

Systematic Review and Meta-Analysis Dental Implants

Clinical evidence on titanium–zirconium dental implants: a systematic review and meta-analysis

**P. Altuna¹, E. Lucas-Taulé¹,
J. Gargallo-Albiol¹,
O. Figueras-Álvarez²,
F. Hernández-Alfaro¹, J. Nart³**

¹Department of Oral and Maxillofacial Surgery, School of Dentistry, Universitat Internacional de Catalunya, Sant Cugat del Vallès, Barcelona, Spain; ²Department of Restorative Dentistry, School of Dentistry, Universitat Internacional de Catalunya, Sant Cugat del Vallès, Barcelona, Spain; ³Department of Periodontology, School of Dentistry, Universitat Internacional de Catalunya, Sant Cugat del Vallès, Barcelona, Spain

P. Altuna, E. Lucas-Taulé, J. Gargallo-Albiol, O. Figueras-Álvarez, F. Hernández-Alfaro, J. Nart: Clinical evidence on titanium–zirconium dental implants: a systematic review and meta-analysis. Int. J. Oral Maxillofac. Surg. 2016; 45: 842–850. © 2016 International Association of Oral and Maxillofacial Surgeons. Published by Elsevier Ltd. All rights reserved.

Abstract. The use of titanium implants is well documented and they have high survival and success rates. However, when used as reduced-diameter implants, the risk of fracture is increased. Narrow diameter implants (NDIs) of titanium–zirconium (Ti–Zr) alloy have recently been developed (Roxolid; Institut Straumann AG). Ti–Zr alloys (two highly biocompatible materials) demonstrate higher tensile strength than commercially pure titanium. The aim of this systematic review was to summarize the existing clinical evidence on dental NDIs made from Ti–Zr. A systematic literature search was performed using the Medline database to find relevant articles on clinical studies published in the English language up to December 2014. Nine clinical studies using Ti–Zr implants were identified. Overall, 607 patients received 922 implants. The mean marginal bone loss was 0.36 ± 0.06 mm after 1 year and 0.41 ± 0.09 mm after 2 years. The follow-up period ranged from 3 to 36 months. Mean survival and success rates were 98.4% and 97.8% at 1 year after implant placement and 97.7% and 97.3% at 2 years. Narrow diameter Ti–Zr dental implants show survival and success rates comparable to regular diameter titanium implants (>95%) in the short term. Long-term follow-up clinical data are needed to confirm the excellent clinical performance of these implants.

Key words: titanium–zirconium; Roxolid; small diameter; narrow diameter; dental implant.

Accepted for publication 11 January 2016
Available online 3 February 2016

The use of dental implants for the replacement of lost teeth is considered a highly predictable treatment option.^{1–7} When the available bone is insufficient to place standard diameter implants, additional surgical

techniques for bone regeneration are usually needed.^{8–10} An alternative treatment option is to place narrow diameter dental implants (NDIs). Several reports have aimed to define the dimension of a narrow

diameter.¹¹ In this review, an implant with a diameter between 3 and 3.5 mm was considered an NDI. The main indications for the use of NDIs are reduced mesiodistal space,¹² reduced crestal width¹³ (narrow

ridge), and reduced amount of interradicular space.^{14–17}

There is great concern regarding the resistance and possible fatigue strength of this type of implant, especially when used in areas with a high occlusal load (posterior areas) or in patients with parafunctional habits.^{18–24} Since NDIs have a reduced contact area with the bone compared to regular diameter implants, this may also compromise the short- and long-term survival rates.^{25,26} For the same reasons, NDIs are not recommended to restore single canines, premolars, and molars.¹⁴ To overcome these problems, titanium alloys with higher tensile and yield strength, such as Ti₆Al₄V, have been used to manufacture NDIs.^{27–30} Several studies have reported on corrosion,^{31–33} toxicity and biocompatibility issues related to aluminium and vanadium,^{31,34,35} and reduced bone responses^{35–37} with the use of this alloy.

To further improve the mechanical strength and biocompatibility, a new titanium–zirconium alloy (Ti–Zr) has been developed (Roxolid; Institut Straumann AG, Basel, Switzerland).³⁸ This material is made of titanium alloyed with 13–15% of zirconium. This metal alloy is highly biocompatible and allows the same surface treatment, sand blasting and acid etching, as commercially pure titanium grade IV.³⁵ The increased biomechanical properties of this material together with its excellent biocompatibility allow the use of NDIs even in clinically challenging situations. However, clinical evidence regarding the use of Ti–Zr NDIs is still limited. The aim of the present systematic review was to report on the clinical performance of Ti–Zr NDIs in clinical trials.

Materials and methods

Search strategy and eligibility criteria

This systematic review was performed in accordance with the PRISMA statement; the PICO(S) questions were used as evaluation criteria in order to identify the Patient or Population, Intervention, Control and Comparison, Outcome, and Study types.³⁹

A literature search was performed to identify available articles reporting on the clinical outcomes of Ti–Zr dental implants. A systematic approach was used to search the National Library of Medicine (Medline via PubMed) for articles published up to December 2014, including the following terms: 'titanium–zirconium' OR 'Ti–Zr' OR 'Roxolid'. The electronic search was supplemented with a manual search of the following publications: *International Journal of Periodontics and*

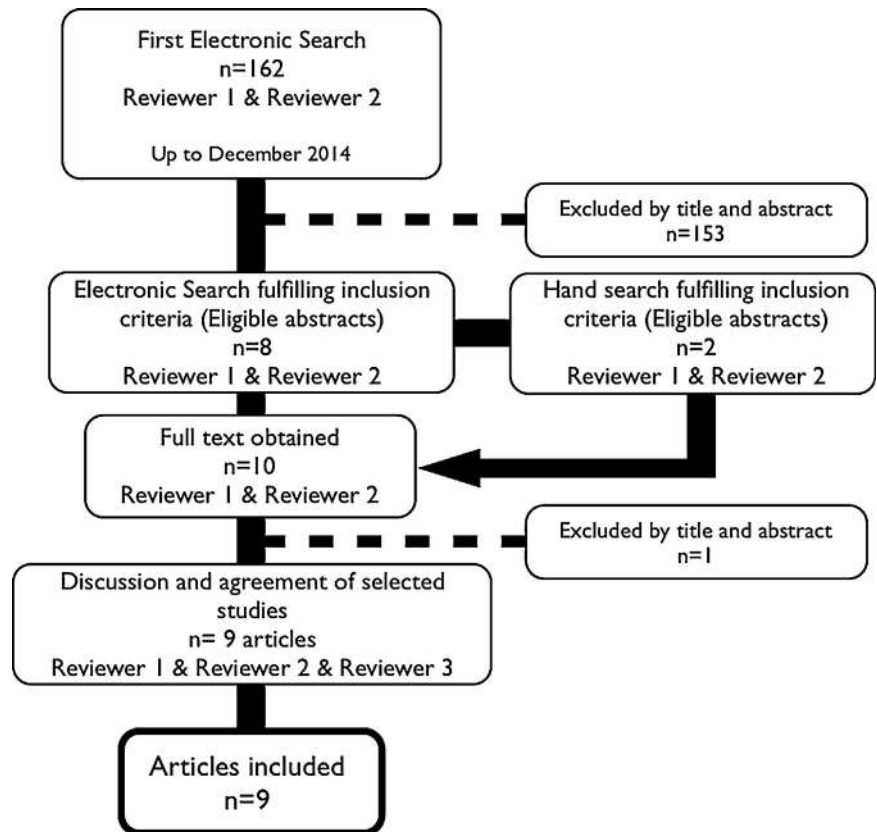


Fig. 1. Flow diagram describing the search strategy.

Restorative Dentistry, International Journal of Oral and Maxillofacial Implants, Journal of Periodontology, Implant Dentistry, Dentistry Today, Journal of Oral Implantology, Quintessence International, International Journal of Oral and Maxillofacial Surgery, Clinical Oral Implants Research, and Journal of Clinical Periodontology (Fig. 1).

The search resulted in a total of 162 hits from which eight abstracts were considered potentially relevant, while the manual search yielded two additional abstracts. Two reviewers (PA, EL) independently evaluated the abstracts against the inclusion and exclusion criteria, and the full-text articles were obtained. A third reviewer (JN) was consulted to confirm the eligibility of the selected articles.

Clinical (human) studies on Ti–Zr dental implants that fulfilled the following inclusion criteria were selected: (1) clinical studies of at least 10 treated patients; (2) prospective studies including randomized-controlled and non-randomized controlled studies and cohort studies; (3) retrospective studies including controlled studies, case-control studies, and single cohort studies; (4) a mean follow-up period of at least 6 months; (5) inclusion of data on the survival rate of the implants.

The following exclusion criteria were applied: (1) articles written in languages other than English; (2) review articles; (3) studies with fewer than 10 patients, or case reports; (4) a mean follow-up period of less than 6 months. The level of agreement between reviewers regarding study inclusion was calculated using the kappa value.

Data extraction

Full text data extraction was performed independently for each eligible article by at least two reviewers (PA, EL). The following variables were extracted from each study: author(s), year of publication, study design, total number of patients, inclusion and exclusion criteria, follow-up duration, study outcomes (survival and success rates, marginal bone loss (MBL), and peri-implant measurements), patient demographics, implant type and manufacturer, total number of implants placed and number of implants in each patient, failed implants, jaw segment, bone regeneration needs, prosthetic complications, and loading protocols.

The methodological quality of the studies included was evaluated by one reviewer (PA) with regard to study design,

randomization method, allocation concealment, blinding to the patient and examiner, and drop-out rates. In addition, the “Levels of evidence” document from the Centre for Evidence-Based Medicine was used to determine the qualitative validity.⁴⁰

Statistical analysis

Due to the heterogeneity of the articles, the difference in reported variables, and the inclusion of only two randomized controlled clinical trials, three objective outcomes could be extracted to perform the meta-analysis. The meta-analysis consisted of a weighted average for survival, success, and MBL, based on a random-effects model, with a confidence interval of 95%. The statistical analysis was performed using R 3.0.2 software (R Foundation for Statistical Computing, Vienna, Austria).

Results

The search of the Medline database via PubMed resulted in a total of nine articles that were considered. After assessment against the defined inclusion and exclusion criteria, nine articles were selected (Table 1). One RCT was excluded because an article with the same study population and a longer follow-up period was found.⁴¹ The overall proportion of inter-reviewer agreement was 100%, indicating an ‘excellent’ level of agreement.

Types of studies

The selected studies included the following study types: two randomized controlled trials,^{42,43} six prospective studies,^{38,44–48} and one retrospective study.⁴⁹ The studies reported cases of single-tooth gap, partial, or fully edentulous patients and implant placement in the anterior and posterior regions of both the maxilla and mandible (Table 1).

Implants and demographic data

All implants placed in the studies included in this review were manufactured by the same company from a Ti–Zr alloy (Roxolid; Institut Straumann AG). Tissue-level and bone-level implants were used, with a reduced implant diameter of 3.3 mm. Bone-level implants had a conical shape and a narrow cross-fit connection. Tissue-level implants had a cylindrical shape and a 4.8-mm platform, with a machined collar design. In contrast to titanium NDIs, Roxolid NDIs are recommended for the restoration of anterior and posterior teeth.

Table 1. Studies included in the review and the main results.

Author	Type of study	Number of patients	Number of implants	Number of failures	Type/area of edentulism	Mean bone loss	Follow-up	Survival Rate	Success Rate
Barter et al. (2012) ³⁸	Prospective single cohort	22	21	1	Mx/Md FPD	0.16 ± 0.42 (1Yr); 0.33 ± 0.54 (2Yr)	24	95.2%	95.2%
Chiapasco et al. (2012) ⁴⁴	Prospective	18	51	0	Mx/Md, SC, FPD, CPD, OD	Not reported (<1 mm)	Up to 24	100%	100%
Benic et al. (2013) ⁴²	Randomized Controlled Trial	40	20	0	Mx/Md, SC	0.22 ± 0.29 Ti; 0.29 ± 0.37 Ti-Zr (6m) 0.40 ± 0.53 Ti; 0.41 ± 0.56 Ti-Zr (1Yr)	12	100%	100%
Akça et al. (2013) ⁴⁶	Prospective single cohort	23	52	0	Mx/Md, SC, FPD, FCD, OD	0.315	Up to 24	100%	100%
Cordaro et al. (2013) ⁴⁹	Retrospective	10	40	0	Mx, OD	0.55 ± 0.50	Up to 16	100%	97.5%
Tolentino et al. (2014) ⁴⁵	Prospective	42	21	1	Mx/Post, SC	Not reported	12	95.2%	95.2%
Quirynen et al. (2015) ⁴³	Randomized Clinical Trial	75	75	1	Md, OD	0.57 ± 0.63 Ti; 0.58 ± 0.60 Ti-Zr (24m) 0.60 ± 0.71 Ti; 0.78 ± 0.75 Ti-Zr (36m)	36	98.7%	98.7%
Al-Nawas et al. (2015) ⁴⁷	Prospective non-interventional	357	603	10	Mx/Md, SC, FPD, FCD, OD	Reported, not standardized	24	97.6%	96.4%
Lambert et al. (2015) ⁴⁸	Prospective	20	39	2	Mx/Md, SC, FPD	0.35	12	94.7%	94.7%

Mx, maxilla; Md, mandible; SC, single crown; FPD, fixed partial denture; CPD, cantilevered fixed partial denture; FCD, fixed complete denture; OD, overdenture.

A total of 607 patients received 922 narrow diameter Ti–Zr implants. Follow-up ranged from 3 to 36 months (Table 1). The patients treated ranged in age from 21 to 76 years, and a higher proportion of women than men were treated in the studies.

Implant placement and loading protocols

Most of the studies followed early or delayed implant placement protocols according to the classification of Esposito et al.⁵⁰ Two articles included immediate implant placement.^{47,48} Early or delayed loading protocols as defined by Weber et al. in 2009 were mostly used.⁵¹ Immediate loading was only described in three articles.^{44,47,48}

Clinical outcomes

For this review, the clinical outcomes of the nine studies were evaluated in terms of the survival and success rates and MBL. Only one of the nine studies did not present well-defined success criteria.⁴² Reported survival rates ranged from 94.7% to 100% and success rates from 94.7% to 100%. Three articles presented a sample size of 20 patients.^{38,45,48} One implant failed in each test group in two articles and two implants in the other, causing a drop in the survival rate.

Three studies reported mean pocket probing depths, with values of 2.69 ± 0.8 mm,⁴⁹ 3.0 ± 0.74 mm,⁴⁵ and 2.9 ± 1.2 mm.⁴² Another study presented a mean probing pocket depth that ranged from 2.21 to 2.89 mm after two years of loading.³⁸ Mean MBL ranged from 0.16 ± 0.42 mm to 0.41 ± 0.56 mm at 1 year after implant placement, and from 0.33 ± 0.54 mm to 0.58 ± 0.60 mm at 2 years. Only one study reported MBL after 3 years of follow-up, with a value of 0.78 ± 0.75 mm (Table 1).⁴³

After normalization of the results, a weighted average was obtained with a confidence interval of 95% for survival, success, and mean MBL. At 12 months after implant placement, the survival and success rates of the 901 implants were 98.4% and 97.8%, respectively, and the MBL reported for 156 implants was 0.36 ± 0.06 mm. At 24 months, the survival and success rates of 676 implants were 97.7% and 97.3%, respectively, and the MBL reported for 148 implants was 0.41 ± 0.09 mm (Figs 2–7).

Surgical and prosthetic complications

Surgical complications described in these articles were limited to local inflammation

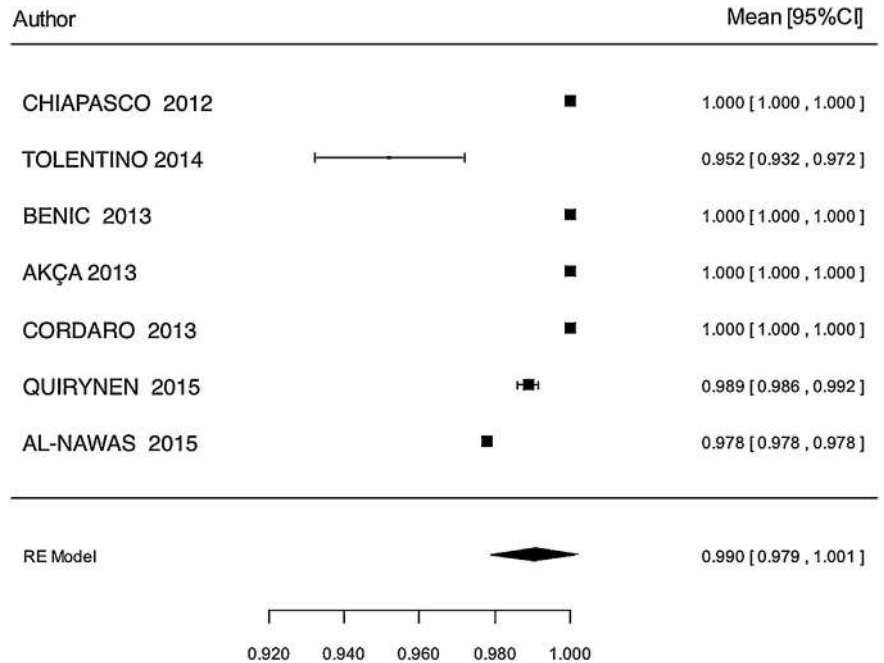


Fig. 2. Survival rates after 1 year.

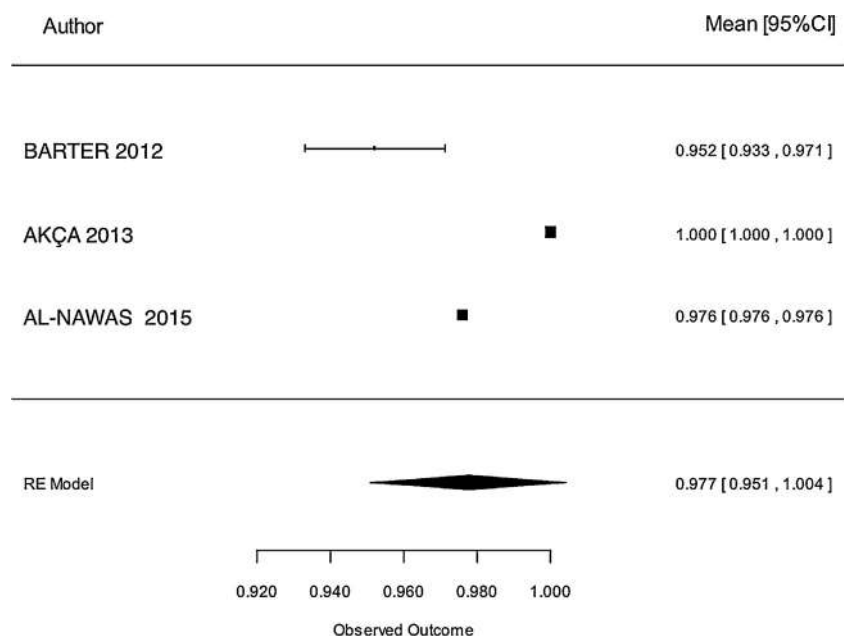


Fig. 3. Survival rates after 2 years.

in one patient.³⁸ In the other studies, no surgical complications occurred. Quirynen et al. reported five cases of minor inflammation during the healing phase.⁴³ No implant fractures occurred in the articles reviewed. The most frequently reported prosthetic complications in the study of Quirynen et al. were prosthesis fracture in nine cases (19%), loosening of a prosthetic component in three cases (6%), and prosthetic maintenance in three cases (6%).⁴³ In another study, four patients (18.2%) had prosthetic complications such

as abutment screw loosening.³⁸ An absence of mobility and no need for prosthesis repair was reported in one study.⁴⁵ There was a 100% prosthetic success rate in three studies.^{42,44,46} Prosthetic complications were not assessed in the other studies.

Bone regeneration needs

No bone regeneration was performed in three of the studies.^{43,45,46} Minor bone regeneration for small defects such as fenestrations or dehiscences was performed

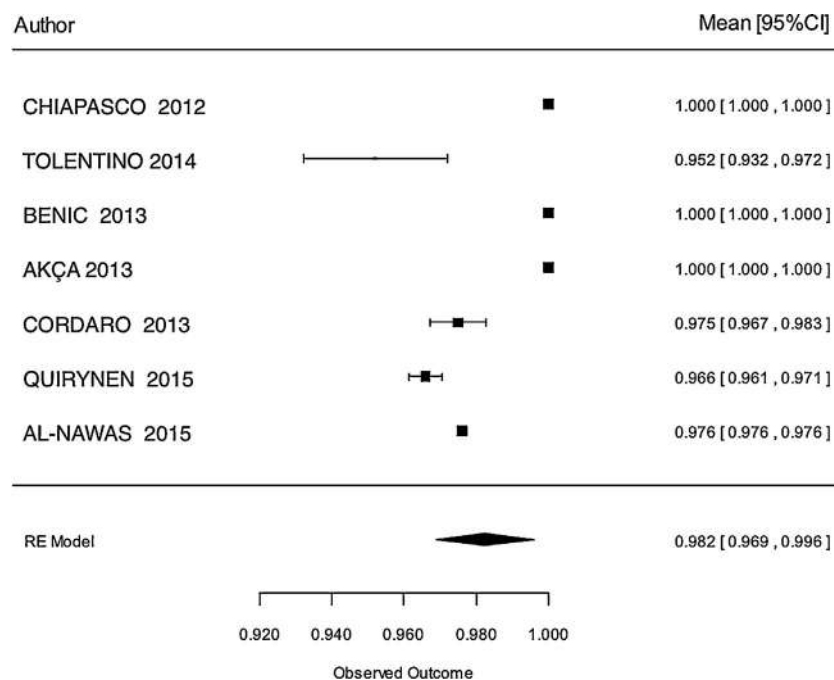


Fig. 4. Success rates after 1 year.

at the time of implant placement in two studies.^{38,42} In the study by Cordaro et al., bone regeneration was avoided in four out of 10 patients (40%) with the use of NDIs.⁴⁹ Another study, using immediately loaded NDIs in partially edentulous patients, reported the same outcome.⁴⁸ More than half of the patients (54%) avoided augmentation procedures in a non-interventional study.⁴⁷ Finally, bone regeneration was not

required in 11 out of 18 patients (61%) in a prospective study by Chiapasco et al.⁴⁴

Discussion

The use of Ti-Zr dental implants is well documented in several in vitro⁵²⁻⁵⁵ and experimental studies in animals,^{35,54,56-59} and these have shown similar results to

conventional grade IV titanium implants. The clinical evidence on Ti-Zr NDIs was analyzed in this review. The nine articles included here reported the use of 922 Ti-Zr NDIs in 607 patients, with a follow-up period of between 3 and 36 months. Very recently, Müller et al. reported the 5-year follow-up of a double-blind, controlled, randomized clinical trial comparing Ti-Zr with titanium NDIs in a split-mouth design.⁶⁰ The cumulative survival rate of 98.9% and bone level change of -0.60 mm confirmed the favourable results of Ti-Zr implants as presented 3 years after implant placement.⁴³

In most of the articles, the definition of a successful implant was that reported by Buser et al.⁶¹ In the studies included in the present review, all survival and success rates were high (94.7% to 100%) and similar to those reported for standard diameter implants.⁶²⁻⁶⁴

Two different designs of Ti-Zr implants were used, namely tissue-level and bone-level implants. Romeo et al. compared Straumann tissue-level implants with a reduced diameter (3.3 mm) with standard diameter implants (4.1 mm) and found no statistically significant difference in the MBL.²¹ In the randomized clinical trial by Quirynen et al., Ti-Zr bone-level implants were compared to titanium grade IV bone-level implants.⁴³ The MBL values were similar in the two groups, which is consistent with the results of this review. The MBLs for Ti-Zr NDIs with tissue-level and bone-level configurations were similar to those reported for titanium implants of similar designs.⁶²⁻⁶⁴

Ti-Zr NDIs were used in the anterior and posterior areas of both jaws and with all types of prosthetic designs. Although single tooth gaps in the anterior area with reduced mesiodistal space or a narrow alveolar ridge are the main indications described in the literature for the use of NDIs, other indications are also known. According to a recent systematic review, patients with a single tooth gap and those who are partially edentulous in the posterior areas can be treated with NDIs.¹¹

Kobayashi et al. compared the tensile strength of pure titanium, alloys containing Zr, and pure zirconium and reported 2.5- to 3-times higher tensile strength for Ti-Zr alloys.⁶⁵ In a recent study, the tensile strength of Ti-Zr, with a value of 953 MPa, was found to be approximately 40% greater than that of commercially pure titanium grade IV.⁶⁶ It seems clear that there is a risk of fracture when using NDIs, but that the risk can be minimized by choosing the strongest materials. The fracture of a tissue-level Roxolid NDI was

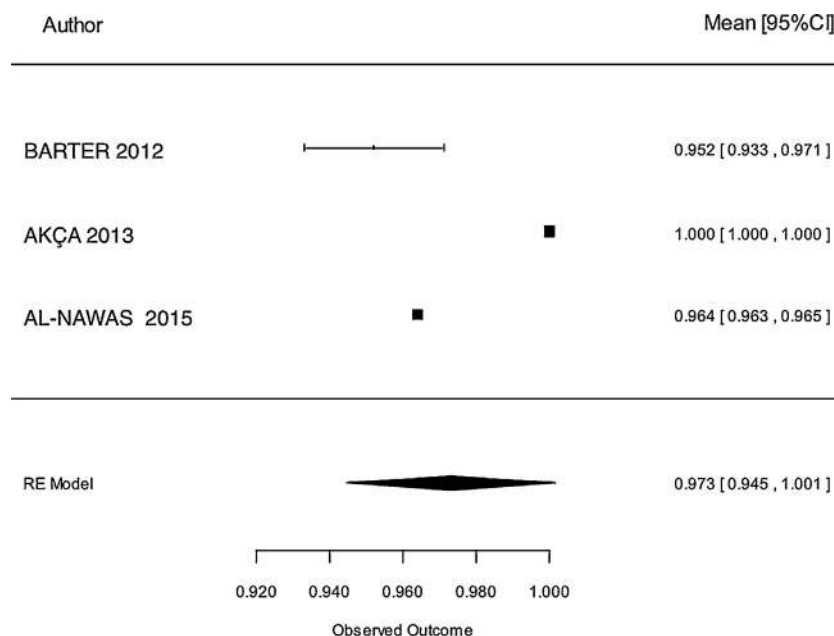


Fig. 5. Success rates after 2 years.

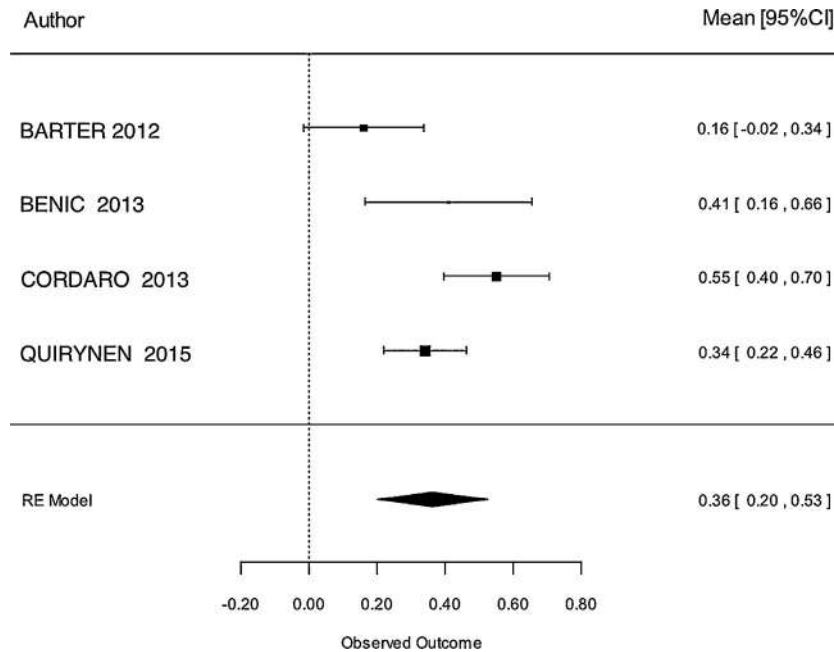


Fig. 6. Mean marginal bone loss after 1 year.

described recently.⁶⁷ In the clinical case presented, a single implant was placed in the canine area with a telescopic abutment to retain a removable partial denture. The reason for failure, according to the article, was mechanical overload and not following the manufacturer's indications for the use of NDIs. In the studies summarized in the current review, no fractures of the NDIs were described. Long-term follow-up data are needed for NDIs placed in load-bearing areas.

Immediate loading of the Ti–Zr implants was described in three of the studies. Only 3% of the cases were immediately loaded in one study,⁴⁷ and one patient received immediate loading in the study by Chiapasco et al.⁴⁴ Immediate loading was performed in all of the patients in one of the studies included, with a survival rate of 94.7% and a success rate of 94.7%, even though this is not routinely needed in daily practice.⁴⁸ One interesting fact about this latter study is

that immediate provisionalization was performed in conjunction with bone augmentation in 40% of the cases.

Bone augmentation is used widely and is considered to be a predictable technique to reconstruct a deficient alveolar ridge.^{8–10,68} One of the most interesting facts about NDIs is their potential ability to reduce the need for bone regeneration, because less residual bone is needed for implant insertion.^{69,70} Several authors have reported the placement of NDIs in compromised situations. In a prospective clinical trial, implants with a diameter of 3.5 mm were placed in edentulous patients with horizontal atrophy and followed for at least 1 year; the resulting survival and success rates were 100% and the MBL was 0.30 ± 0.13 mm.¹³ In another study, 3.3-mm TPS ITI implants were placed in partially and fully edentulous patients with an overall survival rate of 99.4% and success rate of 96.4% after 1 year of loading; the MBL was 0.35 ± 1.05 mm.⁷¹ Both of these studies showed similar results to those presented in this review. In a recent study by Papadimitriou et al., significantly less bone regeneration was needed when NDIs were planned for placement in edentulous patients.⁷² This was also described in the article by Chiapasco et al. included in this review, in which only seven out of 18 patients with horizontally deficient ridges required additional guided bone regeneration.⁴⁴ Lambert et al. found no need for bone regeneration at 40% of all implant sites, thus confirming that NDIs are a less invasive treatment option.⁴⁸

After evaluating grafting needs when using Ti–Zr NDIs, it is reasonable to expect an increase in patient satisfaction due to reduced complexity, costs, and duration of treatment. Accordingly, in a recent review by Pommer et al., minimally invasive treatment options such as flapless implant placement, short implants, or NDIs were compared to bone augmentation techniques. The evidence was limited, but it was concluded that patient satisfaction was generally higher with less bone grafting.⁷³ The quality and level of evidence was limited in general and with a high risk of bias, so caution is advised when interpreting these data.

In conclusion, narrow diameter Ti–Zr dental implants show high survival and success rates (>95%) and marginal bone level changes (<1 mm) that are comparable to those of regular diameter titanium implants in the short term (investigated follow-up periods of up to 36 months). The first results of the 5-year outcomes of Ti–Zr implants recently became available,

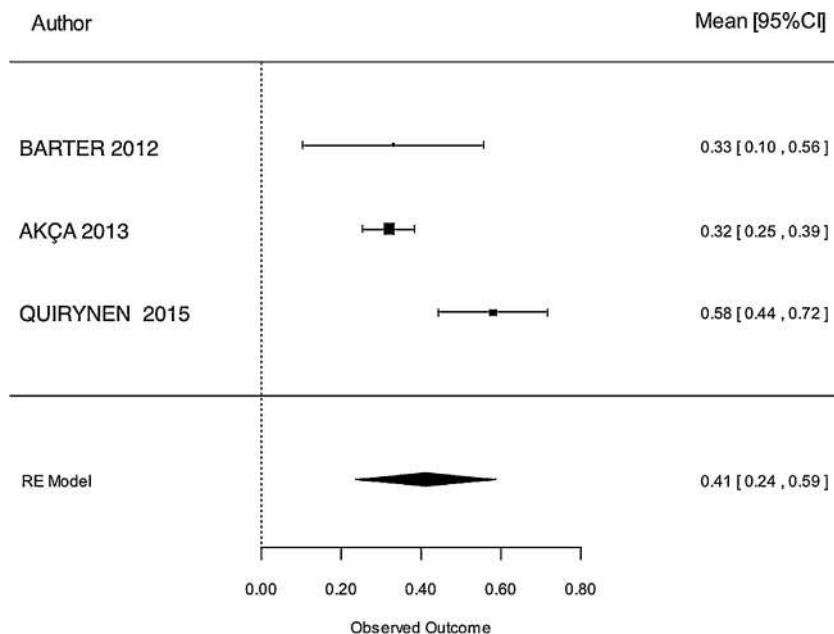


Fig. 7. Mean marginal bone loss after 2 years.

confirming the excellent clinical performance of Ti–Zr even after a longer period of follow-up.⁶⁰ Therefore, NDIs made from this new alloy, which has increased mechanical strength and excellent biocompatibility properties, appear to be a reliable treatment option to restore a reduced mesiodistal space, reduced crestal width (narrow ridge), and reduced amount of interradicular space. Arguably one of the most relevant benefits for the patient is the reduction in complexity, duration, and costs of treatment due to the less frequent requirement for bone grafting. If used as recommended, the new alloy implants appear to be a reliable treatment option. More long-term follow-up clinical data are needed to confirm the evidence in the present studies.

Funding

The article was self-funded.

Competing interests

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria, educational grants, participation in speakers' bureaus, membership, employment, consultancies, stock ownership, or other equity interests, and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

Ethical approval

Not required.

Patient consent

Not required.

Acknowledgements. The authors would like to thank Juan Luis Gómez Martínez and Salvador Taulé Ramirez for the statistical advice.

References

- Buser D, Janner SF, Wittneben JG, Bragger U, Ramseier CA, Salvi GE. 10-year survival and success rates of 511 titanium implants with a sandblasted and acid-etched surface: a retrospective study in 303 partially edentulous patients. *Clin Implant Dent Relat Res* 2012;**14**:839–51.
- Lekholm U, Grondahl K, Jemt T. Outcome of oral implant treatment in partially edentulous jaws followed 20 years in clinical function. *Clin Implant Dent Relat Res* 2006;**8**:178–86.
- Ravald N, Dahlgren S, Teiwik A, Grondahl K. Long-term evaluation of Astra Tech and Brånemark implants in patients treated with full-arch bridges. Results after 12–15 years. *Clin Oral Implants Res* 2013;**24**:1144–51.
- Ostman PO, Hellman M, Sennerby L. Ten years later. Results from a prospective single-centre clinical study on 121 oxidized (TiU-nite) Brånemark implants in 46 patients. *Clin Implant Dent Relat Res* 2012;**14**:852–60.
- Krebs M, Schmenger K, Neumann K, Weigl P, Moser W, Nentwig GH. Long-term evaluation of ANKYLOS(R) dental implants. Part I: 20-year life table analysis of a longitudinal study of more than 12,500 implants. *Clin Implant Dent Relat Res* 2015;**17**(Suppl. 1):e275–86.
- Fischer K, Stenberg T. Prospective 10-year cohort study based on a randomized controlled trial (RCT) on implant-supported full-arch maxillary prostheses. Part I: Sandblasted and acid-etched implants and mucosal tissue. *Clin Implant Dent Relat Res* 2012;**14**:808–15.
- Jemt T, Johansson J. Implant treatment in the edentulous maxillae: a 15-year follow-up study on 76 consecutive patients provided with fixed prostheses. *Clin Implant Dent Relat Res* 2006;**8**:61–9.
- Chiapasco M, Casentini P, Zaniboni M. Bone augmentation procedures in implant dentistry. *Int J Oral Maxillofac Implants* 2009;**24**(Suppl.):237–59.
- Jensen SS, Terheyden H. Bone augmentation procedures in localized defects in the alveolar ridge: clinical results with different bone grafts and bone-substitute materials. *Int J Oral Maxillofac Implants* 2009;**24**(Suppl.):218–36.
- Milinkovic I, Cordaro L. Are there specific indications for the different alveolar bone augmentation procedures for implant placement? A systematic review. *Int J Oral Maxillofac Surg* 2014;**43**:606–25.
- Klein MO, Schiegnitz E, Al-Nawas B. Systematic review on success of narrow-diameter dental implants. *Int J Oral Maxillofac Implants* 2014;**29**(Suppl.):43–54.
- Polizzi G, Fabbro S, Furri M, Herrmann I, Squarzonni S. Clinical application of narrow Brånemark system implants for single-tooth restorations. *Int J Oral Maxillofac Implants* 1999;**14**:496–503.
- Veltri M, Ferrari M, Balleri P. One-year outcome of narrow diameter blasted implants for rehabilitation of maxillas with knife-edge resorption. *Clin Oral Implants Res* 2008;**19**:1069–73.
- Davarpanah M, Martinez H, Tecucianu JF, Celletti R, Lazzara R. Small-diameter implants: indications and contraindications. *J Esthet Dent* 2000;**12**:186–94.
- Lee JS, Kim HM, Kim CS, Choi SH, Chai JK, Jung UW. Long-term retrospective study of narrow implants for fixed dental prostheses. *Clin Oral Implants Res* 2013;**24**:847–52.
- Froum SJ, Cho SC, Cho YS, Elian N, Tarnow D. Narrow-diameter implants: a restorative option for limited interdental space. *Int J Periodontics Restorative Dent* 2007;**27**:449–55.
- Andersen E, Saxegaard E, Knutsen BM, Haanaes HR. A prospective clinical study evaluating the safety and effectiveness of narrow-diameter threaded implants in the anterior region of the maxilla. *Int J Oral Maxillofac Implants* 2001;**16**:217–24.
- Allum SR, Tomlinson RA, Joshi R. The impact of loads on standard diameter, small diameter and mini implants: a comparative laboratory study. *Clin Oral Implants Res* 2008;**19**:553–9.
- Flanagan D. Fixed partial dentures and crowns supported by very small diameter dental implants in compromised sites. *Implant Dent* 2008;**17**:182–91.
- Quek CE, Tan KB, Nicholls JI. Load fatigue performance of a single-tooth implant abutment system: effect of diameter. *Int J Oral Maxillofac Implants* 2006;**21**:929–36.
- Romeo E, Lops D, Amorfini L, Chiapasco M, Ghisolfi M, Vogel G. Clinical and radiographic evaluation of small-diameter (3.3-mm) implants followed for 1–7 years: a longitudinal study. *Clin Oral Implants Res* 2006;**17**:139–48.
- Zinsli B, Sagesser T, Mericske E, Mericske-Stern R. Clinical evaluation of small-diameter ITI implants: a prospective study. *Int J Oral Maxillofac Implants* 2004;**19**:92–9.
- Shemtov-Yona K, Rittel D, Levin L, Machtei EE. Effect of dental implant diameter on fatigue performance. Part I: Mechanical behavior. *Clin Implant Dent Relat Res* 2014;**16**:172–7.
- Shemtov-Yona K, Rittel D, Machtei EE, Levin L. Effect of dental implant diameter on fatigue performance. Part II: Failure analysis. *Clin Implant Dent Relat Res* 2014;**16**:178–84.
- Ivanoff CJ, Sennerby L, Johansson C, Rangert B, Lekholm U. Influence of implant diameters on the integration of screw implants. An experimental study in rabbits. *Int J Oral Maxillofac Surg* 1997;**26**:141–8.
- Petrie CS, Williams JL. Comparative evaluation of implant designs: influence of diameter, length, and taper on strains in the alveolar crest. A three-dimensional finite-element analysis. *Clin Oral Implants Res* 2005;**16**:486–94.
- Parr GR, Gardner LK, Toth RW. Titanium: the mystery metal of implant dentistry. Dental materials aspects. *J Prosthet Dent* 1985;**54**:410–4.
- Calvo-Guirado JL, Gomez-Moreno G, Aguilar-Salvatierra A, Guardia J, Delgado-Ruiz RA, Romanos GE. Marginal bone loss evaluation around immediate non-occlusal

- microthreaded implants placed in fresh extraction sockets in the maxilla: a 3-year study. *Clin Oral Implants Res* 2015;**26**: 761–7.
29. Shapoff CA, Lahey B, Wasserlauf PA, Kim DM. Radiographic analysis of crestal bone levels around Laser-Lok collar dental implants. *Int J Periodontics Restorative Dent* 2010;**30**:129–37.
 30. De Leonardis D, Garg AK, Pecora GE. Osseointegration of rough acid-etched titanium implants: 5-year follow-up of 100 minimatic implants. *Int J Oral Maxillofac Implants* 1999;**14**:384–91.
 31. Steinemann SG. Titanium—the material of choice? *Periodontology* 1998;**2000**(17): 7–21.
 32. Khan MA, Williams RL, Williams DF. Conjoint corrosion and wear in titanium alloys. *Biomaterials* 1999;**20**:765–72.
 33. Olmedo DG, Tasat DR, Duffo G, Guglielmotti MB, Cabrini RL. The issue of corrosion in dental implants: a review. *Acta Odontol Latinoam* 2009;**22**:3–9.
 34. Okazaki Y, Gotoh E. Comparison of metal release from various metallic biomaterials in vitro. *Biomaterials* 2005;**26**:11–21.
 35. Saulacic N, Bosshardt DD, Bornstein MM, Berner S, Buser D. Bone apposition to a titanium–zirconium alloy implant, as compared to two other titanium-containing implants. *Eur Cell Mater* 2012;**23**:273–86. discussion 286–8.
 36. Han CH, Johansson CB, Wennerberg A, Albrektsson T. Quantitative and qualitative investigations of surface enlarged titanium and titanium alloy implants. *Clin Oral Implants Res* 1998;**9**:1–10.
 37. Johansson CB, Han CH, Wennerberg A, Albrektsson T. A quantitative comparison of machined commercially pure titanium and titanium–aluminum–vanadium implants in rabbit bone. *Int J Oral Maxillofac Implants* 1998;**13**:315–21.
 38. Barter S, Stone P, Bragger U. A pilot study to evaluate the success and survival rate of titanium–zirconium implants in partially edentulous patients: results after 24 months of follow-up. *Clin Oral Implants Res* 2012;**23**:873–81.
 39. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gotzsche PC, Ioannidis JP, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. *Br Med J* 2009;**339**: b2700.
 40. Centre for Evidence-Based Medicine. *Levels of evidence*. CEBM; 2009 <http://www.cebm.net/ocebml-levels-of-evidence/>. [Accessibility verified December 10, 2014].
 41. Al-Nawas B, Bragger U, Meijer HJ, Naert I, Persson R, Perucchi A, et al. A double-blind randomized controlled trial (RCT) of titanium–13zirconium versus titanium grade IV small-diameter bone level implants in edentulous mandibles—results from a 1-year observation period. *Clin Implant Dent Relat Res* 2012;**14**:896–904.
 42. Benic GI, Gallucci GO, Mokti M, Hammerle CH, Weber HP, Jung RE. Titanium–zirconium narrow-diameter versus titanium regular-diameter implants for anterior and premolar single crowns: 1-year results of a randomized controlled clinical study. *J Clin Periodontol* 2013;**40**:1052–61.
 43. Quirynen M, Al-Nawas B, Meijer HJ, Razavi A, Reichert TE, Schimmel M, et al. Small-diameter titanium grade IV and titanium–zirconium implants in edentulous mandibles: three-year results from a double-blind, randomized controlled trial. *Clin Oral Implants Res* 2015;**26**:831–40.
 44. Chiapasco M, Casentini P, Zaniboni M, Corsi E, Anello T. Titanium–zirconium alloy narrow-diameter implants (Straumann Roxolid(R)) for the rehabilitation of horizontally deficient edentulous ridges: prospective study on 18 consecutive patients. *Clin Oral Implants Res* 2012;**23**:1136–41.
 45. Tolentino L, Sukekava F, Seabra M, Lima LA, Garcez-Filho J, Araujo MG. Success and survival rates of narrow diameter implants made of titanium–zirconium alloy in the posterior region of the jaws—results from a 1-year follow-up. *Clin Oral Implants Res* 2014;**25**:137–41.
 46. Akca K, Cavusoglu Y, Uysal S, Cehreli MC. A prospective, open-ended, single-cohort clinical trial on early loaded titanium–zirconia alloy implants in partially edentulous patients: up-to-24-month results. *Int J Oral Maxillofac Implants* 2013;**28**:573–8.
 47. Al-Nawas B, Domagala P, Fragola G, Freiberger P, Ortiz-Vigon A, Rousseau P, et al. A prospective non-interventional study to evaluate survival and success of reduced diameter implants made from titanium–zirconium alloy. *J Oral Implantol* 2015;**41**: e118–25.
 48. Lambert F, Lecloux G, Grenade C, Bouhy A, Lamy M, Rompen E. Less invasive surgical procedures using narrow diameter implants: a prospective study in 20 consecutive patients. *J Oral Implantol* 2015;**41**: 693–9.
 49. Cordaro L, Torsello F, Mirisola di Torresanto V, Baricevic M. Rehabilitation of an edentulous atrophic maxilla with four unsplinted narrow diameter titanium–zirconium implants supporting an overdenture. *Quintessence Int* 2013;**44**:37–43.
 50. Esposito M, Grusovin MG, Polyzos IP, Felice P, Worthington HV. Timing of implant placement after tooth extraction: immediate, immediate-delayed or delayed implants? A cochrane systematic review. *Eur J Oral Implantol* 2010;**3**:189–205.
 51. Weber HP, Morton D, Gallucci GO, Rocuzzo M, Cordaro L, Grutter L. Consensus statements and recommended clinical procedures regarding loading protocols. *Int J Oral Maxillofac Implants* 2009;**24**(Suppl): 180–3.
 52. Sista S, Wen C, Hodgson PD, Pande G. The influence of surface energy of titanium–zirconium alloy on osteoblast cell functions in vitro. *J Biomed Mater Res A* 2011;**97**:27–36.
 53. Zhang YM, Chai F, Hornez JC, Li CL, Zhao YM, Trinsnel M, et al. The corrosion and biological behaviour of titanium alloys in the presence of human lymphoid cells and MC3T3-E1 osteoblasts. *Biomed Mater* 2009;**4**:015004.
 54. Ikarashi Y, Kaniwa MA, Tsuchiya T. Cytotoxicity of chemicals used in household products: 1997–2004. *Kokuritsu Iyakuhin Shokuhin Eisei Kenkyusho Hokoku* 2005;**123**:53–6.
 55. Samuel S, Nag S, Nasrazadani S, Ukirde V, El Bouanani M, Mohandas A, et al. Corrosion resistance and in vitro response of laser-deposited Ti–Nb–Zr–Ta alloys for orthopedic implant applications. *J Biomed Mater Res A* 2010;**94**:1251–6.
 56. Shibata N, Okuno O. Bone and fibrous tissue ingrowth into the porous Zr–Ti implants. *Dent Mater J* 1987;**6**:185–200.
 57. Thoma DS, Jones AA, Dard M, Grize L, Obrecht M, Cochran DL. Tissue integration of a new titanium–zirconium dental implant: a comparative histologic and radiographic study in the canine. *J Periodontol* 2011;**82**:1453–61.
 58. Gottlow J, Dard M, Kjellson F, Obrecht M, Sennerby L. Evaluation of a new titanium–zirconium dental implant: a biomechanical and histological comparative study in the mini pig. *Clin Implant Dent Relat Res* 2012;**14**:538–45.
 59. Schwarz F, Mihatovic I, Golubovic V, Eick S, Ighhaut T, Becker J. Experimental peri-implant mucositis at different implant surfaces. *J Clin Periodontol* 2014;**41**:513–20.
 60. Müller F, Al-Nawas B, Storelli S, Quirynen M, Hicklin S, Castro-Laza J, et al. Small-diameter titanium grade IV and titanium–zirconium implants in edentulous mandibles: five-year results from a double-blind, randomized controlled trial. *BMC Oral Health* 2015;**15**:123.
 61. Buser D, Weber HP, Lang NP. Tissue integration of non-submerged implants. 1-Year results of a prospective study with 100 ITI hollow-cylinder and hollow-screw implants. *Clin Oral Implants Res* 1990;**1**:33–40.
 62. Thoma DS, Sanz Martin I, Benic GI, Roos M, Hammerle CH. Prospective randomized controlled clinical study comparing two dental implant systems: demographic and radiographic results at one year of loading. *Clin Oral Implants Res* 2014;**25**:142–9.
 63. Buser D, Wittneben J, Bornstein MM, Grutter L, Chappuis V, Belser UC. Stability of contour augmentation and esthetic outcomes of implant-supported single crowns in the esthetic zone: 3-year results of a prospective study with early implant placement postextraction. *J Periodontol* 2011;**82**:342–9.
 64. Hammerle CH, Jung RE, Sanz M, Chen S, Martin WC, Jackowski J, et al. Submerged

- and transmucosal healing yield the same clinical outcomes with two-piece implants in the anterior maxilla and mandible: interim 1-year results of a randomized, controlled clinical trial. *Clin Oral Implants Res* 2012;**23**:211–9.
65. Kobayashi E, Matsumoto S, Doi H, Yoneyama T, Hamanaka H. Mechanical properties of the binary titanium–zirconium alloys and their potential for biomedical materials. *J Biomed Mater Res* 1995;**29**: 943–50.
 66. Grandin H, Berner S, Dard M. A review of titanium zirconium (TiZr) alloys for use in endosseous dental implants. *Materials* 2012;**5**:1348–60.
 67. Karl M, Krafft T, Kelly JR. Fracture of a narrow-diameter Roxolid implant: clinical and fractographic considerations. *Int J Oral Maxillofac Implants* 2014;**29**:1193–6.
 68. Aghaloo TL, Moy PK. Which hard tissue augmentation techniques are the most successful in furnishing bony support for implant placement. *Int J Oral Maxillofac Implants* 2007;**22**(Suppl.):49–70.
 69. Geckili O, Mumcu E, Bilhan H. Radiographic evaluation of narrow diameter implants after 5 years of clinical function: a retrospective study. *J Oral Implantol* 2011. [Epub ahead of print].
 70. Sohrabi K, Mushantat A, Esfandiari S, Feine J. How successful are small-diameter implants. A literature review. *Clin Oral Implants Res* 2012;**23**:515–25.
 71. Hallman M. A prospective study of treatment of severely resorbed maxillae with narrow nonsubmerged implants: results after 1 year of loading. *Int J Oral Maxillofac Implants* 2001;**16**:731–6.
 72. Papadimitriou DE, Friedland B, Gannam C, Salari S, Gallucci GO. Narrow-diameter versus standard-diameter implants and their effect on the need for guided bone regeneration: a virtual three-dimensional study. *Clin Implant Dent Relat Res* 2014. [Epub ahead of print].
 73. Pommer B, Mailath-Pokorny G, Haas R, Busenlechner D, Furhauser R, Watzek G. Patients' preferences towards minimally invasive treatment alternatives for implant rehabilitation of edentulous jaws. *Eur J Oral Implantol* 2014;**7**(Suppl. 2):S91–109.

Address:

Pablo Altuna

Department of Oral and Maxillofacial Surgery

School of Dentistry

Universitat Internacional de Catalunya

c/ Josep trueta s/n

08195 Sant Cugat del Vallès

Barcelona

Spain

Tel: +34 93 5042000

fax: +34 93 5042031

E-mail: altuna@uic.es