

Effects of Common Surface Modifications on the Mechanical Properties of Miniscrews: A Systematic Review

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Abstract: Aim: The objective of this systematic review was to offer quantitative evidence regarding the influence of surface properties on the mechanical stability of miniscrews. Materials and Methods: The comprehensive search strategy involved querying databases, namely PubMed, Web of Science, and Scopus. PRISMA guidelines were followed to determine relevant studies according to specific eligibility criteria. The final search was conducted on 30 August 2023. In this systematic review, in vivo studies published in the English language were included. Results: A total of 364 articles were viewed, and 17 of them were considered for evaluation. Two of the articles are about human studies, while the rest are about animal studies. The number of miniscrew samples ranged between 18 and 144 (totaling 1097 with a mean of 64.52). Among the surface modifications in the articles, the sandblasting with large grit and acid etching (SLA) method was most frequently applied, followed by acid etching in second place. The control groups' (machined surface) maximum removal torque (MRT) values varied from 2.05 to 50.50 Ncm, while maximum insertion torque (MIT) values varied from 7.23 to 19.25 Ncm. Conclusions: The development of novel applications to improve the surface properties and survival rates of miniscrews is ongoing. In future studies, emerging surface modifications should be evaluated clinically, taking into account their cost and associated harm to the environment.

Keywords: systematic review; dentistry; orthodontics; surface properties; miniscrew



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1. Introduction

1.1. Rationale

In recent years, miniscrews temporarily implanted in alveolar bone have often been used to enhance skeletal anchorage during orthodontic treatment. Situations where patient cooperation is lacking, or adequate anchorage cannot be achieved with traditional extra-oral appliances, result in treatment disruptions [1,2]. Because of such disadvantages, miniscrews were introduced in the 1990s for use in orthodontic treatments [3]. Miniscrews are advantageous because they require minimal patient cooperation, are easy to apply, and are less costly than dental implants [4]. Miniscrews are used both for light and continuous (orthodontic) force applications and for heavy dynamic and rotational (orthopedic) force applications [5]. Therefore, it is important that they remain stable throughout treatment. Over the years, it has been revealed that the main advantage of using miniscrews is a reduction in anchorage loss. The most common complication is root injury in the interradicular area during placement [6]. Miniscrews have excellent mechanical properties and an acceptable failure rate, even when orthopedic appliances are used [7,8]. Despite its limited biocompatibility and low resistance to corrosion, the Ti-6Al-4V alloy has been used extensively for orthodontic miniscrews. While this substitution successfully addresses concerns related to mechanical strength, it adversely affects the osseointegration process [9].

Primary stability is the absence of mobility between implant and bone [10,11]. Mechanical locking occurs between the bone and implant depending on the characteristics

of the implant, bone quality and quantity, and implantation techniques [12–14]. Studies have emphasized that sufficient primary stability is necessary in order to apply orthodontic forces on miniscrews [15,16]. If primary stability cannot be achieved, the desired healing around the screw cannot take place, resulting in premature screw loss [15]. Secondary stability is the stability provided as the bone structure forms around the miniscrew during the healing process [17]. The degree of primary stability formed after miniscrew implantation affects the successful development of secondary stability [18]. In a study evaluating implant stability, Raghavendra et al. reported that primary stability decreases and secondary stability increases after the implants are placed, and osseointegration occurs around the miniscrew as secondary stability increases [17].

Their small size reduces both root injury and the risk of damage to surrounding tissues, and also enables them to be used in many regions of the maxilla and mandible [3,19]. However, in situations requiring prolonged anchorage, due to the limited surface area and reduced bone contact of miniscrews, the success rate may decrease despite their advantages. Some studies have reported that miniscrews also exhibit partial osseointegration [20,21]. For this reason, strategies to accelerate the osseointegration of miniscrews are being developed to increase their survival rate [5,22]. These strategies involve changing the surface topography by roughening the miniscrew surface. Roughening at the microscopic level increases the surface area and mechanical locking, thereby improving stability [23]. However, surface etching processes at the nanoscopic level increase surface energy, matrix protein absorption, and the migration and proliferation of bone cells in the area, resulting in a stronger bone–implant bond [24]. These strategies include efforts such as acid etching; ultraviolet (UV) treatment; anodization; sandblasting with large grit and acid etching (SLA); sandblasting, large-grit, and anodic oxidation (SLAO); resorbable blasting media (RBM); and grit blasting (Figure 1) [25–30].

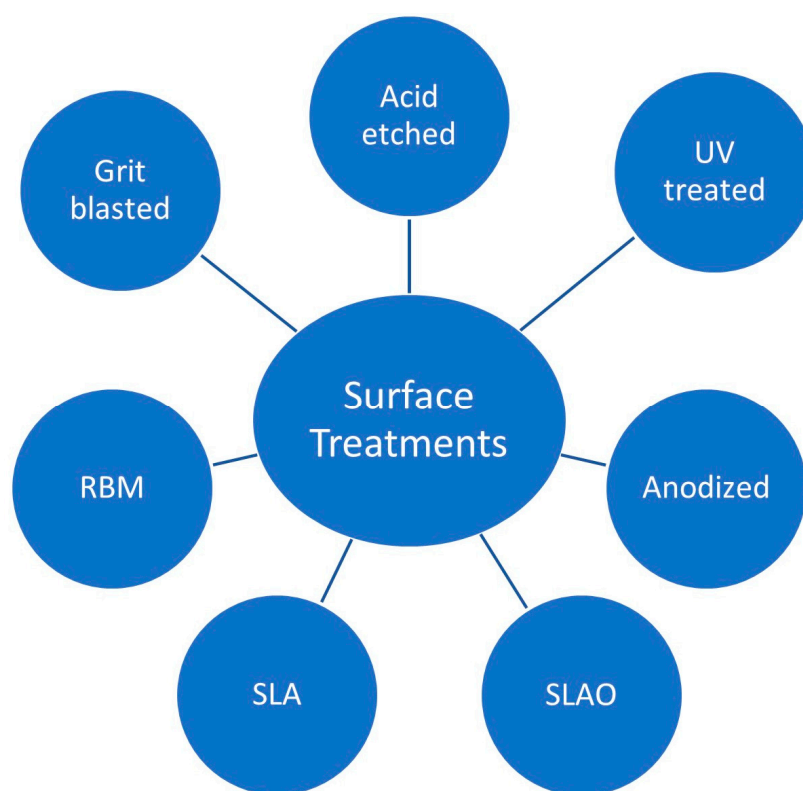


Figure 1. Different surface treatments for orthodontic miniscrews.

1.2. Objectives

This systematic review focused on examining novel surface treatments developed to increase the mechanical stability of orthodontic miniscrews and quantitative effects of surface properties.

2. Materials and Methods

The execution of this study adhered to the quality reporting standards outlined in the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [31].

The research question of the present systematic review was defined according to the following PICO format:

P (Population/Patients): In vivo studies

I (Intervention): Miniscrews with differentiated surface properties

C (Comparison): Miniscrews with machined surfaces

O (Outcome): Alterations in the mechanical stability of miniscrews were assessed through parameters such as maximum insertion and removal torque, and Periotest values

2.1. Search Strategy

The comprehensive search strategy involved querying databases, namely PubMed, Web of Science, and Scopus, using search terms focused on miniscrews, mini-implants, stability, surface treatment, surface property, torque, insertion, removal, and Periotest. The final search was conducted on 30 August 2023.

Titles and abstracts were independently and redundantly reviewed for potential inclusion in the study. The interrater agreement, measured by an intraclass correlation coefficient, was found to be 0.95. Any conflicts that arose were resolved through consensus discussions between the two authors.

2.2. Eligibility Criteria

In vivo studies that evaluated the effects of surface treatments of orthodontic miniscrews on mechanical stability were eligible. These studies were published in the English language with no restriction regarding the date of publication. Both reviewers agreed upon the following exclusion criteria: in vitro studies, opinion articles, editorial letters, reviews, case reports, articles with no control group (machined surface), and studies without a full-text version available (Figure 2).

2.3. Data Collection Process and Data Items

The authors (H.Y., P.G.) selected articles meeting the inclusion criteria. Subsequently, data were gathered and recorded in a standardized Excel file.

2.4. Risk of Bias Assessment

In the initial phase of study inclusion, the authors (H.Y., P.G.) independently assessed the titles and abstracts of each study to minimize potential bias among reviewers. Risk of bias was assessed according to Cochrane's reviewers' handbook [32]. The main domains (random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other sources of bias) were identified as low, moderate, and high risk. The interrater agreement, measured by an intraclass correlation coefficient, was found to be 0.90. Any discrepancies regarding the inclusion or exclusion of a study were resolved through discussions between the authors.

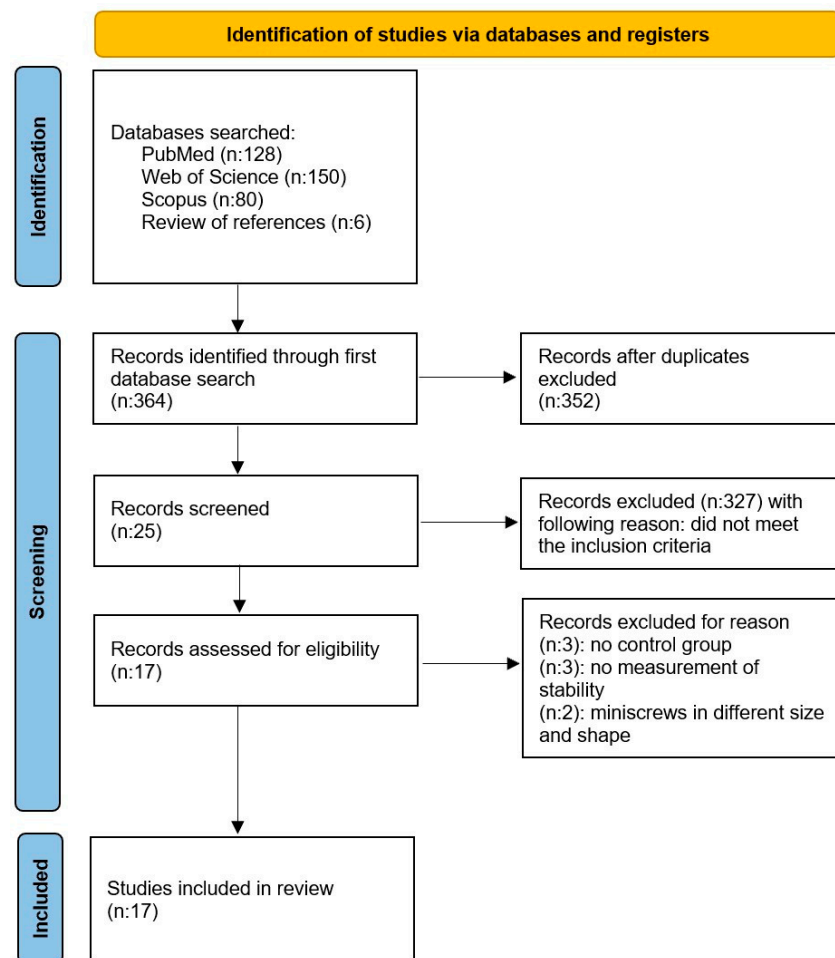


Figure 2. The PRISMA 2020 flow diagram.

2.5. Quality Assessment

The authors (H.Y., P.G.) conducted an assessment of the procedural quality for each study included in the article. The following assessment criteria were scored on a scale of 0 to 1 point, where a higher total score indicated better study quality.

- Group size at least 10 subjects: 1 point.
- Existence of control group: 1 point.
- Sample size calculation: 1 point.
- Detailed information of procedure MRT-MIT-PTV (at least 2 of them): 1 point.
- Force application: 1 point.

Any discrepancies regarding the scoring were resolved through discussion until a consensus was reached.

3. Results

3.1. Study Selection

As a result of the comprehensive evaluation, 364 studies were found in electronic databases including Pubmed (128), WOS (150), and Scopus (80), and via the review of references (6). In terms of duplication, 12 studies were excluded. A total of 352 studies were screened and title and abstract sections were read. After abstract screening, 327 studies were excluded because they did not meet the inclusion criteria. When the full text of the remaining 25 studies were analyzed, 8 studies were rejected. Three had no control group, three had no measurement of stability, and two had miniscrews of different size and shape.

Finally, 17 articles were included in the systematic review. The publication dates of the included articles range from 2009 to 2022. Study selection is shown in Figure 2.

3.2. Study Characteristics

The selected data were included in this systematic review by evaluating author/year, the study type, the study groups, total number of miniscrews used, and the conclusion (Table 1). The studies were conducted between 2009 and 2022. Of the 17 *in vivo* studies, 2 were human studies and 15 were animal studies. Of the animal studies, eight were on rabbits, three were on rats, and four were on dogs. Different surface treatments were compared with the control groups. Anodized surfaces were compared in two of the studies. Anodization, cyclic precalcification, and heat treatment were evaluated in two different studies. Only one of the studies used a resorbable blasting media (RBM) surface. Four used acid etching, one used UV treatment, five used SLA, and two used a sandblasted and acid-etched group (SAE). Loading was applied in five studies. In addition, miniscrews were applied to diabetic patients in only one study. A total of 1097 miniscrews were used in the studies. Maximum insertion torque (MIT) measurements were used in nine studies to evaluate primary stability. Periotest values (PTV) were measured in three studies to evaluate the mobility of miniscrews. Maximum removal torque (MRT) values were measured in 15 studies to evaluate secondary stability.

Table 1. General characteristics of included studies.

Author/Year	Study Type	Groups	Total Number of Miniscrews Used	Conclusion
Park et al./2019 [25]	HS, single-blinded, split-mouth, randomized, 40 patients	CG TG: AEtch	98	The success rate and stability of TG are similar to CG.
Jang et al./2018 [33]	AS, randomized block design, both tibiae of 21 male rabbits	CG TG1: AEtch with calcium chloride immersion TG2: AEtch without calcium chloride immersion	126	MRT at 1 week was significantly higher in TG1 and TG2 than in the CG. MRT at 4 and 7 weeks were highest in TG1 and lowest in the CG.
Karmarker et al./2012 [27]	AS, both tibiae of three mature white rabbits	CG TG: Anodized	36	MRT was significantly higher in TG.
Oh et al./2014 [34]	AS, both tibiae of 16 male Wistar rats	CG TG: Anodization, cyclic precalcification and heat treatment	32	Both at week 3 and 6, MRT values were significantly higher in TG.
Byeon et al./2022 [35]	AS, nine male Sprague Dawley rats	CG TG1: Anodized, heat-treated and cyclic pre-calcification treatment TG2: Anodized and heat-treated	18	Highest MRT value was found in TG1.
Takahashi et al./2016 [26]	AS, 12 male Sprague Dawley rats	CG1: no force CG2: with force TG1: UV-treated—no force TG2: UV-treated—with force	24	Whether force was applied or not, PTV values were significantly higher in UV-treated groups.
Oh et al./2014 [36]	AS, randomized balanced complete block design, 12 New Zealand white rabbits	CG1: Normal CG2: DM TG1: SLA—Normal TG2: SLA—DM	48	Miniscrews in diabetic patients are likely to show results similar to those in healthy patients.

Table 1. Cont.

Author/Year	Study Type	Groups	Total Number of Miniscrews Used	Conclusion
Choi et al./2016 [37]	AS, randomized block design, 12 mature male beagle dogs	CG1: 3-week force CG2: 12-week force TG1: Anodic-oxidized surface—3-week force TG2: Anodic-oxidized surface—12-week force	96	The two types of miniscrews were not significantly different in MIT or MRT after 3 and 12 weeks of loading.
Sirisa-Ard et al./2015 [38]	AS, 24 adult male New Zealand rabbits	CG TG: SLA	47	MRT value was significantly increased at week 0 in TG, but no difference at week 8.
Cho et al./2012 [28]	AS, randomized block design, six male beagle dogs	CG TG1: SLA TG2: SLAO	54	While CG's MIT values were significantly higher than others, SLAO method resulted in greater MRT than CG and TG1.
Gansukh et al./2016 [29]	AS, 24 New Zealand rabbits	CG TG: RBM	96	MIT significantly higher in CG. Significant increase in MRT at 2 weeks in TG but no significant difference at 4 weeks.
Kim et al./2009 [39]	AS, randomized balanced complete block design, 12 male beagle dogs	CG1: CW force CG2: CCW force TG1: SLA—CW force TG2: SLA—CCW force	96	TG showed significantly lower MIT, but no significant difference in MRT.
Espinar-Escalona et al./2016 [30]	AS, 10 female adult New Zealand white rabbits	CG TG1: AEtch TG2: GBlast TG3: GBlast + AEtch	20	TG2 and TG3 showed significantly higher MRT values than CG and TG1.
Vilani et al./2015 [40]	AS, six adult male mongrel dogs	CG1: no force CG2: immediate force TG1: Aetch—no force TG2: Aetch—immediate force	36	High MIT and reduced PTV were observed in all groups, as well as a reduction in MRT in comparison with MIT. No significant difference in PTV, MIT, or MRT between groups.
Moghaddam et al./2021 [41]	HS, single-blinded, split-mouth randomized controlled trial, 31 patients	CG TG: SAE	62	MRT was higher for TG.
Chang et al./2009 [42]	AE, 24 adult New Zealand white rabbits	CG TG1: SLA TG2: SL/NaOH	144	TG1 and TG2 had significantly higher MRT at 12 weeks. MRT was slightly higher for groups without force.
Maino et al./2017 [43]	AE, eight male New Zealand white rabbits	CG1: no force CG2: with force TG1: SAE—no force TG2: SAE—with force	64	MRT was significantly higher for TGs. Force did not significantly affect MRT for any surface or treatment tested, although TG1 tended to have higher MRT

HS: human study; AS: animal study; CG: control group—machined surface; TG: treatment group; MIT: maximum insertion torque; PTV: Periosteal value; MRT: maximum removal torque; UV: ultraviolet; DM: diabetes mellitus; SLA: sandblasted with large grit and acid etching; SLAO: sandblasted, large-grit, and anodic oxidation; RBM: resorbable blasting media; AEtch: acid-etched; GBlast: grit-blasted; GBlast + AEtch: grit-blasted with acid-etched treatment; SL/NaOH: sandblasted and alkaline-etched; SAE: sandblasted and acid-etched group; CW: clockwise; CCW: counter clockwise.

3.3. Main Study Outcome

The aim of this study was to determine the current surface treatments that improve the stability of orthodontic miniscrews and evaluate which surface treatments showed successful results compared to the control groups. The number of miniscrew samples ranged between 18 and 144 (totaling 1097 with a mean of 64.52) (Table 1). Among the

surface modifications in the articles, the SLA method was most frequently applied, followed by acid etching in second place. The control groups' (machined surface) MRT values varied from 2.05 to 50.50 Ncm, while MIT values varied from 7.23 to 19.25 Ncm (Table 2).

Table 2. Details of included studies.

Author/Year	Design of Miniscrew	Insertion Sites	Measurement of Stability	Results
Park et al./2019 [25]	Self-drilling miniscrews (diameter: 1.6 mm; thread length: 6 mm).	Bilaterally, mainly in the posterior buccal area between the second premolar and the first molar in the maxilla or mandible.	MIT PTV: immediately after insertion (PTV-0) and 6 months after insertion (PTV-1)	CG MIT: 13.38 ± 4.0 Ncm PTV-0: -0.28 ± 3.36 PTV-1: 6.42 ± 5.6 TG MIT: 13.62 ± 5.95 Ncm PTV-0: -0.50 ± 2.77 PTV-1: 4.58 ± 5.15
Jang et al./2018 [33]	Conical, self-drilling miniscrews made of a titanium alloy (Ti6Al4V) with a 1.4 mm diameter and a 6 mm thread length.	Inserted into rabbit tibias.	MRT: Week 1, 4, 7	CG MRT-W1: 3.02 ± 0.53 Ncm MRT-W4: 3.43 ± 0.62 Ncm MRT-W7: 3.38 ± 0.54 Ncm TG1 MRT-W1: 4.21 ± 0.44 Ncm MRT-W4: 6.54 ± 0.50 Ncm MRT-W7: 6.62 ± 0.66 Ncm TG2 MRT-W1: 3.97 ± 0.52 Ncm MRT-W4: 5.68 ± 0.58 Ncm MRT-W7: 5.89 ± 0.70 Ncm
Karmarker et al./2012 [27]	Self-drilling titanium alloy miniscrews (ELI, ASTM Grade 23), 6 mm long with a diameter of 1.3 mm at the neck and 1.2 mm at the apex	Placed in the diaphysis of each tibia. In each tibia, three anodized and three machined implants were placed.	MIT MRT: Week 6	CG MIT: 7.23 ± 1.89 Ncm MRT: 2.05 ± 1.07 Ncm TG MIT: 7.05 ± 2.16 Ncm MRT: 3.79 ± 1.39 Ncm
Oh et al./2014 [34]	Self-tapping Ti6Al4V miniscrews with a 1.4 mm diameter and 4 mm length.	Inserted into the medial region of the bilateral tibia diaphysis.	MRT: Week 3, 6	CG MRT-W3: 2.3 ± 1.2 Ncm MRT-W6: 4.1 ± 1.4 Ncm TG MRT-W3: 4.8 ± 2.7 Ncm MRT-W6: 8.4 ± 3.1 Ncm
Byeon et al./2022 [35]	Self-tapping Ti-6Al-4V ELI alloy with a thread diameter of 1.4 mm \times length of 3.3 mm	One each on the distal side under tibia epiphysis	MRT: Week 4	CG MRT: 2.08 ± 0.67 Ncm TG1 MRT: 6.58 ± 0.66 Ncm TG2 MRT: 4.10 ± 0.72 Ncm
Takahashi et al./2016 [26]	Self-tapping titanium miniscrews 4 mm in length and 1.4 mm in diameter.	On both sides, each tibia.	PTV: Week 2	CG1 PTV: 25.7 ± 1.8 CG2 PTV: 28.1 ± 3.5 TG1 PTV: 13.3 ± 2.8 TG2 PTV: 16.0 ± 6.6
Oh et al./2014 [36]	Self-tapping and dull-pitched modified cylinder-type; 1.8 mm in diameter and 8.5 mm in length.	On both sides, each tibia.	MIT MRT: Week 4	CG1 MIT: 13.31 ± 2.75 Ncm MRT: 3.75 ± 0.85 Ncm CG2 MIT: 11.63 ± 4.39 Ncm MRT: 3.94 ± 1.05 Ncm TG1 MIT: 11.50 ± 3.26 Ncm MRT: 5.31 ± 1.07 Ncm TG2 MIT: 11.06 ± 5.19 Ncm MRT: 6.13 ± 2.30 Ncm

Table 2. Cont.

Author/Year	Design of Miniscrew	Insertion Sites	Measurement of Stability	Results
Choi et al./2016 [37]	Self-drilling, cylinder-type titanium aluminum vanadium alloy; 1.45 mm in diameter and 7 mm in length	On both sides, each mandible.	MIT MRT	CG1 MIT: 11.7 ± 4.3 Ncm MRT: 4.3 ± 1.6 Ncm CG2 MIT: 12.5 ± 5.1 Ncm MRT: 4.0 ± 1.5 Ncm TG1 MIT: 11.4 ± 4.1 Ncm MRT: 5.1 ± 2.6 Ncm TG2 MIT: 12.4 ± 4.9 Ncm MRT: 4.1 ± 1.7 Ncm
Sirisa-Ard et al./2015 [38]	Self-drilling, Ti-6Al-4V titanium alloy, 6 mm length, 1.5 mm diameter.	Inserted approximately 3 mm superior to the medial epicondyle.	MRT: Week 0, 8	CG MRT-W0: 5.38 ± 1.48 Ncm MRT-W8: 8.00 ± 2.51 Ncm TG MRT-W0: 7.21 ± 2.41 Ncm MRT-W8: 6.59 ± 1.20 Ncm
Cho et al./2012 [28]	Titanium alloy, cylindrical shape, drill-free-type, 1.45 mm diameter, 8 mm length.	On both sides, each tibia.	MIT MRT	CG MIT: 24.77 ± 3.03 Ncm MRT: 6.57 ± 2.88 Ncm TG1 MIT: 12.43 ± 2.06 Ncm MRT: 8.03 ± 3.09 Ncm TG2 MIT: 13.15 ± 4.40 Ncm MRT: 12.80 ± 4.15 Ncm
Gansukh et al./2016 [29]	Ti-6Al-4V alloy, 6 mm length, 1.6 mm diameter, dual-top.	On both sides, each tibia.	MIT MRT: Week 2, 4	CG MIT: 11.11 ± 2.05 Ncm MRT-W2: 5.45 ± 1.35 Ncm MRT-W4: 6.41 ± 2.3 Ncm TG MIT: 9.57 ± 1.47 Ncm MRT-W2: 7.06 ± 1.78 Ncm MRT-W4: 7.08 ± 3.12 Ncm
Kim et al./2009 [39]	Titanium alloy, cylindrical shape, self-tapping, 1.8 mm diameter, 8.5 mm length	Inserted in buccal side of the maxilla and mandible.	MIT MRT	CG1 MIT: 19.25 ± 8.34 Ncm MRT: 7.45 ± 2.18 Ncm CG2 MIT: 16.52 ± 7.26 Ncm MRT: 6.18 ± 1.73 Ncm TG1 MIT: 15.27 ± 6.65 Ncm MRT: 10.74 ± 8.53 Ncm TG2 MIT: 15.33 ± 8.80 Ncm MRT: 8.43 ± 1.62 Ncm
Espinar-Escalona et al./2016 [30]	Titanium alloy, self-drilling, 2 mm diameter, 9 mm length.	Inserted bone centered at the lateral condyle of knee.	MRT	CG MRT: 18 ± 3 Ncm TG1 MRT: 22 ± 4 Ncm TG2 MRT: 52 ± 10 Ncm TG3 MRT: 57 ± 8 Ncm

Table 2. Cont.

Author/Year	Design of Miniscrew	Insertion Sites	Measurement of Stability	Results
Vilani et al./2015 [40]	Ti6Al4V alloy with 1.5 × 6.0 × 2.0 mm.	Placed buccally between roots in the alveolar bone of the mandible.	MIT MRT PTV-I PTV-F	CG1 MIT: 19.20 ± 1.64 Ncm PTV-I: 0.40 ± 1.51 MRT: 2.60 ± 0.89 Ncm PTV-F: 13.60 ± 6.94
				CG2 MIT: 18.00 ± 1.19 Ncm PTV-I: −0.06 ± 2.67 MRT: 2.75 ± 0.70 Ncm PTV-F: 14.56 ± 4.71 TG1 MIT: 19.00 ± 3.31 Ncm PTV-I: 0.30 ± 1.09 MRT: 4.00 ± 1.00 Ncm PTV-F: 8.70 ± 10.42 TG2 MIT: 15.90 ± 2.68 Ncm PTV-I: −0.20 ± 2.74 MRT: 4.10 ± 1.52 Ncm PTV-F: 7.90 ± 8.02
Moghaddam et al./2021 [41]	Self-drilling, 1.6 mm diameter, 10 mm length, dual-top.	Placed in the attached gingiva between the second premolar and the first molar on both sides.	MIT MRT	CG MIT: 12.42 ± 5.755 Ncm MRT: 8.08 ± 2.481 Ncm TG MIT: 12.10 ± 6.295 Ncm MRT: 15.71 ± 5.563 Ncm
Chang et al./2009 [42]	Tapered-type titanium alloy, 8 mm length, 1.3 mm diameter.	Inserted in tibia metaphysic.	MRT	With/without force during 12 weeks No differences between with and without force in most groups. MRT increased within time. With force, MRT of TG1 increased at 4 weeks, while TG2 showed the highest MRT after 8 weeks.
Maino et al./2017 [43]	Ti6Al4V, 1.5 mm diameter, 6.5 mm length.	Inserted in proximal medial surface of each tibia.	MRT	CG1 MRT: 50.50 ± 14.37 Ncm CG2 MRT: 48.25 ± 15.07 Ncm TG1 MRT: 90.88 ± 35.71 Ncm TG2 MRT: 79.13 ± 11.46 Ncm

CG: control group—machined surface; TG: treatment group; MIT: maximum insertion torque; PTV: Periostest value; MRT: maximum removal torque; PTV-I: Periostest value—initial; PTV-F: Periostest value—final.

In the three papers evaluated, there was no clear difference in stability between the surface treatment group and the control group [25,37,40]. In two of these studies, acid etching was applied as surface treatment. In a human study by Park et al. [25], acid-etched and machined surface treatments were compared. In this study, the overall success rate of miniscrews was found to be 88.8%. The success rates of the two groups were found to be similar. When MIT, PTV (immediately after placement and 6 months after placement) values were analyzed, the acid-etched and machined surface treatments showed similar primary and secondary stability. Vilani et al. [40] also compared the stability of acid-etched and machined surface miniscrews in their animal study. They also evaluated the effect of force on these two different surfaces. High MIT and reduced PTV were observed in all groups, as well as a reduction in MRT in comparison with MIT. Whether force was applied or not, there were no significant differences in PTV, MIT or MRT in any of the groups. Choi et al. [37] compared anodized surfaces and machined surfaces in their study. Both

groups were subjected to force loading and no significant differences were found in the MIT and MRT values measured at week 3 and week 12.

In the remaining 14 studies, differences were found between the stability of the machined surface and other surface treatments [27,28,30,33–36,38,39,41–43]. Unlike other acid-etched studies, Jang et al. [33] immersed miniscrews with acid-etched surfaces in calcium chloride solution. At 1 week after insertion, miniscrews with acid-etched surfaces showed higher MRT values than the control group, whether or not they were immersed in calcium chloride solution. At 4 and 7 weeks, the acid-etched group immersed in calcium chloride solution had the highest MRT value.

Espinar-Escalona et al. [30] found the MRT values of grit-blasted and grit-blasted + acid-etched surfaces significantly higher than acid-etched and machined surfaces. Moghaddam et al. [41] compared SAE-treated surfaces and machined surfaces in their human study. Although the MIT values of these two different surfaces were similar, the MRT value of the SAE surface group was found to be higher. Maino et al. [43] also compared SAE and machined surfaces. In addition, the effect of force on these surfaces was also evaluated. MRT was significantly higher for the machined surface in both the force and non-force groups than the SAE surface. Force did not significantly affect MRT for any surface or treatment. Sirisa-Ard et al. [38] compared SLA and machined surfaces in their study. MRT values measured at 0 and 8 weeks showed no significant difference between SLA and machined surfaces. Oh et al. [36] aimed to investigate the effects of surface-treated miniscrews in diabetic rabbits. In this study, SLA and machined surfaces were compared. MIT values showed no difference between the diabetic and control groups. In surface-treated miniscrews, MRT was higher in both the diabetic and control groups, but there was no significant difference between the diabetic and control groups in MIT, regardless of surface treatment. Kim et al. [39] aimed to evaluate the stability and resistance to rotational moments of early-loaded SLA and machined surface miniscrews. MIT values of SLA miniscrews were found to be lower than the machined surface screws. However, when MRT values were compared, there was no statistical difference between the two surfaces.

Karmarker et al. [27] compared anodized surface and machined surface miniscrews. While there was no difference between the two groups in terms of MIT values, MRT values were found to be significantly higher on the anodized surface. Oh et al. [34] evaluated the stability of miniscrews subjected to anodization, cyclic pre-calcification, and heat treatment. Compared to the control group, MRT values measured at 3 and 6 weeks were higher in the surface treatment group. Byeon et al. [35] evaluated the contribution of cyclic precalcification treatment to osseointegration and the bioactivity of miniscrews. The experimental groups of this study were as follows: anodized and heat-treated group; anodized, heat-treated and cyclic pre-calcification treatment group; and control group. When the MRT values were examined, the highest value was in the anodized, heat-treated and cyclic pre-calcification treatment group.

Cho et al. [28] compared the effects of SLAO and SLA surface treatments on the mechanical stability of miniscrews in vitro and in vivo. In the in vivo study, MRT values were significantly higher in the SLAO group than in the SLA and control group. In contrast, MIT values were higher in the control group compared to the SLA and SLAO groups.

Chang et al. [42] analyzed miniscrews with machined, SLA, and SL/NaOH (alkaline-etched) surfaces implanted in rabbit tibia and reported MRT in the SLA and SL/NaOH groups compared to the machined surface.

In a study by Gansukh et al. [29] evaluating the early stability of miniscrews with machined and RBM surfaces, MIT values were significantly higher with the machined surface compared to the RBM surface. In contrast, MRT values at week 2 were significantly lower in the machined surface group than in the RBM group, which was attributed to greater bone resorption in the early period. At week 4, there was no significant difference in MRT values between the groups.

Takahashi et al. [26] aimed to increase the osseointegration capabilities of miniscrews with UV-treated surfaces and evaluated their stability under loading. Whether force was applied or not, MRT values were significantly higher in UV-treated groups.

3.4. Quality Assessment and Risk of Bias

Two [37,43] of the articles included in the review were assessed as high quality with a score of 6/6 points. Two studies [30,35] were classified as low quality. Additionally, nine articles [26–29,33,34,38,40,42] were considered to have a moderate risk of bias, scoring between three and four points (Table 3). Red indicates high risk of bias, yellow indicates moderate risk of bias, and green indicates low risk of bias in Table 4.

Table 3. Quality assessment.































































Author/Year	Group Size at Least 10 Subjects	Control Group	Sample Size Calculation	Detailed Information of Procedure	MRT-MIT-PTV (at Least Two of Them)	With Force	Total
Park et al./2019 [25]	1	1	0	1	1	1	5
Jang et al./2018 [33]	1	1	0	1	0	0	3
Karmarker et al./2012 [27]	1	1	0	0	1	0	3
Oh et al./2014 [34]	1	1	0	1	0	0	3
Byeon et al./2022 [35]	0	1	0	1	0	0	2
Takahashi et al./2016 [26]	0	1	0	1	0	1	3
Oh et al./2014 [36]	1	1	0	1	1	1	5
Choi et al./2016 [37]	1	1	1	1	1	1	6
Sirisa-Ard et al./2015 [38]	1	1	0	1	0	0	3
Cho et al./2012 [28]	1	1	0	1	1	0	4
Gansukh et al./2016 [29]	1	1	0	1	0	0	3
Kim et al./2009 [39]	1	1	0	1	1	1	5
Espinar-Escalona et al./2016 [30]	0	1	0	0	0	0	1
Vilani et al./2015 [40]	0	1	0	1	1	1	4
Moghaddam et al./2021 [41]	1	1	0	1	1	1	5
Chang et al./2009 [42]	1	1	0	1	0	1	4
Maino et al./2017 [43]	1	1	1	1	1	1	6



MRT: maximum removal torque; MIT: maximum insertion torque; PTV: Periotest value.

Table 4. Risk of bias assessment.

Author/Year	Random Sequence Generation	Allocation Concealment	Blinding of Participants and Personnel	Blinding of Outcome Assessment	Incomplete Outcome Data	Selective Reporting	Other Sources of Bias
Park et al./2019 [25]							
Jang et al./2018 [33]							
Karmarker et al./2012 [27]							
Oh et al./2014 [34]							
Byeon et al./2022 [35]							
Takahashi et al./2016 [26]							
Oh et al./2014 [36]							

Table 4. Cont.

Author/Year	Random Sequence Generation	Allocation Concealment	Blinding of Participants and Personnel	Blinding of Outcome Assessment	Incomplete Outcome Data	Selective Reporting	Other Sources of Bias
Choi et al./2016 [37]							
Sirisa-Ard et al./2015 [38]							
Cho et al./2012 [28]							
Gansukh et al./2016 [29]							
Kim et al./2009 [39]							
Espinar-Escalona et al./2016 [30]							
Vilani et al./2015 [40]							
Moghaddam et al./2021 [41]							
Chang et al./2009 [42]							
Maino et al./2017 [43]							

 : indicates high risk;  : indicates moderate risk;  : indicates low risk of bias.

4. Discussion

Various surface modifications are applied to increase the osteoconductivity/osteoinductivity of miniscrews and consequently strengthen their bond with bone [44]. Surface modifications such as acid etching, sandblasting, grit blasting, and anodizing change the surface topography of miniscrews by creating porous and rough surfaces. These porous or rough surfaces increase stability and positively affect cellular responses [45,46]. Among the articles included in this systematic review, SLA was the most commonly used surface modification method, followed by acid etching.

In two meta-analyses on the effectiveness of miniscrews, the survival rate in the earlier study was 83.6%, which increased to 87.7% in the later study [47,48]. Miniscrew failure rates were reported as 11.5–15.9% by Alharbi et al. [49] and 11% by Cheng et al. [15]. Miniscrews are often preferred in clinical applications because they have a success rate over 80%. However, the effectiveness of miniscrews remains low compared to dental implants, which are more than 90% successful [50,51]. The most important factors affecting the success rate of miniscrews were primary and secondary stability [18].

4.1. Primary Stability

Motoyoshi et al. [16] recommended the insertion torque range for miniscrews as 5–10 Ncm in their study. Chaddad et al. [22] reported that insertion torque values above 15 Ncm would increase miniscrew stability. In this systematic review, MIT measurement was among the criteria included to evaluate primary stability. There are nine articles in which MIT measurement was used [25,27–29,36,37,39–41]. In only three of these articles, MIT values showed significant differences with the control group, and in all three, the MIT values of the control group were higher than the surface-treated group [28,29,39]. In the study of Cho et al. [28], MIT values were higher in the control group compared to the SLA

and SLAO groups, which the authors suggested was because miniscrews with smooth surfaces cause more damage to the bone during insertion, whereas rough surfaces enable a better discharge of blood and bone particles. Only the study by Gansukh et al. [29] showed mean MIT values of RBM surface miniscrews in the range of 5–10 Ncm.

Periotest measurements are generally used to evaluate the mobility of teeth and osseointegration of dental implants [52]. The measurement results vary between -8 and $+50$. The lower the Periotest value the higher the stability, and the higher the Periotest value the lower the stability [53]. This value is also frequently used in *in vitro* and *in vivo* studies to analyze the primary and secondary stability of miniscrews [25,40,54]. In this systematic review, PTV measurement was used in three studies [25,26,40]. Takahashi et al. [26] reported that UV-treated groups showed lower stability than control groups in PTV measurements taken 2 weeks after the placement of miniscrews. Two other studies applied acid etching as a surface modification. There were no differences between the treated groups and the control groups in terms of initial PTV values [25,40].

4.2. Secondary Stability

MRT is the highest reaction force that occurs during the removal of the miniscrew from the bone [55]. MRT measurements in dental implants are generally considered a reliable method for the assessment of osseointegration. They have been frequently used in studies evaluating the secondary stability of orthodontic miniscrews [20].

When the acid-etched method was evaluated in this systematic review, in only one study the acid-etched group was found to be more stable than the control group. In the study by Jang et al. [33], the MRT values of the acid-etched group without immersion in calcium chloride were found to be higher than the control group. Miniscrews with acid-etched surfaces showed better stability when they were immersed in calcium chloride solution, or combined with sandblasting/grit-blasting methods.

There was a contradiction when comparing miniscrews with anodized surfaces in this study. In the study by Karmarker et al. [27], miniscrews with anodized surfaces were found to be more stable than the control group according to the MRT values measured 6 weeks after placement. However, in the study by Choi et al. [37], there was no difference between the control group and the anodized surfaces according to the MRT values measured at 3 weeks and 12 weeks. The use of anodized surfaces in combination with cyclic pre-calcification and heat treatment increased the secondary stability of miniscrews.

According to the study of Oh et al. [36], SLA surfaces are more stable than machined surfaces. In contrast to this article, Kim et al. [39] found no significant differences between SLA surfaces and machined surfaces. Similarly, Sirisa-Ard et al. [38] found no differences between the stability of SLA surfaces and machined surfaces. Cho et al. [28] found the combination of SLA surfaces with anodic oxidation to be more stable than SLA and the control group, according to MRT values.

Similar to the SLA method, the RBM method is also applied by acid etching and sandblasting to change the surface topography of titanium implants. The difference between these two methods is that the SLA method utilizes non-resorbable particles such as alumina for sandblasting, whereas the RBM method utilizes resorbable particles such as HA or calcium phosphate [56]. This provides a low risk of debris contamination and rapid osseointegration in the RBM technique [57]. In a study by Gansukh et al. [29], MRT values at week 2 were significantly lower in the machined surface group than in the RBM group, which was attributed to greater bone resorption in the early period. At week 4, there was no significant difference in MRT values between the groups. The authors suggested that although new bone formation occurred more on the machined surface than on the RBM surface after initial bone resorption, the torque values increased faster with the RBM surface.

4.3. Limitations

This systematic review evaluated the mechanical stability of surface-modified miniscrews. The limitation of this study was the variation between the studies evaluated. The loading or non-loading of miniscrews, and the amount, direction, and duration of force varied. The bone quality in the area where the miniscrew was applied and the variety of animals used in the animal experiments also added to the limitations. Although the measurement methods of mechanical stability in the present study were limited to MIT, MRT, and Periotest values, there were studies using different methods. In the evaluated studies, stability measurements were used in different combinations. When the risk of bias of these studies was evaluated, only two studies were high quality with a score of 6/6 points. Nine studies were considered to have a moderate risk of bias. According to the results of this study, future clinical and laboratory reports are needed, as well as randomized clinical trials.

4.4. Future Trends

Common surface modifications change the chemical and mechanical properties of miniscrews. However, roughening of the miniscrew surface poses a disadvantage both in terms of the risk of contamination and the difficulty of preventing bacterial colonization [58]. Poor oral hygiene leads to the accumulation of anaerobic bacteria around the miniscrew, resulting in the activation of immune cells such as neutrophils and macrophages that migrate to the implant site. This activation causes the release of proinflammatory cytokines such as IL-1 β , IL-6, and TNF- α [59].

Studies on surface modifications of titanium implants have developed over the years. With advances in surface modification technologies, there has been a transition from traditional bioinert surfaces to biocompatible surfaces, and then to bioactive surfaces. As a satisfactory standard could not be reached with bioactive and bioinert coatings, recent studies have applied biomimetic coatings that simulate body fluids. These fourth-generation surface treatments are shedding light on future research [60].

Biomimetic calcium phosphate (BioCaP) coatings have been developed under physiological conditions (37 °C temperature and pH 7.4) under which bioactive agents such as bone morphogenetic protein-2 (BMP-2) can be deposited on the surface [61,62]. Li et al. used histomorphometric analyses to evaluate osteoconductivity by applying BioCaP (amorphous or crystalline) coatings with or without bovine serum albumin (BSA) on miniscrews [63]. Based on their results, the authors concluded that crystalline BioCaP coating is an effective method to accelerate osseointegration and increase the success rate of orthodontic miniscrews [63]. Li et al. aimed to improve the biocompatibility of stainless-steel miniscrews with the two-phase BioCaP coating they developed [64]. In their study, titanium discs were immersed in biomimetic modified Tyrode (BMT) solution for 24 h and stainless-steel discs were immersed in the same solution for 0, 12, 24, 36, or 48 h. The discs were then immersed in a supersaturated calcium phosphate solution for 48 h to form a crystal layer, and BSA was also added to this layer as a model protein during biomimetic mineralization. Their results demonstrated improved roughness and wettability of the smooth stainless-steel surface. Longer BMT coating time was also associated with increased cell seeding efficiency, cell proliferation, and cell spreading area on the surface. They concluded that the two-phase BioCaP application could improve the surface properties of stainless-steel miniscrews [64]. Rodriguez-Fernandez et al. aimed to create a polyethylene glycol (PEG) layer, using plasma coating to create a bacteriostatic effect on the surface of titanium miniscrews [65]. To achieve this layer, they activated the surfaces of titanium miniscrews with argon plasma and then with PEG plasma at different powers (100, 150, and 200 W) for 30 and 60 min. The PEG-coated samples showed more than 80% biocompatibility for fibroblast and osteoblastic cells. The miniscrews treated with only argon plasma activation showed an increase in bacterial colonization. The authors concluded that PEG significantly inhibits bacterial affinity due to its chemical configuration [65]. Bahrami et al. also examined the effects of the antimicrobial photodynamic treatment (aPSDT) of

zinc oxide (ZnO) nanoparticle-coated miniscrews on anaerobic bacteria [66]. The study compared uncoated miniscrews treated with phosphate-buffered saline (PBS) or 0.2% chlorhexidine (CHX) with ZnO nanoparticle-coated miniscrews treated with PBS, light-emitting diode (LED) (aPDT), ultrasound (aSDT), or both LED and ultrasound (aPSDT). They reported that ZnO nanoparticle-coated miniscrews with surface aPSDT had the greatest antimicrobial effect against periopathogenic biofilm. Gene expression levels of proinflammatory cytokines such as IL-1 β , IL-6, and TNF- α were also significantly lower in this group [66].

In recent years, these studies on the surface modifications of miniscrews have aimed to reduce bacterial retention on surfaces or accelerate osseointegration by increasing cell proliferation. ZnO nanoparticle-coated miniscrews with surface aPSDT and PEG-coated miniscrews were found to be successful in reducing bacterial colonization. BioCaP coating showed similar effects on both titanium and stainless-steel miniscrews; it has been found to accelerate osseointegration by increasing the cellular response. However, most of these studies were in vitro studies. Future clinical and laboratory reports are needed, as well as randomized clinical trials.

5. Conclusions

Surface modification is needed to strengthen the miniscrew–bone connection in areas with poor bone quality, to increase clinical success in patients with poor oral hygiene, and in orthodontic treatments where long-term and heavy forces are used. Conventional surface modifications increase the biomechanical stability of miniscrews. Although these methods are currently in use, there is still a search for new methods to improve the osseointegration capacity of miniscrews. These new methods include biomimetic coatings that simulate body fluids, antimicrobial agents, and drugs added to the miniscrew surface. In addition, current studies on the surface modification of miniscrews include not only miniscrews produced from titanium alloys, but also those produced from stainless steel.

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