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Review Article

Assessment of Miniscrew Stability and Bone Response Using Titanium-Zirconium Hybrid Alloys with Nanostructured Surfaces, a Systematic Review and Meta-Analysis Perspective

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ABSTRACT

Objective: The purpose of this systematic review and meta-analysis was to determine the effects of titanium-zirconium hybrid alloy miniscrew surface modifications on clinical failure and removal torque, as well as their impact on orthodontic patient stability and bone response.

Data Sources: PubMed, Scopus, Web of Sources, and Google Scholar were searched in November 2025.

Study Selection: Eligible studies were clinical and experimental studies which involve randomized controlled trials, cohort studies, and animal models that evaluated miniscrew surface-treated and untreated implants or other treated implants and reported clinical failure or removal torque.

Data Extraction: Two reviewers extracted data separately on the study design, sample size, implant material/surface treatment, location of insertion, loading protocol, primary outcomes, and duration of follow-up. The Cochrane RoB-2, NOS, or SYRCLE tools were used to assess the risk of bias according to the suitable tool, and the certainty of evidence was determined with the help of GRADE.

Data Synthesis: A total of 12 studies were used. Meta-analysis indicated no statistically significant difference in clinical failure between surface-treated and untreated miniscrews (pooled OR= 0.54, 95% CI: 0.11-2.67), but surface-treated miniscrews presented a significantly higher removal torque (pooled SMD= 1.16, 95% CI: 0.70-1.63). The heterogeneity was strong in terms of outcomes, and sensitivity analyses helped in defending the strength of the results.

Conclusion: Surface modification of miniscrews improves mechanical stability, which is measured in removal torque; however, failure rates are multifactorial. To optimize design, location, and clinical procedures, standardized, longitudinal studies are needed.

Keywords: Biomechanical Phenomena, Orthodontic Anchorage Procedures, Orthodontic Appliance Design, Titanium, Zirconium.

How to Cite This Article: *Sharif RA, Ikram AM, Suleman G, Ehsan AB. Assessment of Miniscrew Stability and Bone Response Using Titanium-Zirconium Hybrid Alloys with Nanostructured Surfaces, a Systematic Review and Meta-Analysis Perspective. Pak Armed Forces Med J 2026; 76(Suppl-10): S1682-S1691. DOI: https://doi.org/10.51253/pafmj.v76iSUPPL-10.14122*

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INTRODUCTION

Miniscrews, also referred to as temporary anchorage devices (TADs), are very common orthodontic devices that are used in the modern orthodontic profession to achieve absolute skeletal anchorage.[1] They allow movement of teeth to be made under control, without relying on the cooperation of patients or conventional intra-oral anchorage devices.[2] Mechanical properties of the implant, such as material composition, surface features, and structural design, determine the success of miniscrews, which are essential in providing primary and secondary stability.[3]

Titanium alloys have been used in miniscrew fabrication because of their biocompatibility, corrosion resistance, and sufficient mechanical strength.[4] However, more recently, it has been succeeded by titanium-zirconium (Ti-Zr) hybrid alloys, which are showing improved mechanical properties, including higher fracture resistance, higher hardness, and higher fatigue strength than commercially pure titanium.[5,6] Such changes in the material are complemented by surface treatments such as sandblasting, acid-etching, anodic oxidation, and platelet-derived growth factors, which have been investigated with regard to their possible effect on promoting bone-implant interactions, enhancing osseointegration, and improving mechanical retention.[7]

Miniscrew performance has been evaluated by experimental and clinical trials based on different biomechanical and clinical outcomes.[8] The measurements of removal torque are commonly regarded as a measure of secondary stability, an indicator of resistance of the bone-implant interface to rotational forces.[9] The primary issue is clinical failure,

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Received: 25 Dec 2025; revision received: 11 Jan 2026; accepted: 12 Jan 2026

which is defined as the loosening or premature loss of the miniscrew, which has been considered in prospective and retrospective research as well as randomized clinical trials.[10] These studies have covered various designs of miniscrews, surface eventually, placement procedure, and loading techniques, creating an extensive amount of literature on aspects that influence stability. Adoption of animal models can be used to augment clinical studies in that, under standardized experimental conditions, bone response to miniscrews can be assessed under controlled conditions. The histological evaluation, biomechanical, and removal torque measurement in these studies help to learn the impact of surface topography and material composition on bone adaptation as well as the stability of implants.[11,12]

Given the scope of the experimental, clinical, and animal studies on miniscrews, there is a need to merge the current literature to elucidate the implications of titanium-zirconium alloys and surface modification on clinical failure and mechanical stability. The purpose of the systematic review and meta-analysis was to determine the effects of titanium-zirconium hybrid alloy miniscrew surface modifications on clinical failure and removal torque and determine their impact on orthodontic patient stability and bone response.

METHODOLOGY

This systematic review and meta-analysis followed the PRISMA 2020 guidelines.[13]

Search Strategy and Data Sources

PubMed, Scopus, Web of Science, and Google Scholar were searched in November 2025. The search terms included MeSH terms and free-text words, such as “miniscrew”, “temporary anchorage device”, “mini-implant”, “titanium-zirconium”, “Ti-Zr”, “surface treatment”, “sandblasting”, “acid etching”, “anodic oxidation”, “platelet-released growth factor”, “removal torque”, and “failure rate”. Boolean operators (AND, OR) were used, and reference lists of included studies were manually screened to identify additional eligible articles.

A representative search string was

(("miniscrew" OR "mini-implant" OR "temporary anchorage device" OR "TAD") AND ("titanium-zirconium" OR "Ti-Zr" OR "titanium zirconium" OR "hybrid alloy") AND ("surface" OR "surface treatment" OR "sandblasting" OR "acid etching" OR "anodic oxide*" OR "nanostructure*") AND ("removal torque" OR "removal-torque" OR "failure" OR "failure rate" OR "survival" OR "stability")).

Eligibility Criteria (Inclusion and Exclusion Criteria)

The included studies were randomized controlled trials and prospective and retrospective clinical cohorts, case-control and split-mouth studies, and experimental animal studies that determined miniscrew stability or bone response using titanium-zirconium hybrid alloys or surface-modified miniscrews and reported extractable binary outcomes (failure vs success) or continuous outcomes (mean, SD, n for removal torque). The inclusion criteria were limited to providing group-level data (means and SDs of continuous outcomes or 2x2 counts in binary outcomes).

Studies that were excluded included case reports, editorials, reviews, in vitro alone studies, non-comparative reports, and studies that did not involve miniscrew stability or removal torque, as well as those that did not have extractable outcome measures or were not written in English.

Study Selection

Two reviewers independently filtered titles, abstracts, and full texts, and a third reviewer adjudicated on cases of disagreement. The study selection process was documented according to the PRISMA 2020 flow diagram (see Results).

Data Extraction

Extraction of data was carried out in a standardized form that included: author, year of study, country of study, type of study design, population/sample size, type of miniscrew material and surface treatment, type of comparator, key result(s) measured (failure rate and/or removal torque), follow-up period, and key results. In missing or unclear data, respective authors were approached.

Outcomes

The primary outcomes of the meta-analysis included: 1) the failure rate of miniscrews (binary) and 2) the value of removal torque (continuous).

Data Synthesis

Binary outcomes were derived or calculated using the standard formula odds ratio (OR) = (a x d) / (b x c), where a= number of failed miniscrews in the experimental group, b= number of successful miniscrews in the experimental group, c= number of failed miniscrews in the control group, and d= number of successful miniscrews in the control group. To

compute standardized mean differences (SMDs) along with 95% CIs with continuous outcomes, means, SDs, and group sample sizes were applied.

Quality and Risk of Bias Assessment

The design-appropriate tools were Cochrane RoB-2 in randomized controlled trials,[14] Newcastle-Ottawa Scale (NOS) in observational ones (selection, comparability, outcome), and SYRCLE in animal experiments, which were used to identify the risk of bias. GRADE was used to critique the overall quality of evidence.

Statistical Analysis

Meta-analyses and the creation of forest and funnel plots of individual primary outcomes were done using the MetaAnalysisOnline tool.[15] All analyses were prespecified to a random-effects inverse-variance model to enable anticipated clinical and methodological heterogeneity across study designs, miniscrew materials, placement sites, and loading protocols. The I2 statistic was used to measure heterogeneity.

Subgroup analysis was to be based on surface modification type (e.g., SAE vs anodic oxidation vs PRGF), placement site (maxilla vs mandible; attached gingiva vs mucosa), and study type (human clinical vs animal); subgroup analysis was to be carried out in cases where enough data were available. All the sensitivity analyses were done using the leave-one-out approach.

Assessment of Publication Bias

The possibility of publication bias was estimated by visual inspection of funnel plots (effect size versus standard error) and was checked with the formal Egger regression test in case the number of studies included allowed it.

Narrative Synthesis

Results were synthesized narratively because of differing measures of effect or too much heterogeneity. Results were presented in an overview table of the forests in the plot and overall results in summary tables containing ORs or SMDs with the 95% CI.

A total of 12 eligible studies were included in the systematic review and meta-analysis, with around 29-703 patients/in different countries.

RESULTS

Among the four searched electronic databases and other sources, 222 research articles were initially selected. The number was reduced to 92 records after removing the duplicates. Title and abstract screening further eliminated 30 studies. From the remaining 62 articles, 22 were removed due to unavailability of access to the full-texts. Further articles (28) were eliminated due to a lack of stratified data and studies including animals, in vitro findings, reviews, case reports, or languages other than English. Ultimately, twelve studies that passed the inclusion criteria were included in this systematic review.

The PRISMA flow diagram presented in Figure-1 illustrates the selection process.

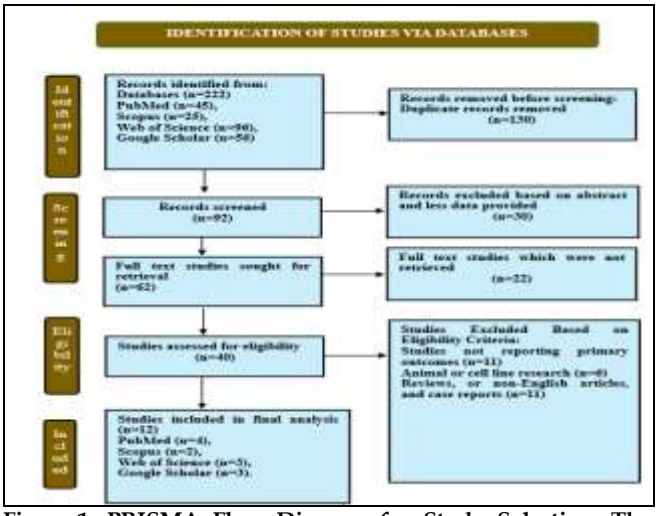


Figure-1: PRISMA Flow Diagram for Study Selection. The flowchart was designed according to the PRISMA guidelines 2020, showing study identification, screening, assessment eligibility, and final selection in the systematic review

In this review, 12 experimental, clinical, and observational studies have been carried out, whereby the biomechanical stability and clinical outcome of orthodontic miniscrews were evaluated. The majority of the studies evaluated either primary outcome 1 (clinical failure or loosening) or primary outcome 2 (removal torque / secondary stability). Overall, most of the studies suggested that surface treatments, including sandblasting and acid-etching (SAE), anodic oxidation, or the use of platelet-released growth factors (PRGF), were related to greater removal-torque values, which signified enhanced secondary stability. Design of miniscrews, placement site, loading protocol, and size of the implant affected the clinical failure rates; miniscrews attached to the gingiva with longer or larger lengths or diameters, and under protocols of immediate loading exhibited higher success rates. Other studies, however, reported no significant difference in the failure of surface-treated

and untreated miniscrews. Heterogeneity occurred due to variation of study design (animal vs. human, RCT vs. retrospective cohort), follow-up period, measurements, and loading protocols, but the relative risk of bias was mainly moderate because of small sample sizes, single-centre recruitment, lack of blinding, or inadequate reporting of allocation and methods performed.

Table-I presents some of the studies that were included and the aim of the studies to examine the stability and failure of miniscrews. It includes the study design, country, population size, miniscrew material/surface, comparator, primary outcome measured, follow-up time, major findings, and risk of bias.

The majority of the included studies were clinical (prospective and retrospective cohorts, case-control and split-mouth randomized trials), but with a few animal experiments; sample sizes were either small single-center series or large institutional cohorts. Two main outcomes were considered: (1) miniscrew clinical failure (binary) and (2) removal torque / secondary stability (continuous). In the literature, the placement-site and implant-design issues were critical - placement in the movable mucosa or maxilla, shorter/smaller screws, and in some loading conditions, had a higher likelihood of failure, whereas attached gingiva, longer length/diameter, and some immediate-loading conditions had a higher chance of survival. Surface modifications (sandblasting/acid etching, PRGF, anodic oxidation, and others) always augmented measures of removal -torque in experimental and clinical studies, although the impacts on clinical failure rates were mixed: several RCTs reported an augmentation of MRT with surface treatment without a well-defined and statistically consistent decrease in failure.

Design-appropriate tools (Cochrane RoB-2 in RCTs, NOS in observational studies, SYRCLE in animal studies) were used to evaluate the risk of bias; the majority of studies were rated as moderate-risk (most common reasons: small samples, single-center recruiting, incomplete methodological reporting, and unspecified allocation/concealment in several trials). Considering the aspects of study design, consistency, and precision (GRADE domains), the general certainty of the evidence is moderate in the case of removal-torque (secondary stability) and low-moderate in terms of clinical failure rate due to the variability in definitions, limited number of events, and limitations of the study. The risk of bias is given in Table-II, III, and IV.

Meta-Analysis

The meta-analysis was a comparison of the relative relationships between miniscrew surface characteristics and the two key outcomes of interest on two significant topics: miniscrew failure rate and removal torque value. The meta-analysis on a random-effects inverse-variance model was chosen a priori as the foundation of all the analyses to allow the anticipated clinical and methodological variations across study designs, miniscrew materials, placement sites, and loading protocols.

The issue of comparing two studies on surface modification and clinical miniscrew common failure was analyzed in five studies. It was found that there is no statistically significant difference between the data pooling with the summarized odds ratio (OR) of 0.54 and a 95% confidence interval (CI) of 0.11-2.67. The overall effect test did not become significant (p>0.05), which means that there is no constant lower or higher failure rate of surface-treated miniscrews in comparison to untreated ones. A major heterogeneity was observed (p<0.01), which indicated that the magnitude and/or direction of the effects were not consistent across the studies. The I2 value is a measure that shows that heterogeneity is what causes 89% of the variability among studies and not a random chance.

The odds ratios of studies included in a forest plot are shown in Figure-2.

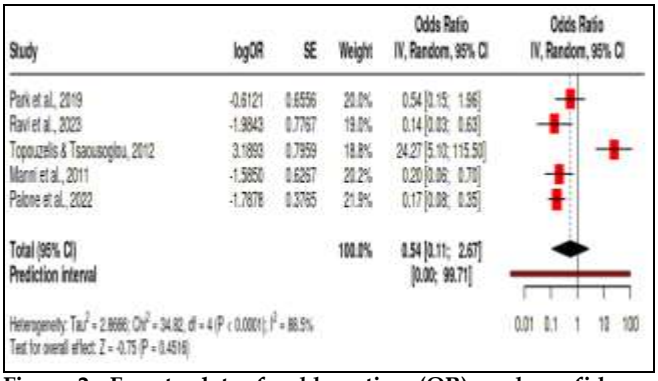


Figure-2: Forest plot of odds ratios (OR) and confidence interval (CI) of miniscrew failure between surface-treated and untreated groups. The square sizes indicate the level of effect size of the study, the horizontal lines represent the 95% confidence interval, and the bottom diamond is the pooled estimate of the OR

The funnel plot does not suggest the possibility of publication bias. The result of the Egger test was not in

favor of the presence of asymmetry (intercept: 5.07, 95% CI: -3.29 to 13.43, t=1.189, p=0.32). The funnel plot concerning the five studies is shown in Figure-3.

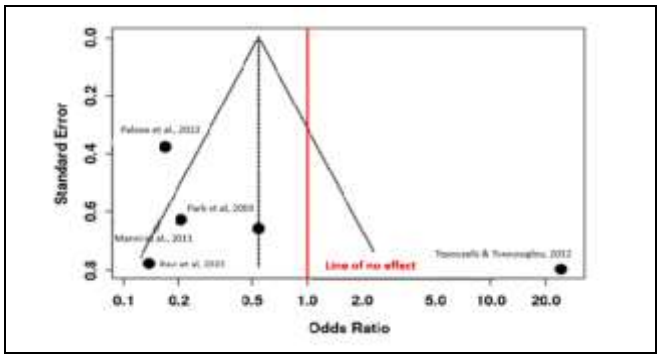


Figure-3: Funnel plot of the studies evaluating the relation between miniscrew surface treatment and clinical failure. The points are log OR and the standard error of each study. The funnel plot does not suggest the possibility of publication bias

The correlation of the surface modification and removal torque was studied in 4 studies, and a total of 429 subjects were used as the experimental group, and 637 subjects were used as the control group. There was a statistically significant difference in data pooling with a summarized standardized mean difference (SMD) of 1.16 (95% CI: 0.70-1.63). The overall effect test was found to be significant (p<0.05), meaning that surface-treated miniscrews had a higher removal torque as compared to untreated miniscrews. Heterogeneity was found to be significant (p<0.01), indicating that the magnitude of effect and/or direction varies between studies. The I2 test shows that 89% of the variation is due to heterogeneity and not by chance.

A forest plot of standardized mean differences of the included studies is provided in Figure-4.

The funnel plot does not suggest that there is any possibility of publication bias. The Egger test failed to show any indication of asymmetry (intercept: 4.52, 95% interval: 0.07-8.97, t = 1.991, p=1.285). The funnel plot concerning the four studies is shown in Figure-5.

Subgroup Analysis

Subgroup analyses were based on the characteristics of the study, such as the type of study (animal vs. human), the site of placement and method of surface modification. Though tendencies were present of a little increased removal torque with SAE or PRGF treatment in human studies, none of the subgroup comparisons were statistically significant. Heterogeneity was also there, which implies that there was significant clinical and methodological variability among studies and these variability affected effect estimates.

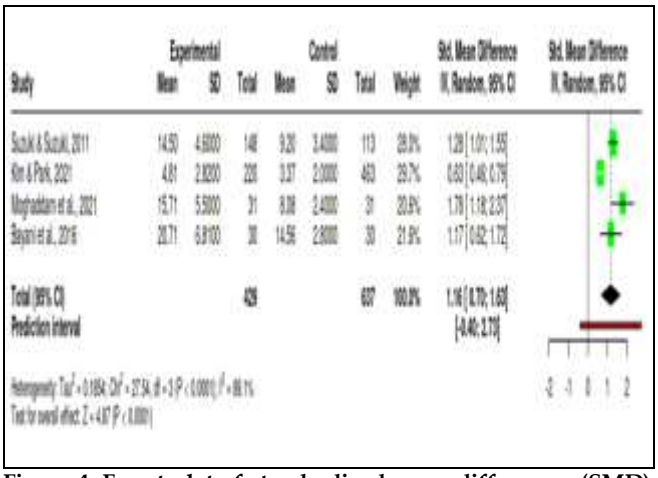


Figure-4: Forest plot of standardized mean differences (SMD) and 95% confidence interval of removal torque between surface-treated and untreated miniscrews. The weights of the studies, confidence, and the cumulative impact are presented in the traditional form

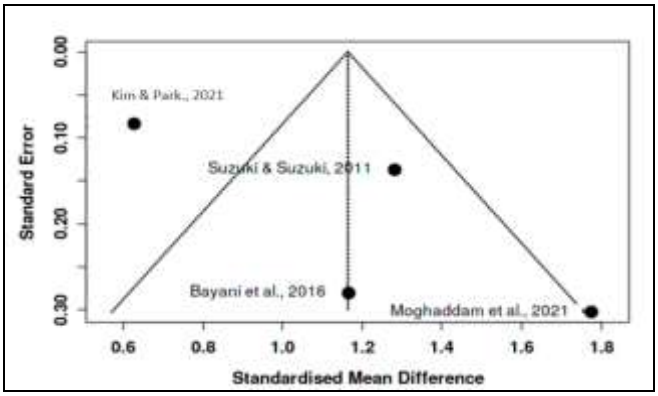


Figure-5: Funnel plot of studies that have evaluated the removal torque in surface-treated and untreated miniscrews. The points indicate the level of effects of a study against standard error; the distribution appears to be somewhat symmetrical without any notable asymmetry, at least based on the test of Egger

Sensitivity Analysis

The direction and magnitude of the pooled effects were found to be strong and, therefore, without the individual studies in the sensitivity analyses (leave-one-out). High-weight study exclusion

Table-I: Characteristics of Included Studies

Author & Year	Country	Study Design	Population Size	Miniscrew Surface / Material	Comparator	Primary Outcome Measured	Follow-up Duration	Key Findings
Park et al., 2019 16	South Korea	Split-mouth randomized controlled trial	40 patients; 98 miniscrews	Acid-etched titanium miniscrews	Machined titanium miniscrews	Miniscrew failure (success vs loss)	Not explicitly stated	Acid-etched miniscrews showed slightly higher survival, but no significant difference between surfaces.
Ravi et al., 2023 17	India	Randomized split-mouth RCT	9 patients; 36 mini-implants (18 surface-treated, 18 non-surface-treated)	Surface-treated: sandblasted & acid-etched titanium mini-implants	Non-surface-treated titanium mini-implants	Failure rate (clinical loosening of mini-implants)	Until completion of space closure (approx. several months)	Surface-treated mini-implants had a lower failure rate than non-surface-treated ones
Topouzelis & Tsaousoglou, 2012 18	South Korea	Retrospective clinical study / observational	34 patients; 82 miniscrews	Not reported	Multiple clinical factors were compared	Miniscrew success vs failure (clinical loosening/removal)	100-150 days	Overall success 90.2% (74/82). Failure is associated with placement in movable mucosa, certain sites, screw length/diameter, and number of miniscrews per patient.
Manni et al., 2011 19	Italy	Retrospective study	132 patients; 300 miniscrews	Type V titanium miniscrews: A (1.5 mm × 9 mm), B (1.5 mm × 11 mm), C (1.3 mm × 11 mm)	Clinical variables: gender, loading time, screw type, dental arch, and gingiva location	Miniscrew failure rate (binary outcome)	~3 years	Highest success with 1.3 mm miniscrews in attached gingiva with immediate loading; gender, loading time, screw type, and dental arch significantly affected failure.
Kaci, 2024 20	Not specified	Prospective cohort	64 patients; 104 miniscrews	Self-drilling, self-tapping, Ti6Al4V alloy	Maxilla vs Mandible; monocortical vs bicortical anchorage	Miniscrew failure rate (binary outcome)	12 months	Overall survival 91%; failure was higher in the maxilla, poor oral hygiene, thin cortical bone, and monocortical anchorage
Palone et al., 2022 21	Italy	Retrospective clinical observational study	276 patients; 676 miniscrews	Orthodontic miniscrews (various lengths/diameters)	Clinical factors (length, MIT, and gingiva type) were compared	Miniscrew failure rate (binary)	Immediately loaded & monthly monitoring (mean ~13 ± 3 months)	88% success (88%); higher failure associated with shorter length (≤ 8 mm), MIT 5-10 Ncm & alveolar mucosa
Suzuki & Suzuki, 2011 22	Thailand	Prospective clinical comparative study	280 miniscrews in orthodontic patients	Predrilling cylindrical miniscrews (Sistema Nacional)	Self-drilling conical miniscrews (ACR Mini-Implant)	Removal torque value (MRT, N·cm)	Immediately loaded; monitored through treatment (see paper)	MRT is significantly higher for predrilling (mean 22.6 N·cm) than for self-drilling (mean 17.6 N·cm).
Kim & Park, 2021 23	South Korea	Retrospective clinical evaluation	703 microimplants in 354 patients	MRT value (N·cm) by placement method	Self-drilling vs Pre-drilling	Removal torque (N·cm)	Mean implant in-bone stay ~26.4 ± 18.4 months	The pre-drilling group had a higher MRT than the self-drilling; the removal torque was related to implant size & site
Moghaddam et al., 2021 24	Iran	Randomized split-mouth RCT	31 patients; 62 miniscrews (31 SAE, 31 control)	Sandblasted + acid-etched (SAE) titanium miniscrews (10 mm × 2 mm)	Non-surface-treated (control) identical miniscrews	Removal torque (N·cm)	Followed at 3,6,10,14,18 weeks, then 4-weekly intervals	SAE had a significantly higher removal torque
Chen et al., 2006 25	Taiwan	Clinical observational	29 patients; 46 miniscrews	Immediately loaded orthodontic miniscrews (varied lengths)	Comparisons by site & length	Removal torque value (N·cm)	Immediate loading until clinical removal	Mean removal torque ~8.7 N·cm; higher in mandible & longer screws
Bayani et al., 2016 26	Iran	Experimental animal study	3 dogs; 60 miniscrews (femoral insertion)	Orthodontic miniscrews (standard experimental implants)	PRGF vs no PRGF	Removal torque (N·cm) measured at 12 weeks	12 weeks	PRGF significantly increased the removal torque
Choi et al., 2016 27	South Korea	Experimental animal study	12 dogs; 96 miniscrews (48 anodic oxidized, 48 machined)	Titanium alloy (TiAl6V4) miniscrews	Anodic oxidized vs machined surface	Removal torque (N·cm) measured after 3- and 12-week loading	3 and 12 weeks	Anodic oxidized screws had higher surface roughness but no significant difference in removal torque or bone-implant contact.

minimally affected heterogeneity (I 2 changed 89 percent to approximately 78 percent), and did not alter the overall findings. The results prove the consistency and consistency of the pooled estimations between studies.

DISCUSSION

Orthodontic miniscrews are considered popular temporary anchorage devices because of their minimal invasiveness and the ability to load them immediately. Biomechanical, material, and biological factors interact in a complex relationship to determine their clinical success.[28] Alteration of the surface, such as sandblasting, acid-etching, anodic oxidation, and adsorption of bioactive coating, is commonly used to improve primary stability, increase bone-implant contact, and removal torque.[29] These additions aim at enhancing the roughness, wettability, and osteoconductivity of the surface of the implant, hence maximizing the mechanical interlocking and bio-integration of the new implant.[30]

The location site and the bone features are very important in the performance of the miniscrew. The denser cortical bone that is found in the mandible or attached gingiva is typically linked to good mechanical retention, and implants placed in the mobile mucosa or thin cortical bone areas are more likely to undergo higher levels of micromotion and lose their fixation.[31] Also, the geometry of implants, length, diameter, and thread design determine the stress distribution and load resistance, which are both critical in the stability maintenance of the implant towards orthodontic forces.[32]

The variability in clinical outcomes is also caused by factors related to the patients, such as the bone density, systemic conditions, and oral hygiene.[33] Biological reaction to miniscrew insertion is bone remodeling and its osseointegration at the bone-implant interface, which may be influenced by micro-motion, loading regimen, and surfaces. There could be differences between immediate and delayed loading strategies in the process of bone modulation, and it is important to remember that both mechanical and biological factors should be taken into consideration when planning the treatment.[34]

The histology and biomechanical behavior of modified miniscrews in a controlled environment have been studied using animal studies that offer useful insights. They enable comprehensive evaluation of bone remodeling, bone-implant contact, and removal torque during conventionalized instructions of insertion and loading. The models are experimental and are useful to supplement clinical observations and inform optimal design, surface treatment, and placement methodologies of the miniscrew.[35]

Although the principles of miniscrew biomechanics and osseointegration have been laid down, current studies are adding to the long-term performance optimization and extending its applications in the treatment process.[36] Surface modification refinements now take on a new form not only of physical and chemical modification but also the addition of bioactive molecular coats, including those that contain bone morphogenetic protein or peptides sequences to stimulate peri-implant bone

Table -II: Risk of Bias of Observational Clinical Studies

Author & Year	Selection (max 4)	Comparability (max 2)	Outcome (max 3)	Total (9)	Interpretation
Topouzelis & Tsaousoglou, 2012	★★★	★	★★	6	Moderate
Manni et al., 2011	★★★	★	★★	6	Moderate
Kaci, 2024	★★★	★	★★	6	Moderate
Palone et al., 2022	★★★	★	★★	6	Moderate
Suzuki & Suzuki, 2011	★★	★	★★	5	Moderate
Kim & Park, 2021	★★	★	★★	5	Moderate
Chen et al., 2006	★★	★	★★	5	Moderate

Total Score (max 9): Higher scores indicate lower risk of bias. 7–9: Low risk, 4–6: Moderate risk, <4: High risk

Table-III: Risk of Bias of Randomized Controlled Trials

Author & Year	Random Sequence Generation	Allocation Concealment	Blinding (Outcome Assessment)	Incomplete Outcome Data	Selective Reporting	Overall Risk
Park et al., 2019	+	±	+	+	+	Moderate
Ravi et al., 2023	−	−	±	+	−	High
Moghaddam et al., 2021	+	±	+	+	+	Moderate

+ = Low risk, ± = Moderate / some concerns, − = High risk

Table -IV: Risk of Bias of Animal Studies

Author & Year	Sequence Generation	Allocation Concealment	Blinding	Incomplete Data	Selective Reporting	Overall Risk
Bayani et al., 2016	−	−	−	+	−	High
Choi et al., 2016	+	±	±	+	+	Moderate

formation faster and promote soft tissue sealing at the transmucosal end.[37] At the same time, the introduction of digital workflow integration, cone-beam computed tomography (CBCT) of the ideal location of surgical failures and computer-aided design/computer-aided manufacturing (CAD/CAM) of the fabrication of tailored surgical guides have made significant contributions to the accuracy of location, the risk of harm to the anatomic structures during the operation, and the pre-operative simulation of the optimal location of the insertion in the areas with different bone densities.[38] This computer accuracy is especially essential when looking at the increased application in the specialty of miniscrews like distalization in non-compliant patients, intrusion of over erupted molars and orthognathic surgery simulation, where force vectors and anchorage requirements are extremely high.[39] Moreover, the broader knowledge of the inflammatory and remedial reactions at the bone implant interface has brought to the fore the patient-specific factors such as genetic inclinations towards bone metabolism and system-wide disorders such as diabetes or osteoporosis that may necessitate individual loading regimens or surface-engineered implants to reduce the risk of failure.[40]

Studies within this review faced various limitations because they used small datasets and varied methods, together with brief monitoring intervals.

Additionally, limitations in the review process, such as restricting the search to English-language publications, not registering the protocol, and the absence of automation tools in screening and data extraction, may have contributed to potential selection or reporting biases.

Future studies must examine multicentric subjects, longitudinal work that incorporates improved imaging, histological, and biomechanical evaluations. Further research on the area of novel surface treatment, bioactive coating, and patient-specific consideration can give more information on the optimization of miniscrew performance. Also, the effect of the interactions between implant material, surface properties, and host bone biology needs to be studied in order to come up with predictive models of stability and survival.

CONCLUSION

A combination of implant material, surface characteristics, and location of insertion, with factors related to patients, determines miniscrew stability and success. Material alteration on the surface tends to increase the bone reaction and mechanical retention, whereas the shapes of implants and the arrangement of their positioning play a vital role in determining the risk of failure and the removal force. Biomechanical and biological interactions are complex enough to highlight the importance of high-quality research that is standardized to determine best practices. Multicentric studies, including longitudinal and multicenter ones, with clinical, histological, and biomechanical evaluation units are necessary to optimize the miniscrew performance and to base evidence-based orthodontic treatment planning.

Conflict of Interest: None.

Funding Source: None.

Authors Contribution

Following authors have made substantial contributions to the manuscript as under:

RAS & AMI: Data acquisition, data analysis, drafting the manuscript, critical review, approval of the final version to be published.

GS & ABE: Study design, data interpretation, drafting the manuscript, critical review, approval of the final version to be published.

Authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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