Effect of surface treatment on the mechanical stability of orthodontic miniscrews:
A systematic review with meta-analysis

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ABSTRACT

Objectives: To provide collective quantitative evidence about the effect of surface treatments on the mechanical stability of orthodontic miniscrews (MSs).

Materials and Methods: The study was registered in PROSPERO (No. CRD42020209652). The research question was defined according to the PICO (population, intervention, control, and outcomes) format. Various research databases were searched for animal and human studies on effects of surface treatment on the mechanical stability of MSs. Both prospective and retrospective in vivo clinical studies published in English were included. The risk of bias was assessed using SYRCLE's risk of bias tool for animal studies. The meta-analysis was conducted using RevMan 5.4.

Results: A total of 109 articles were identified; 14 were included in the systematic review, and seven studies with sandblasting, acid etching (SLA) methods of surface treatment were included for meta-analysis. The number of study participants ranged from 6 to 24 (total n = 185), with a mean of 13.2. A total of 949 MSs were used with a mean of 67.8. The overall success rate for surface-treated MSs ranged from 47.9% to 100%. Forest plot of removal torque values showed significantly higher values for SLA surface-treated MSs compared with controls with a standard mean difference of 2.61 (95% confidence interval = 1.49–3.72, $I^2 = 85\%$). Forest plot of insertion torque showed a standard mean difference of –6.19 (95% confidence interval = –13.63–1.25, $I^2 = 98\%$, $P = .10$).

Conclusions: Surface treatment of MSs improved primary and secondary stability with good osseointegration at the bone-implant surface. However, significant heterogeneity across the studies included in the meta-analysis made it difficult to draw conclusions. (*Angle Orthod.* 2022;92:127–136.)

KEY WORDS: Miniscrews; Surface treatment; Mechanical stability; Systematic review

INTRODUCTION

The introduction of mini-screws (MSs) allowed orthodontists to perform various treatment modalities that were once considered extremely difficult, such as distalization of the whole dentition without loss of anchorage and en masse retraction of anterior teeth.[1–3] The success of MSs depends on their mechanical stability along with the influence of other factors, such as type and intensity of the load, type of gingiva, and level of hygiene near the emergence of the screw.[4,5] Mechanical stability refers to stability over the entire duration of the active phase of treatment, which depends on the MS surface characteristics, screw length and diameter, type of access with or without pilot drilling, bone cortical thickness, and the patient's periodontal health.[6–9] Stability of MSs is a key for successful orthodontic treatment, especially in long-term loading cases to guard against displacement.[9] Modification of the MS surface seems to be a promising factor for improving stability and decreasing failure rate.[10] Various methods have been used to produce an osseointegrated surface, including mechanical and chemical methods or combinations to modify the implant surface.[10–12] These surface treatments have been shown to improve surface topography and roughness,

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remove surface contamination, and improve cell interaction adhesion.[13] Previously, authors have studied various modalities of surface treatment of MSs, such as surface acid etching, sandblasting, plasma ion implantation, anodic oxidation, alkali treatment, and so on.[8,10–23] The present systematic review with meta-analysis was conducted to provide collective quantitative evidence about the effect of these surface treatments on the mechanical stability of MSs.

MATERIALS AND METHODS

This study was conducted in adherence to Preferred Reporting Items for Systematic Reviews (PRISMA) standards of quality for reporting systematic reviews and meta-analyses.[24] The study was registered in PROSPERO (No. CRD42020209652).

Questions

The review sought to examine the quantitative effects of surface treatment on the mechanical stability of orthodontic MSs. The research question was defined according to the PICO format as follows:

P (population/patients): In vivo studies involving humans or animals.
I (intervention): Surface treatment of MSs.
C (comparison): No surface treatment.
O (outcome): Changes in the mechanical stability of MSs, expressed via MS insertion and removal torque, stability, failure after insertion, and degree of osseointegration.

Study Eligibility

Studies published in the English language that investigated the effects of surface treatment on the mechanical stability of MSs were included. Papers were excluded at this stage if they were in vitro studies, case reports, editorial letters, case series, studies without controls, not investigating the effects of surface treatment on the mechanical stability of MSs, and MSs without surface treatment.

Study Identification

Various research databases were searched, including Cochrane library (Cochrane review, Trails), Medline (PubMed, OVID Medline, and Ebsco), Embase (European studies, pharmacologic literature, conference abstract), Web of Knowledge (social science, conference abstract), SCOPUS (conference abstracts, scientific web pages), CINAHL (nursing and allied health), PsycInfo (psychology and psychiatry), ERIC (education) using key terms focused on the specific search strategy (mini-screws, mini-implants, stability, mechanical, surface, treatment, surface treatment, torque, insertion, removal). For grey literature, the following databases were searched: Google Scholar, Open Grey, National Library of Medicine, Social Science Research. For theses: (EthOS, DART-Europe), Institutional repositories (OpenDOAR, Bielefeld Base, Lenus, RIAN, e-publications@RCSI). No beginning date was used, and the last date of the search was August 2020. Additional studies were sought by searching in the reference lists of all articles included.

Study Selection

All the titles and abstracts were screened independently and in duplicate for inclusion in the study. The interrater agreement for study inclusion, as assessed using an intraclass correlation coefficient, was 0.95. Conflicts were resolved by consensus discussion between the two reviewers.

Risk of Bias Assessment

Risk of bias was assessed using SYRCLE's risk of bias tool for animal studies.[25] The selected studies were assessed using the following types of bias: selection bias (domains: sequence generation, baseline characteristics, allocation concealment), performance bias (domains: randomization of animal housing conditions, blinding), detection bias (domains; random outcome assessment, blinding), attrition bias (domain: incomplete outcome data), reporting bias (domain: selective outcome reporting), other (domain: other sources of bias). Each domain was graded as low risk, high risk, or unclear risk depending on yes, no, or unclear judgment, respectively. SYRCLE's risk of bias tool was converted to Agency for Healthcare Research and Quality standards (good, fair, and poor): good quality when all criteria were met (ie, low for each domain), fair quality if one criterion was not met (ie, high risk of bias for one domain) or two criteria unclear, and poor quality if two or more criteria were listed as high or unclear risk of bias or one criterion was not met (ie, high risk of bias for one domain) or two criteria unclear.

Data Extraction and Data Synthesis

The data were extracted independently by the two reviewers using a data extraction sheet, and any differences were resolved by discussion and consensus. The following data were extracted from each included study: first author, publication year, study type, study quality, sample size, inclusion criteria, surface treatment, MSs used, method of analysis, insertion torque values, removal torque values, bone-implant contact ratio, loading information, statistical analysis used, and the authors' conclusion. The meta-

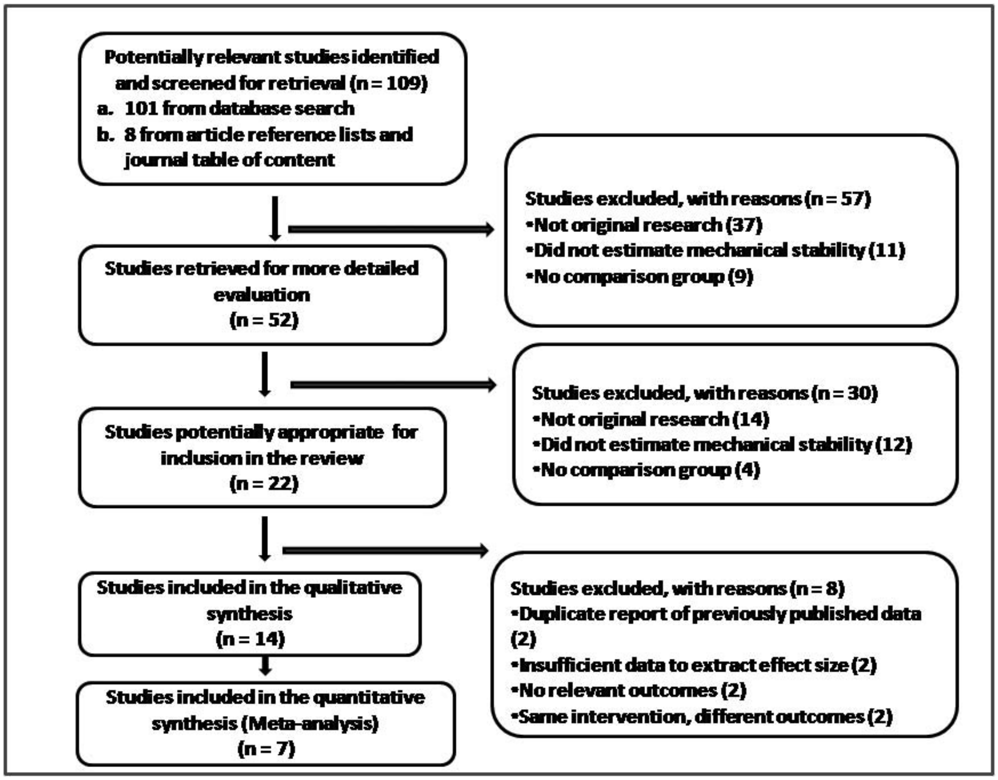

Figure 1. Study selection flow diagram.

analysis was performed using RevMan 5.4, a desktop version of Review Manager software used for Cochrane intervention and flexible reviews. For continuous data, standard mean difference (SMD) was reported with 95% confidence intervals (CIs). In each analysis, I^2 was used to measure the statistical heterogeneity among studies. According to the values of P and I^2, the random-effects model ($0<P<.1$, $I^2 \geq 50\%$) was selected.

RESULTS

Using the search strategy, 101 articles were identified, with an additional eight identified from a review of references and journal indices. From these, 14 studies were included in the systematic review and seven studies with sandblasting, acid etching (SLA) method of surface treatment were included in the meta-analysis (Figure 1).

Table 1. SYRCLE's Risk of Bias Tool for Included Studies[a]

	Risk of Bias Tool						AHRQ
	SB	PB	DB	AB	RB	OB	Rating
Jang et al./2018	Low	Low	High	Low	Low	Low	Fair
Maino et al./2017	High	Low	Low	Low	Low	Low	Fair
Choi et al./2016	Low	Unclear	Low	Low	Unclear	Low	Fair
Sirisa-Ard et al./2015	Low	Low	Low	Low	Low	Low	Good
Gansukh et al./2016	High	High	Low	Unclear	High	Unclear	Poor
Vilani et al./2015	Low	Low	High	Low	Low	Unclear	Fair
Oh et al./2014	High	Unclear	Low	Low	Low	Low	Fair
Cho et al./2013	High	Unclear	Low	High	Low	Low	Poor
Cho et al./2012	Low	Low	Unclear	Low	High	Low	Fair
Ikeda et al./2011	Low	Low	High	Low	Low	Low	Fair
Kim et al./2009	Low	Low	Low	Low	Low	Low	Good
Chang et al./2009	High	Low	Low	Low	Unclear	Low	Fair
Jeon et al./2008	Low	Low	Low	Low	Low	Low	Good
Oh et al./2006	High	High	Low	High	High	Unclear	Poor

[a] AHRQ indicates Agency for Healthcare Research and Quality; AB, attrition bias; DB, detection bias; OB, other bias; PB, performance bias; RB, reporting bias, SB, selection bias.

Table 2. Descriptive Details of Studies Included[a]

Author/Year	Study Type	Study Groups	Total Sample With Age Details	Statistical Analysis	Authors Conclusion
Jang et al./2018	AE, Randomized block design	TG1 = EG TG2 = ECG CG	21 mature New Zealand white male rabbits, 5 months old	One-way ANOVA	Improved stability and osseintegration in EG and ECG group compared with CG. Significantly increased RTV from week 1 to week 7 among EG and ECG compared with CG
Maino et al./2017	AE	TG = SAE CG	8 mature New Zealand white male rabbits, 6 months old	Two-way ANOVA	SAE MSs have higher bone retention and stability than CG. Significantly increased RTV and BIC ratio in SAE compared with CG.
Choi et al./2016	AE, random block design	TG = AO CG	12 mature male beagle dogs, 12–15 months old	Two-way ANOVA	Significant increase in mean surface roughness in AO compared with CG. No significant difference in biomechanical stability between groups.
Sirisa-Ard et al./2015	AE	TG = SLA CG	24 adult male New Zealand rabbits	Bonferroni correction	BIC ratio was significantly higher for SLA than CG; significant increase in RTV at week 0 for SLA compared with CG, but no difference at week 8.
Gansukh et al./2016	AE	TG = RBM CG	24 New Zealand white rabbits, 3 month old	Independent *t*-test	ITV significantly higher in CG compared with RBM, Significant increase in RTV at 2 weeks in RBM group compared with CG, but no significant difference at 4 weeks.
Vilani et al./2015	AE	TG = acid-etched MS CG	6 adult male mongrel dogs	One-way ANOVA	No significant difference in mobility, displacement, ITV, and RTV between acid-etched and CG. Slightly higher ITV for unloaded MS compared with loaded, but difference not significant.
Oh et al./2014	AE	TG 1 = AH TG 2 = APH CG	16 male Wistar rats, 7 weeks old	Independent sample *t*-test	APH treatment enhanced surface roughness and BIC ratio. Significantly increased RTV at 3 and 6 weeks for APH compared with CG.
Cho et al./2013	AE	TG 1 = SLA TG 2 = PIM	4 mature male Beagle dogs, 1 year old	Independent sample *t*-test	No difference in insertion torque, mobility, BIC rate, and bone volume rate between SLA and PIM.
Cho et al./2012	AE, random block design	TG 1 = SLA TG 2 = SLAO CG	6 mature male Beagle dogs, 1 year old	One-way ANOVA	SLAO method induced more favorable osseointegration and greater RTV than the SLA method and by CG.
Ikeda et al./2011	AE	TG = SLA CG	7 mature male foxhound dogs, 1–2 years old	Linear function analysis	SLA surface treatment and loadings had a significant effect on RTV; success rate bone surrounding the MS. No significant difference between ITV.
Kim et al./2009	AE, randomized complete block design	TG = SLA-type surfaces CG = conventional machined surfaces	12 mature male beagle dogs, 7–11 months old	Mixed-model analysis	SLA MSs showed relatively lower ITV, lower angular momentum, and higher RTV than the CG.

Table 2. Continued

Author/Year	Study Type	Study Groups	Total Sample With Age Details	Statistical Analysis	Authors Conclusion
Chang et al./2009	AE	TG 1 = SLA TG 2 = SL/NaOH CG	24 adult New Zealand white rabbits	Three-way ANOVA	SLA and SL/NaOH had significantly higher RTV at 12 weeks compared with CG. RTV was slightly higher for unloaded group compared with loaded MSs.
Jeon et al./2008	AE	TG = SLA CG	11 adult New Zealand white rabbits	Independent *t*-test	SLA group had significantly higher RTV and better osseointegration compared with CG.
Oh et al./2006	AE	TG = SLA CG	10 adult male rabbits	Independent sample *t*-test	SLA group had significantly higher RTV and better osseointegration compared with CG.

[a] AE indicates animal experiment; AH, anodized and heat-treated; ANOVA, analysis of variance; AO, anodic oxidized miniscrew; APH, anodization, cyclic precalcification and heat treatment; BIC, bone to implant contact; CG, control group (untreated machined surface); ECG, acid etched and calcium chloride immersion; EG, acid etched; ITV, insertion torque value; MS, miniscrew; PIM, plasma ion implanted; RBM, resorbable blasting media; RTV, removal torque value; SAE, sandblasted and acid etched group; SLA;, sandblasted, large-grit, and acid-etched; SLAO, sandblasted, large-grit, and anodicoxidation; SL/NaOH, sandblasted alkaline etched; TG, test group.

Study Characteristics

Eight studies were graded as fair, three studies as good, and three studies as poor (Table 1). The data were available from the year 2006 to 2018. Out of the 14 studies included in the review, seven used rabbits, six used dogs, and one used rats. The number of study participants ranged from 6 to 24 (total n = 185), with a mean of 13.2. Eight of the included studies used sandblasting, large grit, acid etching methods of surface treatment (SLA) (Table 2). Loading was applied in nine studies. A total of 949 MSs were used with a mean of 67.8. Removal torque values (RTVs) were assessed in 12 studies, insertion torque values (ITVs) in seven studies, and bone to implant contact ratio was assessed in seven of the included studies. The study period varied from 4 weeks to 16 weeks (Table 3).

Outcome of Studies

Overall success rate for surface treated MSs ranged from 47.9% to 100%. Mean ITV ranged from 9.6 to 41.8. Mean RTV ranged from 3.4 $\pm$ 0.5 to 79.1 $\pm$ 11.4 (Table 4). Forest plot of RTV showed significantly higher values for SLA surface treated MSs than control with an SMD of 2.61 (95% CI = 1.49–3.72, $I^2 = 85\%$, $P < .001$) (Figure 2). Forest plot of ITV showed an SMD of –6.19 (95% CI = –13.63–1.25, $I^2 = 98\%$, $P = .10$), with no statistically significant difference (Figure 3).

DISCUSSION

The success of orthodontic treatment depends on the degree of anchorage achieved, which in turn controls the intensity and direction of the mechanical forces used during treatment.[26,27] MSs were commonly used for anchorage because of their versatality.[2] The present systematic review with meta-analysis was conducted to compare the mechanical stability of surface-treated MSs with conventional untreated machine surface MSs. A total of 14 studies were used in the qualitative synthesis[8,10,12–23] and seven studies[8,10,13,14,18,19,22] in quantitative synthesis of data.

Primary Stability of Surface-treated Miniscrews

The primary stability of MSs is essential because it determines the implant's clinical success rate.[27] It is measured in terms of ITVs, and previous authors have recommended values in a range of 5 Ncm to 10 Ncm for better stability.[28] The roughness produced by surface treatment may provide space for external discharge of blood and bone particles, thus surface-treated MSs are more conducive to insertion with low ITV compared with conventional machined surface MSs, n which the smooth surface might increase the ITV, resulting in greater damage to surrounding bone structures.[29] Surface treatment of MSs facilitates the retention of blood and osteogenic cells through increased surface area and allows migration of these cells at the MS surface. It further enhances fibrin attachment, prevents detachment of fibrin during wound healing, and facilitates bone matrix formation in direct contact with the MSs, thereby improving biocompatibility and stability.[29–32] In the present review, three studies[8,10,18] with SLA surface-treated MSs were used to assess ITV variation, and the forest plot of ITV showed SMD of –6.19 (95% CI = –13.63–1.25, $I^2 = 98\%$, $P = .10$), with no statistically significant difference. Wide variation in torque values could be due to variation in length and diameter of MSs, initial pilot hole

Table 3. Details of MSs Used,Loading Force, Area of Placement of MSs, and Outcome Analysis Used[a]

Author/Year	MS Used	Number and Area of Placement of MS	Rotational Loading Force of MS	Outcome Analysis and Criteria for Analysis Used	Study Period
Jang et al./2018	Conical, self-drilling MS made of a titanium alloy with a 1.4-mm diameter and a 6-mm thread length	6 MSs in each rabbit inserted in tibia; total 126 MSs	No loading	RTV in CCW direction, SEM	7 weeks
Maino et al./2017	Upper head part and a lower threaded portion, made of a titanium alloy with 1.5-mm diameter and 6.5-mm length	4 MSs in each rabbit, inserted in proximal medial surface of each tibia; total 64 MSs	Loaded with 100 g using nickel-titanium coil springs	RTV was done using a digital torque sensor with 0.01 Ncm accuracy and Von Kossa staining and BIC	12 weeks
Choi et al./2016	self drilled, cylinder type, orthodontic titanium-aluminum vanadium alloy with 1.45-mm diameter, 7-mm length; single-threaded	8 MSs in each dog; inserted in intraradicular spaces of the first molar, the fourth premolar, the third premolar, and the second premolar in the mandiblel total 96 MSs	Loaded with 200 to 250 g using nickel-titanium coil springs	RTV, BV/TV, BIC, histomorphometric analyses	12 weeks
Sirisa-Ard et al./ 2015	Self-drilling, made of titanium-aluminum vanadium alloy with 6-mm length with a 1.5-mm diameter	2 MSs in each rabbit; inserted in distal femoral condyle; total 47 MSs	No loading	RTV, BIC, and histomorphometric analyses	8 weeks
Gansukh et al./ 2016	Made of titanium alloy with 6.0-mm length, 1.6-mm diameter, dual-top	4 MSs in each rabbit, placed in tibia; total 96 MSs	No loading	ITV, RTV, BIC, and histomorphometric analyses	4 weeks
Vilani et al./2015	Titanium-aluminum vanadium alloy with 1.5 $\times$ 6.0 $\times$ 2.0 mm	6 MSs in each dog, placed buccally between roots in the alveolar bone of the mandible' total 36 MSs	Loaded with 1.0 N Using nickel-titanium springs for 16 weeks	ITV, RTV, initial and final mobility using Periotest	16 weeks
Oh et al./2014	Self-tapping, made of titanium alloy, 1.4 $\times$ 4 mm	2 MSs in each rat, inserted in tibia; total 32 MSs	No loading	RTV and BIC	6 weeks
Cho et al./2013	Self-drilling tapered made of titanium alloy, 1.45-mm diameter and 6-mm length	8 MSs in each dog, inserted in mandible, total 32 MSs	Loaded with 250–300 g using nickel-titanium coil springs	ITV, mobility, BIC, and bone volume rate.	12 weeks
Cho et al./2012	Cylindrical shape, drill-free type, outer diameter 1.45 mm, inner diameter 1.0 mm, length 8 mm, titanium alloy	6 MSs in each dog, inserted in tibia, inserted perpendicularly into the bone surface, total 54 MSs	No loading	Maximum torque, total energy, and near peak energy during insertion and removal	8 weeks
Ikeda et al./2011	Self-drilling and made of titanium alloy, 6-mm long and 1.8-mm diameter	6 MSs in each dog, inserted in Interradicular areas of the mandibular first and second molars, buccal alveolar bone perpendicular to the cortical plate or parallel to the occlusal plane, total 42 MSs	Loaded with 200 g using nickel-titanium coil springs	ITV, RTV, μCT, BV/TV for cortical and noncortical bone regions Analyses pertained to 2 layers of bone, 6 to 24 μm and 24 to 42 μm, from the MS surface	6 weeks
Kim et al./2009	Cylindrical shape; self tapping and made of titanium alloy, 1.8-mm diameter and 8.5-mm in overall length and had a separate coronal portion	8 MSs in each dog, inserted in buccal bone of the maxilla and mandible, total 96 MSs	Loaded with 150 g using nickel-titanium coil springs at 3 weeks	ITV, RTV, total energy were measured by the computer program	8 weeks
Chang et al./ 2009	Tapered type titanium-alloy MSs 8-mm long, with a diameter of 1.3 mm and a small head	3 MSs in each rabbit, inserted in tibia metaphysic, total 144 MSs	Loaded with 150 g using nickel-titanium coil springs	RTV and BIC, histomorphometric analysis using SEM	12 weeks

Table 3. Continued

Author/Year	MS Used	Number and Area of Placement of MS	Rotational Loading Force of MS	Outcome Analysis and Criteria for Analysis Used	Study Period
Jeon et al./2008	Cylindrical shape, made of titanium alloy, screw-shaped 1.8-mm outer diameter × 9.5-mm length	4 MSs in each rabbit, inserted in tibia metaphysis, total 44 MSs	Loaded with 150–250 g using nickel-titanium coil springs	RTV with 0.01 Ncm accuracy, histologic staining	6 weeks
Oh et al./2006	Screw shaped, made of titanium alloy, length 9.5 mm, outer diameter 1.8 mm	4 MSs in each rabbit, inserted in tibia metaphysis, total 40 MS	Loaded with 150 g using nickel-titanium coil springs	RTV with 0.01 Ncm accuracy, histologic staining	6 weeks

[a] BIC indicates bone to implant contact; BV/TV, bone volume/total volume; CCW, counterclockwise; ITV, insertion torque value; μCT, microcomputed tomography; MS, miniscrew; RTV, removal torque value; SEM, scanning electron microscopy.

size, placement method (monocortical vs bicortical placement, wet vs dry placement), and thickness of cortical bone where the MS was placed.[33–37] Overall success rate ranged from 47.9% to 100%, and no association was seen between success rate and increased insertion torque values, disproving the theory that increased placement torque value would induce peri-implant necrosis and subsequent bone-implant interface degeneration.[14,38] When the length, diameter, and geometry were matched, the ITV was reduced.[35]

Secondary Stability (Retention of MSs)

Retention of MSs depends on their surface roughness and hydrophilicity.[39] A rough surface enhances integrin activity at the implant site, thereby inducing cellular responses like cell sticking, migration, proliferation, and differentiation.[32] Surface treatment enhances the roughness and hydrophilicity of MSs, thereby increasing retention and RTVs. In the present review, seven studies[8,10,13,14,18,19,22] were included that assessed the variation in RTV of SLA surface-treated versus conventional machined surface MSs, and the result showed significantly higher RTV for surface-treated MSs with SMD of 2.61 ($P < .001$). RTV is the measure of bone-implant contact, and increased RTV indicates better osseointegration, with improved secondary stability.[36,37] The new bone formed around inserted MSs is essential for fixation strength in primary stability and for osseointegration in secondary stability, which in turn influence the success rate of MSs.[40] Three of the included studies[14,23,21] showed significantly higher bone-implant contact values for surface-treated MSs. Roughened surfaces of MSs directly influence the healing mechanism at the bone-implant interface, thereby preventing fibrin detachment during wound healing. In contrast, conventional machined surface MSs cannot retain the fibrin matrix during wound contraction. As a result, osteogenic cells differentiate and synthesize bone without reaching the surface of the implant.[39,41,42]

Strengths and Limitations

The present study was the first systematic review with meta-analysis assessing the mechanical stability of surface-treated MSs. The limitation of the present study was significant heterogeneity across the studies included in the meta-analysis. The heterogeneity was caused by variation in the in vivo models, such as placement site of MSs, the animal used in the experiment, follow-up period, and loading or non-loading of MSs. Though for the study we searched for both animal and human studies, all the studies that were included were animal studies due to the lack of

	Surface treated miniscrew			Control				Mean Difference	
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	Year
Oh 2006	8.3	3.1	20	3.3	1.4	20	14.3%	5.00 [3.51, 6.49]	2006
Jeon 2008	6.3	2.2	22	4.5	3.01	22	13.9%	1.80 [0.24, 3.36]	2008
Chang 2009	6.1	1.4	72	2.5	1.5	72	18.5%	3.60 [3.13, 4.07]	2009
Kim 2009	10.74	8.53	48	7.45	2.18	48	9.8%	3.29 [0.80, 5.78]	2009
Cho 2012	8	3.1	12	6.6	2.9	12	10.1%	1.40 [-1.00, 3.80]	2012
Sirisa-Ard 2015	7.2	2.4	23	5.4	1.5	24	15.9%	1.80 [0.65, 2.95]	2015
Vilani 2015	4.1	1.5	18	2.8	0.7	18	17.5%	1.30 [0.54, 2.06]	2015
Total (95% CI)			**215**			**216**	**100.0%**	**2.61 [1.49, 3.72]**	

Heterogeneity: Tau² = 1.70; Chi² = 39.83, df = 6 (P < 0.00001); I² = 85%
Test for overall effect: Z = 4.58 (P < 0.00001)

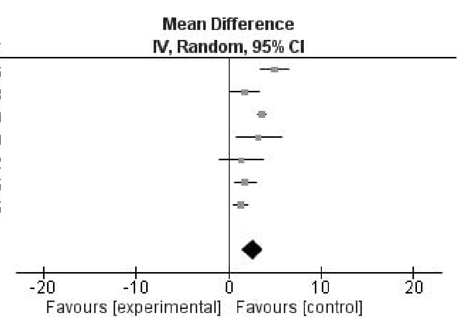

Figure 2. Forest plot of removal torque values.

Table 4. Outcome of Studies Included[a]

Author/Year	Study Group	Overall Success Rate	Placement/ Insertion Torque, Ncm	Removal Torque, Ncm	Degree of Osseointegration
Jang et al./2018	TG1= EG	NA	NA	At week 7 = 5.9 ± 0.7*	Good
	TG2 = ECG	NA	NA	At week 7 = 6.6 ± 0.6*	Good
	CG	NA	NA	At week 7 = 3.4 ± 0.5	Poor
Maino et al./2017	TG = SAE	98.4%	NA	79.1 ± 11.4*	BIC = 62.3 ± 24.2*
	CG	98.4%	NA	48.2 ± 15.06	BIC = 56.3 ± 18.3
Choi et al./2016	TG = AO	100%	12.4 ± 4.9	4.1 ± 1.7	BIC = 41.6 ± 14.1 BV/TV = 35.1 ± 7.4 mean surface roughness = 133.7*
	CG	100%	12.5 ± 5.1	4.0 ± 1.5	BIC = 34.5 ± 14.1 BV/TV = 35.1 ± 9.8 Mean surface roughness = 23.5
Sirisa-Ard et al./ 2015	TG = SLA	NA	NA	At week 0 = 7.2 ± 2.4* At week 8 = 6.6 ±1.2	BIC = 80.5 ± 3.8*
	CG	NA	NA	At week 0 = 5.4 ± 1.5 At week 8 = 8.0 ± 2.5	BIC = 60.2 ± 14.2
Gansukh et al./ 2016	TG = RBM	NA	9.6 ± 1.5	At week 2 = 7.1 ± 1.8* At week 4 = 7.08 ± 3.1	BIC = 69.2 ± 12.5
	CG	NA	11.1 ± 2.05*	At week 2 = 5.5 ± 1.4 At week 4 = 6.4 ± 2.3	BIC –= 68.2 ± 9.1
Vilani et al./2015	TG = SLA	88.8%	15.9 ± 2.7	4.1 ± 1.5*	MD = 0.4 ± 0.2 mm
	CG	77.7%	18.0 ± 1.2*	2.8 ± 0.7	MD = 0.9 ± 1.3 mm
Oh et al./2014	TG 1 = APH	NA	NA	At week 3 = 4.8 ± 2.7* At week 6 = 8.4 ± 3.1*	BIC = 91.5 ± 3.6%*
	CG	NA	NA	At week 3 = 2.3 ± 1.2 At week 6 = 4.1 ± 1.4	BIC = 61.8 ± 12.8%
Cho et al./2013	TG = SLA	100%	16.3 ± 7.8	NA	BIC = 66.2 ± 10
	TG = PIM	93.7%	17.8 ± 8.2	NA	BIC = 63.4 ± 14
Cho et al./2012	TG1 = SLA	NA	12.4 ± 2.1	8.0 ± 3.1	Good
	TG2 = SLAO	NA	13.2 ± 4.4*	12.8 ± 4.2*	Good without intervention of the connective tissue
	CG	NA	24.8 ± 3.0*	6.6 ± 2.9	Poor
Ikeda et al./2011	TG = SLA	100%*	41.8	NA	BV/TV = 1.07e–2 SE
	CG	85.7%	38.8	NA	BV/TV = 1.32e–2 SE
Kim et al./2009	TG = SLA	47.9%	15.27 ± 6.65 for CW	10.74 ± 8.53 CW*	NA
	CG	52.1%	19.25 ± 8.34 for CW*	7.45 ± 2.18 CW	NA
Chang et al./2009	TG1 = SLA	NA	NA	At week 2 = 2.4 ± 1.2 At 1week 12 = 6.1 ± 1.4*	BIC = 87.6
	TG2 = SL/NaOH	NA	NA	At 2 week = 2.7 ± 0.7 At week 12 = 8.9 ± 1.5*	BIC = 88.1
	CG	NA	NA	At week 2 = 2 ± 1.5 At week 12 = 2.5 ± 1.5	BIC = 77.2
Jeon et al./2008	TG = SLA	NA	NA	6.3 ± 2.2**	Good
	CG	NA	NA	4.5 ± 3.01	Poor
Oh et al./2006	TG = SLA		NA	8.3 ± 3.1*	Good
	CG		NA	3.3 ± 1.4	Poor

* $P < .05$.

[a] AO, anodic oxidized miniscrew; APH, anodization, cyclic precalcification and heat treatment; BIC indicates bone to implant contact; BV/TV, bone volume/total volume; CG, control group (untreated machined surface); CW, clockwise rotation; ECG, acid etched and calcium chloride immersion; EG, acid etched; NA, not available; PIM, plasma ion implanted; RBM, resorbable blasting media; SAE, sandblasted and acid-etched group; SLA, sandblasted, large-grit, and acid etched; SLAO, sandblasted, large-grit, and anodicoxidation; SL/NaOH, sandblasted alkaline etched; TG, test group.

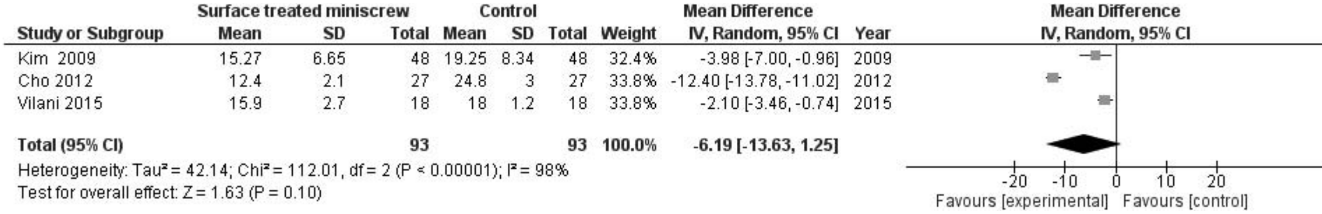

Figure 3. Forest plot of insertion torque values.

clinical studies in humans. The quality assessment of included animal studies rated only three studies as good. The present results point to the need for high-quality randomized controlled trials in future research.

CONCLUSIONS

- Within the limitation of the present study, it can be suggested that surface treatment of MSs improves primary and secondary stability with good osseointegration at the bone-implant surface.

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