Survival of surface-modified short versus long implants in complete or partially edentulous patients with a follow-up of 1 year or more: a systematic review and meta-analysis

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ABSTRACT

Purpose: Short implants are a potential alternative to long implants for use with bone augmentation in atrophic jaws. This meta-analysis investigated the survival rate and marginal bone level (MBL) of surface-modified short vs. long implants.

Methods: Electronic and manual searches were performed for articles published between January 2010 and June 2021. Twenty-two randomized controlled trials (RCTs) comparing surface-modified short and long implants that reported the survival rate with at least 1 year of follow-up were selected. Two reviewers independently extracted the data, and the risk of bias and quality of evidence were evaluated. A quantitative meta-analysis was performed regarding survival rate and MBL.

Results: The failure rates of surface-modified short and long implants differed significantly (risk ratio, 2.28; 95% confidence interval [CI], 1.46, 3.57; \( \text{P}<0.000 \)). Long implants exhibited a higher survival rate than short implants (mean follow-up, 1–10 years). A significant difference was observed in mean MBL (mean difference=−0.43, 95% CI, −0.63, −0.23; \( \text{P}<0.000 \)), favoring the short implants. Regarding the impact of surface treatment in short and long implants, for hydrophilic sandblasted acid-etched (\( \text{P}=0.020 \)) and titanium oxide fluoride-modified (\( \text{P}=0.050 \)) surfaces, the survival rate differed significantly between short and long implants. The MBL differences for novel nanostructured calcium-incorporated, hydrophilic sandblasted acid-etched, and dual acid-etched with nanometer-scale calcium phosphate crystal surfaces (\( \text{P}=0.050, \text{P}=0.020, \text{P}<0.000 \), respectively) differed significantly for short vs. long implants.

Conclusions: Short surface-modified implants are a potential alternative to longer implants in atrophic ridges. Long fluoride-modified and hydrophilic sandblasted acid-etched implants have higher survival rates than short implants. Short implants with novel nanostructured calcium-incorporated titanium surfaces, hydrophilic sandblasted acid-etched surfaces, and dual acid-etched surfaces with nanometer-scale calcium phosphate crystals showed less marginal bone loss than longer implants. Due to high heterogeneity, the MBL results should be interpreted cautiously, and better-designed RCTs should be assessed in the future.

Trial Registration: International Prospective Register of Systematic Reviews (PROSPERO) Identifier: CRD42020160185
INTRODUCTION

Dental implants are the preferred treatment option for edentulous patients when complicated augmentation procedures, such as vertical/horizontal ridge augmentation or sinus lift surgery, are not involved [1]. However, patients often visit dental clinics with atrophic ridges that require the implantologist to convince the patient to undergo time-consuming, lengthy, and costly augmentation procedures. Short implants are now used as an alternative to augmentation procedures in atrophic jaws. However, short implants have been reported to have lower survival rates due to the crown-to-implant discrepancy, inability to bear the occlusal loads long-term, and reduced bone-to-implant contact [2-7]. Among the various factors that affect implant osseointegration, the surface of the implant is known to have a positive influence [7-8]. Jemat et al. [9] stated that implant surface modification accelerates osseointegration by altering the surface energy and promoting cell proliferation and growth in the local environment. Deporter et al. [10] also reported that implant surface modification played a vital role in the success and survival of short implants. Implant surface modification can be subdivided into additive and subtractive methods [9]. Additive methods include impregnation or coating of the material, while subtractive methods increase the roughness of the surface by removing the material with different blasting substances, grits, and anodization methods [11].

A plethora of information is available on the success rates of short implants relative to long implants. However, very little is known about the influence of implant surface modification on the survival rates of short and long implants. Therefore, the aim of this systematic review was to analyze the survival/success rates of different surface-treated short implants in comparison with similarly treated long implants. The null hypotheses of this meta-analysis are that no differences exist in the survival rates of surface-modified short and long implants and that no differences exist in the marginal bone level (MBL) between surface-modified short and standard implants.

MATERIALS AND METHODS

Search strategy and study selection

This systematic review was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (www.prisma-statement.org). The concept of the study was submitted to and assessed by the Center for Reviews and Dissemination’s International Prospective Register of Systematic Reviews (PROSPERO) (Reg. No. CRD42020160185).

The research question for this systematic review was presented in the patient, intervention, comparison, and outcome format.

- Patient (P): Partially or completely edentulous patients receiving 1 or more implants in the maxilla and/or mandible.
- Intervention (I): Short implants (≤8 mm) with a modified surface in the partially or completely edentulous maxilla and/or mandible.
• Comparison (C): Long implants (>8 mm) with a modified surface in the partially or completely edentulous maxilla and/or mandible.
• Outcome (O): Effect of surface modification of implants on the survival/failure of short and long implants.

**Inclusion criteria**
All titles and abstracts of the studies were examined, and relevant studies were selected. Only human, clinical randomized controlled trials (RCTs) with the aim of contrasting surface-modified short with long implants were included. RCTs with at least 1 year of follow-up were chosen to assess the survival and failure rates of short and long implants with modified surfaces.

**Exclusion criteria**
Animal studies, retrospective or prospective studies, case reports, reviews, non-clinical studies, explanations of techniques, or clinical trials with insufficient information regarding short and long implants were not considered. Studies published in any language other than English were excluded. Studies in which the surface modification of implants was not mentioned were excluded.

**Search methods for study identification**
An electronic search was conducted to identify studies focused on the clinical performance of surface-modified short and long implants. For that purpose, the PubMed, Cochrane, Clinical Trial Registry, Science Direct, Google Scholar, and Directory of Open Access Journals (DOAJ) databases were searched between January 2010 and June 2021. The search protocol was restricted to the English language. The MeSH terms used in this search were “short implants” OR “short dental implant” AND “long implant” OR “long dental implant” OR “regular implant” OR “conventional implant” AND “surface coated” OR “surface treated” OR “surface modified” AND “success rate” OR “survival rate” OR “failure” AND “marginal bone loss” OR “marginal bone level” OR “periimplant bone loss” OR “periimplant bone level.” The following terms were used in an advanced Google search: all of the words “short dental implants” with at least 1 of the words “short dental implants” “long dental implants” “regular implants” “conventional surface modified surface coated.” However, no filters were used while searching the Cochrane, Science Direct, Google Scholar, or DOAJ databases.

The titles and abstracts of the searched papers were initially screened by 2 independent reviewers for possible inclusion. Any discrepancies between the reviewers were discussed until a consensus was reached. The summary of study searches is given as a PRISMA flowchart (Figure 1).

Data including study design, number of patients, number of implants at baseline, implant length (in mm), number of short implants, number of long implants, implant surface, manufacturing company, location, duration of follow-up, number of failed short and long implants, MBL at follow-up, cumulative implant survival, and success rate were extracted from the included articles. No missing information in the included articles jeopardized the analysis of the selected studies.
Method of analysis

Data collection and analysis

The relevant data from the included publications were collected in data extraction files. Prior to scoring, the rating forms were tested by all reviewers. Each reviewer first determined each study’s eligibility for inclusion in the systematic reviews, based on the reported parameters. The data from the included studies were summarized based on clinical and radiographic outcomes in the follow-up period. Two reviewers (RM and MP) evaluated titles, abstracts, and full texts. If opinions diverged, the disagreements among the examiners were re-examined, and decisions were made unanimously or by a third reviewer.

A meta-analysis was performed to evaluate whether significant differences in the survival rate and MBL existed between short and long implants with certain surface modifications. The risk ratios of implant survival rate and mean differences (MDs) in MBL were calculated using a fixed-effect model in which the heterogeneity was shown to be low (I²≤50%) and a random-effect model in which the heterogeneity was high (I²>50%). All analyses were performed with RevMan Manager 5.3 software (Cochrane, London, UK).
Quality assessment of the articles

The quality of the selected studies was assessed using the Cochrane collaboration tool (http://ohg.cochrane.org) [11] for RCTs, which accounts for random sequence generation, allocation concealment, blinding of participants, incomplete outcome data, selective reporting, and other sources of bias. The overall risk of bias for randomized trials was determined with the Cochrane Risk of Bias 2.0 tool (Cochrane). The quality of evidence was analyzed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach with GRADEpro GDT software (McMaster University and Evidence Prime Inc., Hamilton, Canada) [12].

RESULTS

A systematic electronic search yielded 3,140 references, including 2,954 from PubMed/MEDLINE, 180 from Google Scholar, 6 from the Cochrane Library, and none from the DOAJ and Science Direct databases. After the removal of duplicate references and title and abstract screening, 27 full texts were screened. Twenty-two RCTs [13-34] were included in the final review. Three studies did not compare surface-modified short and surface-modified long implants [35-37], and 2 articles that reported the outcomes of the same RCT at different follow-up times were counted as a single study [38,39].

Risk of bias and quality of evidence

The Risk of Bias 2.0 tool indicated that all of the studies showed a low risk of bias considering random sequence generation, allocation concealment (selection bias), incomplete outcome data (attrition bias), selective reporting (reporting bias), and other sources of bias, except 4 studies with high risk of bias [19,22,26] due to lack of data on randomization and blinding [26,30], missing outcome data [15], and selective reporting [14]. One study was underpowered because the data available for analysis after drop-out were not sufficient [19] (Figure 2).

According to the GRADE system, the pool of studies on implant survival rate and MBL constituted high-quality evidence (Supplementary Tables 1 and 2). However, the wide confidence intervals (CIs) and high risk of bias in a small number of studies should also be considered, and the results should be interpreted with caution.

Descriptions of the studies

The 22 studies are summarized in Table 1 [13-34]. All studies compared the survival rates and MBLs of surface-modified/surface-treated short vs. long implants. Certain studies provided data in the form of differences in marginal bone loss at baseline and follow-up, but such data were not used in the present meta-analysis to assess MBL. Seven studies were analyzed regarding the survival rates of short vs. long fluoride-modified implants [14,19,23,28,29,33,34]; however, only 5 studies could be evaluated regarding MBL [14,23,28,33,34]. Three studies used conventional sandblasted acid-etched surface implants [15,27,30], and 5 studies evaluated the survival rates and MBL of implants with nanostructured calcium phosphate-modified surfaces [13,17,20,25,31]. Five studies assessed the survival rates of hydrophilic sandblasted acid-etched implants (209 short vs. 218 long) [18,21,22,26,32]; however, only 3 studies evaluated the MBL [18,21,22]. Felice et al. [16,24] examined dual acid-etched surfaces coated with nanometer-scale calcium phosphate crystals (with 90 short and 91 long implants), and these 2 studies were included in the meta-analysis regarding survival rate and MBL.
In 1,472 patients, a total of 1,100 surface-modified short and 1,118 surface-modified long implants were evaluated. At the end of the follow-up period, 1,045 short implants and 1,094 long implants had survived (Table 2). Table 3 summarizes the details of each type of implant surface studied, including the corresponding survival rates. The mean follow-up period was 3.52±2.24 years (range, 1–10 years).

### Implant survival rate

Twenty-two studies [13–34] showed that 55 of 1,100 short implants and 24 of 1,118 long implants failed (Table 1). The RR for overall survival rate between the 2 groups was 2.28 and was statistically significant (Z=3.61; P=0.0003; 95% CI, 1.46, 3.57) (Table 4 and Figure 3). Surface-modified short implants showed higher failure rates than long implants. The influence of surface modification on the implants of different length was further evaluated. Only the hydrophilic sandblasted acid-etched and fluoride-modified titanium oxide surfaces showed statistically significant differences in the survival rates of short vs. long implants (Z=3.61; P=0.0003; 95% CI, 1.46, 3.57) (Figure 4). This indicates that hydrophilic sandblasted acid-etched and titanium

![Figure 2. Risk of bias of included studies. Green: low risk, yellow: moderate risk, red: high risk.](https://jpis.org/plus.cap/plus.cap/plus.cap/plus.cap/minus.cap)
Table 1. Characteristics of all included studies

| Author & Year | Study design | No. of patient implants | No. of long implants | Location | Implant surface | Additional information | Manufacturer | Smokers | Follow-up period (yr) | No. of patients lost to follow-up | No. of short implants failed | No. of long implants failed | Survival rate (%) | MBL |
|---------------|-------------|------------------------|---------------------|----------|-----------------|------------------------|--------------|---------|----------------------|-------------------------------|---------------------------|------------------------|-----------------|------|
| Pistilli et al. (2013) | RCT | 80 | 80 | Maxilla=40, Mandible=40 | Novel nanostructured calcium incorporated titanium surface | - | MegaGen Implant | 7 | 1 | 2 | 1 | 2 | 97.5 | 95 | 1.18 (0.29) 1.36 (0.28) |
| Gulje et al. (2013) | RCT | 95 | 208 | Maxilla=35 implants, Mandible=61 implants | Fluoride treated nanostructured surfaces | 4 mm diameter | OseoSpeed TX, Astra Tech Implant System, Dentsply Sirona Implants | 8 | 1 | 1 | 3 | 1 | 97.9 | 99 | 0.2 (0.22) 0.41 (0.46) |
| Romeo et al. (2014) | RCT | 94 | 54 | Maxilla=32 implants, Mandible=40 implants | SLA surface | - | Staumann Implant System | 8 | 5 | 5 | 1 | 0 | 90 | 100 | 2.97 (0.47) 2.99 (0.3) |
| Felice et al. (2014) | RCT | 60 | 121 | Maxilla | Nanotite (dual-acid-etched surface coated with nanometer scale crystals of calcium phosphate) | - | BioMet 3i | 23 | 5 | 8 | 5 | 3 | 91.66 | 96.72 | 2.24 (0.47) 3.01 (0.74) |
| Esposito et al. (2014) | RCT | 30 | 128 | Maxilla n=15 implants, Mandible n=15 (56 implants) | Novel nanostructured calcium incorporated titanium surface | - | MegaGen Implant | 6 | 3 | 6 | 5 | 2 | 91.66 | 97 | 1.57 (0.55) 1.87 (0.50) |
| Rossi et al. (2016) | RCT | 45 | 60 | Maxilla n=37 implants, Mandible n=33 | SLActive | 4.1 mm diameter | Straumann AG, Waldenburg, Switzerland | Test group: NS=32, FS=15, S=13 | 5 | - | 4 | 1 | 86.7 | 96.7 | 2.30 (0.5) 2.64 (0.56) |
| Schincaglia et al. (2015) | RCT | 97 | 122 | Maxilla | Fluoride treated nanostructured surfaces | Transmucosal implants | OseoSpeed TX, Astra Tech Implant System, Dentsply Sirona Implants | Test group: NS=32, FS=15, S=13 | 1 | 3 | 0 | 0 | 100 | 100 | -0.22 (0.4) -0.3 (0.45) |
| Bechara et al. (2017) | RCT | 33 | 90 | Maxilla | Novel nanostructured calcium-incorporated surface | - | MegaGen Implant | 15 | 3 | 0 | 0 | 2 | 100 | 95.6 | 0.27 (0.08) 0.20 (0.07) |
| Nedir et al. (2017) | RCT | 12 | 37 | Maxilla | SLActive | Transmucosal healing | Institut Steumann AG | - | 5 | - | 1 | 2 | 94.1 | 90.0 | 0.6 (0.7) 0.7 (1.4) |
| Sahrmann (2016) | RCT | 96 | 94 | Maxilla=42 implants, Mandible=56 | SLActive | Transmucosal healing | Straumann AG, Waldenburg, Switzerland | 23 | 3 | 16 | 1 | 0 | 98 | 100 | 0.19 (0.63) 0.33 (0.71) |

(continued to the next page)
Table 1. (Continued) Characteristics of all included studies

| Author & Year | Study design | No. of patient implants | No. of short implants | No. of long implants | Location | Implant surface | Additional information | Manufacturer | Smokers | Follow-up period (yr) | No. of patients lost to follow-up | No. of short implants failed | No. of long implants failed | Survival rate (%) | MBL | Short implants | Long implants |
|---------------|--------------|-------------------------|-----------------------|---------------------|----------|----------------|---------------------|--------------|---------|-----------------------|-----------------------------|-----------------------------|-----------------------------|--------------------------|-----|----------------|----------------|
| Pohl et al. (2017) [23] | RCT | 101 | 52 | 52 | Maxilla | Fluoride treated nanostructured surfaces | Transmucosal healing | OsseoSpeed TX, Astra Tech Implant System, Dentsply Sirona Implants | - | 3 | Short=2 (2 implants) | 0 | 100 | 0 | 100 | 0.45 (0.55) | 0.45 (0.55) |
| Felice et al. (2018) [24] | RCT | 66 | 30 | 30 | Mandible | Nanotite (dual-acid-etched surface coated with nanometer scale crystals of calcium phosphate) | - | Biomet 3i | Test group=12 | 8 | 12 | 5 | 3 | 83.33 | 90 | 2.34 (0.53) | 3.13 (0.76) |
| Gastaldi et al. (2018) [25] | RCT | 80 | 40 | 40 | Maxilla | Nanostructured calcium-incorporated (5×5 mm) | Platform switching 4.0 mm diameter | MegaGen | Test group=7 | 3 | 7 | 2 | 2 | 95 | 95 | 1.33 (0.38) | 17 (0.36) |
| Naenni et al. (2018) [26] | RCT | 86 | 40 | 46 | Maxilla=12 (short); 22 (long) | Maxilla=8 (short); 24 (long) | SLActive | All implants were placed according to a nonsubmerged 1-stage surgical protocol | 21 patents | 5 | 8 | 4 | 0 | 91 | 100 | -0.29 mm (IQR, −0.92, 0.23) | -0.15 mm (IQR, −0.93, 0.41) |
| Storelli et al. (2018) [27] | RCT | 17 | 20 | 20 | Mandible=30 | Maxilla=10 | SLA | Diameter=4.1 mm Machined transmucosal neck=2.8 mm | 6 patients | 5 | 5 | 0 | 0 | 95 | 100 | 3.26 (0.77) | 3.14 (0.94) |
| Thoma et al. (2018) [28] | RCT | 90 | 67 | 70 | Maxilla | Fluoride treated nanostructured surfaces | - | OsseoSpeed TX, Astra Tech Implant System, Dentsply Sirona Implants | 46 patients | 5 | 5 | 1 | 0 | 99 | 100 | 0.45 (0.79) | 0.45 (0.91) |
| Zadeh et al. (2018) [29] | RCT | 95 | 101 | 101 | Maxilla=104 implants | Maxilla=105 implants | Fluoride treated nanostructured surfaces | Platform switched Internal conical connection Microthreads | 8 ex-smoker=26 | 3 | 5 | 4 | 1 | 96 | 99 | Mean bone gain=0.04 (0.43) | Mean bone loss=0.02 (0.76) |
| Shah et al. (2018) [30] | RCT | 50 | 25 | 25 | Maxilla=23 | Mandible=27 | Conventional sandblasted and acid etched surface | Non-submerged with customised healing abutment | MIS even | 1 | 7.5 short and 2 long implants | 4 | 1 | 84 | 96 | - | - |

(continued to the next page)
Table 1. (Continued) Characteristics of all included studies

| Author & Year | Study design | No. of patients | No. of short implants | No. of long implants | Location | Implant surface | Additional information | Manufacturer | Smokers | Follow-up period (yr) | No. of patients lost to follow-up | No. of short implants failed | No. of long implants failed | Survival rate (%) | MBL | Short implants (μm) | Long implants (μm) | Short implants (μm) | Long implants (μm) |
|---------------|--------------|----------------|----------------------|---------------------|----------|----------------|----------------------|--------------|---------|---------------------|-----------------------------|--------------------------|--------------------------|---------------------|-----|--------------------|--------------------|--------------------|--------------------|
| Felice et al. (2019) [31] | RCT | 30 | 128 | 60 | Maxilla | Nanostructured calcium-incorporated | - | MegaGen | 6 patients | 5 | 6 | 5 | 2 | 91.66 | 97 | 1.83 (0.65) | 2.24 (0.63) |
| Shi et al. (2019) [32] | RCT | 225 | 150 | 75 | Maxilla | Straumann standard plus implants (SLActive) | - | Institute Straumann AG, Basel, Switzerland | - | 1 | 8 | Group 1=1 | 2 | Group 1=96 | Group 3=100 | 0.32±0.26 | 0.32±0.26 |
| Guida et al. (2020) [33] | RCT | 30 | 150 | 75 | Mandible | Fluoride treated nanostructured surfaces | - | OsseoSpeed TX, Astra Tech Implant System, Dentsply Sirona Implants | 4 | 3 | - | 0 | 0 | 100 | 100 | 0.36 (0.33) | 0.25 (0.19) |
| Hadzik et al. (2021) [34] | RCT | 30 | 30 | 15 | Maxilla | Fluoride treated nanostructured surfaces | - | OsseoSpeed TX, Astra Tech Implant System, Dentsply Sirona Implants | Excluded | 7 | - | 2 | 0 | 87 | 100 | 0.22 (0.46) | 0.34 (0.24) |

RCT: randomized control trial, IQR: interquartile range, NS: non-smoker, FS: frequent smoker, S: smokers, OsseoSpeed: fluoride treated nanostructured surfaces, -: not mentioned.

aData at the follow-up period.
Table 2. Summary of survival rates of short and long implants

| Total No. of RCT | Total No. of patients | Total No. of implants (survived implants) | Total No. of long implant (survived implants) | Total No. of failed short implants | Total No. of failed long implants |
|-----------------|-----------------------|------------------------------------------|----------------------------------------------|-----------------------------------|----------------------------------|
| 22              | 1,472                 | 2,218                                    | 1,100 (1,045)                                | 1,118 (1,094)                     | 55                               | 24                               |

RCT: randomized control trial.

Table 3. Summary of data of implant surfaces

| Implant surface                                           | No. of studies | Total No. of implants | Total No. of short implants | Total No. of long implants | Total No. of failed short implants | Total No. of failed long implants | Survival rate (%) |
|-----------------------------------------------------------|----------------|-----------------------|------------------------------|----------------------------|-----------------------------------|----------------------------------|--------------------|
| Hydrophilic sandblasted acid-etched [18,21,22,26,32]      | 5              | 427                   | 209                          | 218                        | 16                                | 5                               | 92.3               |
| Conventional sandblasted acid-etched [15,27,30]           | 3              | 144                   | 245                          | 73                         | 13                                | 10                              | 91.5               |
| Titanium modified fluoride treated nanostructured surfaces [14,19,23,28,29,33,34] | 7              | 960                   | 485                          | 475                        | 10                                | 2                               | 98                 |
| Novel nanostructured calcium-incorporated surface [13,17,20,25,31] | 5              | 506                   | 245                          | 261                        | 13                                | 10                              | 95                 |
| Dual-acid-etched surface coated with nanometer scale crystals of calcium phosphate [24,31] | 2              | 181                   | 90                           | 91                         | 10                                | 5                               | 88.88              |

Table 4. Summary of meta-analyses comparing survival rate of different surface modified short vs. conventional implants

| Implant surface                                           | Studies | Pooled RR (95% CI) | P value | I² value (%) | Z value | Statistical model (method) |
|-----------------------------------------------------------|---------|--------------------|---------|--------------|---------|---------------------------|
| Short vs. Long implants                                   | 22      | 2.28 (1.46, 3.57)  | 0.003   | 0            | 3.61    | Fixed effects             |
| Titanium modified fluoride treated nanostructured surfaces [14,19,23,28,29,33,34] | 7        | 3.54 (1.00, 12.59) | 0.05    | 0            | 1.96    | Fixed effects             |
| Novel nanostructured calcium-incorporated surface [13,17,20,25,31] | 5        | 3.54 (0.33, 14.69) | 0.02    | 0            | 1.24    | Fixed effects             |
| Hydrophilic sandblasted acid-etched [18,21,22,26,32]      | 5        | 3.54 (0.33, 14.69) | 0.02    | 0            | 1.24    | Fixed effects             |
| Conventional sandblasted acid-etched [15,27,30]           | 3        | 3.54 (0.77, 16.48) | 0.01    | 0            | 1.62    | Fixed effects             |
| Dual-acid-etched surface coated with nanometer scale crystals of calcium phosphate [24,31] | 2        | 2.01 (0.72, 5.81)  | 0.18    | 0            | 1.34    | Fixed effects             |

P value (≤0.05): statistically significant. RR: risk ratio, CI: confidence interval.
oxide fluoride-modified short implants failed 3 and 3.54 times more frequently, respectively, than correspondingly surface-modified long implants. The survival rates of implants with nanostructured calcium phosphate-modified surfaces ($P=0.42; \text{RR}=1.38; 95\% \text{ CI}, 0.63, 3.01$), conventional sandblasted acid-etched surfaces ($P=0.10; \text{RR}=3.56; 95\% \text{ CI}, 0.77, 16.48$), and dual acid-etched surfaces coated with nanometer-scale calcium phosphate crystals ($P=0.18; \text{RR}=2.07; 95\% \text{ CI}, 0.72, 5.61$) were statistically insignificant between short and long implants (Figures 6-8). The wide CIs also indicate the uncertain impacts of the surface changes, which are due to the limited number of studies involving each surface. The absolute effect of the failure rate of all short implants irrespective of surface was 2.1% greater than that of the long implants (Supplementary Table 1).
Marginal bone loss

Seventeen studies [13-34] assessed the differences in MBL around the implants using mean values (mm), and only the final follow-up data of the studies were used (Table 5). In all of these studies, the MBL was calculated as the linear measurement from the coronal margin of the implant shoulder to the most coronal point of bone-to-implant contact. The overall analysis showed a highly significant difference between short and standard implants (P<0.0001; MD=-0.43; 95% CI, -0.63, -0.23) with I²=97% (Figure 9). Overall, the marginal bone loss was smaller among the short implants. A statistically significant difference was observed with nanostructured calcium phosphate-modified surface implants (P=0.05; MD=-0.23; 95% CI, -0.45, -0.00); however, the results should be taken with caution, as the heterogeneity (I²) observed was 94% (Figure 10). The differences in MBL between short and long implants was statistically insignificant for titanium oxide fluoride-modified (P=0.61; MD=-0.04; 95% CI, -0.28, 0.34) and conventional sandblasted acid-etched implants (P=0.86; MD=0.03; 95% CI, -0.28, 0.34) (Figures 11 and 12). However, the assessment of the hydrophilic sandblasted acid-etched surface (P=0.02; MD=-0.23; 95% CI, -0.42, -0.04) and the dual acid-etched surface coated with nanometer-scale calcium phosphate crystals

Table 5. Summary of meta-analyses comparing marginal bone level of different surface modified short vs. conventional implants

| Implant surface | Studies | Pooled MD (95% CI) | P value | P value (%) | Z value | Statistical model (method) |
|-----------------|---------|--------------------|---------|-------------|---------|---------------------------|
| Short vs. Long implants [13-18,20-25,27,28,31,33,34] | 17 | -0.43 (-0.63, -0.23) | <0.0001 | 97 | 4.30 | Random effects |
| Titanium modified fluoride treated nanostructured surfaces [14,23,28,33,34] | 5 | -0.04 (-0.21, 0.12) | 0.61 | 82 | 0.51 | Random effects |
| Novel nanostructured calcium-incorporated surface [13,17,20,25,31] | 5 | -0.23 (-0.45, -0.00) | 0.05 | 94 | 1.98 | Random effects |
| Hydrophilic sandblasted acid-etched [18,21,22] | 3 | -0.23 (-0.42, -0.04) | 0.02 | 0 | 2.42 | Fixed effects |
| Conventional sandblasted acid-etched [15,28] | 2 | 0.03 (-0.28, 0.34) | 0.86 | 0 | 0.17 | Fixed effects |
| Dual-acid-etched surface coated with nanometer scale crystals of calcium phosphate [24,31] | 2 | -0.78 (-0.96, -0.59) | 0.0001 | 0 | 8.28 | Fixed effects |

P value (≤0.05): statistically significant.
MD: mean difference, CI: confidence interval.
Surface-modified short versus long implants

Figure 9. Forest plot of the marginal bone level analysis of all short and long implants irrespective of surface. SD: standard deviation, MD: mean difference, CI: confidence interval.

Figure 10. Forest plot of the marginal bone level analysis of nanostructured calcium-incorporated short and long implants. SD: standard deviation, MD: mean difference, CI: confidence interval.

Figure 11. Forest plot of the implant survival rate and subgroup analysis of short and long implants with fluoride-treated nanostructured surfaces. SD: standard deviation, MD: mean difference, CI: confidence interval.

Figure 12. Forest plot of the marginal bone loss analysis of short and long implants with hydrophilic sandblasted acid-etched surface topography. SD: standard deviation, MD: mean difference, CI: confidence interval.
Surface-modified short versus long implants

**Complications**

**Mechanical**

Fifteen studies assessed mechanical complications, such as abutment fracture, prosthesis and screw loosening, crown failure, minor chipping and screw loosening, and prosthesis decementation [11,14-17,21,25,27,30-35,37] (Table 6).

![Figure 13](https://doi.org/10.5051/jpis.2007340367)

**Figure 13.** Forest plot of the marginal bone loss analysis of short and long implants with sandblasted large-grit acid-etched surfaces. SD: standard deviation, MD: mean difference, CI: confidence interval.

![Figure 14](https://doi.org/10.5051/jpis.2007340367)

**Figure 14.** Forest plot of the marginal bone loss analysis of short and long implants with dual acid-etched surfaces coated with nanometer-scale calcium phosphate crystals. SD: standard deviation, MD: mean difference, CI: confidence interval.

(P<0.0001; MD=-0.78; 95% CI, -0.96, -0.59) revealed statistically significant differences between short and long implants (Figures 13 and 14).

| Study or Subgroup | Short implants Mean | SD | Total | Long implants Mean | SD | Total | Weight | Mean Difference IV, Random, 95% CI | Mean Difference IV, Fixed, 95% CI |
|-------------------|---------------------|----|--------|-------------------|----|--------|--------|---------------------------------|---------------------------------|
| Romeo et al. 2014 | 2.87                | 0.47| 26     | 2.99              | 0.9 | 29     | 66.4%  | -0.02 [-0.40, 0.36]              | -0.02 [-0.40, 0.36]              |
| Storelli et al. 2018 | 3.26              | 0.77| 20     | 3.14              | 0.94 | 20     | 33.6%  | 0.12 [0.41, 0.65]                | 0.12 [0.41, 0.65]                |
| Total (95% CI)    | 96                  | 100.0%| 48     | 100.0%            | 48  | 48     |        | 0.03 [-0.28, 0.34]               | 0.03 [-0.28, 0.34]               |

(continued to the next page)
### Table 6. (Continued) Data of the implant complications

| Study                        | Mechanical                          | Biological                                                                 | Complications of short implants | Complications of long implants |
|------------------------------|-------------------------------------|-----------------------------------------------------------------------------|--------------------------------|--------------------------------|
| Esposito et al. (2014) [17]  | 3 abutments loosening               | Post-augmentation paraesthesia                                              | 12                             | 13                             |
|                              |                                     | Sinus epithelium perforation                                                |                                |                                |
|                              |                                     | 3 abscesses (peri-implantitis)                                               |                                |                                |
|                              |                                     | Peri-implant mucositis                                                      |                                |                                |
| Rossi et al. (2016) [18]     |                                     | Fracturing of surrounding bone around short implants                        | Not mentioned                   | Not mentioned                   |
| Schincaglia et al. (2015)    | Not mentioned                       | Not mentioned                                                               | Not mentioned                   | Not mentioned                   |
| Bechara et al. (2017) [20]   | No mechanical complications         | Intraoperative & immediately postoperative: 3 were                          | 0                              | 19                             |
|                              |                                     | (intraoperative bleeding) and 16 were (1 patient                           |                                |                                |
|                              |                                     | experienced pain and swelling after surgery, and 14                        |                                |                                |
|                              |                                     | patients experienced swelling alone                                         |                                |                                |
|                              |                                     | Late postoperative complication: one patient                               |                                |                                |
|                              |                                     | experienced a (chronic sinus infection with complete                       |                                |                                |
|                              |                                     | graft loss) which led to the loss of 2 implants                            |                                |                                |
| Nedir et al. (2017) [21]     | -                                   | mBI, probing depth                                                         | 1                              | 3                              |
| Sahrmann et al. (2016) [22]  | Loosening of abutment screw=3       | Bleeding on probing=62 (30 short and 32 long implants)                      | Not mentioned                   | Not mentioned                   |
|                              |                                     | Probing depth >5 mm=5 (short implants)                                      |                                |                                |
|                              |                                     | Recession=2 short implants and 1 long implant                              |                                |                                |
| Pohl et al. (2017) [23]      | Loosening or a fracture of the abutment screw=10                            | -                                                                           | Not mentioned                   | Not mentioned                   |
| Felice et al. (2018) [24]    | Crown failure                       | Intra-surgical haemorrhage and mandibular graft failure                     | 8 patients (prosthetic=1       | 14 patients                     |
|                              |                                     | Transient paraesthesia of the lip                                          | implants)                       |                                |
| Gastaldi et al. (2018) [25]  | Prosthetic screw loosening          | Intra-surgical haemorrhage                                                  | 1 patients (2)                  | 2 patients (2)                  |
|                              |                                     | Fracture of the osteotomised mandibular graft plate                         |                                |                                |
|                              |                                     | Maxillary sinus perforation                                                 |                                |                                |
| Naenni et al. (2018) [26]    | Minor chipping and screw loosening  | -                                                                           | Not mentioned                   | Not mentioned                   |
| Shah et al. (2018) [30]      |                                     | -                                                                           | -                              | -                              |
| Storelli et al. (2018) [27]  | Decementation (n=2)                 | Mucositis (n=5)                                                            | 15 implants (9 patients)        | 13 implants (13 patients)       |
|                              | Chipping (n=6)                      |                                                                              |                                |                                |
| Thomaset al. (2018) [28]     | Fracture of abutment screw, screw loosening, chipping of veneering ceramic, lost crown and loss of retention (decementation of crown) | -                                                                           | 21                             | 14                             |
| Zadeh et al. (2018) [29]     | Abutment fracture, Prosthesis and screw loosening                           | -                                                                           |                                |                                |
| Felice et al. (2019) [31]    | Prosthesis decementation            | Sinus membrane perforation                                                  | 16                             | 12                             |
|                              |                                     | Paraesthesia                                                               |                                |                                |
|                              |                                     | Abscess around implants                                                     |                                |                                |
| Shi et al. (2019) [32]       | Not mentioned                       | Sinus membrane perforation                                                  | 7                              | 6                              |
| Guida et al. (2020) [33]     | Fracture of the acrylic veneer=3 patients (short implants)                  | Wound dehiscence=1 patient (long implant group)                            | Not mentioned                   | Not mentioned                   |
|                              | (short implants)                    | Peri-implant mucositis=2 (1 in each group)                                  |                                |                                |
| Hadzik et al. (2021) [34]    | Chipping of the ceramic             | Abutment screw loosening without the decementation of the crown             | Not mentioned                   | Not mentioned                   |
|                              | Decementation of the crown          | 40% short implants                                                          |                                |                                |
|                              |                                      | 60% long implants                                                           |                                |                                |

*: no data available.
Biological
Seventeen studies reported biological complications, such as sinus membrane perforation, abscess formation, peri-implantitis, paresthesia, nasal bleeding and headache, fracturing of the bone surrounding short implants, intraoperative hemorrhage, and mandibular graft failure [11,15-18,20-24,29,32,36] (Table 6).

DISCUSSION

To our knowledge, this is the first meta-analysis to compare the survival rate and MBL between surface-treated short (≤8 mm) and long (>8 mm) implants.

No consensus yet exists in the literature regarding the definition of short implants. In recent studies, implants of ≤8 mm were defined as short and implants of >8 mm as long or standard [40,41]. Other researchers insist that implants 8 mm and shorter should be considered short and implants 6 mm and shorter extra-short implants [42]. Overall, the recent literature indicates that short implants have a length equal to or less than 8 mm. Thus, in this meta-analysis, we defined short implants as ≤8 mm and long implants as >8 mm. In all of the included studies, surviving implants were defined as implants that remained functional post-loading, while failed implants were those that were mobile and were removed from the patient. Innumerable studies and reviews have assessed the effects of implant length on the survival rate and MBL based on data from prior to 2010, so RCTs published in the last 11 years (2010–2021) were selected. All studies compared the survival rates and MBLs of surface-modified short vs. long implants with at least 1 year of follow-up.

The results of this meta-analysis indicated that surface alteration influenced the impact of implant length on the survival rate and MBL. The risks of failure of hydrophilic sandblasted acid-etched and fluoride-modified implants were 3 to 3.54 times greater in short than in long implants. Similarly, significantly reduced bone loss (~0.23 to ~0.78 mm) was observed in short implants modified with novel nanostructured calcium-incorporated titanium surfaces, dual acid-etched surfaces coated with nanometer-scale calcium phosphate crystals, or hydrophilic sandblasted acid-etched surfaces.

The present study reports a survival rate of 95% for surface-modified short and 97.8% for surface-modified long implants, which is similar to systematic reviews that showed 93% and 99% survival rates for short and long implants, respectively [43,44]. However, the present study reports an additional effect or improvement of surface modification on the survival rate of short implants. Histologic studies have shown that the surface modification of implants may positively affect osseointegration, but the overall implant survival rate is also affected by various clinical confounding factors, including prosthetic loading, bone quality, and crown-to-implant ratio.

Each type of implant surface modification has a demonstrated functional role. For example, a calcium phosphate dual acid-etched surface exhibits low bacterial adherence, a fluoride-modified surface promotes short healing time and facilitates early loading, and a hydrophilic sandblasted acid-etched surface has been shown to have high surface energy [45]. The present review reports that hydrophilic sandblasted acid-etched surface topography has a positive effect on the success/survival rate of implants irrespective of length; however, nothing can be definitely concluded on the effect of hydrophilic sandblasted...
acid-etched surface topography modification on the survival rates of short vs. long implants [18,21,22,26,32]. The MBLs of short and long implants with hydrophilic sandblasted acid-etched surfaces were improved due to the high surface energy and improved wettability of that topography [45,46].

The reasons for the failures of short and long implants were not specified in most of the studies. However, a few studies reported the reasons for the failure of short implants as “early failures” (caused by chronic sinus infection with loss of integration/implant stability) and type IV bone quality [18]. Also, data regarding failed short and long implants over follow-up periods of 1, 5, 8, and 10 years in some studies indicated that most of the implant failures occurred in the first year of loading; no differences were present in the implant failure rate at the end of 5 or 10 years of follow-up compared to 1 year of follow-up [13-34].

The external validity of the present study regarding the MBL indicates relatively low generalizability to similar populations. The substantial heterogeneity observed in the MBL was present because most studies have reported superior MBL around short implants, and few have done so for long implants. This is a limitation of the present study. Zadeh et al. [29] reported a maximum of 1 mm of bone loss around short implants and 1–3 mm of bone loss around long implants at 3 years. The author reported that this could be due to increased generation of heat during surgery with deeper osteotomy preparation, stress shielding, or a manifestation of the more crestal position of the head of the long implant.

The majority of studies have compared the outcomes of short and long implant placement in conjunction with vertical augmentation/maxillary sinus lift procedures. These studies have demonstrated that the survival rates and MBLs associated with surface-modified short implants are comparable to those associated with longer implants placed in sites with vertical ridge or maxillary sinus augmentation. However, patients with long implants had a higher frequency of complications and graft failure, thereby affecting the overall survival rate associated with long implants. Therefore, short implants have emerged as a viable alternative with lower morbidity and a lower surgical complication rate.

When other variables that can influence osteointegration are taken into account (for instance, the selection of appropriate-diameter [wider] implants and the resting of the flared neck below the crestal bone level in implants placed in type III or IV bone), implant length is not a confounding factor for survival rate. The use of short implants with poor bone quality (type IV) has been identified in a few studies.

The present meta-analysis included studies with good study design and analysis, indicating that these RCTs have high internal and external validity, as measured by the GRADE score. However, due to the imprecision and uncertainty of the included RCTs, MBL analyses should be extrapolated with caution. When evaluating the effect of surface treatment on variations in implant length, we did not take into account the effects of smoking, implant diameter, platform switching or matching, bone quality, or mechanical or biological complications. Future studies should also compare the survival rates of surface-modified short and long implants not placed in conjugation with augmentation procedures.

In conclusions, this study describes the impact of surface modification on the survival rate and MBL in implants of different lengths. For implants with fluoride-modified and hydrophilic sandblasted acid-etched surfaces, long implants have better survival rates than
short implants. Short implants with novel nanostructured calcium-incorporated titanium surfaces, hydrophilic sandblasted acid-etched surfaces, and dual acid-etched surfaces coated with nanometer-scale calcium phosphate crystals showed reduced marginal bone loss relative to longer implants of the same surface types. In certain cases in which extensive augmentation procedures are needed, short implants may still be an alternative to long implants, as augmentation procedures increase the risk of complications.

SUPPLEMENTARY MATERIALS

Supplementary Table 1
GRADE score of survival rate of surface modified short and long implants

Click here to view

Supplementary Table 2
GRADE score of marginal bone level of surface modified short and long implants

Click here to view

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