic success addresses the restoration's usability, retention, comfort, and maintenance requirements. Although these outcomes are interrelated, they are not interchangeable: an implant may remain physically present despite clinical complications or remain stable without supporting a functional prosthesis. In a prospective observational study, two-year implant survival was 92.3%, whereas clinical success based on modified Albrektsson criteria was 78.6%, partly because of peri-implant bone loss [9]. Similarly, another cohort reported five-year survival and success rates of 92.4% and 74.9%, respectively [8]. These differences show why implant retention alone cannot adequately characterize overall rehabilitation success.

The interpretation of implant failure also depends on the criteria used to define the event. Clinical deterioration, recognition of failure, the decision to remove an implant, and actual removal may occur at different times. Consequently, an implant that no longer meets predefined clinical success criteria may remain in situ, particularly when further surgery is deferred. Conversely, radiographic bone loss or other potentially manageable complications do not necessarily indicate irreversible failure or loss of prosthetic function. Studies should therefore specify whether failure refers

to predefined clinical criteria, planned removal, or actual implant loss and document the corresponding assessment dates. Whenever feasible, distinguish causes of implant loss, including failed osseointegration, peri-implant disease, mechanical complications, and removal during oncologic surgery [8,9]. Table 1 summarizes the distinct outcome definitions, time origins, reporting units, and potential interpretive limitations relevant to implant rehabilitation studies.

Endpoint	Operational definition	Timing and reporting unit	Principal interpretive limitation
Physical implant loss	Implant removed or spontaneously lost; document date and reason	Time from placement to loss; implant	Equating the decision to remove an implant with completed removal
Implant survival	Implant remains in situ at a specified time; distinguish loaded and unloaded implants	Implant placement as origin; implant	Interpreting physical retention as sustained clinical or prosthetic success
Clinical implant success	Prespecified stability, peri-implant health, and radiographic criteria, with functional requirements where applicable	Defined assessment times; implant. Specify the origin if analyzed longitudinally	Comparing studies using different success criteria or assessment times
Prosthetic success	Prosthesis remains usable and meets predefined functional, comfort, and maintenance criteria	From prosthesis delivery; prosthesis, with corresponding patient outcomes	Equating implant retention with a functioning prosthesis
Site-matched ORNJ	ORNJ diagnosed using stated criteria and anatomically matched to the implant region	Record RT, placement, and ORNJ dates; site and patient. Specify the origin for time-to-event analysis	Inferring causation from anatomical or temporal association alone
Patient benefit	Oral function and quality of life assessed using specified instruments	Baseline and defined follow-up assessments; patient	Inferring patient benefit from implant retention alone

Table 1: Outcome definitions, assessment timing, and reporting units in studies of dental implant rehabilitation after head and neck radiotherapy.

Note. Definitions are provided to clarify outcome reporting and interpretation; they do not constitute a newly validated classification system. RT, radiotherapy; ORNJ, osteoradionecrosis of the jaw.

Ultimately, the clinical value of implant-supported rehabilitation extends beyond fixture retention. Patients may experience difficulties with prosthesis insertion, hygiene, comfort, or maintenance associated with xerostomia, restricted mouth opening, or anatomical alterations following cancer treatment. Oral-health-related quality of life and functional outcomes should therefore be evaluated alongside implant survival and peri-implant health, ideally from baseline through prosthetic delivery and

subsequent follow-up [10]. Reporting these outcomes separately provides a more comprehensive understanding of rehabilitation without equating implant retention with sustained patient benefit.

Implant-level versus patient-level outcomes

Dental implant rehabilitation commonly involves placing multiple implants within the same patient, underscoring the importance of the unit of analysis when interpreting reported

outcomes. Implant-level survival describes the performance of individual fixtures, whereas patient-level outcomes may reflect at least one implant failure, successful prosthetic rehabilitation, or treatment-related complications such as ORNJ. These measures address different clinical questions and should not be considered interchangeable. For example, several implant failures concentrated within one patient may substantially influence the implant-level failure proportion without affecting an equivalent proportion of patients. Conversely, losing a single implant may compromise an entire prosthetic restoration, depending on its design and remaining support. Studies should therefore report the numbers of patients, implants, and prostheses, together with the corresponding outcomes at each level [8-10].

Implants placed within the same patient share biological and treatment-related characteristics, including radiation exposure, smoking history, oral hygiene, reconstructive anatomy, and follow-up. Consequently, statistical analyses treating these implants as independent observations may produce inaccurate standard errors and confidence intervals. Patient-clustered variance estimators or hierarchical models can account for within-patient dependence in implant-level analyses, although these adjustments do not replace patient-level outcome reporting. Also, specify the numbers of implants placed, successfully loaded, and available for assessment at relevant follow-up intervals. Attrition due to cancer progression, death, or discontinuation of rehabilitation may influence observed outcomes, particularly when success is calculated only among patients who complete prosthetic treatment or return for evaluation [8-10].

Radiation exposure and implant-site risk

Radiation exposure is an important consideration in dental implant rehabilitation, but its clinical implications depend on the dose received by the tissues surrounding the implant site rather than the prescribed tumor dose alone. Spatial heterogeneity in dose distribution, anatomical location, reconstructive procedures, and local tissue conditions further complicate the assessment of implant-related risks [8,11-13]. Radiation dose should therefore be interpreted alongside the characteristics of the proposed implant site and the patient's clinical circumstances. Particular attention is warranted for osteoradionecrosis of the jaw (ORNJ), which represents a distinct clinical outcome that may also contribute to implant failure [15-17].

Clinical interpretation of the 50 Gy recommendation

The 2024 ISOO-MASCC-ASCO clinical practice guideline identifies jaw regions receiving at least 50 Gy as being at risk for ORNJ and recommends avoiding dental extractions and implant placement in these areas when alternative therapeutic options are available [17]. This guidance provides a precautionary framework for invasive dental procedures in irradiated tissues, not a validated implant-specific failure threshold. Radiation-associated injury does not necessarily follow a sharply defined dose boundary, and exposure below 50 Gy should not be interpreted as a guarantee of safety. The clinical implications of radiation dose may also vary according to irradiated tissue volume, anatomical location, fractionation schedule, local tissue condition, and patient-related factors.

Observational implant studies provide complementary evidence but do not establish a universally applicable dose threshold. In a retrospective cohort of 121 irradiated patients receiving 751 implants, Wolf, *et al.* reported an association between implant-site doses exceeding 50 Gy and implant failure after adjustment for selected clinical variables [8]. Alberga, *et al.* examined 56 implants placed in the native mandible before postoperative volumetric modulated arc therapy and observed five implant losses, all at sites receiving mean doses above 50 Gy; they also observed peri-implant bone loss at doses exceeding 40 Gy [11]. However, the limited number of losses restricts the interpretation of a numerical threshold. Similarly, Visch, *et al.* reported differences in implant outcomes by site-specific radiation exposure, along with associations involving anatomical location and resection history [20]. Although these findings support consideration of local radiation dose during implant planning, heterogeneity in study populations, exposure assessment, and outcome definitions limits the generalizability of individual dose cutoffs. Accordingly, the 50 Gy guideline recommendation should inform individualized risk assessment rather than serve as a binary predictor of implant success or failure.

Site-specific dosimetry and spatial assessment

Modern radiotherapy generates spatially heterogeneous dose distributions across the mandible, maxilla, and reconstructed tissues. As a result, the prescribed tumor dose, whole-jaw dose-volume parameters, and the dose received by an individual implant bed may differ markedly. For implants present during

radiotherapy, the original treatment plan can be spatially related to the fixture location and surrounding bone; for implants considered after treatment, evaluate the planned osteotomy site and adjacent tissues relative to the available dose distribution. Pertinent considerations include the anatomical delineation of the assessed region, choice of dose metric, fractionation schedule, and uncertainties associated with image registration, particularly when resection, reconstruction, tooth loss, or bone remodeling has altered local anatomy [8,11-13,21]. Observational data indicate that implant-bed and tumor-bed exposures may differ, supporting local dosimetric assessment rather than exclusive reliance on prescribed tumor dose [12].

Evidence from ORNJ investigations further supports evaluating spatial radiation exposure. Sijtsema, *et al.* developed a local mandibular dose-response model using 16 anatomical elements and reported associations between ORNJ and local dose, nearby preradiotherapy extractions, and smoking [15]. Renouf, *et al.* analyzed the anatomical correspondence between dental extractions, local dose, and subsequent ORNJ, highlighting associations involving postradiotherapy extraction at the affected site [16]. Additional cohorts have identified relationships between mandibular dose-volume parameters and ORNJ risk [22-24]. Nevertheless, ORNJ and implant failure represent distinct clinical outcomes, and radiation dose associations observed in ORNJ cohorts should not be extrapolated uncritically as predictors of implant loss or impaired osseointegration.

For clinical assessment, a consistent definition of the implant site is important, considering the intended osteotomy volume, adjacent bone, local dose gradients, and anatomical changes since radiotherapy. Where relevant, image registration methods and uncertainties should be documented. Whole-jaw and regional dose-volume measures provide information about broader radiation exposure, whereas implant-bed dosimetry more directly characterizes exposure at the proposed surgical site. These approaches are complementary; however, the incremental predictive value of site-specific metrics over broader jaw dose parameters for implant failure remains insufficiently established [25]. Consequently, dosimetric findings should be interpreted alongside local tissue conditions, reconstructive anatomy, and other clinical factors.

Anatomical, reconstructive, and host factors

Implant rehabilitation outcomes may differ according to anatomical location, bone origin, reconstructive technique, and local tissue conditions. The native mandible and maxilla, vascularized osseous free flaps, and nonvascularized bone grafts differ in vascular supply, structural characteristics, soft-tissue coverage, and conditions for prosthetic loading. A meta-analysis reported a higher likelihood of implant failure in irradiated grafted bone than in irradiated native bone (odds ratio 2.26, 95% confidence interval 1.50-3.40), although differences in reconstruction techniques, treatment eras, and patient populations limit generalizability [3]. A large reconstructive cohort also documented implant loss in native and fibula-flap bone, as well as ORNJ following implantation, with tobacco exposure associated with ORNJ [26]. These observations support consideration of the specific anatomical and reconstructive setting rather than treating all grafted or reconstructed sites as equivalent.

The presence of a vascularized free flap does not, by itself, establish its radiation exposure or the condition of the surrounding soft tissues. Implant placement during reconstruction before adjuvant radiotherapy differs from delayed implantation into previously irradiated reconstructed bone [27], while implant trajectory, prosthetic design, mucosal characteristics, and access for hygiene may further influence outcomes. Xerostomia and restricted mouth opening can complicate prosthetic maintenance even when bone conditions appear favorable. Smoking, diabetes, oral hygiene, systemic treatment, and oncologic status also require consideration, although observational cohorts cannot always separate their individual effects reliably [3,8,26]. Document antiresorptive and other medications associated with jaw osteonecrosis because overlapping exposures may complicate risk assessment and diagnostic attribution [28]. Table 2 summarizes selected clinical studies and guidance relevant to implant outcomes, radiation exposure, and ORNJ, together with their principal interpretive limitations.

Treatment sequence and attribution of osteoradionecrosis

The temporal relationship among radiotherapy, implant placement, prosthetic loading, ORNJ, and implant loss is central to clinical interpretation. Implants may be present before radiotherapy, inserted during oncologic reconstruction before

Study and design	Population or unit	Principal finding	Interpretive limitation
Ettl., <i>et al.</i> [9], prospective observational study	52 enrolled patients; 234 implants evaluable at two years	Implant survival 92.3%; clinical success 78.6%	Attrition and differences in endpoint definitions
Wolf., <i>et al.</i> [8], retrospective cohort	121 patients; 751 implants	Implant-site dose above 50 Gy associated with failure; five-year survival 92.4% versus success 74.9%	Observational confounding, correlated implants, and endpoint differences
Alberga., <i>et al.</i> [11], cohort study	28 patients; 56 implants placed before RT	Five losses, all at implant-site mean doses above 50 Gy	Only five events; dose associations not statistically significant
Visch., <i>et al.</i> [20], prospective cohort	130 patients; 446 implants placed after RT	Survival differed by implant-site dose (below 50 vs. ≥ 50 Gy), jaw location, and resection history	Historical treatment era; limited transferability to modern RT
Schiegnitz., <i>et al.</i> [3], systematic review and meta-analysis	Studies comparing irradiated and nonirradiated implant sites	Greater implant failure in irradiated bone (OR 1.97) and irradiated grafted versus native bone (OR 2.26)	Heterogeneous populations, outcomes, and follow-up
Sijtsema., <i>et al.</i> [15], local ORNJ model	219 patients; 16 mandibular regions per patient	Local dose, ipsilateral preradiotherapy extractions, and smoking associated with ORNJ	ORNJ, not implant failure, was the endpoint
Renouf., <i>et al.</i> [16], matched case-control study	171 patients, including ORNJ cases and controls	Dose and postradiotherapy extraction at the eventual ORNJ site associated with ORNJ	Observational associations do not establish causality; endpoint differs from implant failure
Peterson., <i>et al.</i> [17], clinical practice guideline	Multidisciplinary evidence synthesis	Jaw regions receiving ≥ 50 Gy considered at risk for ORNJ; alternatives to implantation recommended where feasible	Precautionary recommendation, not a validated implant-failure threshold

Table 2: Selected clinical evidence and guidance informing dental implant rehabilitation and jaw-related risks after head and neck radiotherapy.

Notes: The studies represent different populations, treatment sequences, exposure measurements, and clinical endpoints; their findings should not be interpreted as directly interchangeable. Implant survival, clinical success, and ORNJ are distinct outcomes. Dose-related associations derived from ORNJ studies do not establish implant-specific failure thresholds. Odds ratios are reproduced from the respective studies and should not be compared as equivalent effect estimates. RT, radiotherapy; ORNJ, osteoradionecrosis of the jaw; OR, odds ratio.

adjuvant treatment, or placed later in previously irradiated tissues, and these pathways involve different biological and clinical circumstances. Accordingly, document the chronology and anatomical relationship of subsequent complications before attributing implant failure or ORNJ to a specific event or treatment exposure.

An implant may be present before radiotherapy, inserted during oncologic reconstruction before adjuvant radiotherapy, or placed

after completion of radiotherapy. These scenarios should not be grouped indiscriminately because the biological state of the implant bed and the timing of implantation relative to radiation exposure differ substantially. In the first setting, an already integrated implant and its supporting tissues are subsequently irradiated; in the second, healing and osseointegration may occur during the interval before or during adjuvant treatment; and in the third, implant surgery is performed in previously irradiated tissues. The intervals from radiotherapy to implant placement,

from implantation to loading, and from each event to ORNJ or implant loss should therefore be reported explicitly rather than summarized using broad terms such as “early” and “late” [11,13,20,29].

Evidence regarding a universally safe waiting interval for implantation after radiotherapy remains limited. Small retrospective studies cannot establish a definitive interval that eliminates risk, and findings from post-radiotherapy dental extraction should not be extrapolated directly to implant surgery because the procedures differ in tissue injury, indication, and healing requirements [29,30]. Treatment timing should therefore be considered together with site-specific radiation exposure, local tissue condition, reconstructive anatomy, and the anticipated functional benefit of rehabilitation.

The appearance of necrotic bone after implant placement does not, by itself, establish that implantation caused ORNJ or that ORNJ caused subsequent implant failure. Several temporal patterns are possible: radiation-associated bone injury may have been present but clinically unrecognized before surgery; implant placement may precipitate manifestation of previously subclinical injury; peri-implant infection or mechanical breakdown may precede secondary necrosis; or ORNJ may develop later at a dose-exposed site and contribute to implant loss. These mechanisms may overlap. Attribution should therefore consider the ORNJ definition used, preoperative clinical and imaging findings, anatomical concordance between the implant and lesion, site-specific radiation exposure, the timing of implantation, loading, ORNJ diagnosis, and implant loss, as well as evidence of infection or recurrent disease [16-18].

Anatomical concordance is equally important. ORNJ arising in a distant jaw segment should not automatically be attributed to

an implant elsewhere. Even when the lesion and implant occupy the same region, the first clinical or radiographic abnormality may precede the date of formal diagnosis, particularly in retrospective studies. Accordingly, reports should distinguish clearly site-matched events from temporally associated but causally uncertain events and from complications judged unrelated to the implant. Such distinctions can improve reporting transparency but should not replace established ORNJ diagnostic criteria [16,18].

The international interdisciplinary consensus on ORNJ emphasizes that inconsistent definitions and grading systems hinder incidence estimates and comparative research [18]. Imaging should therefore be selected according to the clinical question. Cone-beam CT or diagnostic CT can characterize osseous changes when indicated, whereas MRI or PET/CT may be useful when soft-tissue involvement or recurrent malignancy is suspected; none is a mandatory universal screening modality before implant placement. Because imaging findings may overlap between ORNJ, treatment-related changes, osteomyelitis, medication-related osteonecrosis, and recurrent disease, interpretation should incorporate the patient’s cancer history, prior examinations, RT plan, and dose at the proposed site [17,18,31]. A normal-appearing mucosa does not exclude underlying radiation-related bone injury, and when the diagnosis remains uncertain, oncologic assessment may be necessary before attributing a complication to implant surgery.

Figure 1 summarizes the three principal clinical pathways according to the timing of implant placement relative to radiotherapy and highlights the distinct exposure sequences and follow-up considerations associated with each.

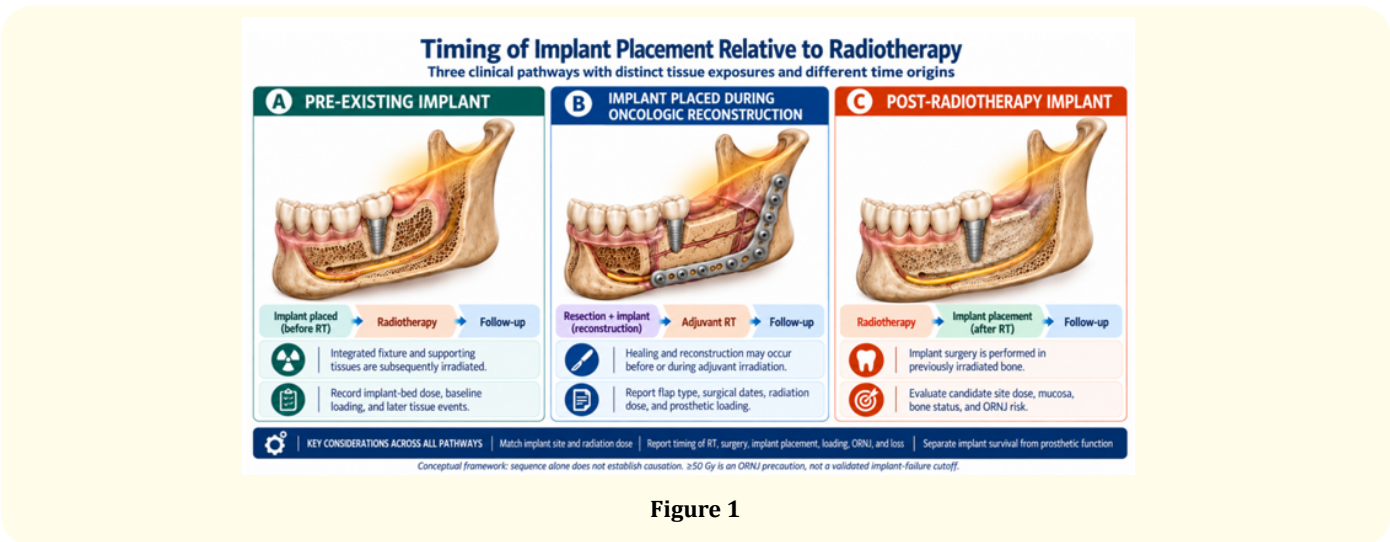


Figure 1

Integrated pre-implant assessment and treatment planning

Pre-implant evaluation following head and neck radiotherapy should integrate anticipated functional benefit with assessment of the proposed implant site, local radiation exposure, reconstructive anatomy, and the patient's oncologic and medical context. No single variable—including radiation dose or elapsed time since radiotherapy—is sufficient to determine implant suitability. Multidisciplinary assessment can help identify appropriate implant sites, alternative prosthetic strategies, and the level of post-treatment surveillance required.

The initial step is to define the rehabilitation objective. Consider baseline dentition, anticipated improvements in mastication, speech, comfort, or prosthetic retention, patient preferences, maintenance capacity, and nonimplant alternatives. Implant-supported rehabilitation may offer substantial benefit when conventional prosthetic options are limited, but fixture retention alone is inadequate if a functional and maintainable prosthesis cannot ultimately be achieved [9,10,32]. Discuss active disease status, prognosis, and the sequencing of oncologic treatment with the cancer care team.

When feasible, review the original radiotherapy plan with a radiation oncologist or dosimetrist to characterize exposure at candidate implant sites. Relevant data include the dose at the intended osteotomy region, local dose gradients, jaw subsite, prior or planned radiotherapy courses, and uncertainties in image registration. The ≥ 50 Gy ORNJ guideline should prompt consideration of alternative restorative options at higher-dose sites but should not replace individualized clinical judgment [17]. When the original treatment plan is unavailable, this limitation should be documented rather than substituting the prescribed tumor dose for the actual dose received at the implant bed.

Subsequent clinical assessment should focus on local tissue and disease status. Evaluation should include mucosal coverage, periodontal or peri-implant infection, exposed bone, wound healing, salivary function, trismus, hygiene accessibility, and reconstructive anatomy before elective implant placement [33]. Imaging should be selected according to the clinical indication and interpreted in the context of prior studies when available. If ORNJ or recurrent malignancy is suspected, appropriate diagnostic evaluation should precede implantation [17,18,31]. Exposure to antiresorptive or

antiangiogenic therapies should also be documented because these agents may complicate diagnosis and management [28].

The surgical and prosthetic plan should be aligned with the overall risk profile. Consider the number and location of implants, the need for grafting, the anticipated loading strategy, prosthetic design, maintenance requirements, and the feasibility of achieving adequate hygiene. A less invasive prosthetic approach may be favored when it provides acceptable function with lower procedural burden or risk. Treatment planning should balance anticipated functional benefit against local tissue risk and should not imply that a particular radiation dose or waiting interval alone guarantees safety [2-5,17,20].

Shared decision-making is especially important when multiple implant sites or rehabilitation strategies are feasible. Discuss the intended functional benefit, limitations of conventional prosthetic options, candidate implant sites and their estimated radiation exposures, relevant clinical and imaging findings, and available alternatives transparently. The site with the lowest radiation dose is not invariably optimal if bone volume, soft-tissue coverage, hygiene accessibility, or prosthetic geometry are unfavorable. Conversely, a high-dose region may remain unsuitable despite considerable rehabilitation need; oncologic treatment dose should not be reduced to accommodate potential future implant placement [17].

Follow-up should be an integral part of rehabilitation, not solely a means of quantifying implant survival. Surveillance should encompass healing, loading status, peri-implant and mucosal health, prosthetic function, hygiene, symptoms, and radiographic findings when indicated. The emergence of exposed bone, persistent pain, implant mobility, or changes in prosthetic fit should prompt evaluation for ORNJ, infection, mechanical complications, or recurrent disease. Accurate dating and anatomical localization of such events may help distinguish early failure of osseointegration from later deterioration of a previously functioning rehabilitation [8,9,17,18].

Time-to-event analysis and competing risks

In studies evaluating dental implant outcomes following head and neck cancer treatment, mortality may precede implant failure and should be considered when estimating event probabilities over time. Treating death solely as a censoring event can cause

conventional Kaplan-Meier methods to overestimate the absolute probability of implant failure because patients who die are no longer able to experience the event. When death constitutes a competing event, cumulative incidence methods are more appropriate for estimating absolute event probabilities. Investigations should explicitly specify the time origin, censoring criteria, and whether the analytic objective is to estimate implant-level failure, patient-level occurrence of implant loss, or completion of functional rehabilitation [19,34].

Precise definition of the time origin is also essential. Implants should enter risk sets at the time of placement, and comparisons between implants inserted before versus after radiotherapy should account for differences in treatment sequencing and eligibility. ORNJ arising after implantation should not be treated as a baseline characteristic in analyses of subsequent implant outcomes. In complex datasets, time-varying or multistate models may help distinguish transitions involving implant retention, ORNJ development, implant loss, and death; however, transparent descriptive timelines may be preferable when event counts are limited. These analytical considerations complement—but do not replace—appropriate accounting for multiple implants within individual patients and clear specification of failure-event definitions [8,9,19,34].

Evidence gaps and priorities

Published cohorts are frequently constrained by limited event counts, inconsistent definitions of implant success and failure, incomplete implant-site dosimetry, selection of patients with more favorable prognoses, and heterogeneous access to reconstructive and prosthetic interventions [2-5,11]. Meta-analyses remain subject to these limitations inherent in the primary literature. Future prospective registries should systematically capture patient-, implant-, and prosthesis-level identifiers; site-specific radiation exposure and registration methodology; bone origin and reconstructive technique; chronology of radiotherapy and implant placement; standardized clinical and imaging findings for ORNJ; loading and maintenance history; reason and date of implant loss; mortality; and patient-reported functional outcomes. Existing consensus minimum data elements for ORNJ offer a valuable foundation for components of this framework [18].

Particular priority should be given to variables that elucidate the anatomical and temporal relationships between exposure

and outcome. Studies should retain detailed records of the location of each implant and any ORNJ lesion, radiation dose at both sites, preoperative imaging dates and mucosal findings, and the rationale for non-delivery or abandonment of a prosthesis. Reasons for implant removal should differentiate among failed osseointegration, peri-implant disease, mechanical complications, oncologic resection, and ORNJ-associated loss. Such reporting would enable investigators to determine whether ORNJ preceded, coincided with, or followed an implant complication while preserving cases in which causal attribution remains uncertain [16,18].

Radiation dose should ideally be analyzed as a continuous exposure, with exploration of potential nonlinear associations when sample size permits, rather than by repeatedly deriving dichotomous cutoffs from limited datasets. Site-specific dose, dose-volume parameters, reconstructive anatomy, host characteristics, and procedure-related variables require external validation before incorporation into clinically useful prediction models. Competing risks should be addressed when mortality can preclude observation of implant failure, and the analytical strategy should be aligned with the intended estimand [19,34].

Prospective studies should prespecify the target population, primary outcome, time origin, exposure definition, and assessment schedule. Prediction models developed within a specific cancer site, radiotherapy era, or reconstructive context require external validation before broader application. The incremental value of site-specific imaging or dosimetry should be evaluated according to whether it improves clinical decision-making, modifies prosthetic strategies, identifies patients who may benefit from closer surveillance, or improves functional outcomes. Multicenter collaboration is likely to be essential because clinically significant events are infrequent relative to the number of candidate predictors [2-5,11].

Finally, rehabilitation research should avoid defining success solely among patients who receive a prosthesis and remain available for follow-up. A patient-centered trajectory begins with treatment eligibility and encompasses individuals who do not undergo implantation, never reach prosthetic loading, change treatment preference, experience cancer recurrence, or die. Reporting these transitions would provide a more accurate estimate of the proportion of patients ultimately achieving sustained functional

benefit and would help distinguish treatment effects from selection of patients with more favorable prognoses.

Review limitations

Several limitations should be acknowledged in this narrative review. We identified the literature through targeted searches rather than a formal systematic review protocol, and we did not conduct a structured risk-of-bias assessment or quantitative synthesis. Study selection was guided by clinical relevance and contribution to the review’s principal domains, introducing potential selection bias and limiting reproducibility compared with a systematic review. The underlying evidence base is heterogeneous, with variability in cancer site, radiotherapy technique and era, implant timing, reconstructive strategy, anatomical location, dose assessment, outcome definitions, and follow-up duration. As a result, direct comparison of reported survival, success, and complication rates across studies is inherently constrained.

Additional limitations of the evidence base include small event counts, retrospective study designs, incomplete site-specific dosimetry, inconsistent reporting of prosthetic outcomes and patient-reported benefit, and variable handling of multiple implants within individual patients. Definitions and grading systems for ORNJ also differ across studies, and the temporal and anatomical relationship between ORNJ and implant failure is frequently incompletely documented. These limitations constrain causal inference and preclude identification of a universally applicable radiation-dose threshold or waiting interval for implant placement. Consequently, this review should be regarded as a clinically oriented synthesis of current evidence rather than as a

formal evidence-grading exercise or a source of validated decision rules.

Conclusion

Dental implant rehabilitation following head and neck radiotherapy may confer substantial functional benefit for carefully selected patients; however, treatment decisions should consider more than implant retention alone. Balance the anticipated benefit of rehabilitation against site-specific radiation exposure, bone and mucosal integrity, reconstructive anatomy, oncologic status, prosthetic feasibility, and long-term maintenance requirements. The ≥ 50 Gy ORNJ guideline provides a clinically useful risk framework for higher-dose jaw regions but should not be construed as a universal threshold for implant failure or as a binary criterion for implant suitability.

Interpreting outcomes also requires clear differentiation among implant survival, clinical success, prosthetic function, patient-reported benefit, ORNJ, and implant loss. When complications occur, document their anatomical location and temporal sequence relative to radiotherapy, implant placement, loading, and other interventions before assigning causality. Future investigations should prioritize standardized outcome definitions, site-specific dosimetry, comprehensive patient- and implant-level reporting, appropriate handling of competing risks and clustered data, and external validation of predictive models. Pending more robust evidence, individualized multidisciplinary planning based on site-specific exposure, tissue condition, expected functional benefit, and longitudinal follow-up remains preferable to rigid dose or waiting-time rules.

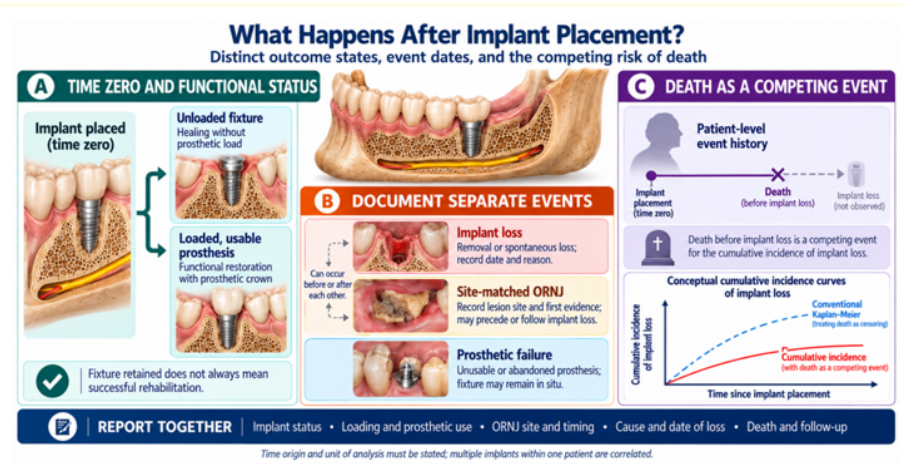


Figure 2: Conceptual outcome states and event chronology after dental implant placement. Implant retention, functional prosthetic rehabilitation, implant loss, site-matched ORNJ, and prosthetic failure represent distinct outcomes that require separate definitions and event dates. Death before implant loss acts as a competing event when estimating the cumulative incidence of implant loss. The figure is a conceptual framework and not a validated outcome model.

Conflict of Interest

The authors declared that they have no conflict of interests.

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