Success of dental implants in patients with large bone defect and analysis of risk factors for implant failure: a non-randomized retrospective cohort study

Hasegawa, Takumi ; Sasaki, Aki ; Saito, Izumi ; Arimoto, Satomi ; Yatagai, Nanae ; Hiraoka, Yujiro ; Takeda, Daisuke ; Kakei, Yasumasa ;…

(Citation)
Clinical Oral Investigations,26(3):2743-2750

(Issue Date)
2022-03

(Resource Type)
journal article

(Version)
Accepted Manuscript

Success of dental implants in patients with large bone defect and analysis of risk factors for implant failure: A non-randomized retrospective cohort study

Takumi Hasegawa, DDS, PhD [1*], Aki Sasaki, DDS [1], Izumi Saito, DDS, PhD [1], Satomi Arimoto, DDS, PhD [1], Nanae Yatagai, DDS, PhD [1], Yujiro Hiraoka, DDS [1], Daisuke Takeda, DDS, PhD [1], Yasumasa Kakei, DDS, PhD [1], Masaya Akashi, DDS, PhD [1]

[1] Department of Oral and Maxillofacial Surgery, Kobe University Graduate School of Medicine

*Corresponding author: Takumi Hasegawa, DDS, PhD, Department of Oral and Maxillofacial Surgery, Kobe University Graduate School of Medicine, 7-5-1, Kusunoki-cho, Chuo-ku, Kobe 650-0017, Japan. Tel: +81-78-382-6213 / Fax: +81-78-351-6229

E-mail: hasetaku@med.kobe-u.ac.jp

ABSTRACT

Objectives: This study aimed to retrospectively investigate the success and survival rates of dental implants used for dentomaxillary prostheses at our hospital and the risk factors associated with large bone defects.

Materials and Methods: 138 external joint system implants used for dentomaxillary prostheses in 40 patients with large bone defects were included in this study. The alveolar bone at the site of implant insertion was evaluated using panoramic radiography and computed tomography. Various risk factors (demographic characteristics, dental status, and operative factors such as the employment of alveolar bone augmentation, the site, the length, and diameter of implants) for implant failure and complete implant loss were investigated using univariate and multivariate analyses. The associations between the variables and the success and survival rates of dental implants were analyzed using the multivariate Cox proportional hazard models.

Results: The 10-year overall success and survival rates were 81.3% and 88.4% in this study. Multivariable analysis showed that the male sex (HR 6.22), shorter implants (≤ 8.5mm) (HR 5.21), and bone augmentation (HR 2.58) were independent predictors of success rate. Bone augmentation (HR 5.14) and narrow implants (≤ 3.3mm) (HR 3.86) were independent predictors of the survival rate.

Conclusion: Male sex, shorter or narrow implants, and bone augmentation were independent risk factors for dental implants used in dentomaxillary prostheses in patients with large bone defects.

Clinical Relevance: Clinicians should consider these risk factors and pay close attention to the management of these patients.

Key words: dental implant, failure, success, dentomaxillary prosthesis, oncologic patients

INTRODUCTION

Dental implants are widely used for prosthetic reconstruction for the loss of dentition, and their survival rate is high [1-4]. Dental implants have more advantages than conventional prosthetic treatments such as bridges and dentures. The successful placement of dental implants requires certain bone widths and heights [5]. Therefore, guided bone regeneration (GBR) and a prosthodontically correct are performed in patients with suboptimal local conditions such as less bone volume or an unfavorable interarch relationship. However, large bone defects can make the application of dental implants difficult in patients with periodontal disease, postatrophy, trauma, orthodontic treatment, and congenitally missing teeth such as resulting from a cleft palate and those receiving oral cancer treatment. In patients with trauma and post-treatment oral cancer, the bone and keratinized gingiva lack peri-implant tissue. Prosthetic rehabilitation with dental implants is being increasingly provided to patients with postoperative head and neck cancers [6-12]. Furthermore, implants have been used to improve the quality of life of patients [10, 11], with previous studies reporting survival rates of 67–100% [7-9, 11, 12].

The oral microbial ecosystem is already shaped in utero and prepares the infant for future microbial encounters [13]. The microbial colonization is codependent on proper gingival tissue structure and function [14]. In addition, the microbial biofilm tissue is shown to actively contribute to alveolar bone turnover [15]. Metal corrosion and tribocorrosion of dental implants affect the biofilm around the implant and lead to peri-implant inflammation and implant failure [16]. Several previous studies have focused on the survival rates of dental implants, determining whether the dental implants are removed [17-21]. Recently, the importance of the success rate of dental implants has been recognized [6, 22, 23]. The success of dental implants is determined by criteria such as persistent subjective complaints, peri-implant infection, and continuous bone loss [24]. However, these criteria for the success of dental implants were mainly adopted for non-oncologic patients without large bone defects [22, 23]. Therefore, there are controversies surrounding the relationships between some risk factors and the success rate of dental implants used for dentomaxillary prostheses in patients with large bone defects, including oncologic patients. In this study, the success and survival rates of dental implants used for dentomaxillary prostheses at our hospital and various risk factors in patients with large bone defects were retrospectively investigated.

MATERIALS & METHODS

This non-randomized retrospective cohort study was approved by the institutional ethics committee of the Kobe University Graduate School of Medicine (Authorization number: 210172). The requirement of informed consent from participants was waived, due to the observational nature of the study. Instead, the information about this study and granted opportunities for refusal to participate in this study were published. A total of 1,112 dental implants were placed by dentists at the Department of Oral and Maxillofacial Surgery, Kobe University Graduate School of Medicine, in 155 male patients and 181 female patients between July 2003 and April 2019; 138 dental implants used for dentomaxillary prostheses in 40 patients with large bone defect were included in this study. Transplanted bones such as the fibula, bone defects with oronasal communication, and large alveolar bone defects due to external factors were defined as a large bone defect in this study. Patients with defects of the skin, nose, or eyeballs requiring epithesis were excluded from this study. The reasons for the large bone defects are as follows: 38 patients underwent oral cancer surgery, one patient had trauma, and one patient had a congenital disease. The mean age of the patients was 69.3 ± 11.4 years (range: 44–90 years). The implants used were Brånemark System Mk III® TiUnite/Groovy (n=113) and KYOCERA system EMINEO® (n=26). Before surgery, each patient was informed about the possible complications, including the potential risks during the procedure. In 3 patients, the implantation was performed concurrently with tumor resection. The implantation was performed as a two-stage surgical procedure. 22 patients were fitted with removable prostheses with obturators in the maxilla with oronasal communication. All patients had implant-supported dentures with bars, magnets, or locator abutments. The success of an implant was based on the following criteria according to Buser et al. [24]: 1) absence of persistent subjective complaints such as pain, foreign body sensation, and/or dysesthesia; 2) absence of peri-implant infection with suppuration or mobility; and 3) absence of a continuous radiolucency around the implant. Implants with a history of acute infection with suppuration and progressive bone loss were classified as unsuccessful but surviving. The alveolar bone at the site of implant insertion was evaluated using panoramic radiography and computed tomography (CT). Radiologically, the marginal bone status was evaluated by single-tooth peri-apical radiographs, if possible. In panoramic radiography, the marginal bone status was calibrated by using the known width of the coronal cylinders of the implants. Marginal bone loss was measured using the distance from the implant shoulder to the marginal (mesial and distal) bone level. The axial plane of the medical CT images was set parallel to the occlusal plane, and continuous 0.625-mm slices were taken. Coronal and sagittal images were reconstructed from the raw data. The CT images were used supplementarily.

The predictive variables, including patient age, sex, smoking habits, general health (history of steroid treatment, diabetes mellitus, osteoporosis), history of radiation therapy, employment of alveolar bone augmentation, the site of implant insertion (incisal/molar), bone loss around the rest of the natural teeth, the type of tooth loss (intermediate or free end), the type of edentulousness (complete or partial), mechanical coupling between implants, and the length (≤ 8.5 or ≥ 10 mm) and diameter (≤ 3.3 or ≥ 3.75 mm) of implants, were investigated. The data were introduced into a multivariate Cox proportional hazard model; the dental implants were categorized based on their lengths (≤ 8.5 or ≥ 10 mm) and diameters (≤ 3.3 or ≥ 3.75 mm). The primary and secondary outcomes were the success and survival rates of dental implants, respectively. The endpoint was the failure of an implant, loss to follow-up, or April 2020. All the factors considered to affect the success and survival of dental implants are listed in Tables 1 and 2.

Statistical analysis

SPSS 22.0 (SPSS, Chicago, IL) and Ekuseru-Toukei 2012 (Social Survey Research Information Co., Ltd., Tokyo, Japan) were used for the statistical analyses. The associations between the variables and the success of dental implants were analyzed with Mann-Whitney U non-parametric test for ordinal variables and Fisher's exact test or the Chi-squared test for categorical variables. Cumulative success and survival rates were calculated using the Kaplan–Meier product-limit method. Significance among the curves was determined using the log-rank test. Probabilities of less than 0.05 were considered representative of significance. Histories of steroid treatment, diabetes mellitus, and osteoporosis were excluded from the multivariate analysis because there was no implant failure implant in these patients. All the variables associated with the success and survival rates were introduced into the multivariate Cox proportional hazard models. The hazard ratio (HR) and the 95% confidence intervals (CIs) were also calculated.

RESULTS

The mean follow-up duration for the surviving implants was 65.0 months (range: 12–179 months). Alveolar bone augmentation was performed for 42 implants (30.4%). The most common method of implantation was the sinus lift (27 implants, 19.6%) (Table 3). The fixture sizes are shown in Fig. 1. The most common fixture size selected was 3.75 mm for the diameter and 10 mm for the length (32 implants; 23.2%), followed by 3.75 mm for the diameter and 11.5 mm for the length (26 implants; 18.8%). The risk factors for implant failure and loss are shown in Tables 1 and 2. Univariate analysis showed that being male was a significant risk factor for implant failure ($p < 0.05$) (Table 1), and bone augmentation and the lack of mechanical coupling were significant risk factors for implant loss ($p < 0.05$) (Table 2). The other risk factors for implant failure and loss were not significant (Tables 1 and 2).

Multivariable Cox proportional hazard analysis showed that being a male (Hazard ratio, HR 6.22; 95% confidence interval, CI 1.76-22.03; P = 0.005), shorter implant length (≤ 8.5mm) (HR 5.21; 95% CI 1.98-13.7; P = 0.001), and bone augmentation (HR 2.58; 95% CI 1.05–6.3; P = 0.039) were independent predictors of success rate (Table 4). On the other hand, bone augmentation (HR 5.14; 95% CI 1.56-16.86; P = 0.007) and narrow implants (≤ 3.3mm) (HR 3.86; 95% CI 1.05-14.4; P = 0.043) were independent predictors of survival rate (Table 5).

Of the 138 dental implants, 21 failed, and the 10-year overall success rate was 81.3% in this study (Fig. 2); 13 were lost, and the 10-year overall survival rate was 88.4% in this study (Fig. 3). For the failure cases (not success), the median duration until implant failure was 17 months, with a range of 2–60 months. For the implants that were lost, 2 failed before loading, and 11 failed after loading. The median duration until implant loss was 17 months, with a range of 2–61 months. Eight of the 13 cases of complete loss of implants (61.5%) associated with the dentomaxillary prostheses seemed attributable to premature loading or overloading. The loss of two implants in the mandible before loading seemed attributable to heat-induced bone tissue injury. The loss of two implants before loading in the maxilla seemed attributable to poor primary stability. One implant was surgically removed during the treatment of a recurrent tumor.

DISCUSSION

In this retrospective study, the success and survival rates of dental implants used in dentomaxillary prostheses at our hospital and the risk factors associated with large bone defects were demonstrated. The importance of the success rate of dental implants has been recognized recently [6, 22, 23]. In the previous study, the 10-year overall survival and success rates of 907 Brånemark System Mk III® TiUnite/Groovy implants were 96.7% and 92.0% [4]. However, the success rates of dental implants were mainly reported for non-oncologic patients without large bone defects [22, 23]. Large bone defects can make the placement of dental implants difficult in patients with various diseases. The higher rate of failure in oncologic patients than in non-oncologic patients is attributed to the changes in oral anatomy and side effects [6]. In this study, the 10-year overall success and survival rates were 81.3% and 88.4%. In previous reports, the survival rates ranged from 67 to 100% [7-9, 11, 12]. Ettl et al. reported that the overall 2-year success rate was within the range of 78.6–87.6% [6]. The results of this study were similar to those of previous studies. Misch et al reported that the optimal success of implants classified into four groups focuses on pain, mobility, radiographic bone loss, and exudate history [23]. However, they suggested that the primary criteria for assessing the implant quality or health are pain and mobility. In this study, the cases of bone loss with a continuous radiolucency around the implant without clinical symptoms were classified as a failure. The use of an external joint system in this study may affect the marginal bone loss without clinical symptoms. Additionally, the case of an implant that was removed because of the treatment of a recurrent tumor was classified as a failure. Therefore, these reasons may result in a higher failure rate in this study.

In general, GBR is well-known as a predictable technique for dental implantation. The survival rate of dental implants placed in GBR sites ranged from 93.75% to 100% [25]. The success rate ranged from 61.5% to 100% [25]. However, some investigators have reported bone transplantation as a risk factor [6, 7, 26]. In this study, bone augmentation was an independent predictor of survival and success. Four (20.8 %) of the 13 lost dental implants were located in the fibular and scapular reconstruction flap. For transplanted bones, such as the fibula and scapula, the prosthodontic loading of dental implants caused by the thick soft tissue leads to inadequate height of the alveolar bone. Inadequate bone quality and bone resorption associated with the lack of blood supply causes implant failure [27]. In contrast, Attia et al. reported that the 1- and 11-year cumulative implant survival rates were 93% and 78% in vascularized fibula free flaps after mandibular reconstruction as excellent clinical outcomes [28]. Kramer et al. reported that the success rate was 96.1% in 51 dental implants of 16 patients who received free fibula grafts in a prospective study [12]. The management of soft tissue is necessary if the keratinized gingiva is lacking in the transplanted bone around the dental implants. Several investigators have reported the importance of keratinized gingiva for peri-implant health [29, 30]. In some reports, the presence of enough keratinized gingiva was beneficial for maintaining the marginal bone around the dental implants [30, 31]. Therefore, it is important to determine if the soft tissue and bone requirements are acceptable before applying dental implants to transplanted bone, although vestibuloplasties were often performed in combination with the placement of a free palatal gingival graft.

In this study, being male (HR 6.22) was an independent predictor of success rate. Various factors underlying the high failure rate of dental implants in male patients have been hypothesized. First, some studies have reported that men develop severe periodontal disease more frequently than women [32, 33]. Chrcanovic et al. suggested that an increase in the susceptibility to periodontitis may increase the susceptibility to peri-implantitis [34]. Second, the higher prevalence of smokers may contribute to the higher risk of dental implant failure in men than in women. Vervaeke et al. demonstrated that smoking and recall compliance were significant risk factors for dental implant failure and peri-implant bone loss [35]. However, smoking history and bone loss around the rest of the natural teeth were not independent predictors of success based on the univariate and multivariate analyses in this study. Third, the higher bite forces in men may be associated with a higher risk of dental implant failure. Repeated lateral bite forces on the superstructure of dental implants may cause loosening of the abutment screw that may result in marginal bone loss [36]. Under normal conditions, the overloading of dental implants may not be problematic. However, in oncologic patients with dentomaxillary prostheses, mucosal pressure support may be insufficient for bite force. Lastly, there are individual differences in the oral micro biofilm, which is already shaped in utero [13]. The microbial biofilm tissue affects the gingival tissue structure, function, and alveolar bone turnover [14, 15]. There is a distinct microbial signature in peri-implantitis, different from that in periodontitis [37]. Metal corrosion and tribocorrosion of the dental implant affect the peri-implant biofilm leading to peri-implant inflammation and implant failure [16]. Although the biological effects do not occur in all implant-carrying patients as biological responses are different in individuals, corrosion and tribocorrosion are important in determining the course of an implant. Therefore, in the future, investigation of peri-implant biofilms with consideration to implant-related environmental factors may lead to efficacious peri-implantitis therapies. However, these findings and speculations should be carefully considered because there may be several confounding factors.

Conceptually, short and narrow implants are often placed during compromised clinical situations. Short implants have limited areas of contact with bone and are susceptible to bone loss around dental implants because of the short length. The predictability of short implants is still controversial [38-40]. Some investigators have suggested the use of short implants instead of augmentation procedures in posterior sites with inadequate bone [38-40]. Conversely, Carosi et al. reported a slightly higher failure risk associated with short dental implants, compared with standard dental implants, placed after bone augmentation procedures in a meta-analysis [41]. Some previous studies have demonstrated lower predictability and higher failure rates of short implants [4, 42, 43]. In this study, the use of a shorter implant ($\leq$ 8.5mm) (HR 5.21) was an independent predictor of success. In cases of short implants, the diameter of the implant may play a role. Wider diameter implants have greater contact area between the implant surface and the surrounding bone [44]. As a result, mechanical stability and osseointegration improve. Some investigators have tried to reduce the stress dissipation in the crestal region and decrease the marginal bone loss by increasing the implant diameter [45-47]. In this study, all of the failed short implants were regular diameter (3.75 or 4 mm) implants. In addition, splinting short dental implants reduces the overloading and bone loss around the dental implants because of the reduction in occlusal stress [4, 48–50]. Therefore, wider diameter and splinting of implants may have to be considered when a short implant is inserted in patients with large bone defects. The predictability of an implant with a narrow diameter is still controversial. Some authors have reported that the use of narrow-diameter implants increases the risk of implant fracture [51, 52]. On the other hand, some recent studies have reported that implants with narrow diameters have success and survival rates similar to those of implants with longer diameters [53, 54]. Sánchez et al. reported implant survival rates above 90% in a literature review, and they concluded that narrow-diameter implants were predictable [55]. In this study, the use of a narrow implant ($\leq$ 3.3mm) (HR 3.86) was an independent predictor of survival. However, in this study, only 3 narrow-diameter implants were lost, and 2 of the 3 completely lost implants were inserted in the scapular bone with 66 Gy of radiation. Therefore, the risk of narrow-diameter implants should be carefully considered because of the small population.

This study was limited by its non-randomized, retrospective nature, which meant that other risk factors, such as indices of oral hygiene and years of operator experience, could not be examined. Two different implant systems were used in this study, although with the same external joint system. In addition, there was a complexity of defect morphology and non-uniform prosthetic treatment due to the large bone defect. Therefore, the possibility of selection bias could not be completely excluded, although a multivariate analysis was performed to decrease the effect of the confounding factors as much as possible. A large-scale, prospective cohort study is needed to evaluate the predictors of the success of the dental implants used in dentomaxillary prostheses in patients with large bone defects.

In conclusion, the success and survival rates of dental implants used in dentomaxillary prostheses and the various risk factors in patients with large bone defects were demonstrated in this study. Multivariable analysis showed that being male (HR 6.22), the use of shorter implants (≤ 8.5mm) (HR 5.21), and bone augmentation (HR 2.58) were independent predictors of success; bone augmentation (HR 5.14) and the use of narrow implants (≤ 3.3mm) (HR 3.86) were independent predictors of survival. The findings of this study will contribute to the successful treatment of patients with large bone defects by dentists using dental implants for dentomaxillary prostheses.

Declarations

Compliance with Ethical Standards

Conflict of Interest: Takumi Hasegawa, Aki Sasaki, Izumi Saito, Satomi Arimoto, Nanae Yatagai, Yujiro Hiraoka, Daisuke Takeda, Yasumasa Kakei, and Masaya Akashi declare that they have no conflict of interest.

Funding: We received no sources of study funding, including those of an institutional or departmental nature.

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: For this type of study, formal consent is not required. Informed consent from participants was waived, due to the observational nature study. Instead, the information regarding this study and granted occasions of refusing to participate in this study were published.

AUTHOR CONTRIBUTIONS

Study design: T Hasegawa, D Takeda, Y Kakei, M Akashi

Acquisition of data: T Hasegawa, A Sasaki, I Saito, S Arimoto, N Yatagai, Y Hiraoka

Analysis and interpretation of data: T Hasegawa, S Arimoto, D Takeda, Y Kakei

Writing original draft: T Hasegawa

Writing - review & editing: S Arimoto, N Yatagai, D Takeda, Y Kakei, M Akashi

Statistical analysis: T Hasegawa

Supervision: M Akashi

Project administration: T Hasegawa, M Akashi

Funding acquisition: M Akashi

REFERENCES

[1] Busenlechner D, Fürhauser R, Haas R, Watzek G, Mailath G, Pommer B (2014) Long-term implant success at the Academy for Oral Implantology: 8-year follow-up and risk factor analysis. J Periodontal Implant Sci. 44(3):102-8.

[2] Charyeva O, Altynbekov K, Zhartybaev R, Sabdanaliev A (2012) Long-term dental implant success and survival--a clinical study after an observation period up to 6 years. Swed Dent J. 36(1):1-6.

[3] Wittneben JG, Millen C, Brägger U (2014) Clinical performance of screw- versus cement-retained fixed implant-supported reconstructions--a systematic review. Int J Oral Maxillofac Implants. Suppl:84-98.

[4] Hasegawa T, Kawabata S, Takeda D, Iwata E, Saito I, Arimoto S, Kimoto A, Akashi M, Suzuki H, Komori T (2017) Survival of Branemark System Mk III implants and analysis of risk factors associated with implant failure. Int J Oral Maxillofac Surg. 46(2):267-273.

[5] Chiapasco M, Zaniboni M, Boisco M (2006) Augmentation procedures for the rehabilitation of deficient edentulous ridges with oral implants. Clin Oral Implants Res. Suppl 2:136-59.

[6] Ettl T, Junold N, Zeman F, Hautmann M, Hahnel S, Kolbeck C, Müller S, Klingelhöffer C, Reichert TE, Meier JK (2020) Implant survival or implant success? Evaluation of implant-based prosthetic rehabilitation in head and neck cancer patients-a prospective observational study. Clin Oral Investig. 24(9):3039-3047.

[7] Hessling SA, Wehrhan F, Schmitt CM, Weber M, Schlittenbauer T, Scheer M (2015) Implant-based rehabilitation in oncology patients can be performed with high long-term success. J Oral Maxillofac Surg. 73(5):889-96.

[8] Javed F, Al-Hezaimi K, Al-Rasheed A, Almas K, Romanos GE (2010) Implant survival rate after oral cancer therapy: a review. Oral Oncol. 46(12):854-9.

[9] Fierz J, Hallermann W, Mericske-Stern R (2013) Patients with oral tumors. Part 1: Prosthetic rehabilitation following tumor resection. Schweiz Monatsschr Zahnmed. 123(2):91-105.

[10] Fierz J, Bürgin W, Mericske-Stern R (2013). Patients with oral tumors. Part 2: Quality of life after treatment with resection prostheses. Resection prosthetics: evaluation of quality of life. Schweiz Monatsschr Zahnmed 123(3):180-91.

[11] Katsoulis J, Fierz J, Iizuka T, Mericske-Stern R (2013) Prosthetic rehabilitation, implant survival and quality of life 2 to 5 years after resection of oral tumors. Clin Implant Dent Relat Res. 15(1):64-72.

[12] Kramer FJ, Dempf R, Bremer B (2005) Efficacy of dental implants placed into fibula-free flaps for orofacial reconstruction Clin Oral Implants Res. 16(1):80-8.

[13] Kaan AMM, Kahharova D, Zaura E (2021) Acquisition and establishment of the oral microbiota. Periodontol 2000. 86(1):123-141.

[14] Darveau RP, Curtis MA (2021) Oral biofilms revisited: A novel host tissue of bacteriological origin. Periodontol 2000. 86(1):8-13.

[15] Hathaway-Schrader JD, Novince CM (2021) Maintaining homeostatic control of periodontal bone tissue. Periodontol 2000. 86(1):157-187.

[16] Kotsakis GA, Olmedo DG (2021) Peri-implantitis is not periodontitis: Scientific discoveries shed light on microbiome-biomaterial interactions that may determine disease phenotype. Periodontol 2000. 86(1):231-240.

[17] Shaw RJ, Sutton AF, Cawood JI, Howell RA, Lowe D, Brown JS, Rogers SN, Vaughan ED (2005) Oral rehabilitation after treatment for head and neck malignancy. Head Neck. 27(6):459-70.

[18] Yerit KC, Posch M, Seemann M, Hainich S, Dortbudak O, Turhani D, Ozyuvaci H, Watzinger F, Ewers R (2006) Implant survival in mandibles of irradiated oral cancer patients. Clin Oral Implants Res. 17(3):337-44.

[19] Nelson K, Heberer S, Glatzer C (2007) Survival analysis and clinical evaluation of implant-retained prostheses in oral cancer resection patients over a mean follow-up period of 10 years. J Prosthet Dent. 98(5):405-10.

[20] Schliephake H, Neukam FW, Schmelzeisen R, Wichmann M (1999) Long-term results of endosteal implants used for restoration of oral function after oncologic surgery. Int J Oral Maxillofac Surg. 28(4):260-5.

[21] Watzinger F, Ewers R, Henninger A, Sudasch G, Babka A, Woelfl G (1996) Endosteal implants in the irradiated lower jaw. J Craniomaxillofac Surg. 24(4):237-44.

[22] Papaspyridakos P, Chen CJ, Singh M, Weber HP, Gallucci GO (2012) Success criteria in implant

dentistry: a systematic review. J Dent Res. 91(3):242-8.

[23] Misch CE, Perel ML, Wang HL, Sammartino G, Galindo-Moreno P, Trisi P, Steigmann M, Rebaudi A, Palti A, Pikos MA, Schwartz-Arad D, Choukroun J, Gutierrez-Perez JL, Marenzi G, Valavanis DK (2008) Implant success, survival, and failure: the International Congress of Oral Implantologists (ICOI) Pisa Consensus Conference. Implant Dent. 17(1):5-15.

[24] Buser D, Janner SF, Wittneben JG, Brägger U, Ramseier CA, Salvi GE (2012) 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. 14(6):839-51.

[25] Clementini M, Morlupi A, Canullo L, Agrestini C, Barlattani A (2012) Success rate of dental implants inserted in horizontal and vertical guided bone regenerated areas: a systematic review. Int J Oral Maxillofac Surg. 41(7):847-52.

[26] Schiegnitz E, Al-Nawas B, Kämmerer PW, Grötz KA (2014) Oral rehabilitation with dental implants in irradiated patients: a meta-analysis on implant survival. Clin Oral Investig. 18(3):687-98.

[27] Hessling SA, Wehrhan F, Schmitt CM, Weber M, Schlittenbauer T, Scheer M (2015) Implant-based rehabilitation in oncology patients can be performed with high long-term success. J Oral Maxillofac Surg. 73(5):889-96.

[28] Attia S, Wiltfang J, Pons-Kühnemann J, Wilbrand JF, Streckbein P, Kähling C, Howaldt HP, Schaaf H (2018) Survival of dental implants placed in vascularised fibula free flaps after jaw reconstruction. J Craniomaxillofac Surg 46(8):1205-1210.

[29] Perussolo J, Souza AB, Matarazzo F, Oliveira RP, Araújo MG (2018) Influence of the keratinized mucosa on the stability of peri-implant tissues and brushing discomfort: A 4-year follow-up study. Clin Oral Implants Res. 29(12):1177-1185.

[30] Suárez-López Del Amo F, Lin GH, Monje A, Galindo-Moreno P, Wang HL (2016) Influence of Soft Tissue Thickness on Peri-Implant Marginal Bone Loss: A Systematic Review and Meta-Analysis. J Periodontol. 87(6):690-9.

[31] Thoma DS, Naenni N, Figuero E, Hämmerle CHF, Schwarz F, Jung RE, Sanz-Sánchez I (2018) Effects of soft tissue augmentation procedures on peri-implant health or disease: A systematic review and

meta-analysis. Clin Oral Implants Res. Suppl 15:32-49.

[32] McGrath C, Bedi R (2003) Measuring the impact of oral health on quality of life in Britain using OHQoL-UK(W). J Public Health Dent. 63(2):73-7.

[33] Shiau HJ, Reynolds MA (2010) Sex differences in destructive periodontal disease: exploring the biologic basis. J Periodontol. 81(11):1505-17.

[34] Chrcanovic BR, Albrektsson T, Wennerberg A (2015) Dental implants inserted in male versus female patients: a systematic review and meta-analysis. J Oral Rehabil. 42(9):709-22.

[35] Vervaeke S, Collaert B, Cosyn J, Deschepper E, De Bruyn H (2015) A multifactorial analysis to identify predictors of implant failure and peri-implant bone loss. Clin Implant Dent Relat Res. Suppl 1:e298-307.

[36] Katsuta Y, Watanabe F (2015) Abutment screw loosening of endosseous dental implant body/abutment joint by cyclic torsional loading test at the initial stage. Dent Mater J. 34(6):896-902.

[37] Dabdoub SM, Tsigarida AA, Kumar PS (2013) Patient-specific analysis of periodontal and peri-implant microbiomes. J Dent Res. 92(12 Suppl):168S-75S.

[38] Srinivasan M, Vazquez L, Rieder P, Moraguez O, Bernard JP, Belser UC (2014) Survival rates of short (6 mm) micro-rough surface implants: a review of literature and meta-analysis. Clin Oral Implants Res. 25(5):539-45.

[39] Esposito M, Buti J, Barausse C, Gasparro R, Sammartino G, Felice P (2019) Short implants versus longer implants in vertically augmented atrophic mandibles: A systematic review of randomised controlled trials with a 5-year post-loading follow-up. Int J Oral Implantol (Berl). 12(3):267-280.

[40] Bitaraf T, Keshtkar A, Rokn AR, Monzavi A, Geramy A, Hashemi K (2019) Comparing short dental implant and standard dental implant in terms of marginal bone level changes: A systematic review and meta-analysis of randomized controlled trials. Clin Implant Dent Relat Res. 21(4):796-812.

[41] Carosi P, Lorenzi C, Lio F, Laureti M, Ferrigno N, Arcuri C (2012) Short implants (≤6mm) as an alternative treatment option to maxillary sinus lift. Int J Oral Maxillofac Surg. S0901-5027(21)00055-2. doi: 10.1016/j.ijom.2021.02.014. Online ahead of print.

[42] Papaspyridakos P, De Souza A, Vazouras K, Gholami H, Pagni S, Weber HP (2018) Survival rates of short dental implants (≤6 mm) compared with implants longer than 6 mm in posterior jaw areas: A

meta-analysis. Clin Oral Implants Res. Suppl 16:8-20.

[43] Vazouras K, de Souza AB, Gholami H, Papaspyridakos P, Pagni S, Weber HP (2020) Effect of time in function on the predictability of short dental implants (≤6 mm): A meta-analysis. J Oral Rehabil. 47(3):403-415.

[44] Chang SH, Lin CL, Hsue SS, Lin YS, Huang SR (2012) Biomechanical analysis of the effects of implant diameter and bone quality in short implants placed in the atrophic posterior maxilla. Med Eng Phys. 34(2):153-60.

[45] Himmlová L, Dostálová T, Kácovský A, Konvicková S (2004) Influence of implant length and diameter on stress distribution: a finite element analysis. J Prosthet Dent 91(1):20–25.

[46] Anitua E, Tapia R, Luzuriaga F, Orive G (2010) Influence of implant length, diameter, and geometry on stress distribution: a finite element analysis. Int J Periodontics Restorative Dent 30(1):89–95.

[47] Baggi L, Cappelloni I, Di Girolamo M, Maceri F, Vairo G (2008) The influence of implant diameter and length on stress distribution of osseointegrated implants related to crestal bone geometry: a three-dimensional finite element analysis. J Prosthet Dent 100(6):422–431.

[48] Guichet DL, Yoshinobu D, Caputo AA (2002) Effect of splinting and interproximal contact tightness on load transfer by implant restorations. J Prosthet Dent. 87(5):528-35.

[49] Naert I, Koutsikakis G, Duyck J, Quirynen M, Jacobs R, van Steenberghe D (2002) Biologic outcome of implant-supported restorations in the treatment of partial edentulism. part I: a longitudinal clinical evaluation. Clin Oral Implants Res. 13(4):381-9.

[50] Bergkvist G, Simonsson K, Rydberg K, Johansson F, Dérand T (2008) A finite element analysis of stress distribution in bone tissue surrounding uncoupled or splinted dental implants. Clin Implant Dent Relat Res. 10(1):40-6.

[51] Schwarz MS (2000) Mechanical complications of dental implants. Clin Oral Implants Res. Suppl 1:156-8.

[52] Allum SR, Tomlinson RA, Joshi R (2008) The impact of loads on standard diameter, small diameter and mini implants: a comparative laboratory study. Clin Oral Implants Res. 19(6):553-9.

[53] Sohrabi K, Mushantat A, Esfandiari S, Feine J (2012) How successful are small-diameter implants? A

literature review. Clin Oral Implants Res. 23(5):515-25.

[54] Degidi M, Piattelli A, Carinci F (2008) Clinical outcome of narrow diameter implants: a retrospective study of 510 implants. J Periodontol. 79(1):49-54.

[55] González-Valls G, Roca-Millan E, Céspedes-Sánchez JM, González-Navarro B, Torrejon-Moya A, López-López J (2021) Narrow Diameter Dental Implants as an Alternative Treatment for Atrophic Alveolar Ridges. Systematic Review and Meta-Analysis. Materials (Basel). 14(12):3234.

TABLE CAPTIONS

Table 1 Factors affecting the success rates of implants

Table 2 Factors affecting the survival of implants

Table 3 Methods of alveolar bone augmentation

Table 4 Results of multivariate Cox proportional hazards analysis of predictors of the success of dental implants

Table 5 Results of multivariate Cox proportional hazards analysis of predictors of the survival of dental implants

FIGURE CAPTIONS

Fig. 1 Implant size

Fig. 2 Overall success rate

Fig. 3 Overall survival rate

FIGURE LEGENDS: None

Table 1. Factors affecting the success rates of implants

Variables	Success n (%)	Failure n (%)	P value
Sample size (dental implants)	117 (84.8)	21 (15.2)	
Sex			
Male	65 (55.6)	18 (85.7)	0.014 *
Female	52 (44.4)	3 (14.3)	
Age			
Range (Years)	44–90	44–83	
Mean ± SD	68.5 ± 12.2	67.9 ± 10.5	0.801 **
Smoking			
No	90 (76.9)	14 (66.7)	0.409 *
Yes	27 (23.1)	7 (33.3)	
Steroid therapy			
No	117 (100.0)	21 (100.0)	N/A
Yes	0 (0)	0 (0)	
Diabetes Mellitus			
No	100 (85.5)	20 (95.2)	0.309 *
Yes	17 (14.5)	1 (4.8)	
Osteoporosis			
No	101 (86.3)	21 (100.0)	0.131 *
Yes	16 (13.7)	0 (0)	
Radiation therapy			
No	105 (89.7)	19 (90.5)	1.000 *
Yes	12 (10.3)	2 (9.5)	
The type of edentulous			
Completely	84 (71.8)	11 (52.4)	0.122 *
Partially	33 (28.2)	10 (47.6)	
The type of tooth loss			
Intermediate missing	19 (16.2)	4 (19.0)	0.753 *
Free end missing	98 (83.8)	17 (81.0)	
The site of dental implants			
Maxilla	74 (63.3)	10 (47.6)	0.226 *
Mandible	43 (36.8)	11 (52.4)	
The region of dental implants			
Incisal	52 (44.4)	11 (52.4)	0.635 *

Molar	65 (55.6)	10 (47.6)	
Bone augmentation			
No	84 (71.8)	12 (57.1)	0.202 *
Yes	33 (28.2)	9 (42.9)	
Mechanical coupling between implants			
Separated	48 (41.0)	12 (57.1)	0.134 *
Coupled	66 (56.4)	7 (33.3)	
Unknown	3 (2.6)	2 (9.5)	
Length of dental implants			
≤ 8.5 mm	21 (17.9)	9 (42.9)	0.078 *
≥ 10 mm	96 (82.1)	12 (57.1)	
Diameter of dental implants			
≤ 3.3 mm	10 (8.5)	3 (14.3)	0.418 *
≥ 3.75 mm	107 (91.5)	18 (85.7)	
Bone loss around rest natural tooth			
No	19 (8.5)	1 (14.3)	0.418 *
Yes	98 (91.5)	20 (85.7)	

*: Fisher's exact test. **: Mann–Whitney U test. ***: Chi-squared test. N/A: not applicable

Table 2. Factors affecting the survival of implants

Variables	Survival n (%)	Loss n (%)	P value
Sample size (dental implants)	125 (90.6)	13 (9.4)	
Sex			
Male	73 (58.4)	10 (76.9)	0.244 *
Female	52 (41.6)	3 (23.1)	
Age			
Range (Years)	44–90	63–83	
Mean ± SD	68.2 ± 12.3	70.9 ± 7.1	0.512 **
Smoking			
No	96 (76.8)	8 (61.5)	0.307 *
Yes	29 (23.2)	5 (38.5)	
Steroid therapy			
No	125 (100.0)	13 (100.0)	N/A
Yes	0 (0)	0 (0)	
Diabetes Mellitus			
No	107 (85.6)	13 (100.0)	0.217 *
Yes	18 (14.4)	0 (0)	
Osteoporosis			
No	109 (87.2)	13 (100.0)	0.363 *
Yes	16 (12.8)	0 (0)	
Radiation therapy			
No	113 (90.4)	11 (84.6)	0.622 *
Yes	12 (9.6)	2 (15.4)	
The type of edentulous			
Completely	84 (71.8)	11 (52.4)	0.122 *
Partially	33 (28.2)	10 (47.6)	
The type of tooth loss			
Intermediate missing	23 (18.4)	0 (0)	0.125 *
Free end missing	102 (81.6)	13 (100.0)	
The site of dental implants			
Maxilla	77 (61.6)	7 (53.8)	0.397 *
Mandible	48 (38.4)	6 (46.2)	
The region of dental implants			
Incisal	59 (47.2)	4 (30.8)	0.382 *

Molar	66 (52.8)	9 (69.2)	
Bone augmentation			
No	84 (71.8)	12 (57.1)	0.003 *
Yes	33 (28.2)	9 (42.9)	
Mechanical coupling between implants			
Separated	54 (43.2)	9 (69.2)	0.024 *
Coupled	71 (56.8)	2 (15.4)	
Unknown	0 (0)	2 (15.4)	
Length of dental implants			
≤ 8.5 mm	21 (17.9)	9 (42.9)	0.763 *
≥ 10 mm	96 (82.1)	12 (57.1)	
Diameter of dental implants			
≤ 3.3 mm	10 (8.5)	3 (14.3)	0.107 *
≥ 3.75 mm	107 (91.5)	18 (85.7)	
Bone loss around rest natural tooth			
No	19 (15.2)	1 (7.7)	0.692 *
Yes	106 (84.8)	12 (92.3)	

*: Fisher's exact test. **: Mann–Whitney U test. ***: Chi-squared test. N/A: not applicable

Table 3. Methods of alveolar bone augmentation

Methods	Number of dental implants n (%)
None	96 (69.6)
Sinus lift	27 (19.6)
Reconstruction of fibula flap	8 (5.8)
Guided bone regeneration	3 (2.2)
Indirect sinus lift	2 (1.4)
Reconstruction of scapular flap	2 (1.4)

Table 4. Results of multivariate Cox proportional hazards analysis of predictors of the success of dental implants

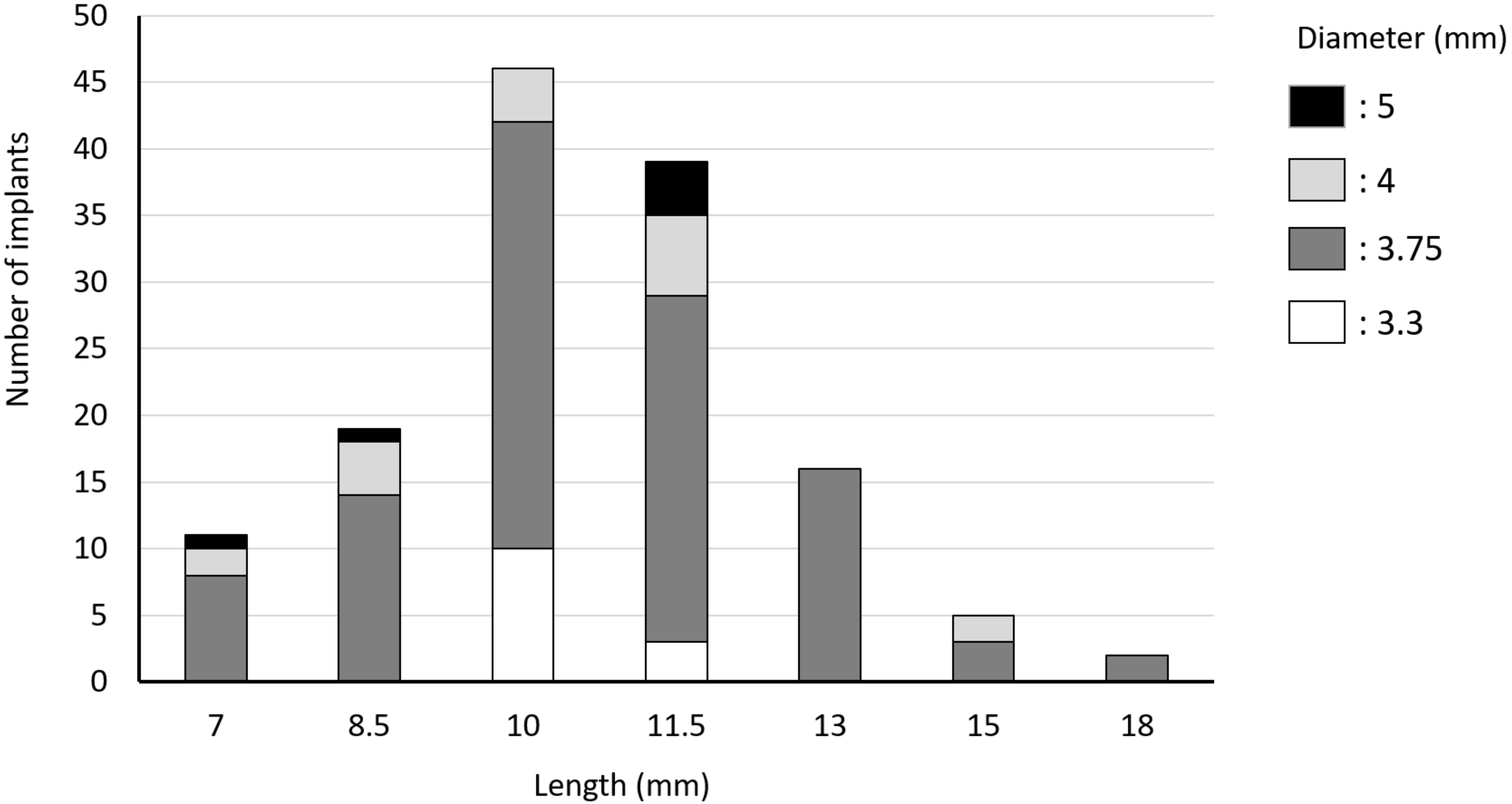
			95 % CI	
Variable	P value	Hazards ratio	Lower	Upper
Male	0.005	6.223	1.758	22.031
The shorter implant (< 8.5mm)	0.001	5.208	1.984	13.669
Bone augmentation	0.039	2.576	1.047	6.341

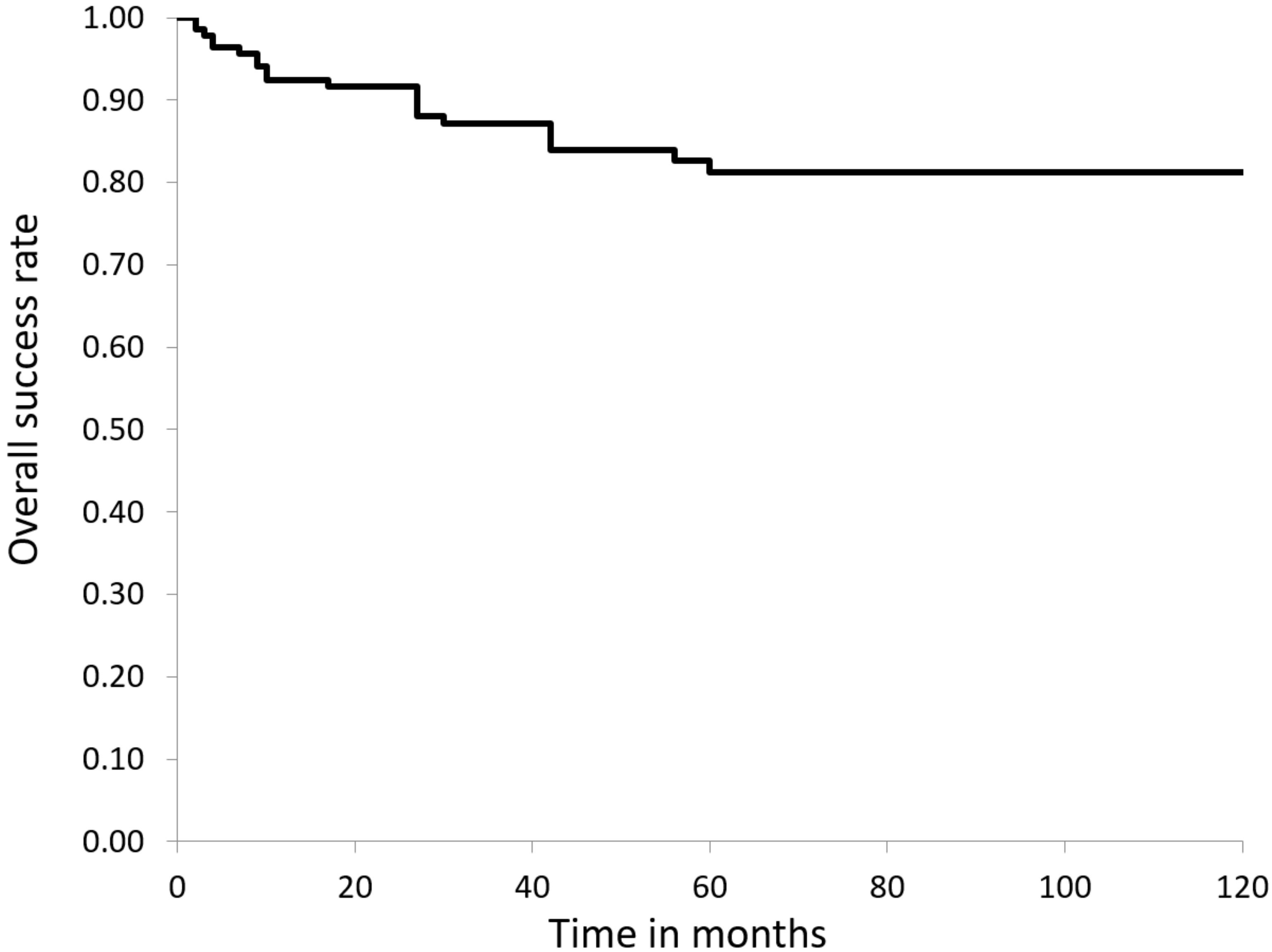
CI: Confidence interval

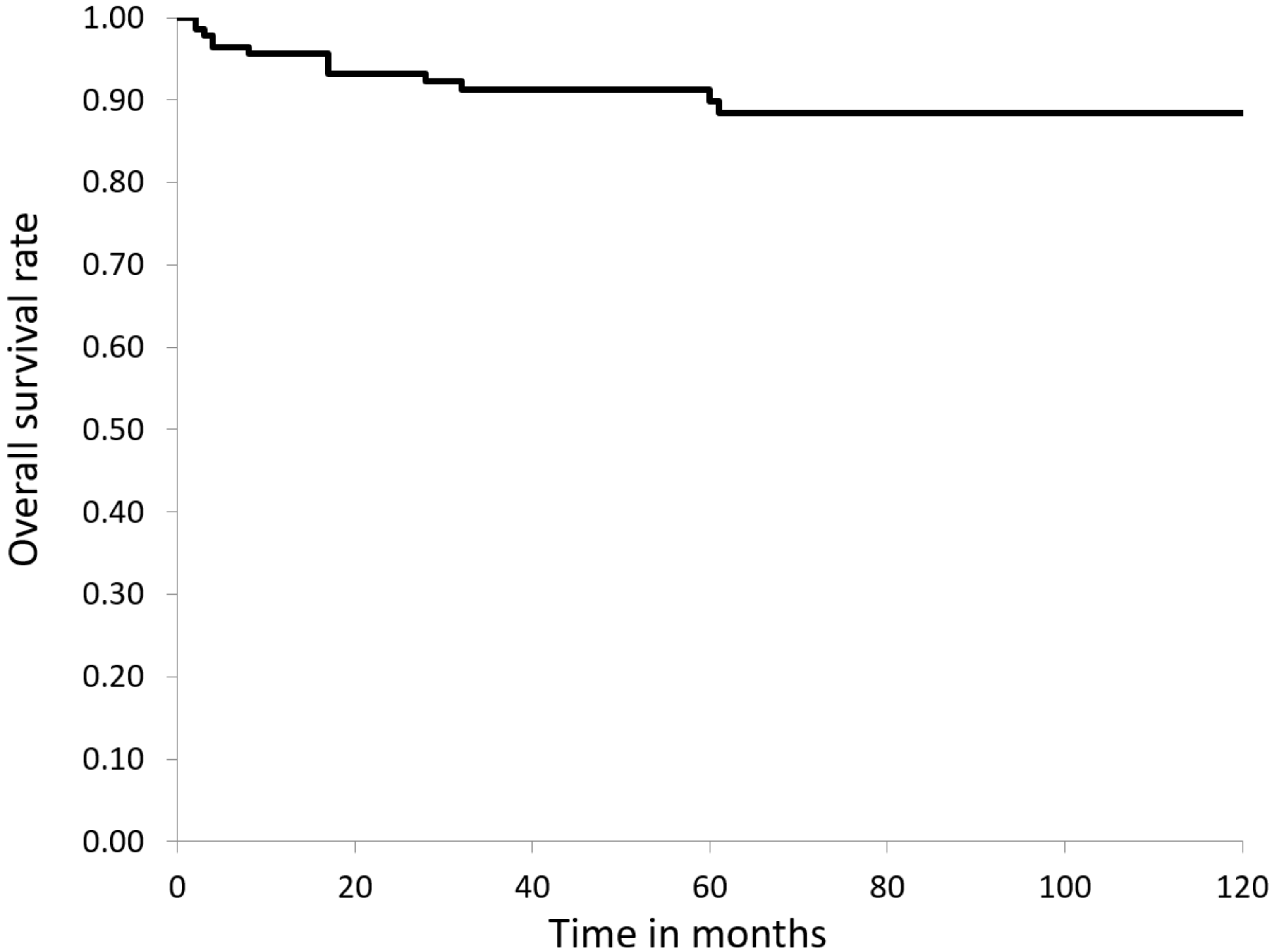
Table 5. Results of multivariate Cox proportional hazards analysis of predictors of the survival of dental implants

			95 % CI	
Variable	P value	Hazards ratio	Lower	Upper
Bone augmentation	0.007	5.136	1.564	16.863
Narrow implant (≤ 3.3 mm)	0.043	3.875	1.045	14.371

CI: Confidence interval


Number of implants
50
45
40
35
30
25
20
15
10
5
0
7
8.5
10
11.5
13
15
18
Length (mm)
Diameter (mm)
: 5
: 4
: 3.75
: 3.3


1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Overall success rate
0
20
40
60
80
100
120
Time in months


1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Overall survival rate
0
20
40
60
80
100
120
Time in months