REVIEW ARTICLE

Critical factors for the success of orthodontic mini-implants: A systematic review

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Introduction: This systematic review was undertaken to discuss factors that affect mini-implants as direct and indirect orthodontic anchorage. **Methods:** The data were collected from electronic databases (Medline [Entrez PubMed], Embase, Web of Science, Cochrane Library, and All Evidence Based Medicine Reviews). Randomized clinical trials, prospective and retrospective clinical studies, and clinical trials concerning the properties, affective factors, and requirements of mini-implants were considered. The titles and abstracts that appeared to fulfill the initial selection criteria were collected by consensus, and the original articles were retrieved and evaluated with a methodologic checklist. A hand search of key orthodontic journals was performed to identify recent unindexed literature. **Results:** The search strategy resulted in 596 articles. By screening titles and abstracts, 126 articles were identified. After the exclusion criteria were applied, 16 articles remained. The analyzed results of the literature were divided into 2 topics: placement-related and loading-related factors. **Conclusions:** Mini-implants are effective as anchorage, and their success depends on proper initial mechanical stability and loading quality and quantity. (Am J Orthod Dentofacial Orthop 2009;135:284-91)

The growing demand for minimum compliance and maximum curative effects has made the temporary anchorage device (TAD) more promising as an excellent alternative to traditional orthodontic anchorage. Endosseous dental implants have served successfully as anchorage structures for orthodontic appliances, especially in patients whose dental elements lack quantity or quality.[1] Tipped mandibular second molars were uprighted with implants in a third molar extraction site.[2] Palatal implants have been used to reinforce anchorage in Angle Class II malocclusion patients in whom retraction of anterior teeth was achieved after the maxillary first premolars were extracted.[3] However, because of their disadvantages—complicated surgical procedure, long healing time, and limited implant sites—they are difficult to use as routine clinical anchorage.

In 1983, Creekmore and Eklund[4] placed a vitallium screw in the anterior nasal spine of a patient with a deep impinging overbite to intrude the maxillary incisor. Although the clinical results were exciting, the technique did not gain immediate acceptance because it was premature to be used clinically without an adequate understanding of reliability or pathology. In 1997, Kanomi[5] reported a successful case with a mini-screw (diameter, 1.2 mm; length, 6 mm), with the mandibular incisors intruded 6 mm with no root resorption or periodontal pathologic evidence. Park[6] then presented a case using 1-stage surgical microscrews with healing in an open method in 1999, generating serious interest in mini-implants as a source of skeletal anchorage because of their superiority for few anatomic limitations, simple placement, and versatile applications.[7] Surgical microscrews have been substituted for specially designed orthodontic mini-implants that are more suitable as conventional orthodontic anchorage fixtures.[8]

The generally accepted protocol for successful and predictable placement of mini-implants includes atraumatic surgical technique, short healing period, biocompatible materials, and patient management.[9] To encourage regeneration and osseointegration, rather than repair with fibrous encapsulation, a primary healing environment at the bone-implant surface should be created.[10]

The aims of this article were to review and critically analyze the available literature about mini-implants (screws) and to discuss, based on scientific evidence, factors that might influence this modality with immediate or early loading.

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MATERIAL AND METHODS

The method for this review was based on the guidelines published in the *American Journal of Orthodontics and Dentofacial Orthopedics*,[11] and a cross-disciplinary systematic review was conducted according to the recommendations of the National Health Service Center for Reviews and Dissemination.[12] Internationally published research literature, review articles, bibliographies, and relevant citations in articles in all languages were included, and databases were searched back to their inception. In the initial phase of the review, a computerized literature survey was performed by searching the MEDLINE database (Entrez PubMed, www.ncbi.nlm.nih.gov) (from 1966 to week 3 of June 2007), the Cochrane Library (www.cochrane.org/reviews), and the CRD Database of Ongoing Reviews to find systematic reviews, meta-analyses, and literature reviews. Terms used in this literature search were *mini-implant, mini-screw, micro-implant, micro-screw, screw, temporary anchorage device (TAD); orthodon; immediate, early,* and *loading*.

Additionally, after the electronic literature search, a hand search of key orthodontic journals was undertaken to identify recent unindexed articles.

The review was restricted to peer-reviewed articles dealing with mini-implants, when the implant diameter was smaller than 2.5 mm.[13] The following inclusion criteria were initially used to select appropriate articles: articles on mini-implant (screw) and microimplant (screw) used as orthodontic anchorage, data only from human subjects, language in English, randomized controlled studies (RCTs), prospective clinical studies, and retrospective clinical studies.

Exclusion criteria included articles on standard dental implants, onplants, palatal implants, miniplates used as orthodontic anchorage, miniscrews or microscrews for dental surgery, and implant materials research; animal studies; in-vitro studies; case reports and case series; technique presentations of mini-implant and microimplant; review articles and letters; articles that did not follow the objective of this review; and articles in a language other than English.

Data collection and quality analysis

Data from the retrieved studies were collected based on year of publication, study design, materials (implant materials, shape, diameter, length), implant number, loading quantity, healing period, treatment or observation duration, success rate, posttreatment observation, and authors' conclusions.

The eligibility of the articles identified by search engines was determined by reading their titles and abstracts. Two reviewers (Y.C. and W.T.Z.) independently assessed all articles with respect to the inclusion and exclusion criteria, and the kappa score measuring the level of agreement was 0.88. The data were extracted from each article separately without blinding to the authors, and intraexaminer conflicts were resolved by discussing each article to reach a consensus. All articles that appeared to meet the inclusion criteria on the basis of their abstracts in which relevant information was provided were also retrieved.

A quality evaluation of the methodologic soundness of each article was performed for the RCTs according to the methods described by Feldmann and Bondemark,[14] with an extension of the quality appraisal to controlled clinical trials. The following characteristics were used: study design, sample size and prior estimate of sample size, valid measurement methods, method-error analysis, blinding in measurements, adequate statistics, and confounding factors. Ten variables were evaluated in the study: RCT, 3 points; prospective study, 1 point; retrospective study, 0 point; adequate sample, 1 point; previous estimate size, 1 point; adequate selection description, 1 point; method-error analysis, 1 point; blinding in measurement, 1 point; adequate statistics provided, 1 point; and confounders included in analysis, 1 point. The quality of each study was categorized as low (0-4 points), medium (5-8 points), or high (9-11 points).

RESULTS

Electronic and hand searches identified 596 titles and abstracts on implants as anchorage, of which 470 were excluded at the first stage according to the inclusion criteria. The remaining 126 articles, for which the abstracts seemed to be potentially useful, were retrieved. Twenty-one studies actually fulfilled the initial selection criteria after we read the complete article. At the final stage of article selection, 5 were rejected because they were case series. Finally, only 16 articles that met all inclusion criteria remained.[7,9,15-28] A flow diagram of the literature search is shown in the Figure. A methodologic quality checklist was used to evaluate the selected articles (Table I). Data about the 16 studies are listed in Table II, and a qualitative analysis of sample size, loading period, and success rate is also given.

Placement methods

From the 16 studies selected for this study, the self-tapping placement method was used in 14.

The relationship between the diameters of the pilot drill and the implant shows that, in 6 of the 14 studies, a 1.5-mm diameter pilot drill was used for the 2.0-mm diameter implants[15,20,23-26]; the survival rates were 85%[15] to 100%.[23] Costa et al[15] reported that 2 of 16

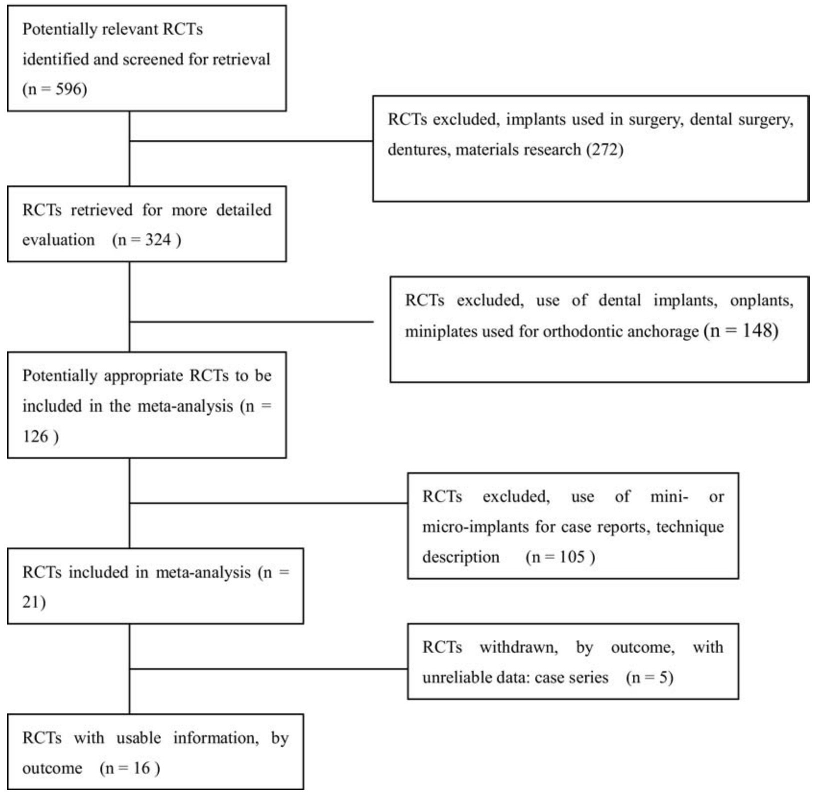

Fig. Flow diagram of the literature search.

Table I. Quality evaluation of 16 studies

Author	*Sample size*	*Previous estimate size*	*Study design*	*Selection description*	*Valid measurement methods*	*Method-error analysis*	*Blinding in measurements*	*Adequate statistics provided*	*Confounding factors*	*Judged quality standard*
Costa[15]	Adequate	Yes	P	Inadequate	Yes	No	No	No	No	Low
Freudenthaler[16]	Adequate	Yes	P	Adequate	Yes	No	No	No	No	Low
Gelgor[9]	Adequate	Yes	P	Adequate	Yes	Yes	No	Yes	No	Medium
Motoyoshi[17]	Adequate	Yes	P	Adequate	Yes	No	No	Yes	No	Medium
Wiechmann[18]	Adequate	Yes	P	Adequate	Yes	No	No	Yes	No	Medium
Kuroda[19]	Adequate	Yes	P	Adequate	Yes	No	No	Yes	No	Medium
Park[20]	Adequate	Unknown	P	Adequate	Yes	No	No	No	No	Low
Miyawaki[21]	Adequate	Unknown	P	Adequate	Yes	No	No	Yes	No	Medium
Fritz[22]	Adequate	Unknown	P	Inadequate	No	No	No	No	No	Low
Liou[23]	Adequate	Yes	P	Adequate	Yes	Yes	No	Yes	No	Medium
Cheng[24]	Adequate	Unknown	P	Adequate	Yes	No	No	Yes	No	Medium
Park[7]	Adequate	Yes	P	Adequate	Yes	Yes	No	Yes	No	Medium
Tseng[25]	Adequate	Unknown	R	Adequate	Yes	No	No	Yes	No	Medium
Park[26]	Adequate	Unknown	P	Adequate	Yes	No	No	Yes	No	Medium
Chen[27]	Adequate	Unknown	R	Adequate	Yes	No	No	Yes	No	Medium
Xun[28]	Adequate	Yes	P	Adequate	Yes	Yes	No	Yes	No	Medium

P, Prospective clinical study; *R,* retrospective clinical study.

mini-implants became loose and lost after 2 months of loading. Freudenthaler et al[16] used a 2-mm diameter twist drill for 2-mm diameter implants with immediate loading of 12 implants. At the third week, 1 implant was removed because poor initial stability and problems caused impingement of the implant head, and inflammatory reactions in the surrounding movable mucosa necessitated the premature removal of 2 implants.

Table II. Summarized data of 16 studies retrieved

Author	*Study design*	*Patient sample age*	*Manufacturer*	*Materials*	*Diameter/length*	*Success rate*
Costa[15]	P	14	Cizeta	Ti	2.0 mm/9 mm	87.5% (14/16)
Freudenthaler[16]	P	8; 4 f, 4 m 21.1 y (13-46 y)	Leibinger	Ti	2.0 mm/13 mm	75% (9/12)
Gelgor[9]	P	25; 18 f, 7 m 11.3-16.5 y	Leibinger	Pure Ti	1.8 mm/14 mm	100% (44)
Motoyoshi[17]	P	41; 37 f, 4 m 24.9 y (13.3-42.4 y)	ISA	Ti	1.6 mm/8 mm	85.5% (124)
Wiechmann[18]	P	49 (36 f, 13 m) 26.9 y (13.5-46.2)	Dentos Duel-Top	Ti alloy Ti	1.1 mm/10 mm 1.6 mm/6-8 mm	86.8% (133)
Kuroda[19]	P	75 (63 f, 12 m) 21.8 y (± 8.2)	Dentos Keisei Medical Industrial	Ti alloy Ti	1.3 mm/6-10 mm 2.0-2.3 mm/7/11 mm	88.6% (79) 81.1% (37)
Park[20]	P	73; 47 f, 26 m 0	Osteomed/Leibinger/Avana	Ti alloy	1.2 mm/6-10 mm 2.0 mm/12 mm	93.3% (180)
Miyawaki[21]	P	51; 42 f, 9 m 21.8 y ± 7.8	Unknown	Ti	1.0 mm/6 mm 1.5 mm/11 mm 2.3 mm/1.4 mm	0 (0/10) 83.9% (101) 85% (23)
Fritz[22]	P	17; 10 f, 7 m 29.9 ± 14 y (13-51)	Jeil medical corp	Ti alloy	1.4, 1.6, 2.0 mm/6, 8, 10 mm	70% (36)
Liou[23]	P	16; 22-29 y	Leibinger	Pure Ti	2.0 mm/17 mm	100% (32)
Cheng[24]	P	44; 38 f, 6 m 29 ± 8.9 (13-55 y)	Leibinger	Pure Ti	2.0 mm/5-15 mm	91.4% (92)
Park[7]	P	13; (11-28.3 y)	Leibinger/Osteomed/Dentos	Ti	12 mm/6 mm	90% (30)
Tseng[25]	R	25 (14 f, 11 m) 29.9 y (22-44)	Stryke-Leibinger	Ti	2.0 mm/8-10 mm	91.1% (45)
Park[26]	P	87; 35 m, 52 f (15.5 y)	Leibinger/Osteomed/ Dentos/KLS-Martin	Ti alloy Ti	1.2 mm/5-10 mm 2.0 mm/10-15 mm	91.6% (227)
Chen[27]	R	29 (20 f, 9 m) 29.8 y (19-57)	Dentas	Ti alloy	1.2 mm/6-8 mm	84.7% (59)
Xun[28]	P	12; (14.3-27.2 y)	Unknown	Ti alloy	1.6 mm/7 mm	No evaluation

P, Prospective clinical study; *R,* retrospective clinical study; *f,* female; *m,* male; *Ti,* titanium.

Park et al[7,26] and Park[20] used a 0.9-mm diameter drill for 1.2-mm mini-implants, for an over 90% overall success rate. Kuroda et al[19] made screw holes with a 1.6-mm twist drill for 2.0- to 2.3-mm diameter implants and a 1.0-mm twist drill for 1.3-mm diameter implants.

We considered the relationship between the length of the pilot drill and the length of the implant. Motoyoshi et al[17] drilled a pilot hole with a bit with diameter of 1.3 mm and a length of 8 mm for implants of 1.6 mm diameter and 8 mm length with 200 g of immediate loading. They had an 85.5% success rate. They attributed the high success rate to the peak placement torque of 5 to 10 N per centimeter. Chen et al[27] and Tseng et al[25] used a twist drill to penetrate only the cortical level of bone for implants of 6 and 8 mm length and recommended that the intrabone length of the implants should be at least 6 mm.

Only 2 articles referred to a self-drilling method, performed manually by an orthodontist with a screwdriver without predrilling and achieved by changing the point of the implant to a sharp conical shape with a pitch.[22,28] Fritz et al[22] omitted pilot holes in the maxilla and, when appropriate, in the mandible, since they could impair the primary stability of the implants. They had 11 failed fixtures before the end of treatment, and 5 implants had increased mobility but continued to meet their anchorage requirements and were not evaluated as failures. Xun et al[28] put 2 implants of 1.6-mm diameter in the buccal alveolar bone between the molars in the mandible and 1 in the posterior midpalatal area in the maxilla with the self-drilling method. Two weeks after implantation, about 150 g of intrusion loading was applied on each side. The maxillary and mandibular first molars were intruded by averages of 1.8 and 1.2 mm, respectively.

Loading protocol

From the 16 articles, 6 evaluated TADs with immediate loading. The self-tapping method was used for implant placement in those studies, which used different

Table II. Continued

Placement method	Healing period (wk)	Force applied (g)	Force period (mo)	Position	Application
Self-tapping	0	<200		Nontooth bearing area	Direct anchorage
Self-tapping	0	150		Bicortical area of mandible	Protract molar
Self-tapping	0	Indirect 250	4.6	Palate	Indirect anchorage
Self-tapping	0	<200 g	>6	Posterior part of both jaws	Anterior teeth retraction
Self-tapping	0	1-200 g	6	Interradicular area	Direct anchorage
Self-tapping	0-12	50-200 g	12	Interradicular area	Direct anchorage
Self-tapping	<4	Various	5	Buccal/interradicular area/retromolar palate	Direct/indirect anchorage
Self-tapping	2-3	150-200	15.8	Various	Direct anchorage
Self-drilling	Various	200	Unclear	Interradicular area	Direct anchorage
Self-tapping	2	2-400	9	Zygomatic buttress of maxilla	Direct anchorage
Self-tapping	2-4	1-200		Posterior jaws	Direct anchorage
Self-tapping	2-3	150-200	12.3	Interradicular area	Direct anchorage
Self-tapping	2	100-200 g	16	Anterior and posterior jaws, ramus	Direct anchorage
Self-tapping	2	150-200 g	15	Interradicular area	Direct anchorage
Self-tapping	2	100-200 g	20	Interradicular area	Direct anchorage
Self-drilling	2	150	4.6	Bicortical area of mandible, palate	Direct anchorage

types of implants with various diameters and lengths. The success rates ranged from 75%[16] to 100%.[9] Ten evaluated TADs with early loading; the TADs were retrieved after healing times of 2 to 4 weeks. The implant diameter was 1.0 to 2.3 mm, and the length was 5 to 17 mm. The success rates ranged from 0%[20] to 100%.[22]

Cheng et al[24] placed the mini-implants in the mandibular and maxillary posterior zones to intrude and upright the molars and to retract and protrude the posterior teeth. Implant mobility or complete exfoliation was found for 15 implants. Four failed before the application of orthodontic load, and 6 implants were lost after loading of less than a month. Chen et al[27] found that 3 of 9 microimplants failed before loading; 2 were due to fracture during placement.

In most of the studies, the orthodontic load was 100 to 200 g as direct anchorage. Liou et al[23] supplied a 400-g early loading on the implants at the zygomatic buttress of the maxilla to create a mass retraction of the anterior teeth, and all 32 miniscrews remained stable clinically for 9 months. They found that miniscrews were displaced and might move according to the orthodontic loading in some patients.

Gelgor et al[9] placed implants with a diameter of 1.8 mm and a length of 14 mm into a 1.5-mm diameter hole at a site 5 mm behind the incisive canal and 3 mm to the right or left of the raphe for indirect loading over a period between 3 and just over 6 months. They found a slight anchorage loss, which was attributed to mesial tipping of the first premolars during molar distalization.

Miyawaki et al[21] thought that the diameter of the screws was significantly associated with their stability. They reported that the 1-year success rate of implants with a 1.0-mm diameter was significantly less than that of implants with diameters of 1.5 and 2.3 mm. The latter 2 sizes showed no difference. Wiechmann et al[18] also studied implants with diameters of 1.1 and 1.6 mm in the palate and the buccal aspects of the maxilla and the mandible; they had a high success rate for the large-diameter group. However, Park[20] reported implants with a diameter of 2.0 mm had the lowest success rate (the sample size was small), and Kuroda et al[19] further confirmed that small-diameter implants had a higher success rate than larger ones.

Quality analysis

A quality analysis of the 16 studies, summarized in Table I, shows that search quality and methodologic soundness was medium in 12 and low in the rest. The main drawback of the study design in all articles was that there was no comparison group. Two articles had inadequate selection descriptions and small sizes, implying low power.[16,21] Most studies did not include a method-error analysis. Blinding in measurements was not done properly, and no study considered the risk of confounding factors. Twelve studies used proper statistical methods, but the choices were generally not explained. A critical analysis showed that no study fulfilled all requirements for an RCT. However, because these studies were the best current knowledge on the anchorage ability of mini- implants, the results were collected and analyzed.

DISCUSSION

A systematic review with a strict protocol and a thorough search strategy was performed to analyze the effectiveness of mini-implants as orthodontic anchorage. To ensure that the most valid and reliable results were obtained, the articles were selected according to inclusion and exclusion criteria. Some well-known articles might have been excluded.[1-3]

After reviewing all published articles on implants, only 16 satisfied the inclusion criteria for clinical trials with mini-implants as orthodontic anchorage. When the methodologic checklist was applied, most of these articles obtained medium-quality scores, but some had low-quality scores. As for dental implants, the reasons for mini-implant failure include improper surgical technique and loading protocol, host factors (smoking, management factors, and parafunctional habits), and implant elements.

Placement-related factors

The self-tapping method used in 14 studies has been the main approach in mini-implant placement. The use of a pilot drill is important, even though the surgical protocol for placement of mini-implants is simpler than that of standard dental implants, because it is more aseptic and precise and less traumatic, since its width and depth affect the initial stability of the implants and the secondary osseointegration. From the articles collected for our study, the proper width of the pilot drill should be 0.2 to 0.5 mm less than the implant diameter, and the depth should be less to obtain proper initial mechanical stability; this was the most important factor for successful immediate and early loading.

The optimal stress for enhancing the initial stability was considered to be neither a high nor a low value. Because Motoyoshi et al[17] found that implant placement torque of the failure group was significantly greater than that of the success group, they warned that, with high levels of stress, necrosis and local ischemia of the surrounding bone could be caused when the implant diameter is much larger than that of the pilot hole. Melsen and Costa[29] stated that overheating during drilling, poor primary stability caused by overdrilling, inflammation, or local disturbances could have prevented normal healing in the early period. The theory was further supported by the higher cumulative survival of mini-implant systems in the maxilla than in the mandible.[20,21,27] Because bone density is high in the mandible, implants can have high placement torque and good initial stability. Overheating of the pilot drill causing bone damage, might contribute to the high failure rate, so copious irrigation with saline solution was needed.

The self-drilling method, a new technique, was used in 2 studies.[22,28] Its placement procedure is simplified, without pilot drilling and incision. Even though success rates were diverse, it was believed that failure rates might be further reduced with increasing clinical experience and perfecting of the placement technique.

A study with dogs demonstrated that the self-drilling implant had high placement torque and high bone-implant contact values.[10] Because their placement torque was high, self-drilling mini-implants at the posterior and inferior aspects of the mandible were not recommended because they have been reported to have a high breakage rate.

Loading-related factors

With the trend to shorten orthodontic treatment time and reduce the patient's inconvenience, immediate loading has been proposed as an alternate approach. We found that a healing time seems unnecessary for mini-implants, because the 6 studies with immediate loading had high success rates. It was reported that some failures also happened before loading. Several experimental studies have shown that immediate loading of the threaded implant does not necessarily lead to fibrous tissue healing.[10,30,31] Instead, a bone-to-implant contact developed over time; this is comparable with that of implants that are loaded conventionally.

Associated with the loading quantity, most mini-implants can withstand 100 to 200 g of horizontal early or immediate loading successfully; that is enough to sustain the various orthodontic tooth movements. Costa et al[15] attributed failures to torsional stress and concluded that a force system generating a moment to the implant in the unscrewing direction caused an implant to fail. Because loosening, breakage, and dislocation were reported in the studies with early or immediate force, overloading should be avoided, and the implant site should be some distance from anatomic structures.

Related to anchorage methods, direct implant anchorage permitted direct transmission of forces to the implants, since there was often no need for teeth to be involved in the anchorage system. Even though a disadvantage of immediate and early loading was associated with dislocation of mini-implants in low bone quantity, the anchorage teeth remained stable. Direct orthodontic loading offered the advantage of shorter treatment time. As indirect anchorage, the mini-implants were stable, but a slight anchorage loss was shown by maxillary incisor proclination and increased overjet at the end of movement.[9]

Size-related factors

Mini-implants were thought to have many advantages, such as versatile placement sites, little bone trauma, immediate loading, and so on. Some authors thought decreased diameter was associated with a decrease in the cumulative survival rate, whereas the length of implants had no statistically significant effect on implant failure, and they suggested that the intrabone part of mini-implants should be at lest 6 mm. However, in the most recent studies, small mini-implants are receiving more attention because higher success rates were reported than with miniplates and long, large diameter screws in clinical applications.[18,19] They have been considered unlikely to touch the roots if they are placed in a tooth-bearing area.

A volumetric tomographic image analysis for the maxilla and the mandible suggested that safe zones for placement of mini-screws was a maximum diameter of 1.2 to 1.3 mm, and implants with a diameter of 2 mm cannot be considered safe for placement in the posterior interradicular spaces of the maxilla, except between the first molar and the second premolar on the palatal side, and between the canine and the first premolar.[32] Mini-implants with a diameter less than 1.5 mm were intended for tooth-bearing areas, particularly in the interradicular area.

CONCLUSIONS

The following conclusions should be considered with caution because only a secondary level of evidence was found.

1. For self-tapping mini-implants, the diameter and the length of the implant should be 0.2 to 0.5 mm larger than the width and the depth of the bone hole for optimal placement torque.
2. For mini-implants, healing time is unnecessary.
3. The selection of the tooth-bearing mini-implant size depends on the bone available.

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