Check for updates

https://doi.org/10.4047/jap.2024.16.3.151

Prediction of lifespan and assessing risk factors of large-sample implant prostheses: a multicenter study

Jeong Hoon Kim[1†], Joon-Ho Yoon[2†], Hae-In Jeon[1], Dong-Wook Kim[4,5], Young-Bum Park[1], Namsik Oh[3]*

[1]Department of Prosthodontics, College of Dentistry, Yonsei University, Seoul, Republic of Korea
[2]Department of Prosthodontics, NHIS Ilsan Hospital, Goyang, Republic of Korea
[3]Department of Dentistry, School of Medicine, Inha University, Incheon, Republic of Korea
[4]Department of Information and Statistics, Research Institute of Natural Science, Gyeongsang National University, Jinju, Republic of Korea
[5]Department of Bio & Medical Bigdata (BK21 Plus), Gyeongsang National University, Jinju, Republic of Korea

PURPOSE. This study aimed to analyze factors influencing the success and failure of implant prostheses and to estimate the lifespan of prostheses using standardized evaluation criteria. An online survey platform was utilized to efficiently gather large samples from multiple institutions. **MATERIALS AND METHODS.** During the one-year period, patients visiting 16 institutions were assessed using standardized evaluation criteria (KAP criteria). Data from these institutions were collected through an online platform, and various statistical analyses were conducted. Risk factors were assessed using both the Cox proportional hazard model and Cox regression analysis. Survival analysis was conducted using Kaplan-Meier analysis and nomogram, and lifespan prediction was performed using principal component analysis. **RESULTS.** The number of patients involved in this study was 485, with a total of 841 prostheses evaluated. The median survival was estimated to be 16 years with a 95% confidence interval. Factors found to be significantly associated with implant prosthesis failure, characterized by higher hazard ratios, included the 'type of clinic', 'type of antagonist', and 'plaque index'. The lifespan of implant prostheses that did not fail was estimated to exceed the projected lifespan by approximately 1.34 years. **CONCLUSION.** To ensure the success of implant prostheses, maintaining good oral hygiene is crucial. The estimated lifespan of implant prostheses is often underestimated by approximately 1.34 years. Furthermore, standardized form, online platform, and visualization tool, such as nomogram, can be effectively utilized in future follow-up studies. [J Adv Prosthodont 2024;16:151-62]

KEYWORDS

Dental implant; Dental prosthesis failure; Survival analysis; Longevity

ORCID

Jeong Hoon Kim
https://orcid.org/0000-0003-3993-7418

Joon-Ho Yoon
https://orcid.org/0000-0002-4571-7342

Hae-In Jeon
https://orcid.org/0009-0007-9137-0953

Dong-Wook Kim
https://orcid.org/0000-0002-4478-3794

Young-Bum Park
https://orcid.org/0000-0003-4177-1947

Namsik Oh
https://orcid.org/0000-0002-0155-7746

Corresponding author
Namsik Oh
Department of Dentistry, School of Medicine, Inha University, 27, Inhang-ro, Jung-gu, Incheon, 22332, Republic of Korea
Tel +82328902470
E-mail onsdo@inha.ac.kr

Received January 4, 2024 / **Last Revision** May 13, 2024 / **Accepted** June 14, 2024

†These authors contributed equally in this study.

This research was supported by a grant of the Korea Health Technology R&D Project through the Korea Health Industry Development Institute (KHIDI) and funded by the Ministry of Health and Welfare, Republic of Korea (grant number: HC16C2335).

https://doi.org/10.4047/jap.2024.16.3.151

INTRODUCTION

Dental implants have emerged as an effective treatment for tooth loss, widely used in oral rehabilitation. Unlike conventional fixed dental prostheses (FDP) that require the preparation of abutment teeth and removable dental prostheses (RDP) that can reduce masticatory efficiency and cause discomfort during use,[1,2] dental implants effectively address these shortcomings.

However, dental implants present unique challenges due to their direct integration into the jawbone without involvement of the periodontal ligament (PDL) and the abutment structure connecting to the upper implant prosthesis. These characteristics may lead to additional complications beyond those typically associated with conventional FDP and RDP.[3]

To address these complications and failures, regular check-ups and patient education are essential. Numerous studies have investigated the lifespan and durability of failed prostheses, aiming to identify factors influencing success and failure. Early studies, dating back to the 1970s by researchers such as Schwartz, Foster, and Valderhaug, primarily focused on comparing the usage periods of traditional prostheses.[4-6] Subsequent research has shifted towards analyzing survival rates over specific periods, particularly investigating dental implants separately from traditional FDP and RDP. Several systematic reviews have consistently reported a high survival rate for dental implants.[7-10] Although this rate may vary depending on factors such as patient age, implant specifications, bone quality, and prosthesis materials, most studies consistently report 5-year and 10-year survival rates exceeding 90%.[11,12]

However, the majority of previous studies was confined to a single institution or involved only a few institutions, often with insufficient sample sizes.[13,14] Each institution uses different medical record forms, which presents challenges in efficiently collecting and managing large amounts of data. To address this issue, we utilized an online platform to collect substantial samples from multiple institutions and employed standardized evaluation criteria established in previous studies. This study aims to evaluate risk factors associated with the failure of implant prostheses and predict their lifespan based on the collected information.

MATERIALS AND METHODS

The study design was approved by the Inha University Hospital Institutional Review Board (IRB approval #INHAUH 2017-01-012-001), and written informed consent was obtained from each participant prior to the start of the study.

In previous studies, United States Public Health Service (USPHS) criteria and California Dental Association (CDA) rating system have been widely utilized for evaluating dental prostheses. USPHS criteria is intuitive but lacks objectivity, while CDA rating system is more objective but have limitations in assessing a various type of prostheses. Korean Academy of Prosthodontics (KAP) criteria are standardized evaluation criteria that incorporate the strengths of USPHS criteria and CDA rating system, while addressing their limitations (Fig. 1).[15,16]

According to the KAP criteria, we conducted a survey on patients who visited 16 institutions from May 1, 2017, to April 30, 2018.

To reduce selection bias, prostheses related to the patient's chief complaint were excluded. The fabrication year of the prostheses was determined based on the patient's statements. Prostheses for which the exact fabrication year and month could not be recalled by the patient were excluded from the study.

The examiners, who were prosthodontists, received training in research content and examination methods through workshops. Furthermore, additional training workshops were conducted at each institution. After thorough examiner training, the following items were investigated through patient interviews, as well as clinical and radiological assessments of implant prostheses in the oral cavity:

Patient age, gender, type of prosthesis, type of clinic, duration of prosthesis usage, national health insurance coverage, type of antagonist, plaque index, ratio of prosthesis units to implant body.

In the 'type of clinic' category, 'non-licensed practitioner (NL)' means illegal practitioners without a dentist license. And 'unknown' indicated cases where the patient received treatment at a medical institution but couldn't recall whether it was a dental hospital or

KAP criteria: Prosthesis evaluation form (for implant)

Examination date: _______ Y / _____ M / _____ D

<table>
<tr><td>Institution</td><td colspan="2"></td><td>Patient ID</td><td></td><td>Examiner</td><td colspan="4"></td></tr>
<tr><td>Patient information</td><td>Name</td><td></td><td>Date of birth</td><td></td><td>Gender</td><td>M</td><td></td><td>F</td><td></td></tr>
<tr><td>Chief complaint</td><td colspan="9"></td></tr>
<tr><td rowspan="4">Treated location</td><td colspan="9">8 ☐ 7 ☐ 6 ☐ 5 ☐ 4 ☐ 3 ☐ 2 ☐ 1 ☐ | 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐</td></tr>
<tr><td colspan="9">8 ☐ 7 ☐ 6 ☐ 5 ☐ 4 ☐ 3 ☐ 2 ☐ 1 ☐ | 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐</td></tr>
<tr><td colspan="9">[Notation] ◯: Abutment =: Pontic or connector of splinted crown</td></tr>
<tr><td colspan="9">Are there any other prostheses inside the oral cavity? ☐ Yes ☐ No</td></tr>
<tr><td>Type of prosthesis</td><td colspan="9">☐ Single unit FDP type ☐ FDP type ☐ RDP type</td></tr>
<tr><td>Type of clinic</td><td colspan="9">☐ Dental hospital ☐ Local clinic ☐ Non-licensed ☐ Unknown</td></tr>
<tr><td>Date of treatment</td><td colspan="9">_____________ Y (Please write the exact year, not a range)</td></tr>
<tr><td>Type of antagonist</td><td colspan="9">☐ Natural teeth or FDP ☐ RDP ☐ Implant prosthesis</td></tr>
<tr><td>Plaque index</td><td colspan="9">☐ 0 ☐ 1 ☐ 2 ☐ 3</td></tr>
<tr><td>Grade of prosthesis</td><td colspan="9">☐ A ☐ B ☐ C ☐ D</td></tr>
<tr><td rowspan="4">Reason for failure</td><td colspan="2">Biologic</td><td colspan="7">☐ Osseointegration failure ☐ Peri-implantitis</td></tr>
<tr><td colspan="2">Mechanical</td><td colspan="7">☐ Abutment fracture ☐ Fixture fracture ☐ Food impaction
☐ Prosthesis fracture ☐ Inappropriate proximal contact
☐ Loss of retention</td></tr>
<tr><td colspan="2">Esthetic</td><td colspan="7">☐ Gingival recession ☐ Discoloration</td></tr>
<tr><td colspan="9">[Multiple selection allowed]</td></tr>
</table>

[Prosthesis evaluation principles]
(Use the following flowchart. If evaluating with a flowchart is unclear, utilize the criteria below)
A: Without any defects.
B: Adjustments are necessary, but it is still functioning properly and isn't harmful to surrounding tissue.
C: With significant defects, but it may be temporarily usable, not suitable for long-term use.
D: Immediate removal is necessary
A&B: Success / C&D: Failure

[Each prosthesis requires an individual questionnaire]

Fig. 1. Implant prosthesis evaluation form (KAP criteria).

https://doi.org/10.4047/jap.2024.16.3.151

a local clinic.

The cases were evaluated with standardized criteria and categorized into ABCD grades:

Grade A indicates a prosthesis without any defects. Grade B indicates a prosthesis that functions properly, causing no harm to surrounding tissues but requiring minor adjustment. Grade A and B are classified as 'Success'.

Grade C indicates a prosthesis with defects that prevent long-term use and allow only temporary use. Grade D indicates a prosthesis that is harmful to the surrounding tissue, requiring immediate removal. Grade C and D are classified as 'Failure'.

To consolidate data collected from multiple institutions, an online survey form (Fig. 2)[17] was utilized, and various statistical analyses were conducted.

Cox proportional hazards model was used to analyze risk factors related to the failure of implant prostheses, and Kaplan-Meier analysis was conducted to interpret the survival probability.

In addition, nomogram was used as a visualization tool to provide an intuitive assessment of risk factors and survival probability. Each variable was assigned a point based on its hazard ratio (HR) from the Cox proportional hazards model. By summing these points into a total score, the survival probability can be calculated.

In this study, rather than using multiple linear regression (MLR) for estimating lifespan, which can be adversely affected by imperfect linear independence among independent variables, we employed principal component analysis (PCA). This extended approach was chosen due to the diverse factors influencing the lifespan of implant prostheses and the need to account for interrelationships among these variables. Subsequently, a biological age score (BAS) was calculated through PCA to estimate the lifespan of implant prostheses.

Statistical analyses were conducted using R version 3.4 (The R Foundation for Statistical Computing, Vienna, Austria), with statistical significance set at a P value < .05.

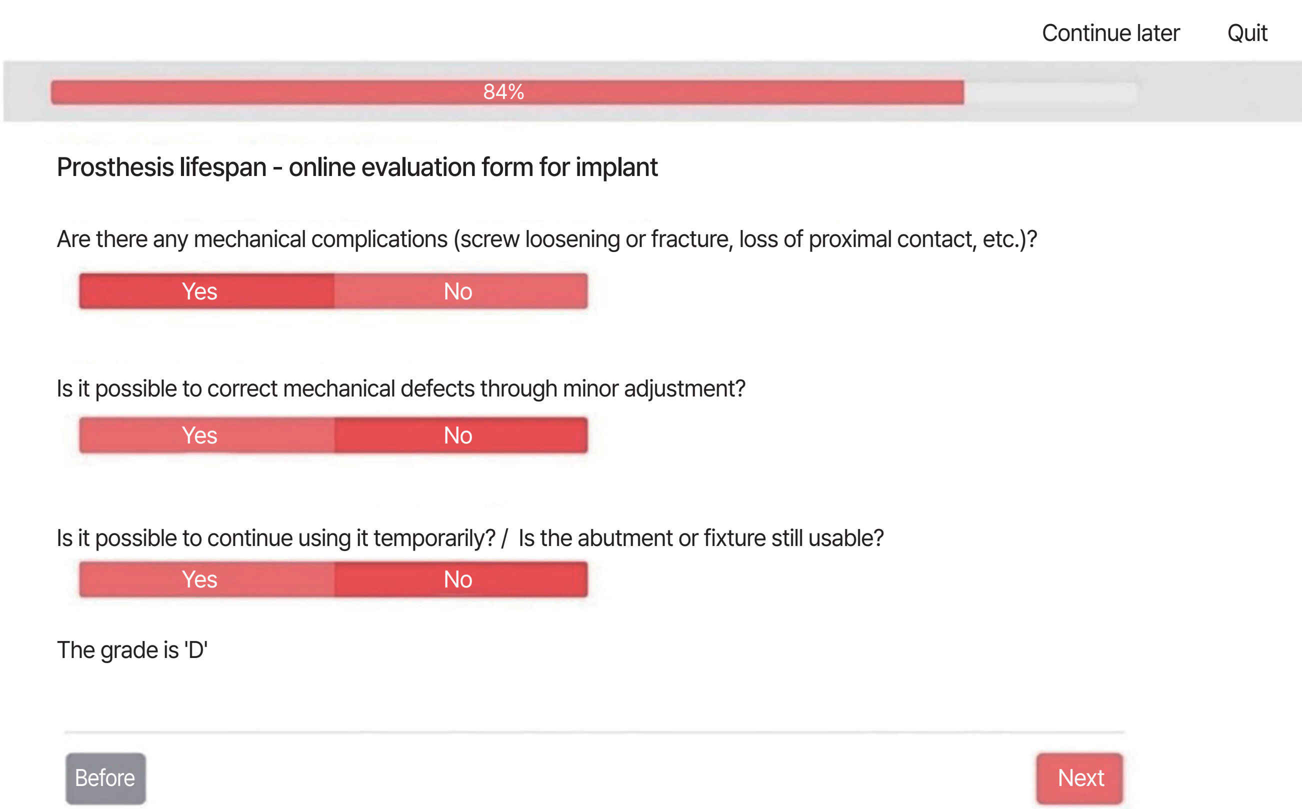

Fig. 2. Procedure of an online survey platform.

RESULTS

A total of 841 cases were collected, including single crown type, fixed full denture type, fixed partial denture type, and removable implant overdenture type, with 485 patients meeting the study criteria. The median survival was analyzed to be 16 years, with a 95% confidence interval.

In the multivariate Cox proportional hazards model, statistically significant factors associated with implant prosthesis failure include type of clinic, type of antagonist, and plaque index ($P < .05$) (Table 1). Specifically, receiving treatment from a non-licensed practitioner (NL) increased the risk of failure (HR = 5.5 (1.216-24.630), $P = .03$). Having implant prostheses as antagonist also increased the risk compared to FDP with natural teeth abutment (HR = 1.9 (1.152-3.334), $P = .01$) and a plaque index of 3 demonstrated higher hazard ratio (HR = 2.5 (1.207-5.249), $P = .01$).

Kaplan-Meier analysis was conducted to interpret the survival probability for these three factors. When comparing the prognosis based on the type of clinic (Fig. 3), dental hospital (Hos) showed the best prognosis, but the median survival could not be evaluated. The estimated median survival was 16 years for local clinic (LC), 7 years for non-licensed practitioners (NL), 15 years for unknown. In the comparison based on the type of antagonist (Fig. 4), FDP and RDP showed similar trends, while implant prostheses showed a relatively decreasing trend. The estimated median survival was 16 years for FDP, 17 years for RDP, and 12 years for implants prostheses. When comparing based on the plaque index (Fig. 5), the estimated median survival was 13 years for plaque index 2 and 3, 15 years for plaque index 0, and 18 years for plaque index 1.

Table 1. Hazard ratios and associated factors for implant prosthesis failure

		Uni-variate		Multi-variate	
		HR (95% CI)	*P*-value	HR (95% CI)	*P*-value
Age		0.9 (0.982-1.011)	.60	0.9 (0.980-1.011)	.57
Sex	Male	1		1	
	Female	0.8 (0.590-1.201)	.34	0.8 (0.581-1.211)	.35
Type	Single	1			
	FDP	0.8 (0.570-1.155)	.24		
	RDP	1.1 (0.456-2.527)	.87		
Type of clinic	Hos	1			
	LC	1.5 (0.882-2.664)	.13	1.8 (0.999-3.170)	.05
	NL	4.4 (0.999-19.197)	.05	5.5 (1.216-24.630)	.03
	Unknown	1.3 (0.726-2.472)	.35	1.5 (0.783-2.782)	.23
Insurance	Yes	1		1	
	No	0.1 (0.027-0.480)	.01	0.1 (0.018-1.059)	.06
Antagonist	FDP	1		1	
	RDP	1.0 (0.632-1.739)	.85	0.9 (0.564-1.637)	.88
	Implant	1.7 (1.026-2.820)	.04	1.9 (1.152-3.334)	.01
Plaque Index	0	1			
	1	0.8 (0.556-1.340)	.51	0.9 (0.560-1.414)	.62
	2	1.4 (0.809-2.456)	.22	1.4 (0.777-2.490)	.27
	3	2.3 (1.168-4.801)	.01	2.5 (1.207-5.249)	.01
Unit/Implant		1.0 (0.534-2.020)	.91		

HR: hazard ratio, FDP: fixed dental prosthesis, RDP: removable dental prosthesis, Hos: dental hospital, LC: local clinic, NL: non-licensed practitioners.

https://doi.org/10.4047/jap.2024.16.3.151

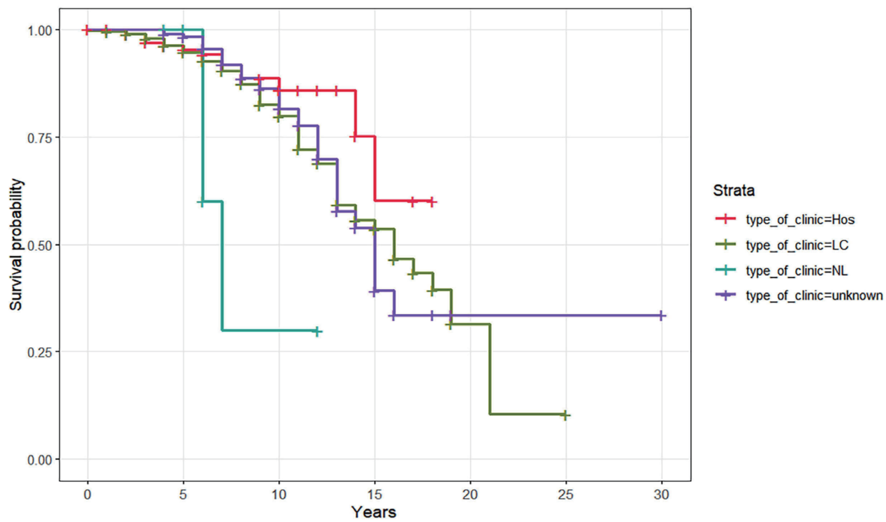

Fig. 3. Evaluation of survival probability by type of clinic.
Hos: dental hospital, LC: local clinic, NL: non-licensed practitioners.

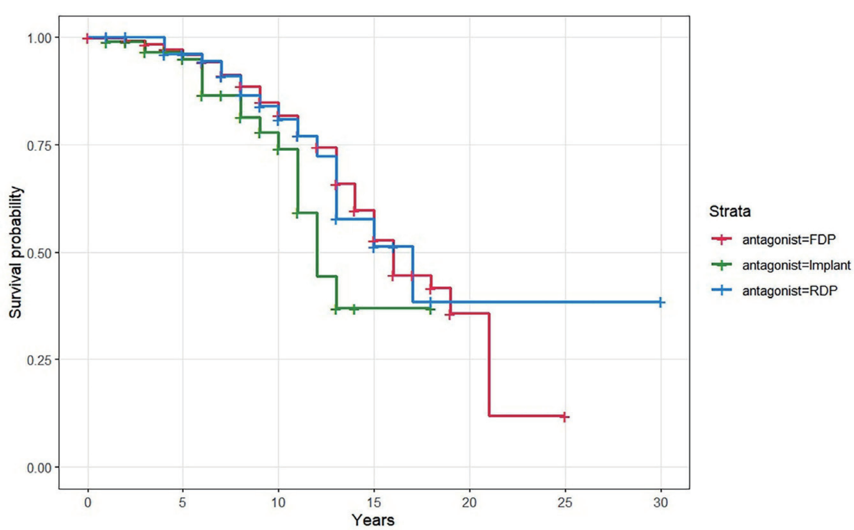

Fig. 4. Evaluation of survival probability by type of antagonist.
FDP: fixed dental prosthesis, RDP: removable dental prosthesis.

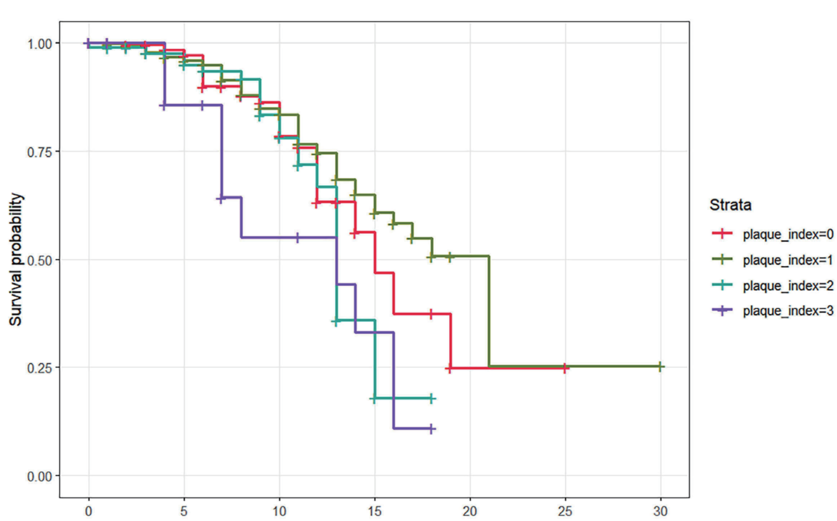

Fig. 5. Evaluation of survival probability by plaque index score.

Nomogram facilitates a more intuitive analysis of survival probability (Fig. 6). In the process of creating nomogram, statistically significant factors appeared in the following order: insurance coverage, type of clinic, plaque index, type of antagonist, ratio of prosthesis unit to implant body, age, and gender. In the categories of 'insurance coverage', 'type of clinic', 'plaque index', and 'type of antagonist', the responses 'yes', 'NL', '3', and 'implant' were each assigned points of 100, 83, 53, and 36, respectively. Each item is assigned specific points, and the cumulative total points obtained by summing these scores allow for the assessment of the survival probability of the implant prosthesis under specific conditions.

Based on the principal component analysis, the biological age score (BAS) was calculated, and the estimated results are presented in Fig. 7 and Table 2. In Fig. 7, the data points are evenly distributed around the fit line, indicating relatively low variability. However, a larger number of data points are positioned below the line. This indicates that the estimated values have been underestimated compared to the actual lifespan of the prosthesis. This trend is also evident in Table 2, where failed prostheses exhibit close alignment between estimated and actual lifespan values. For implant prostheses that did not fail, the estimates suggest a potential usage extension of approximately 1.34 years beyond the estimated lifespan.

DISCUSSION

Implant failure can be influenced by various factors, including device factors (implant length, diameter, surface, etc.), anatomic factors (bone quality), factors related to occlusion or loading (parafunctional habits, cantilever design), systemic risk factors (smoking, endocrine diseases), microbial factors (infection), and others.[12,18] Studies focusing on prosthetic failure, including technical or mechanical complications, and related reviews have reported that factors like the

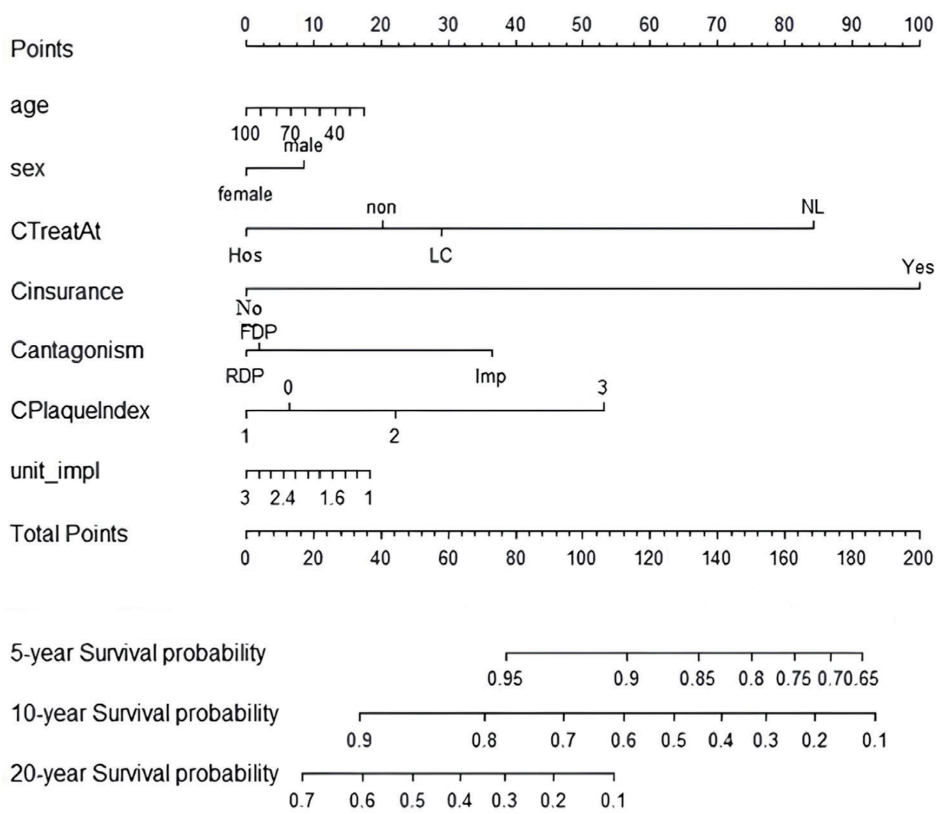

Fig. 6. Nomogram for predicting the survival probability of implant prostheses.

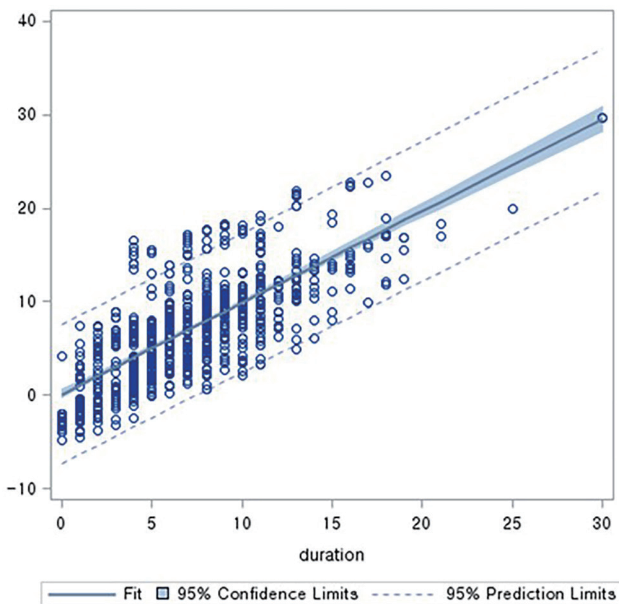

Fig. 7. Estimation of implant prosthesis lifespan. Horizontal axis: actual prosthesis usage duration, Vertical axis: estimated prosthesis lifespan.

Table 2. The difference between estimated prosthesis lifespan and actual prosthesis usage duration (estimated value - actual value)

	N	Mean	SD	Min	Max
Total	841	-1.13	3.8417	-11.46	14.28
Success	708	-1.34	3.6894	-9.91	9.83
Failure	133	-0.01	4.4232	-11.46	14.28

SD: standard deviation, Min: minimum, Max: maximum

three-dimensional position or axis of the implant, screw torque value, implant body type (internal or external connection system), and prosthesis material can influence failure in single or multiple unit implant-fixed dental prostheses. For implant-retained overdentures, factors such as implant angulation, implant placement location (maxilla or mandible), prosthesis material, and antagonist have been found to affect the outcome.[11]

In this study, the presence of implant prostheses as antagonists was found to have a significant impact on implant failure. Additionally, higher plaque index scores and treatment by non-licensed practitioners were identified as associated factors contributing to failure. However, it's important to note that the sample size of cases treated by non-licensed practitioners was very small (6 cases out of 841), necessitating cautious interpretation. Reevaluation with a larger sample size in future studies will be important to ascertain whether these findings hold true.

Research on risk factors is important because it can offer insights to both patients and clinicians on critical aspects to focus on for successful implant therapy. In the review by Paquette *et al.*,[18] it was mentioned that patients should consider modifying their smoking habits, while clinicians should consider implant specifications and design, site preparation, and loading strategy. And it was emphasized that both patients and clinicians should focus on effective long-term oral biofilm management. This aligns with the findings of our study, which demonstrated that a higher plaque index has a significant impact on implant prosthesis failure. Furthermore, clinicians should exercise greater caution in selecting an appropriate occlusal scheme based on the type of antagonist. This is important because implants lack a periodontal ligament (PDL) unlike natural teeth, which results in reduced proprioception and delayed perception of overload or occlusal interference. Additionally, the absence of a PDL diminishes the cushioning effect, leading to uneven distribution of occlusal forces into the surrounding alveolar bone.[19-21] Furthermore, according to the research by Kinsel and Lin,[22] when occlusion is established between implants without appropriate management of parafunction, mechanical complications significantly increase. Therefore, it is crucial to exercise extreme caution when establishing the occlusal scheme for implants, particularly when they are in occlusion with other implants.

In survival analysis, the median is often considered a more appropriate measure than the mean. Survival analysis deals with events occurring over time, and in many cases, the data does not follow a normal distribution, making it challenging to apply the mean. Additionally, survival data often exhibits left-skewness or asymmetrical characteristics, and the mean is sensitive to such asymmetry or outliers (extreme values), which can result in an inaccurate representation of the central tendency of the data. Therefore, in this study, the median was chosen as the representative measure to accurately reflect the central tendency of the survival data. However, it is important to note that the median does not consider the influence of the right tail of the survival curve, specifically beyond the 50% mark. Additionally, if there are a significant number of outliers, the median can result in significantly lower values compared to the mean. Therefore, in future follow-up studies, considering both the mean and the median, depending on the analysis objectives and data characteristics, may prove to be beneficial.[21,23,24]

A nomogram is used to visually represent regression analysis, presenting a predictive model in an easily interpretable graph.[25] Each element is assigned a score, and by summing these scores to obtain the total points, one can intuitively understand the corresponding survival probability. Figure 8 illustrates an example of the nomogram used in this study. Intuitive visualization tools like nomograms are beneficial not only for clinicians and researchers but also for patients. It can be effectively utilized as educational material to explain the estimated prognosis of implant prostheses under specific conditions. This facilitates the identification of factors requiring improvement for successful implant treatment.

When predicting the lifespan of implant prostheses, the use of conventional multiple linear regression (MLR) methods may result in issues related to multi-

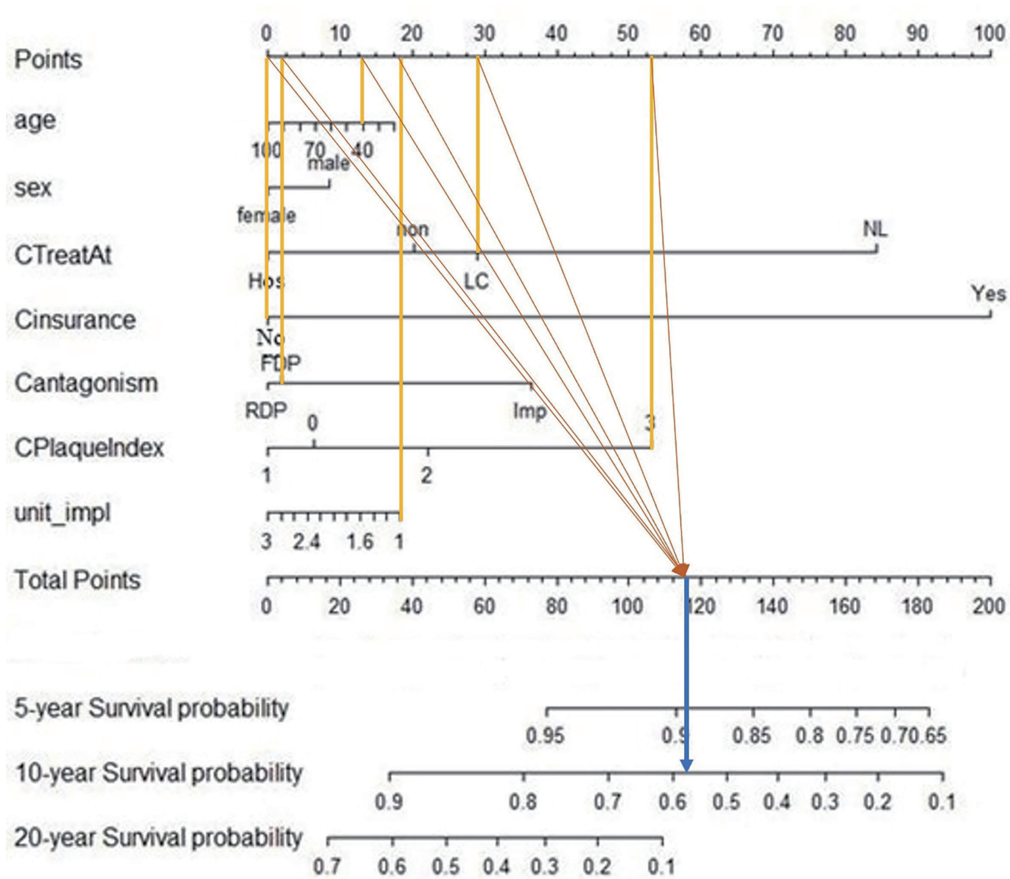

Fig. 8. An example of the nomogram in this study.
Case information: a 40-year-old female patient, treatment at LC, without insurance coverage, antagonist is FDP, plaque index is 3, ratio of prosthesis units to implant body is 1.
Total score: 115
5-year survival probability: 0.89
10-years survival probability: 0.58

collinearity, which can adversely impact data analysis. In this study, focusing on the lifespan (aging) of intraoral implant prostheses, various factors play a significant role. Specifically, when considering prosthesis usage duration, the criteria can become ambiguous. In survival analysis targeting patients, it is feasible to accurately determine the time of a patient's death. However, with dental prostheses, it is challenging to ascertain when the observed 'failure' state at the time of examination began and how long it has been ongoing. Even if an event that could be classified as the 'failure' of the prosthesis occurred long before the examination, if the patient was unaware of it, the measurement of the prosthesis's usage duration could be much longer than the actual time of failure. Including such uncertain factors as crucial considerations in estimating lifespan is indeed ambiguous.[26-28] In situations like those described in this study, where variables exhibit correlation or high complexity, the use of principal component analysis (PCA) is recommended. First, a correlation analysis between the duration of prostheses and relevant parameters was conducted. The related variables were then selected through redundancy analysis and standardized. Based on the PCA results, biological age scores were calculated.

In the lifespan estimation model (Fig. 7, Table 2), there was a tendency for the estimated values to be underestimated compared to the actual values. This discrepancy arises because the lifespan of prostheses classified as 'success' was measured based on the date of examination. In reality, 'successful prostheses' are expected to remain functional for a longer period. However, in the controlled conditions of PCA where data was collected at the time of examination, this estimation is considered to be underestimated.

This study holds significant value in standardizing diverse medical record forms across institutions into a unified format and efficiently collecting data using an online survey platform. But there are clear limitations that need improvement. Compared to other recent big data studies,[29,30] the sample size in this study is still too small to classify it as a big data study. However, in these big data studies with large sample size, extracting and analyzing meaningful information from pre-existing data pools can limit the diversity of results obtained. In contrast, this study collected data through direct patient interviews and clinical and radiographic assessments conducted by well-trained prosthodontists from multiple institutions. Consequently, the data available for analysis in this study is highly diverse, enabling the conduct of complex causal analyses for various phenomena. Through the gathering and analysis of such diverse information, we anticipate gaining insights into the necessary efforts for providing successful implant treatment to patients and ensuring its maintenance and management. This knowledge can then be effectively applied in clinical practice, benefiting both patients and healthcare providers.

By enhancing and continuously collecting data in future research, studies with much larger sample sizes can be conducted. It's important to note that while a large sample size can amplify errors in sampling, study design, and related biases, it can also contribute to more reliable research. It enables studies on rare events and streamlines research protocols, thereby reducing cost and time. It can contribute to an overall improvement in the quality of research.[31,32]

CONCLUSION

Successful implant prosthodontic treatment requires effective management of risk factors, particularly emphasizing the improvement of oral hygiene. The estimated lifespan of implant prostheses is often underestimated. We anticipate that standardized criteria, an online survey platform, and visualization tools for statistical analysis will efficiently facilitate future follow-up studies.

REFERENCES

1. Helkimo E, Carlsson GE, Helkimo M. Chewing efficiency and state of dentition. A methodologic study. Acta Odontol Scand 1978;36:33-41.
2. Prithviraj DR, Madan V, Harshamayi P, Kumar CG, Vashisht R. A comparison of masticatory efficiency in conventional dentures, implant retained or supported overdentures and implant supported fixed prostheses: a literature review. J Dent Implant 2014;4:153.
3. Schwarz MS. Mechanical complications of dental im-

plants. Clin Oral Implants Res 2000;11:156-8.

4. Schwartz NL, Whitsett LD, Berry TG, Stewart JL. Unserviceable crowns and fixed partial dentures: lifespan and causes for loss of serviceability. J Am Dent Assoc 1970;81:1395-401.
5. Foster LV. Failed conventional bridge work from general dental practice: clinical aspects and treatment needs of 142 cases. Br Dent J 1990;168:199-201.
6. Valderhaug J. A 15-year clinical evaluation of fixed prosthodontics. Acta Odontol Scand 1991;49:35-40.
7. Papaspyridakos P, Chen CJ, Chuang SK, Weber HP, Gallucci GO. A systematic review of biologic and technical complications with fixed implant rehabilitations for edentulous patients. Int J Oral Maxillofac Implants 2012;27:102-10.
8. Di Francesco F, De Marco G, Gironi Carnevale UA, Lanza M, Lanza A. The number of implants required to support a maxillary overdenture: a systematic review and meta-analysis. J Prosthodont Res 2019;63:15-24.
9. Pieralli S, Kohal RJ, Rabel K, von Stein-Lausnitz M, Vach K, Spies BC. Clinical outcomes of partial and full-arch all-ceramic implant-supported fixed dental prostheses. A systematic review and meta-analysis. Clin Oral Implants Res 2018;29:224-236.
10. Jung RE, Zembic A, Pjetursson BE, Zwahlen M, Thoma DS. Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. Clin Oral Implants Res 2012;23:2-21.
11. Sailer I, Karasan D, Todorovic A, Ligoutsikou M, Pjetursson BE. Prosthetic failures in dental implant therapy. Periodontol 2000 2022;88:130-44.
12. Raikar S, Talukdar P, Kumari S, Panda SK, Oommen VM, Prasad A. Factors affecting the survival rate of dental implants: a retrospective study. J Int Soc Prev Community Dent 2017;7:351-5.
13. Lekholm U, Gunne J, Henry P, Higuchi K, Lindén U, Bergström C, van Steenberghe D. Survival of the Brånemark implant in partially edentulous jaws: a 10-year prospective multicenter study. Int J Oral Maxillofac Implants 1999;14:639-45.
14. Scheller H, Urgell JP, Kultje C, Klineberg I, Goldberg PV, Stevenson-Moore P, Alonso JM, Schaller M, Corria RM, Engquist B, Toreskog S, Kastenbaum F, Smith CR. A 5-year multicenter study on implant-supported single crown restorations. Int J Oral Maxillofac Implants 1998;13:212-8.
15. Yoon JH, Park YB, Yoo JJ, Youn SH, Oh NS. Establishment of online evaluation system for an analysis on the longevity of dental prostheses. J Korean Acad Adv Gen Dent 2019;8:7-19.
16. Yoon JH, Park YB, Youn SH, Oh NS. Korea Academy of Prosthodontics criteria for longevity studies of dental prostheses. J Korean Acad Prosthodont 2016;54:341-53.
17. Yonsei University Dental Hospital. Survey for lifetime of dental prosthesis [Internet]. Seoul (KR): Daumsoft; c2017 [cited 2023 Sep 20]. Available from: http://www.prostholife-survey.com/limesurvey.
18. Paquette DW, Brodala N, Williams RC. Risk factors for endosseous dental implant failure. Dent Clin North Am 2006;50:361-74.
19. Kim Y, Oh TJ, Misch CE, Wang HL. Occlusal considerations in implant therapy: clinical guidelines with biomechanical rationale. Clin Oral Implants Res 2005;16:26-35.
20. Sheridan RA, Decker AM, Plonka AB, Wang HL. The role of occlusion in implant therapy: a comprehensive updated review. Implant Dent 2016;25:829-38.
21. Messori A, Becagli P, Trippoli S. Median versus mean lifetime survival in the analysis of survival data. Haematologica 1997;82:730.
22. Kinsel RP, Lin D. Retrospective analysis of porcelain failures of metal ceramic crowns and fixed partial dentures supported by 729 implants in 152 patients: patient-specific and implant-specific predictors of ceramic failure. J Prosthet Dent 2009;101:388-94.
23. Barker C. The mean, median, and confidence intervals of the Kaplan-Meier survival estimate-computations and applications. The American Statistician 2009;63:78-80.
24. Ben-Aharon O, Magnezi R, Leshno M, Goldstein DA. Median survival or mean survival: which measure is the most appropriate for patients, physicians, and policymakers? Oncologist 2019;24:1469-78.
25. Yang JY, Jeon SY, Lee HS. Prediction models and visualizations according to outcome variables using R-focusing on regression analyses. J Health Info Stat 2022;47:S21-30.
26. Abdi H, Williams LJ. Principal component analysis. Wiley interdisciplinary reviews: computational statis-

tics 2010;2:433-59.
27. Jia L, Zhang W, Jia R, Zhang H, Chen X. Construction formula of biological age using the principal component analysis. Biomed Res Int 2016;2016:4697017.
28. Nakamura E, Miyao K, Ozeki T. Assessment of biological age by principal component analysis. Mech Ageing Dev 1988;46:1-18.
29. Mordechai F, Tali C, Jonathan M, Ori P, Yaron B, Ram S, Guy T. The effect of type of specialty (periodontology/oral surgery) on early implant failure: a retrospective "Big-Data" study from a nation-wide dental chain in Israel. Clin Oral Investig 2022;26:6159-63.
30. Bakker MH, Vissink A, Raghoebar GM, Visser A. General health status of Dutch elderly receiving implant-retained overdentures: A 9-year big data cross-sectional study. Clin Implant Dent Relat Res 2021;23:228-35.
31. Schneeweiss S, Avorn J. A review of uses of health care utilization databases for epidemiologic research on therapeutics. J Clin Epidemiol 2005;58:323-37.
32. Kaplan RM, Chambers DA, Glasgow RE. Big data and large sample size: a cautionary note on the potential for bias. Clin Transl Sci 2014;7:342-6.