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Dental Implant Outcomes in Osteoporotic and Osteopenic Women: A Systematic Review on Premenopausal Care

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ABSTRACT: To synthesize the available human clinical evidence on dental implant outcomes and preoperative risk assessment in women with osteoporosis or osteopenia, with particular attention to the applicability of the evidence to premenopausal care. The review protocol was prospectively registered in PROSPERO (CRD420261509680). PubMed/MEDLINE, Scopus and Web of Science were searched for primary human clinical studies evaluating osteoporosis, osteopenia, bone mineral density, menopausal status, bone turnover, or anti-osteoporotic treatment in relation to dental implant outcomes. Eligible observational studies were synthesized narratively because of clinical and methodological heterogeneity. Risk of bias was assessed using design-appropriate JBI critical appraisal tools and ROBINS-I when applicable. Eight primary human studies formed the principal clinical evidence base. Implant survival was generally high, but findings were heterogeneous for early or repeated implant failure, marginal bone loss, implant stability, local bone characteristics, and bone turnover. One retrospective study reported associations between osteopenia/osteoporosis and selected first, repeated, and early implant-failure outcomes. Osteoporosis and osteopenia should not be interpreted as uniform predictors of dental implant failure. The available evidence supports individualized assessment of systemic skeletal status, local bone characteristics, menopausal status, bone turnover, medication exposure, and conventional implant-related risk factors. Evidence remains insufficient to define a validated premenopausal osteoporosis-specific preoperative protocol.

1. INTRODUCTION

Dental implant therapy is a predictable treatment modality for the rehabilitation of partial and complete edentulism; nevertheless, successful treatment remains dependent on the biological and mechanical characteristics of the recipient bone. Primary implant stability is determined predominantly by local bone density and quality, implant geometry, and surgical technique, whereas secondary stability develops through biological osseointegration and peri-implant bone remodeling. These processes are particularly relevant in patients with systemic disorders affecting skeletal metabolism, because compromised bone quality may influence initial fixation, bone healing, and maintenance of peri-implant bone. In a prospective clinical cohort, implant stability was specifically evaluated in patients with osteoporosis using resonance frequency analysis and Periotest measurements, illustrating the clinical importance of monitoring osseointegration in this population (Sachelarie et al., 2025).

Osteoporosis is a systemic skeletal disorder characterized by reduced bone mass and deterioration of bone microarchitecture. Its relevance to implant dentistry extends beyond systemic bone mineral density (BMD), because osteoporosis may also alter the mineral content and architecture of the alveolar bone, reduce residual ridge volume, delay bone healing, and decrease the amount of bone available for stable bone-to-implant contact. Clinical literature further indicates that systemic skeletal density is related to mandibular bone density and that osteoporotic patients may exhibit reduced bone mass, lower density, and thinner cortical plates. Consequently, osteoporosis should not necessarily be considered a contraindication to implant therapy, but rather a systemic condition requiring careful assessment of patient- and bone-related risk factors before treatment (Sirous et al., 2026).

This issue is particularly relevant in women because skeletal homeostasis is closely influenced by hormonal status. Estrogen participates in the regulation of osteoclastic and osteoblastic activity, and disturbances in estrogen signaling can shift bone remodeling toward increased resorption. At the oral level, osteoporosis and periodontal deterioration share several biological mechanisms, including altered bone remodeling, increased osteoclastic activity, impaired osteoblastic function, elevated pro-inflammatory cytokines such as IL-1 β and TNF- α , and dysregulation of the RANKL/OPG pathway. These mechanisms may increase susceptibility of alveolar bone to resorption and impair its regenerative capacity (Sirous et al., 2026).

Although these relationships have been studied extensively after menopause, the period preceding menopause deserves greater attention. Hormonal and metabolic changes occur across a continuum rather than beginning abruptly after the final menstrual period, while women who develop osteoporosis or osteopenia before menopause may represent a clinically distinct group. Importantly, the currently available evidence is concentrated predominantly in postmenopausal, older, or mixed osteoporotic populations, rather than specifically in premenopausal women. The most recent synthesis also indicates that associations between low BMD and periodontal deterioration are particularly evident in peri- and postmenopausal women. This imbalance in the evidence base limits direct extrapolation to premenopausal women with established osteoporosis and represents an important knowledge gap for implant treatment planning (Sirous et al., 2026).

Changes in female hormonal status may also be reflected locally at potential implant sites. In a cross-sectional clinical study of 155 postmenopausal women who had undergone dental implant placement, menopause-related characteristics were associated with crestal cortical bone thickness. Crestal cortical bone is clinically important because it contributes to implant support and stability, whereas thinning of this structure may compromise the mechanical environment surrounding an implant. Although this study provides indirect rather than direct evidence for premenopausal women, it reinforces the principle that systemic and reproductive factors should be considered when evaluating local bone conditions before implant surgery (Kumar et al., 2025).

The clinical consequences of osteoporosis for implant outcomes remain incompletely resolved. Long-term implant survival can remain high despite reduced systemic BMD, suggesting that osteoporosis alone does not inevitably result in implant failure. For example, a recent clinical study of patients receiving pharmacological treatment for osteoporosis or osteopenia reported survival rates of 92.8% at the patient level and 96.2% at the implant level over a mean observation period of 57.9 months. However, marginal bone loss was associated with the type and administration route of anti-osteoporotic medication. These findings suggest that the clinically relevant question is not simply whether implants survive in patients with osteoporosis, but which systemic and local factors modify peri-implant bone behavior and whether these factors can be identified or optimized before surgery (Lee et al., 2025).

This distinction becomes even more important when early implant failure is considered. Frumkin et al. evaluated osteopenia and osteoporosis as risk factors for first and repeated implant failure and reported a significant relationship between these skeletal conditions and implant failure. Osteoporosis was also significantly correlated with early implant failure ($p = 0.0044$). These findings contrast with studies reporting high overall survival and suggest that long-term implant survival may conceal clinically relevant vulnerabilities occurring during the early healing and osseointegration phases. The evidence therefore supports a greater focus on early outcomes—including primary and secondary stability, early failure, marginal bone remodeling, and osseointegration—rather than relying exclusively on final implant survival (Frumkin et al., 2024).

Prospective clinical evidence further demonstrates that successful osseointegration remains achievable in patients with compromised skeletal status. Sachelarie et al. followed patients with osteoporosis for 12 months and reported ISQ values of 67.04 ± 5.42 at 6 months and 68.93 ± 4.83 at 12 months, with corresponding improvement in implant mobility measurements. Similarly, a recent prospective study of postmenopausal women stratified according to BMD reported 100% cumulative implant survival, a mean 12-month implant stability value of 71.4 ± 5.52 , and mean peri-implant bone loss of 0.54 ± 0.35 mm. Taken together with evidence of increased early failure in other cohorts, these findings demonstrate substantial clinical heterogeneity and emphasize the need to identify which patient characteristics and management strategies account for favorable or unfavorable outcomes (Sachelarie et al., 2025; Cho et al., 2025).

An important limitation of conventional implant planning is that radiographic bone density alone may not adequately characterize skeletal competence. Bone strength depends on both BMD and bone quality, the latter encompassing microarchitecture, turnover, mineralization, microdamage, and characteristics of the organic matrix. Consequently, preoperative evaluation based exclusively on local radiographic appearance may overlook systemic abnormalities in bone metabolism that could influence implant healing (Yasuda et al., 2020).

This concept is supported by clinical evidence involving bone turnover markers (BTMs). Yasuda et al. assessed osteocalcin, bone-specific alkaline phosphatase, ICTP, and NTX together with computed-tomographic bone density before implant surgery. Patients with abnormally elevated BTMs demonstrated significantly lower cancellous bone density at the intended implant site, and abnormal BTM values were more frequent among women. The authors therefore proposed that evaluation of female implant candidates may require consideration of both biochemical bone turnover and local cancellous bone density. Although the study did not specifically enroll women with diagnosed osteoporosis and therefore does not constitute direct evidence for the target population of the present review, it provides clinically relevant support for a multidimensional preoperative assessment strategy (Yasuda et al., 2020).

Pharmacological history represents another critical component of preoperative risk evaluation. Patients with osteoporosis may receive bisphosphonates, RANKL inhibitors, bone-formation stimulators, or other agents that modify skeletal turnover. In the clinical cohort reported by Lee et al., marginal bone loss before prosthetic treatment was significantly associated with RANKL inhibitor and bone-formation stimulator use, whereas post-prosthetic marginal bone loss was associated with the route of drug administration. Thus, the presence of osteoporosis cannot be evaluated independently from its treatment; medication type, route, duration, and timing relative to implant surgery may all be relevant components of individualized risk assessment (Lee et al., 2025).

Preclinical evidence provides additional biological plausibility for therapeutic optimization but must be distinguished from human clinical evidence. Systemic strontium ranelate has demonstrated a tendency toward enhanced peri-implant bone quality and osseointegration in animal models, although the reported effect was moderate and requires further validation. Experimental osteoporosis models have also demonstrated that implant surface modification can improve biomechanical stability and bone occupancy during healing, while the investigators explicitly caution that these findings cannot be directly extrapolated to clinical practice. Similarly, zoledronic-acid-based implant functionalization combined with an osteoinductive agent accelerated peri-implant repair in ovariectomized osteoporotic rats. These studies identify potentially important therapeutic directions but also highlight the gap between experimental strategies and validated preoperative interventions for women undergoing dental implantation (Scardueli et al., 2018; Gehrke et al., 2026; Paludetto et al., 2025).

Collectively, the available evidence therefore presents an apparent paradox. Osteoporosis and osteopenia may compromise alveolar bone characteristics, implant stability, marginal bone maintenance, and early osseointegration, yet successful long-term implant therapy remains achievable in many affected patients. Current evidence is also heterogeneous in study design, skeletal

assessment methods, medication exposure, menopausal status, implant characteristics, and reported outcomes. Recent literature explicitly acknowledges that most clinical studies are observational, heterogeneous, and frequently characterized by relatively short follow-up, limiting the certainty of conclusions regarding osteoporosis and implant therapy. Most importantly for the present review, direct clinical evidence addressing premenopausal women with osteoporosis remains particularly sparse; much of the available evidence is derived from postmenopausal women, older adults, mixed-sex osteoporosis cohorts, or experimental models.

This evidence gap has direct implications for preoperative decision-making. Rather than treating osteoporosis as a binary contraindication, contemporary implant planning requires an integrated evaluation of systemic skeletal status, local alveolar bone quantity and quality, bone turnover, medication exposure, periodontal condition, modifiable risk factors, and the anticipated biological demands of implant placement. Determining which of these assessments and management strategies are supported by clinical evidence is particularly important for younger women with compromised skeletal health, in whom evidence extrapolated from elderly or postmenopausal populations may not be directly applicable.

Therefore, the aim of this systematic review was to critically evaluate the available evidence on preoperative assessment, management, and risk-reduction strategies in women with osteoporosis or osteopenia undergoing dental implant therapy, with particular emphasis on premenopausal women. The review specifically examined their effects on early implant failure, implant survival and success, primary and secondary implant stability, osseointegration, marginal and peri-implant bone changes, and early implant-related complications. A further objective was to identify clinically relevant evidence gaps and determine whether current data are sufficient to support individualized preoperative risk assessment in this population.

2. MATERIALS AND METHODS

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to ensure methodological rigor, transparency, and reproducibility (Page et al., 2021). The objective of this review was to systematically evaluate the available clinical evidence regarding preoperative assessment, management, and risk-reduction strategies in women with osteoporosis or osteopenia undergoing dental implant therapy, with particular emphasis on premenopausal women and on outcomes related to implant stability, osseointegration, marginal peri-implant bone changes, implant survival, and early implant failure.

The review protocol and eligibility criteria were developed a priori according to the PICOS (Population, Intervention/Exposure, Comparison, Outcomes, and Study Design) framework (Amir-Behghadami and Janati, 2020). The review protocol was prospectively registered in PROSPERO (CRD420261509680). Because direct clinical evidence specifically involving premenopausal women with established osteoporosis was expected to be limited, menopausal status was predefined as an important population characteristic to be extracted and considered during evidence synthesis rather than being used as an absolute search restriction.

2.1. Search Strategy

A comprehensive electronic literature search was conducted in PubMed, Scopus and Web of Science to identify primary clinical studies evaluating osteoporosis, osteopenia, or reduced bone mineral density in relation to dental implant assessment, management, and clinical outcomes. The search strategy combined controlled vocabulary, where applicable, with free-text terms related to osteoporosis/osteopenia, women and menopausal status, dental implantation, preoperative assessment and management, bone quality, and implant outcomes using Boolean operators (AND, OR). The complete database-specific search strategies are provided in Supplementary Table S1.

Database	Search string	Filters / limits applied
PubMed	("Osteoporosis"[Mesh] OR "Osteoporosis, Postmenopausal"[Mesh] OR "Bone Density"[Mesh] OR osteopor*[tiab] OR osteopeni*[tiab] OR "low bone mass"[tiab] OR "low bone mineral density"[tiab] OR "reduced bone density"[tiab] OR postmenopaus*[tiab] OR premenopaus*[tiab] OR perimenopaus*[tiab] OR menopaus*[tiab]) AND ("Dental Implants"[Mesh] OR "Dental Implantation,	Humans; English language; no publication-date restriction

Database	Search string	Filters / limits applied
	Endosseous"[Mesh] OR "dental implant*" [tiab] OR "endosseous implant*" [tiab] OR "implant-supported" [tiab] OR "implant-retained" [tiab] OR osseointegrat* [tiab] AND ("Treatment Outcome" [Mesh] OR "implant survival" [tiab] OR "implant failure" [tiab] OR "implant success" [tiab] OR osseointegration [tiab] OR "marginal bone loss" [tiab] OR "peri-implant bone loss" [tiab] OR "implant stability" [tiab] OR "bone-to-implant contact" [tiab])	
Scopus	TITLE-ABS-KEY ((osteopor* OR osteopeni* OR "low bone mass" OR "low bone mineral density" OR "reduced bone density" OR "bone density" OR postmenopaus* OR premenopaus* OR perimenopaus* OR menopaus*) AND ("dental implant*" OR "endosseous implant*" OR "implant-supported" OR "implant-retained" OR osseointegrat*) AND ("implant survival" OR "implant failure" OR "implant success" OR osseointegration OR "marginal bone loss" OR "peri-implant bone loss" OR "implant stability" OR "bone-to-implant contact" OR "treatment outcome*"))	Document type: Article; Language: English; Subject area: Medicine/Dentistry
Web of Science (Core Collection)	TS=((osteopor* OR osteopeni* OR "low bone mass" OR "low bone mineral density" OR "reduced bone density" OR "bone density" OR postmenopaus* OR premenopaus* OR perimenopaus* OR menopaus*) AND ("dental implant*" OR "endosseous implant*" OR "implant-supported" OR "implant-retained" OR osseointegrat*) AND ("implant survival" OR "implant failure" OR "implant success" OR osseointegration OR "marginal bone loss" OR "peri-implant bone loss" OR "implant stability" OR "bone-to-implant contact" OR "treatment outcome*"))	Language: English; Document type: Article; Index: SCI-EXPANDED

2.2. Study Selection

All records retrieved from the electronic searches were imported into EndNote 21 (Clarivate Analytics, Philadelphia, PA, USA) for reference management and duplicate removal. Following deduplication, two independent reviewers screened the titles and abstracts of all identified records against the predefined eligibility criteria.

Potentially relevant studies were subsequently retrieved in full text and independently assessed by the same reviewers. Reasons for exclusion at the full-text stage were recorded and categorized into five groups: (1) wrong population (no women with osteoporosis, osteopenia, or reduced BMD); (2) no relevant dental implant or preoperative bone-assessment outcomes; (3) non-original articles (reviews, meta-analyses, editorials, letters, expert opinions, conference abstracts); (4) animal, in-vitro, or laboratory studies; and (5) case reports, duplicate reports of the same cohort, or insufficient extractable data.

Disagreements between reviewers were resolved through discussion and consensus. When consensus could not be reached, a third reviewer was consulted.

Studies such as Frumkin et al., which evaluated osteoporosis and osteopenia as risk factors for first and repeated implant failure, were considered eligible because they provided primary human clinical data directly relevant to implant survival and early failure (Frumkin et al., 2024). Similarly, prospective studies directly comparing implant-related outcomes between women with and without osteoporosis, such as the study by Tabrizi et al., were eligible for the clinical evidence synthesis (Tabrizi et al., 2021). Tabrizi et al. included 90 female patients, used dual-energy X-ray absorptiometry for skeletal assessment, and evaluated marginal bone loss 12 months after loading.

Studies restricted to postmenopausal women, including Liapaki et al., were retained when they provided directly relevant clinical evidence regarding osteopenia/osteoporosis, antiresorptive treatment, osseointegration, or implant failure; however, their menopausal status was explicitly recorded and their evidence was considered indirect with respect to the primary premenopausal population of interest (Liapaki et al., 2022). Liapaki et al. evaluated 207 postmenopausal women and 386 implants in a retrospective cohort design.

The study-selection process is summarized in the PRISMA 2020 flow diagram (**Figure 1**), including identification, duplicate removal, title/abstract screening, full-text assessment, reasons for exclusion, and final inclusion.

2.3. Eligibility Criteria

Eligibility criteria were established a priori according to the PICOS framework.

Population (P): Human female patients with diagnosed osteoporosis, osteopenia, reduced BMD, or low bone mass who were candidates for or underwent dental implant therapy. Premenopausal women represented the population of primary interest. Because of the anticipated scarcity of studies restricted specifically to premenopausal osteoporosis, studies involving broader female populations, including peri- and postmenopausal women, were eligible when osteoporosis/osteopenia-related dental implant outcomes could be extracted. Mixed-sex cohorts were considered only when osteoporosis/osteopenia-specific implant data were available and were categorized separately according to population applicability.

Intervention/Exposure (I/E): Preoperative assessment, preparation, optimization, or risk-reduction approaches related to compromised skeletal status before dental implant placement. Relevant exposures included osteoporosis, osteopenia, reduced BMD, systemic or local bone-quality assessment, DXA-derived T-scores, bone turnover assessment, anti-osteoporotic medication, metabolic or nutritional optimization, periodontal/oral preparation, bone augmentation where clinically indicated, and modification of implant treatment planning according to skeletal or alveolar bone status.

Comparison (C): Women with normal BMD or without osteoporosis/osteopenia; standard or routine preoperative management; untreated versus medically treated osteoporosis/osteopenia; alternative therapeutic or assessment strategies; or other clinically relevant comparator groups. Studies without a formal control group were considered when they provided extractable longitudinal clinical outcome data directly relevant to the review question.

Outcomes (O): Primary outcomes were early implant failure or loss, implant survival/success, primary and secondary implant stability, and osseointegration. Secondary outcomes included marginal bone loss, peri-implant bone-level changes, alveolar or cancellous bone density/quality, peri-implant bone remodeling, postoperative complications, bone regeneration, and other clinically relevant implant-related complications.

Study Design (S): Original peer-reviewed human clinical research, including prospective and retrospective cohort studies, case-control studies, cross-sectional studies when directly relevant to preoperative implant-site assessment, controlled clinical studies, randomized clinical trials, and non-randomized clinical trials.

Studies were excluded if they: (1) did not investigate dental implant therapy; (2) did not evaluate osteoporosis, osteopenia, reduced BMD, or another predefined skeletal exposure relevant to the review question; (3) did not provide clinically relevant implant or preoperative bone-assessment outcomes; (4) were animal, in-vitro, cadaveric, or laboratory studies; (5) were systematic reviews, meta-analyses, narrative reviews, scoping reviews, editorials, letters, expert opinions, or book chapters; (6) were isolated case reports or insufficiently informative case series; (7) were conference abstracts without sufficient extractable data; (8) represented duplicate reports of the same cohort without additional relevant outcomes; or (9) lacked sufficient methodological or outcome information for extraction.

2.4. Data Extraction

Two reviewers independently extracted data from all eligible studies using a standardized and pilot-tested data extraction form. Disagreements were resolved by discussion and consensus; when consensus could not be achieved, a third reviewer was consulted.

The following information was extracted from each study: first author and year of publication; country and clinical setting; study design; sample size; number of patients and implants; age and sex distribution; menopausal status (premenopausal,

perimenopausal, postmenopausal, mixed, or not reported); definition and diagnostic method for osteoporosis or osteopenia; BMD and T-score where reported; skeletal assessment method, including DXA; systemic and local bone-quality measures; bone turnover markers; relevant comorbidities; smoking status; osteoporosis-related medication and treatment status; medication type, route, and duration where available; preoperative assessment or management strategy; bone grafting or regenerative procedures; implant site; implant number, dimensions, surface, and design where reported; loading protocol; comparator characteristics; duration of follow-up; and all predefined implant outcomes.

For clinical outcomes, data were extracted on early and overall implant failure, implant survival/success, reimplantation failure, primary and secondary implant stability, ISQ/RFA and Periotest measurements, osseointegration, marginal bone loss, peri-implant bone-level changes, and postoperative or biological complications.

For example, Frumkin et al. contributed data on first and repeated implant failure and the relationship between osteoporosis and early implant failure (Frumkin et al., 2024). Tabrizi et al. contributed DXA-defined osteoporosis status and 12-month marginal bone loss outcomes (Tabrizi et al., 2021), whereas Liapaki et al. contributed data concerning postmenopausal osteopenia/osteoporosis treatment status and implant failure at second-stage uncovering (Liapaki et al., 2022).

When multiple reports described the same or overlapping patient cohort, the publication providing the most complete and relevant dataset was used as the primary source, while supplementary information from companion publications was incorporated only when it provided non-duplicative data.

2.5. Risk of Bias and Quality Assessment

The risk of bias (RoB) assessment of the studies included in this systematic review was performed using design-specific critical appraisal tools. Because the eligible evidence predominantly consisted of observational clinical studies evaluating osteoporosis, osteopenia, bone mineral density, menopausal status, anti-osteoporotic medication, and other patient-related factors in relation to dental implant outcomes, the Joanna Briggs Institute (JBI) Critical Appraisal Tools were used according to the design of each included study (Barker et al., 2023).

For cohort studies, the JBI Critical Appraisal Checklist for Cohort Studies was applied. This tool evaluates the comparability of study groups, measurement of exposures, identification and management of confounding factors, validity and reliability of outcome assessment, adequacy and completeness of follow-up, and appropriateness of the statistical analysis. Particular attention was given to potential confounding by age, menopausal status, smoking, diabetes and other systemic conditions, severity of osteoporosis or osteopenia, bone mineral density, anti-osteoporotic medication, implant location, bone augmentation procedures, and other clinical factors potentially affecting implant stability, osseointegration, marginal bone loss, and implant survival.

Case-control studies were evaluated using the JBI Critical Appraisal Checklist for Case-Control Studies, which assesses comparability and appropriate matching of cases and controls, validity and reliability of exposure measurement, identification and management of confounding factors, appropriateness of outcome assessment, adequacy of the exposure period, and suitability of the statistical analysis. Analytical cross-sectional studies were assessed using the JBI Critical Appraisal Checklist for Analytical Cross-Sectional Studies, including evaluation of participant inclusion criteria, description of the study population and setting, validity of exposure and outcome measurements, identification and management of confounding factors, and appropriateness of statistical analysis.

For non-randomized studies evaluating a specific clinical intervention, when applicable, the Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool was used (Sterne et al., 2016). ROBINS-I assesses seven domains: bias due to confounding, bias in the selection of participants into the study, bias in the classification of interventions, bias due to deviations from intended interventions, bias due to missing data, bias in the measurement of outcomes, and bias in the selection of the reported result. Domain-level judgments were categorized as low, moderate, serious, or critical risk of bias, or as no information.

Two reviewers independently performed the risk-of-bias assessments. Each signaling question was evaluated according to the guidance provided for the corresponding appraisal instrument. Disagreements between reviewers were resolved through discussion and consensus; when consensus could not be reached, a third reviewer was consulted. Risk-of-bias judgments were

not used as an automatic criterion for study exclusion but were incorporated into the interpretation and synthesis of the findings. The results of the risk-of-bias assessment are summarized in Section 3.8.

2.6. Evidence Synthesis

Because of substantial clinical and methodological heterogeneity in populations, exposure definitions, outcome measurements, and follow-up periods, quantitative pooling was not considered appropriate and the results were synthesized narratively according to clinically relevant outcome domains. An explicit evidence hierarchy was applied: primary human clinical studies informed the results; systematic reviews and clinical guidance were used only for contextual interpretation; and animal studies were used only to support biological plausibility and were not counted as included clinical evidence. A formal GRADE assessment was not performed.

3. RESULTS AND DISCUSSION

3.1. Study Selection and Characteristics

The included primary human studies demonstrated substantial clinical and methodological heterogeneity in terms of study design, participant characteristics, skeletal-status definitions, exposure assessment, follow-up duration, and implant-related outcomes. The evidence base consisted predominantly of prospective and retrospective observational studies, together with case-control and analytical cross-sectional investigations.

The principal exposures included osteoporosis and osteopenia, bone mineral density (BMD), postmenopausal skeletal status, age at menopause, anti-osteoporotic medication, and biochemical indices of bone turnover. Outcomes included implant survival and failure, early implant failure, marginal bone loss (MBL), implant stability, peri-implant clinical parameters, crestal cortical bone thickness, local cancellous bone density, and bone turnover markers (BTMs). The characteristics and principal findings of the eight included primary human studies are summarized in **Table 1**.

Because of substantial heterogeneity in study populations, exposure definitions, outcome measurements, and follow-up periods, quantitative pooling was not considered appropriate, and the results were synthesized narratively according to clinically relevant outcome domains.

Table 1. Characteristics and principal findings of the eight primary human clinical studies included in the evidence synthesis.

Study	Design / population	Sample	Principal outcome	Key finding
Frumkin et al. 2024	Retrospective observational; osteopenia/osteoporosis	Multiple analyses >100 patients	First, repeated, early failure	OPN/OP associated with selected first/repeated failure outcomes; early failure $p=0.0044$.
Tabrizi et al. 2021	Prospective cohort; women; posterior maxilla; DXA	90 women analyzed	12-month MBL	1.20 ± 0.29 vs 0.87 ± 0.15 mm; $p=0.001$; association, not causality.
Liapaki et al. 2022	Retrospective cohort; postmenopausal women	207 women; 386 implants	Failure at uncovering	4.1% untreated vs 0.5% treated/supplemented; treatment not independently significant after regression.
Yasuda et al. 2020	Case-control / preoperative assessment	18 patients	BTMs and CT cancellous density	Abnormally high BTMs associated with

				lower cancellous density at implant sites.
Lee et al. 2025	Retrospective clinical cohort; osteoporosis/osteopenia medication	111 patients; 209 implants	Survival and MBL	96.2% implant-level survival; medication characteristics associated with MBL, not survival.
Kumar et al. 2025	Cross-sectional; postmenopausal women	155 women	Crestal cortical thickness	Thickness differed by age-at-menopause group; cross-sectional association only.
Sachelarie et al. 2025	Prospective pilot; osteoporosis vs type 2 diabetes	50 patients; 29 osteoporosis	ISQ and Periotest	Osteoporosis ISQ 67.04 ± 5.42 at 6 months and 68.93 ± 4.83 at 12 months.
Cho et al. 2025	Prospective; postmenopausal women	36 women; 45 implants	Survival, ISQ, bone loss, BMD/BTMs	100% 1-year survival; ISQ 71.4 ± 5.52 ; bone loss 0.54 ± 0.35 mm.

3.2. Implant Survival and Failure

Overall, implant survival remained high in several of the included clinical studies, although the association between osteoporosis/osteopenia and implant failure was not uniform across the evidence base (Lee et al., 2025; Frumkin et al., 2024; Cho et al., 2025; Liapaki et al., 2022).

Frumkin et al. (2024) reported a significant association between osteopenia/osteoporosis and selected implant-failure outcomes. Osteopenia/osteoporosis was associated with second-implant failure when compared with patients without osteopenia/osteoporosis ($p = 0.0353$). Implant location was also associated with second-implant failure, with a higher failure rate in the maxilla than in the mandible ($p = 0.0299$). In the analysis of first implant failure, osteopenia/osteoporosis remained significant in multivariable logistic regression ($p = 0.0065$). A significantly greater proportion of early failures occurring within the first year was also observed among patients with osteopenia or osteoporosis ($p = 0.0044$).

In contrast, Cho et al. (2025) prospectively evaluated 36 postmenopausal women receiving 45 implants and reported 100% cumulative implant survival at 12 months, including women with reduced skeletal BMD.

Lee et al. (2025) evaluated 111 patients treated pharmacologically for osteoporosis or osteopenia who received 209 implants. During a mean observation period of 57.9 months, survival was 92.8% at the patient level and 96.2% at the implant level. No evaluated demographic or medication-related variable showed a statistically significant association with implant survival.

Liapaki et al. (2022) evaluated 207 postmenopausal women and 386 implants. The untreated group comprised 93 women with 197 implants, whereas the treated/supplemented group comprised 114 women with 189 implants. Failure rates at stage-two uncovering were 4.1% and 0.5%, respectively; the unadjusted chi-square comparison was significant ($p=0.022$), but univariate and multivariable regression did not identify significant associations between treatment status, age, implant location, bone grafting, and implant failure. Both groups showed a low overall failure rate (Liapaki et al., 2022).

3.3. Marginal and Peri-Implant Bone Changes

Greater between-study variability was observed for marginal and peri-implant bone outcomes than for implant survival (Lee et al., 2025; Cho et al., 2025; Tabrizi et al., 2021).

In the prospective study by Cho et al. (2025), mean peri-implant bone loss at 12 months was 0.54 ± 0.35 mm. Clinical peri-implant parameters, including plaque scores, probing depth, and bleeding on probing, remained stable during follow-up, and no implant failures were recorded.

Lee et al. (2025) identified significant associations between anti-osteoporotic treatment characteristics and MBL. Pre-prosthetic MBL was associated with RANKL inhibitor use ($p = 0.032$) and bone-formation stimulators ($p = 0.022$). RANKL-inhibitor monotherapy remained associated with pre-prosthetic MBL ($p = 0.039$), whereas post-prosthetic MBL was associated with the injection route of drug administration ($p = 0.011$).

Tabrizi et al. (2021) evaluated 90 women with implants placed in the posterior maxilla. At 12 months after loading, mean MBL was 1.20 ± 0.29 mm in the osteoporotic group and 0.87 ± 0.15 mm in the non-osteoporotic group ($p = 0.001$). The authors reported an association between skeletal T-score and MBL but cautioned that the study did not establish a causal relationship between osteoporosis and MBL.

Collectively, peri-implant bone remodeling showed more variable associations with skeletal status and treatment characteristics than did absolute implant survival (Lee et al., 2025; Cho et al., 2025; Tabrizi et al., 2021).

3.4. Implant Stability and Osseointegration-Related Outcomes

Prospective studies generally demonstrated maintenance or improvement of implant stability during follow-up despite impaired systemic skeletal status (Sachelarie et al., 2025; Cho et al., 2025).

Sachelarie et al. (2025) prospectively followed 50 participants, including 29 patients with osteoporosis and 21 patients with type 2 diabetes. At six months, mean ISQ was significantly higher in the osteoporosis group than in the diabetes group (67.04 ± 5.42 vs 62.10 ± 5.46 ; $p = 0.0215$). At 12 months, mean ISQ values were 68.93 ± 4.83 and 65.79 ± 3.87 , respectively. Corresponding 12-month Periotest values were -3.34 ± 1.59 and -2.81 ± 1.44 .

Cho et al. (2025) similarly reported a mean 12-month implant stability of 71.4 ± 5.52 ISQ, accompanied by 100% implant survival.

Accordingly, the available prospective evidence did not demonstrate a consistent deterioration in secondary implant stability among patients with reduced skeletal status during the evaluated follow-up periods (Sachelarie et al., 2025; Cho et al., 2025).

3.5. Bone Mineral Density, Bone Turnover, and Local Bone Quality

Several studies investigated skeletal and local bone characteristics that may provide information beyond the binary endpoint of implant survival (Kumar et al., 2025; Cho et al., 2025; Yasuda et al., 2020).

Yasuda et al. (2020) evaluated BTMs and CT-derived cancellous bone density in 18 partially edentulous patients before implant placement. Abnormal BTM values were more frequently observed among women, and cancellous bone density at planned implant sites was significantly lower in patients with abnormally elevated BTMs than in patients with normal BTM values.

Cho et al. (2025) monitored BMD and BTMs during the one-year implant-treatment period. Only limited systemic changes were observed during follow-up, while implant survival and clinical outcomes remained favorable.

Kumar et al. (2025) assessed crestal cortical bone thickness in 155 postmenopausal women. Women reporting menopause at ≤ 45 years had an overall mean cortical thickness of 4.0 ± 1.1 mm, whereas those reporting menopause after 45 years had an overall mean of 3.2 ± 1.0 mm. Because the study was cross-sectional, these data demonstrate an association with age at menopause but do not establish that menopausal timing caused the observed cortical differences.

3.6. Anti-Osteoporotic Medication and Implant Outcomes

Evidence specifically examining anti-osteoporotic therapy was limited and heterogeneous (Lee et al., 2025; Liapaki et al., 2022).

In the medication-focused cohort of Lee et al. (2025), implant-level survival remained 96.2% over a mean follow-up of 57.9 months. Medication-related variables were not significantly associated with implant survival; however, associations were identified between medication characteristics and peri-implant MBL.

Liapaki et al. (2022) likewise found low failure rates in treated/supplemented and untreated postmenopausal groups; after regression analysis, treatment status was not independently associated with implant failure at uncovering. Accordingly, the available evidence does not support a simple drug-exposure-versus-survival relationship (Lee et al., 2025; Liapaki et al., 2022).

3.7. Menopause-Specific Findings and Applicability to the Target Population

Evidence specifically addressing female reproductive aging was substantially more limited than the broader evidence concerning osteoporosis and osteopenia (Kumar et al., 2025; Cho et al., 2025; Liapaki et al., 2022).

Cho et al. (2025) studied postmenopausal women and reported 100% implant survival at one year, mean implant stability of 71.4 ± 5.52 ISQ, and mean peri-implant bone loss of 0.54 ± 0.35 mm. Kumar et al. (2025) evaluated 155 postmenopausal women and identified differences in crestal cortical bone thickness according to age at menopause.

Importantly, the female-specific evidence was derived predominantly from postmenopausal populations (Kumar et al., 2025; Cho et al., 2025; Liapaki et al., 2022). Direct primary clinical evidence evaluating dental implant outcomes specifically in premenopausal women with osteoporosis or women during the menopausal transition was not identified among the included studies.

3.8. Risk of Bias and Methodological Quality

Risk-of-bias assessment identified substantial methodological variability across the included observational studies. The most recurrent methodological concerns involved participant selection and residual confounding.

Retrospective studies were additionally vulnerable to selection and information bias inherent to record-based ascertainment. Frumkin et al. (2024), however, incorporated multivariable logistic regression. Prospective studies generally used more standardized outcome measurements but frequently remained limited by small samples and restricted populations. Sachelarie et al. (2025) included 50 participants, Cho et al. (2025) included 36 postmenopausal women, and Yasuda et al. (2020) included 18 participants.

The study-level judgments are presented in **Table 2** and **Figure 2**, and the proportional distribution of harmonized methodological concerns across domains is summarized in **Figure 3**. These harmonized graphical categories are descriptive and do not constitute numerical summary scores of the design-specific appraisal instruments.

Table 2. Study-level risk-of-bias judgments across harmonized methodological domains.

Study	Selection	Exposure / group classification	Confounding	Outcome measurement	Follow-up / missing data	Statistical analysis & reporting
Frumkin et al., 2024	Some concerns / unclear	Some concerns / unclear	Some concerns / unclear	Low concern	Low concern	Low concern
Tabrizi et al., 2021	Some concerns / unclear	Low concern	Some concerns / unclear	Low concern	Some concerns / unclear	Low concern
Liapaki et al., 2022	Some concerns / unclear	Low concern	Some concerns / unclear	Low concern	Some concerns / unclear	Some concerns / unclear
Yasuda et al., 2020	Some concerns / unclear	Low concern	High concern	Low concern	Low concern	Low concern
Lee et al., 2025	Some concerns / unclear	Low concern	Some concerns / unclear	Low concern	Low concern	Low concern
Kumar et al., 2025	Some concerns / unclear	Low concern	High concern	Low concern	Not applicable	Low concern
Sachelarie et al., 2025	Some concerns / unclear	Low concern	High concern	Low concern	Some concerns / unclear	Low concern
Cho et al., 2025	Some concerns / unclear	Low concern	Some concerns / unclear	Low concern	Low concern	Low concern

3.9. Overall Synthesis of Clinical Outcomes

Across the included studies, osteoporosis and osteopenia were not consistently associated with reduced dental implant survival (Sachelarie et al., 2025; Lee et al., 2025; Frumkin et al., 2024; Cho et al., 2025; Tabrizi et al., 2021; Liapaki et al., 2022). Cho et al. (2025) reported 100% survival at one year, whereas Lee et al. (2025) reported 96.2% implant-level survival during a mean follow-up of 57.9 months.

However, greater variability was observed for early and repeated implant failure, marginal and peri-implant bone remodeling, local bone density, cortical morphology, and biochemical indices of bone turnover (Sachelarie et al., 2025; Kumar et al., 2025; Lee et al., 2025; Frumkin et al., 2024; Cho et al., 2025; Yasuda et al., 2020; Tabrizi et al., 2021). Frumkin et al. (2024), in particular, identified significant associations between osteoporosis/osteopenia and selected implant-failure outcomes, whereas prospective cohorts generally demonstrated favorable survival and implant stability.

Taken together, the available evidence does not support osteoporosis as a uniform predictor of dental implant failure (Sachelarie et al., 2025; Lee et al., 2025; Frumkin et al., 2024; Cho et al., 2025; Yasuda et al., 2020; Tabrizi et al., 2021; Liapaki et al., 2022). Instead, compromised skeletal health showed heterogeneous associations with specific bone-quality, remodeling, and early-healing outcomes (Sachelarie et al., 2025; Kumar et al., 2025; Lee et al., 2025; Frumkin et al., 2024; Cho et al., 2025; Yasuda et al., 2020; Tabrizi et al., 2021).

Most importantly, direct evidence in premenopausal women with osteoporosis remains sparse, because the female-specific implant literature was predominantly derived from postmenopausal populations (Kumar et al., 2025; Cho et al., 2025; Liapaki et al., 2022).

Table 3. Synthesis of principal clinical outcome domains across the included studies.

Outcome domain	Studies contributing	Main quantitative findings	Interpretation
Implant survival / failure	Frumkin 2024; Liapaki 2022; Lee 2025; Cho 2025	Lee: 96.2% implant-level survival (mean 57.9 months). Cho: 100% at 12 months. Liapaki: 4.1% untreated vs 0.5% treated/supplemented at uncovering; treatment not independently significant after regression. Frumkin: associations with selected first/repeated and early failure outcomes.	Survival was generally high; early/repeated failure findings were heterogeneous.
Marginal / peri-implant bone changes	Tabrizi 2021; Lee 2025; Cho 2025	Tabrizi: 1.20 ± 0.29 vs 0.87 ± 0.15 mm at 12 months ($p=0.001$). Cho: 0.54 ± 0.35 mm at 12 months. Lee: medication class/route associated with selected MBL outcomes.	Bone-level outcomes were more variable than absolute implant survival.
Implant stability / osseointegration-related outcomes	Sachelarie 2025; Cho 2025	Sachelarie osteoporosis group: ISQ 67.04 ± 5.42 at 6 months and 68.93 ± 4.83 at 12 months. Cho: 12-month ISQ 71.4 ± 5.52 .	Prospective evidence showed maintained or improved secondary stability.
Local bone quality / BMD / BTMs	Yasuda 2020; Kumar 2025; Cho 2025	Yasuda: elevated BTMs associated with lower	Local bone biology and turnover may add

		cancellous density. Kumar: cortical thickness 4.0 ± 1.1 mm (menopause ≤ 45 y) vs 3.2 ± 1.0 mm (>45 y). Cho: limited BMD/BTM changes.	information beyond systemic BMD alone.
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3.10. Principal Findings

The principal finding of this systematic review is that osteoporosis and osteopenia should not be interpreted as uniform predictors of dental implant failure. Across the available clinical evidence, implant survival was generally high, whereas greater heterogeneity was observed for early and repeated implant failure, marginal and peri-implant bone remodeling, local bone quality, cortical morphology, bone turnover, and implant stability (Sachelarie et al., 2025; Kumar et al., 2025; Lee et al., 2025; Frumkin et al., 2024; Cho et al., 2025; Yasuda et al., 2020; Tabrizi et al., 2021; Liapaki et al., 2022). This distinction is clinically relevant because implant survival represents a relatively coarse endpoint and may not fully capture biologically relevant alterations occurring at the bone–implant interface during healing and subsequent remodeling.

The clinical findings illustrate this apparent discrepancy. Cho et al. (2025) prospectively followed 36 postmenopausal women receiving 45 implants and reported 100% cumulative survival at one year, a mean 12-month implant stability value of 71.4 ± 5.52 ISQ, and mean peri-implant bone loss of 0.54 ± 0.35 mm, with only minor changes in systemic BMD and BTMs. Similarly, Lee et al. (2025) reported 96.2% implant-level survival and 92.8% patient-level survival among medically treated patients with osteoporosis or osteopenia over a mean observation period of 57.9 months.

These favorable survival outcomes contrast with the retrospective findings of Frumkin et al. (2024), who identified significant associations between osteopenia/osteoporosis and selected implant-failure outcomes. Osteopenia/osteoporosis was associated with second-implant failure ($p = 0.0353$), remained significant in multivariable analysis of first-implant survival ($p = 0.0065$), and osteoporosis was associated with early implant failure ($p = 0.0044$).

Rather than being mutually contradictory, these findings indicate substantial clinical heterogeneity. The relationship between impaired skeletal status and implant outcomes appears to vary according to the endpoint examined, patient population, local bone conditions, medication exposure, implant location, surgical variables, and duration of observation (Lee et al., 2025; Frumkin et al., 2024; Cho et al., 2025). Accordingly, the available evidence does not demonstrate that osteoporosis uniformly compromises dental implant survival; instead, its associations appear more variable for specific early-failure and peri-implant bone outcomes. This interpretation is consistent with recent systematic reviews and meta-analyses, which generally report comparable implant survival in osteoporotic and non-osteoporotic populations while showing greater uncertainty for marginal bone loss and other bone-level outcomes (Lemos et al., 2023; Santiago Junior et al., 2018; Shibli et al., 2025; Kim et al., 2025).

3.11. Implant Survival Versus Peri-Implant Bone Outcomes

A central finding of the present review is the distinction between implant survival and peri-implant bone maintenance. The generally favorable survival observed in the included clinical studies is consistent with the broader literature summarized by Sirous et al. (2026), in which implant survival remained high in osteoporotic populations despite evidence suggesting greater susceptibility to peri-implant bone changes.

This distinction is supported directly by Lee et al (Lee et al., 2025). Although overall implant survival remained high, pre-prosthetic MBL was significantly associated with RANKL inhibitor use ($p = 0.032$) and bone-formation stimulators ($p = 0.022$). RANKL-inhibitor monotherapy was also associated with pre-prosthetic MBL in the relevant medication comparison ($p = 0.039$), whereas post-prosthetic MBL was associated with the injection route of anti-osteoporotic therapy ($p = 0.011$).

Tabrizi et al. (2021) likewise reported greater MBL in osteoporotic patients receiving implants in the posterior maxilla, supporting the possibility that peri-implant bone remodeling may reveal skeletal-status-related differences that are not necessarily reflected in implant loss.

Therefore, reliance on implant survival alone may underestimate biologically relevant differences between patients with normal and compromised skeletal health. An implant may remain clinically functional despite measurable changes in marginal bone

remodeling. This may partly explain why survival-based studies tend to provide relatively reassuring findings whereas studies assessing MBL, local bone characteristics, bone turnover, and early failure yield a more heterogeneous pattern (Lee et al., 2025; Frumkin et al., 2024; Cho et al., 2025; Yasuda et al., 2020; Tabrizi et al., 2021).

The present findings therefore support evaluating implant survival together with longitudinal bone-level and biological outcomes rather than treating survival as the sole indicator of successful implant therapy. Earlier clinical studies likewise suggest that skeletal and local bone density can influence implant stability or marginal bone behavior even when absolute survival remains favorable (Merheb et al., 2016; Toy and Uslu, 2020; Corcuera-Flores et al., 2016).

3.12. Bone Quality May Be More Informative Than BMD Alone

Another important finding concerns the relationship between systemic BMD and local bone quality. Although BMD is fundamental to the clinical assessment of osteoporosis, it may not completely characterize the biological environment in which implant osseointegration occurs.

Yasuda et al. (2020) evaluated biochemical BTMs together with CT-derived cancellous bone density before implant placement. Patients with abnormally elevated BTMs demonstrated significantly lower cancellous bone density at the intended implant site, while abnormal BTM values were more frequently observed among women.

Importantly, bone quality extends beyond BMD and encompasses characteristics such as microarchitecture, turnover, mineralization, microdamage, and properties of the bone matrix (Yasuda et al., 2020). Consequently, patients with comparable systemic BMD may not necessarily have equivalent local implant-site characteristics or remodeling capacity.

The findings of Kumar et al. (2025) provide additional evidence that local bone morphology may vary considerably within female populations. Among 155 postmenopausal women, crestal cortical bone thickness differed according to age at menopause, with overall mean values of 4.0 ± 1.1 mm in women with menopause at ≤ 45 years and 3.2 ± 1.0 mm in those with menopause after 45 years.

Taken together, these observations suggest that skeletal assessment relevant to implant therapy may require consideration of several complementary dimensions, including systemic BMD, local cortical and cancellous architecture, biochemical bone turnover, and site-specific bone characteristics (Kumar et al., 2025; Yasuda et al., 2020). However, current evidence does not establish that routine measurement of all these parameters improves implant outcomes. CBCT-based clinical work in postmenopausal women further supports the relevance of site-specific bone assessment during implant planning (Tadinada et al., 2015).

3.13. Menopause and Estrogen-Related Skeletal Changes

Menopause represents an important biological context for interpreting the relationship between osteoporosis and dental implant therapy. Estrogen deficiency is associated with alterations in skeletal remodeling and has been linked to changes in pathways regulating bone resorption and formation. The mechanistic framework summarized by Sirous et al. (2026) includes estrogen deficiency, inflammatory mediators, and altered RANK/RANKL/OPG signaling as potential links between systemic osteoporosis and oral bone metabolism.

Nevertheless, the clinical evidence directly linking reproductive aging with implant outcomes remains limited.

Kumar et al. (2025) evaluated 155 postmenopausal women and demonstrated differences in crestal cortical bone thickness according to age at menopause. However, because the study was cross-sectional, the observed association should not be interpreted as evidence that age at menopause itself caused the differences in cortical morphology.

Cho et al. (2025) provide more direct prospective implant evidence but studied an established postmenopausal population with a mean age of 68 years. Despite differences in skeletal status, the study reported 100% one-year implant survival, satisfactory secondary stability, limited peri-implant bone loss, and minimal changes in systemic BMD and BTMs.

This distinction is particularly important for the research question of the present review. Most female-specific evidence was obtained from postmenopausal women, whereas direct evidence concerning premenopausal women with osteoporosis or women during the menopausal transition was sparse (Kumar et al., 2025; Cho et al., 2025; Liapaki et al., 2022).

Consequently, results obtained in established postmenopausal osteoporosis should not be automatically extrapolated to younger women. Future studies should distinguish premenopausal, perimenopausal, and postmenopausal populations and evaluate whether reproductive stage modifies the relationship between systemic skeletal health and implant outcomes. This caution is consistent with contemporary osteoporosis guidance and premenopausal osteoporosis literature, which emphasize that diagnosis, fracture risk, and treatment considerations differ substantially by reproductive stage and underlying cause (Compston et al., 2019; Eastell et al., 2019; LeBoff et al., 2022; Pepe et al., 2020; Abraham et al., 2013; Khosla et al., 2012). Estrogen-related skeletal remodeling provides biological plausibility for stage-specific differences, while periodontal literature suggests that menopause may also modify oral inflammatory and bone-related outcomes (Civiletto-S Martin et al., 2026; Goyal et al., 2017; Zhu et al., 2022).

3.14. Implant Stability and Osseointegration

The available prospective evidence indicates that successful secondary implant stability can be achieved in patients with osteoporosis, although the evidence remains limited.

Sachelarie et al. (2025) reported mean ISQ values of 67.04 ± 5.42 at six months and 68.93 ± 4.83 at 12 months among patients with osteoporosis. These findings demonstrated maintenance of implant stability during follow-up.

Cho et al. (2025) similarly reported a mean 12-month implant stability value of 71.4 ± 5.52 ISQ, with no implant failures during one year of observation.

However, these results should not be interpreted as demonstrating equivalence between osteoporotic and healthy bone. Sachelarie et al. (2025) compared patients with osteoporosis with patients with type 2 diabetes rather than with a systemically healthy control group and included only 50 participants. Cho et al. (2025) included only 36 postmenopausal women and explicitly acknowledged the need for larger multicenter studies.

Therefore, current prospective evidence supports the feasibility of successful osseointegration in patients with compromised skeletal status, but it does not establish that osteoporosis has no effect on the kinetics or biological quality of early osseointegration (Sachelarie et al., 2025; Cho et al., 2025). More broadly, implant-stability literature emphasizes that resonance frequency analysis and insertion torque are complementary surrogate measures rather than direct histological measures of osseointegration (Quesada-Garcia et al., 2009; Lages et al., 2018).

3.15. Anti-Osteoporotic Medication as a Potential Effect Modifier

The present review also highlights the importance of distinguishing osteoporosis itself from its pharmacological treatment. Bisphosphonates, RANKL inhibitors, and bone-formation stimulators modify skeletal remodeling through different mechanisms and therefore cannot necessarily be considered a homogeneous exposure.

Lee et al. (2025) provide the most directly relevant medication-focused evidence among the included studies. Although implant-level survival remained high, medication-related differences were identified for MBL. Pre-prosthetic MBL was associated with RANKL inhibitors and bone-formation stimulators, whereas post-prosthetic MBL was associated with the injection route of anti-osteoporotic treatment (Lee et al., 2025).

These observations suggest that evaluation of an implant candidate with osteoporosis may require consideration not only of the diagnosis but also of medication class, administration route, treatment duration, skeletal status, and potentially bone-turnover activity.

At the same time, the available evidence is insufficient to determine whether modification of anti-osteoporotic treatment before implant placement improves clinical outcomes. The broader literature also emphasizes the need to consider medication-related osteonecrosis of the jaw in patients receiving antiresorptive therapy (Sirous et al., 2026).

Accordingly, the associations identified in the current evidence should not be interpreted as support for routinely discontinuing, switching, or initiating anti-osteoporotic medication solely to improve implant outcomes. Contemporary guidance and systematic reviews of antiresorptive therapy support individualized assessment rather than automatic interruption of osteoporosis treatment before implant placement; the evidence for implant failure and MRONJ remains limited and treatment-

specific (Ali et al., 2025; Mirza et al., 2025; Ruggiero et al., 2022; Walter et al., 2016; Ata-Ali et al., 2016; de-Freitas et al., 2016; Mendes et al., 2019; Lin et al., 2025; Santos et al., 2026).

3.16. Biological Plausibility from Preclinical Evidence

Animal evidence was excluded from the primary human clinical synthesis and is discussed only as mechanistic context.

Scardueli et al. (2018) systematically reviewed five animal studies investigating systemic strontium ranelate and reported an overall tendency toward improved peri-implant bone quality and titanium implant osseointegration, although the magnitude of the effect was moderate and methodological heterogeneity was substantial. The review itself was explicitly based on animal studies and therefore provides mechanistic rather than direct clinical evidence.

More recent experimental evidence suggests that implant-surface characteristics may modify healing in compromised bone. Gehrke et al. (2026) used an ovariectomy-plus-glucocorticoid osteoporosis model in rabbits. Implants with additional acid conditioning demonstrated significantly greater ISQ at 28 days ($p < 0.0001$), greater removal torque (30.1 ± 4.18 vs 25.6 ± 3.95 Ncm), and increased bone-area fraction occupancy, although BIC did not significantly differ between surfaces.

Paludetto et al. (2025) similarly demonstrated in ovariectomized rats that implant functionalization with zoledronic acid combined with ruterpy accelerated peri-implant repair and improved several microarchitectural parameters.

These experimental findings provide biological plausibility for surface modification and modulation of bone remodeling as potential approaches for improving osseointegration under osteoporotic conditions (Scardueli et al., 2018; Gehrke et al., 2026; Paludetto et al., 2025). Nevertheless, animal models cannot establish clinical effectiveness in women with osteoporosis, and these interventions should therefore be regarded as investigational rather than validated preoperative strategies. These preclinical observations should be interpreted separately from clinical evidence; they support biological plausibility but cannot establish patient-level effectiveness or safety.

3.17. Clinical Implications for Preoperative Assessment

The findings of this review support an individualized rather than diagnosis-based approach to preoperative implant assessment. Osteoporosis alone does not appear to justify automatic exclusion from implant therapy because high implant survival and satisfactory stability were reported in several osteoporotic and postmenopausal cohorts (Sachelarie et al., 2025; Lee et al., 2025; Cho et al., 2025).

At the same time, variability in early failure, MBL, local bone characteristics, and bone turnover indicates that a binary osteoporosis diagnosis may provide insufficient information for individual risk stratification (Kumar et al., 2025; Lee et al., 2025; Frumkin et al., 2024; Yasuda et al., 2020; Tabrizi et al., 2021).

A comprehensive assessment may therefore need to consider systemic skeletal status, local implant-site bone quantity and quality, menopausal status, medication exposure, bone turnover, relevant systemic comorbidities, and conventional implant-related risk factors. Yasuda et al. (2020), for example, demonstrated an association between abnormal BTMs and reduced cancellous bone density at the planned implant site.

However, this should not be interpreted as evidence that all such investigations are mandatory before every implant procedure. The available studies do not provide sufficiently robust comparative evidence to define a standardized osteoporosis-specific preoperative protocol.

The appropriate interpretation is therefore one of risk stratification rather than automatic contraindication. This is particularly relevant for premenopausal women, for whom direct clinical evidence remains insufficient (Kumar et al., 2025; Cho et al., 2025; Liapaki et al., 2022). In addition, radiomorphometric evidence suggests that dental imaging may provide supportive information about reduced skeletal BMD, but it should not replace standard osteoporosis diagnosis or systemic assessment (Heuchert et al., 2024).

3.18. Methodological Limitations and Certainty of the Evidence

The findings of this systematic review should be interpreted in light of several limitations of the available evidence.

First, the clinical evidence was predominantly observational and heterogeneous in study design, participant selection, definitions of osteoporosis and osteopenia, skeletal assessment, medication exposure, implant location, follow-up duration, and outcome definitions (Sachelarie et al., 2025; Kumar et al., 2025; Lee et al., 2025; Frumkin et al., 2024; Cho et al., 2025; Yasuda et al., 2020; Tabrizi et al., 2021; Liapaki et al., 2022).

Second, residual confounding remains an important limitation. Age, smoking, diabetes and other systemic diseases, menopausal status, medication exposure, local bone characteristics, implant location, surgical procedures, augmentation, and prosthetic factors may independently or jointly influence implant outcomes. Adjustment for these variables was inconsistent across the included studies.

Third, several clinically informative prospective studies had relatively small samples. Yasuda et al. (2020) included 18 patients, Sachelarie et al. (2025) included 50 participants, and Cho et al. (2025) included 36 women receiving 45 implants. These sample sizes limit precision and reduce the reliability of subgroup analyses.

Fourth, follow-up duration differed substantially. The one-year findings of Cho et al. (2025), for example, provide useful evidence regarding early osseointegration and peri-implant changes but cannot establish whether subtle skeletal differences influence long-term complications.

Finally, indirectness represents a major limitation in relation to the target population of this review. Much of the female-specific evidence was derived from postmenopausal populations (Kumar et al., 2025; Cho et al., 2025; Liapaki et al., 2022), while direct prospective evidence specifically addressing premenopausal women with osteoporosis remains scarce.

Therefore, although the available evidence is sufficient to challenge the assumption that osteoporosis uniformly predicts implant failure, it is insufficient to establish a validated premenopausal osteoporosis-specific preoperative management protocol.

Because the evidence was predominantly observational, clinically heterogeneous, and often based on small or selected samples, confidence in outcome-specific conclusions is limited. A formal GRADE assessment was not performed; therefore, no GRADE certainty rating is claimed in this manuscript.

3.19. Future Research

Future studies should move beyond the binary question of whether osteoporosis “causes” dental implant failure and instead determine which dimensions of compromised skeletal health are associated with clinically relevant implant outcomes.

Prospective multicenter studies should simultaneously characterize systemic BMD, local cortical and cancellous bone characteristics, biochemical BTMs, menopausal stage, anti-osteoporotic medication exposure, implant location, implant-surface characteristics, primary and secondary stability, MBL, early failure, and long-term implant survival.

Particular priority should be given to premenopausal and perimenopausal women, who remain poorly represented in the current clinical literature (Kumar et al., 2025; Cho et al., 2025; Liapaki et al., 2022). Studies should prospectively distinguish reproductive stages and determine whether hormonal status, systemic BMD, local jawbone characteristics, and bone-turnover activity provide independent or complementary prognostic information.

The preclinical evidence additionally provides a rationale for translational investigation of implant-surface modification and local modulation of bone remodeling (Scardueli et al., 2018; Gehrke et al., 2026; Paludetto et al., 2025). However, adequately powered clinical trials are required before these approaches can be incorporated into routine management of patients with compromised skeletal health.

Future research should also standardize definitions of osteoporosis/osteopenia, implant failure, MBL, and osseointegration outcomes and should provide sufficiently long follow-up to distinguish early healing effects from late implant complications.

3.20. Overall Interpretation

Taken together, the available evidence supports a clinically important distinction between implant survival and the biological quality of peri-implant healing. Osteoporosis and osteopenia were not consistently associated with reduced absolute implant survival, and successful implant therapy was documented even among postmenopausal women and medically treated patients with compromised skeletal status (Sachelarie et al., 2025; Lee et al., 2025; Cho et al., 2025).

Nevertheless, selected studies identified associations with early or repeated implant failure (Frumkin et al., 2024), MBL (Lee et al., 2025; Tabrizi et al., 2021), local cancellous bone density and bone turnover (Yasuda et al., 2020), and cortical morphology (Kumar et al., 2025). Thus, the available evidence is more heterogeneous for bone-level and early-healing outcomes than for absolute implant survival.

Accordingly, osteoporosis should neither be regarded as an automatic contraindication to dental implantation nor interpreted as biologically irrelevant. Current evidence instead supports individualized risk assessment while highlighting substantial uncertainty regarding the optimal preoperative strategy.

Most importantly, direct evidence applicable specifically to premenopausal women with osteoporosis remains insufficient (Kumar et al., 2025; Cho et al., 2025; Liapaki et al., 2022). The principal unresolved question is therefore not simply whether implants can survive in osteoporotic bone, but which patient-specific skeletal and clinical characteristics identify susceptibility to adverse early healing or peri-implant bone remodeling and which preoperative interventions can meaningfully reduce that risk.

4. CONCLUSION

Current clinical evidence indicates that osteoporosis and osteopenia are not consistently associated with reduced dental implant survival, and successful implant therapy can be achieved in patients with compromised systemic skeletal status. Nevertheless, the available studies demonstrate greater heterogeneity in early and repeated implant failure, marginal and peri-implant bone remodeling, local bone quality, cortical morphology, bone turnover, and implant stability than in absolute implant survival (Sachelarie et al., 2025; Kumar et al., 2025; Lee et al., 2025; Frumkin et al., 2024; Cho et al., 2025; Yasuda et al., 2020; Tabrizi et al., 2021; Liapaki et al., 2022).

These findings suggest that osteoporosis should not be considered an automatic contraindication to dental implant therapy. Instead, preoperative evaluation should be individualized and should consider systemic skeletal status together with local implant-site bone characteristics, menopausal status, bone turnover, anti-osteoporotic medication exposure, relevant systemic comorbidities, and conventional implant-related risk factors (Sachelarie et al., 2025; Sirous et al., 2026; Kumar et al., 2025; Lee et al., 2025; Cho et al., 2025; Yasuda et al., 2020). However, current evidence is insufficient to establish a standardized osteoporosis-specific preoperative management protocol.

A major evidence gap concerns premenopausal and perimenopausal women, because most female-specific clinical evidence has been derived from postmenopausal populations (Kumar et al., 2025; Cho et al., 2025; Liapaki et al., 2022). Consequently, findings from older postmenopausal cohorts should not be directly extrapolated to younger women with compromised skeletal health.

Future prospective, adequately powered multicenter studies should specifically investigate premenopausal and perimenopausal women and integrate systemic BMD, local bone quality, biochemical bone turnover, medication exposure, menopausal stage, implant stability, marginal bone changes, and long-term implant outcomes. Such studies are required to determine which factors meaningfully predict adverse implant outcomes and to develop evidence-based, individualized preoperative risk-reduction strategies.

In conclusion, the current evidence supports a shift from diagnosis-based exclusion toward individualized risk assessment: osteoporosis alone does not determine implant failure, while bone quality, remodeling activity, treatment exposure, and patient-specific characteristics may be more relevant to peri-implant healing and clinical outcome.

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FIGURE LEGENDS

Figure 1. PRISMA 2020 flow diagram of study identification, screening, eligibility assessment, and inclusion.

Figure 2. Risk-of-bias assessment of the included observational studies. Traffic-light plot showing study-level methodological concerns across harmonized domains. Green indicates low concern, yellow indicates some concerns/unclear, red indicates high concern, and grey indicates not applicable.

Figure 3. Summary of risk-of-bias judgments across the included observational studies. Proportional distribution of low concern, some concerns/unclear, and high concern judgments across harmonized methodological domains; categories are descriptive and do not constitute numerical summary scores.

Figure 1

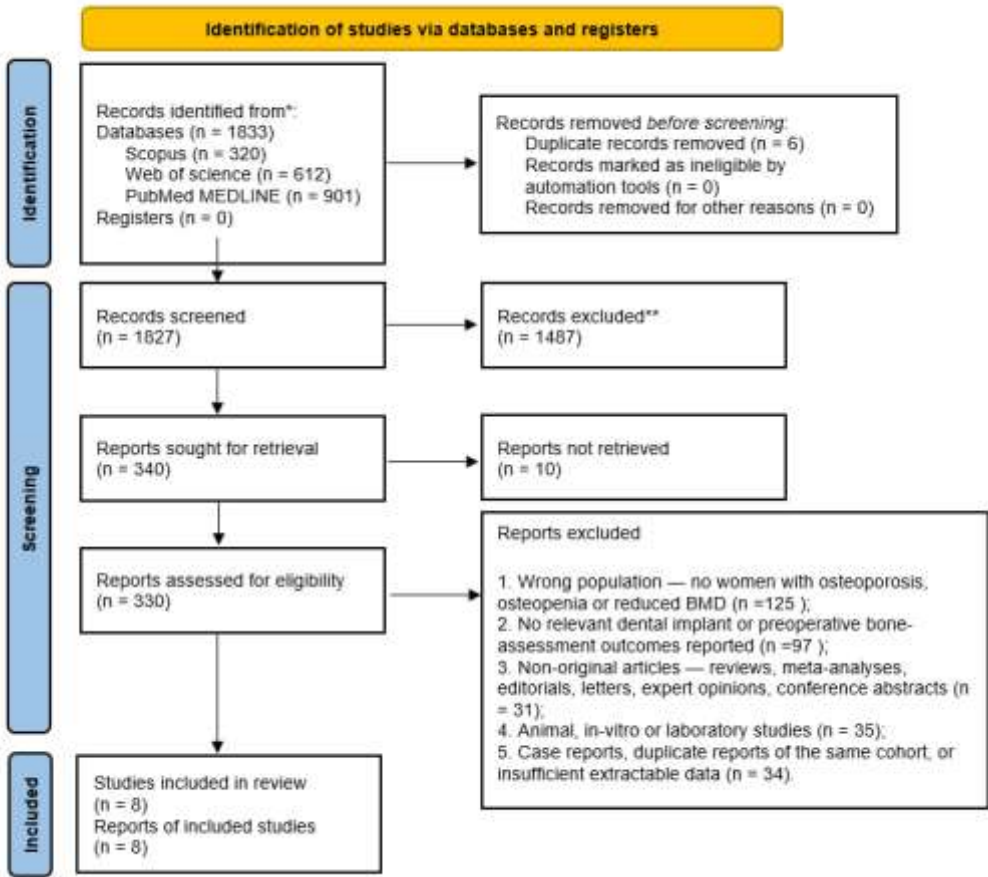


Figure 2

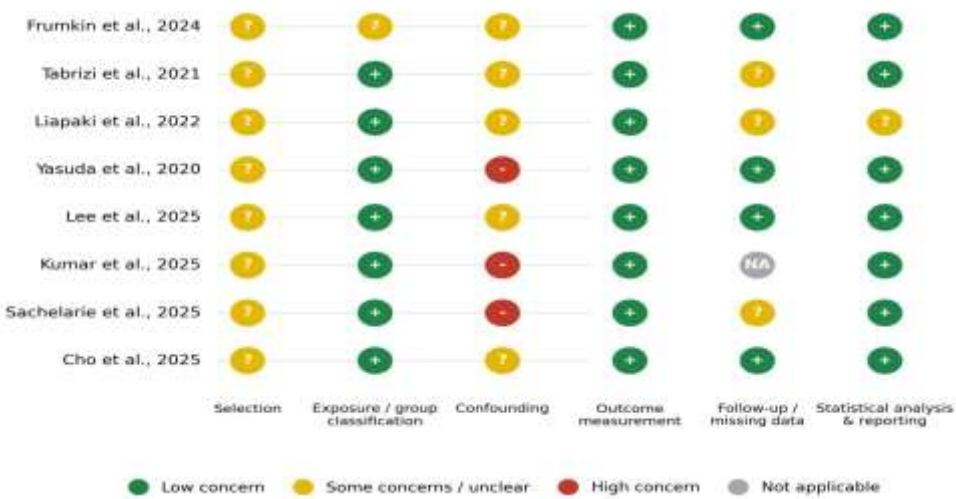


Figure 3

