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

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

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2024년 6월

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Dental implants have become an effective treatment for missing teeth and are used for oral rehabilitation of patients. However, these treatments are associated with various complications and causes of failure. Therefore, regular checkups and patient education are essential. To provide objective data for this purpose, research on the estimated lifespan of failed prostheses and analysis of implant survival rates during specific periods are ongoing. However, most previous studies have limitations, such as being conducted at a single institution or a limited number of institutions, and having insufficient sample sizes.

In this study, we aimed to collect a substantial amount of standardized data from multiple institutions for the analysis of implant prostheses. We assessed the factors influencing the failure of implant prostheses and conducted analyses related to prosthesis lifespan prediction. Data collected from the 16 institutions were aggregated into a single database using an online platform for statistical analysis. We used the Cox proportional hazard model, Kaplan-Meier analysis, nomogram, and principal component analysis in statistical analysis.

The median lifespan estimated from the survival analysis was 16 years within a 95% confidence interval. Statistically significant factors influencing the failure of implant prostheses include the type of clinic, type of antagonist dentition, and plaque index. Specifically, receiving treatment from a non-licensed practitioner, having an implant as an antagonist dentition, and having a plaque index of 3 were associated with increased failure rates. For prostheses that have not failed at the specific time, it was expected that they can be used for an average of 1.34 years longer than estimated.

For successful implant prosthodontic treatment, patients and dentists should maintain good oral hygiene. Prosthesis lifespan tends to be underestimated. Visualization tools, such as nomograms, provide intuitive information that is beneficial for practitioners, researchers, and patients. The utilization of standardized forms and an online platform enabled the efficient collection and analysis of a large number of samples. If this approach is applied to follow-up studies, it can facilitate large-scale big data research.

Key words: Dental implant, implant prosthesis failure, prosthesis survival analysis, prosthesis lifespan prediction, big data, multicenter study

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1. INTRODUCTION

According to the OECD Health Status Report 2023, as of 2021, the life expectancy of South Koreans is 83.6 years, ranking third globally after Japan and Switzerland and significantly exceeding the OECD average of 80.3 years[1]. This increase in life expectancy has been attributed to advancements in medical technology and social welfare systems. In the present era, living longer and healthier are major concerns for many people. Considering this global trend of increasing senior populations, it is crucial to focus on improving quality of life in the long term. In particular, elderly patients with poor oral health, which in turn affects their overall health, experience a significant decline in their quality of life[2].

Eating well is fundamental for living a healthy life. The relationships among oral health, dietary habits, nutritional status, and overall health are complex[3, 4]. Inadequate nutrition can affect oral health; conversely, poor oral health can lead to restrictions in food intake[5]. This is primarily because mastication efficiency is directly influenced by the number of functional teeth in the oral cavity. Patients with more than 20 functional teeth in the mouth demonstrated superior masticatory efficiency compared to patients with fewer than 20 teeth[5]. Traditional methods for improving masticatory function involve the use of a fixed dental prosthesis (FDP) or removable dental prosthesis (RDP). However, successful FDPs require sound abutment teeth, and RDPs exhibit significantly lower masticatory efficiency than natural teeth[6, 7].

Dental implants have been introduced as an alternative to traditional prostheses. In the 1950s, Brånemark established the concept of osseointegration using biocompatible titanium-alloy implants, which led to rapid advancements in the field of dentistry. The masticatory efficiency of implant-supported prostheses (implant prostheses) cannot be considered equivalent to that of natural dentition but is significantly superior to that of RDP[7]. This has been substantiated by numerous studies indicating an enhancement in the quality of life of patients[8].

However, owing to the characteristics of implants, in which the implant body directly integrates with the jawbone and the presence of an abutment structure, specific complications can arise in addition to those observed in traditional prostheses[9]. Implant failure can occur due to these complications, and patients who have experienced such failures exhibit a significantly reduced satisfaction with implant therapy[10].

Regular checkups and patient education are essential for addressing implant failures. To provide objective data, researchers haves consistently evaluated the lifespan of prostheses and identified the risk factors influencing their success and failure. Early studies dating back to the 1970s by Schwartz, Foster, and Valderhaug primarily involved simple comparisons of the lifespan of traditional prostheses. Subsequently, research shifted to analyzing survival rates over specific periods. However, as previously mentioned, implant prostheses exhibit specific complications; therefore, they have been investigated as distinct forms of prostheses. Several systematic reviews have reported the high survival rates of dental implants[5-8]. Although factors such as patient age, implant specifications, bone quality, prosthesis materials, and other variables can influence outcomes, studies generally report a survival rate of >90% at 5 or 10 years[11, 12].

However, most of these previous studies were limited to a single or few institutions, and research conducted at multiple centers also had insufficient sample sizes[13, 14]. This is believed to be a problem arising from the difficulty in aggregating a large volume of data across different healthcare institutions owing to variations in medical record forms. If a form with standardized criteria for intuitive evaluation is shared, data collected remotely from various institutions can address the limitations of previous studies. The successful establishment of an online platform is expected to facilitate the participation of a greater number of researchers and enable broader and more detailed data collection, ultimately enhancing the overall quality of the research. Therefore, in this study, we aimed to utilize an online platform to collect large samples from multiple institutions, assess the factors influencing the failure of implant prostheses, and create a model for predicting the lifespan of implant prostheses.

2. MATERIALS AND METHODS

2.1. Selection of research subjects

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 before the start of the study.

Data were collected from patients who visited 16 institutions between May 1, 2017, and April 30, 2018. The participating institutions are as follows:

Jeonbuk National University Dental Hospital, Chosun University Dental Hospital, DanKook University Dental Hospital, Gachon University Gil Medical Center, Inha University Hospital, Kyung Hee University Dental Hospital, Kyungpook National University Dental Hospital, National Health Insurance Service Ilsan Hospital, Pusan National University Dental Hospital, Seoul National University Dental Hospital, Veterans Health Service Medical Center, Wonkwang University Dental Hospital, and Yonsei University Dental Hospital.

To reduce selection bias, prostheses related to the patient's chief complaint and those manufactured by the investigating institution were excluded. Consequently, the exact year and month of prosthesis fabrication relied on the patient's statement, leading to the exclusion of cases in which this information could not be clearly provided. In addition, this study focused solely on ‘implant prostheses’ and excluded cases of biological complications.

2.2. Examination and data collection

Prosthodontists and residents from each institution participated as examiners. Prior to their participation, they received training through workshops on the contents of the study and survey methods. Additional training was provided at each institution. After training, the examiners assessed the implant prostheses in the oral cavity through patient interviews, clinical evaluations, and radiographic assessments. The examination was conducted based on the KAP criteria, which are standardized assessment criteria established in previous studies[15, 16] (Figure 1).

The following variables were investigated: patient age, gender, type of prosthesis, type of clinic, duration of prosthesis use, insurance coverage, type of antagonist dentition, plaque index, and ratio of the prosthesis unit to the implant body.

In the 'type of clinic' category, 'non-licensed' referred to illegal practitioners without a dentist license, and 'unknown' indicated cases where the patient received treatment at a medical institution but could not recall whether it was a dental hospital or a local clinic. ‘Insurance coverage’ referred to the applicability of the South Korean National Health Insurance. In other words, it signifies the benefits of public health care, which is the social insurance of the Republic of Korea. Patients with private medical insurance were not included in this study.

According to the flowchart, the grades of the prostheses were assessed as A, B, C, and D (Figure 2): Grade A indicates a state without any defects. Grade B implies that adjustments to the prosthesis are necessary, but it is still functioning properly and does not harm the surrounding tissues. Grades A and B were evaluated as ‘success’. Grade C indicates that the prosthesis has significant defects and, although it may be temporarily usable, it is unsuitable for long-term use. Grade D indicates that immediate removal is necessary, owing to a prosthesis with defects that cause harm to the surrounding tissues. Grades C and D are evaluated as ‘failure’.

Data collected from the 16 institutions were aggregated at one institution using an online platform (Daumsoft’s LimeSurvey)[17] (Figure 3). Sensitive personal information was encrypted during data collection to prevent individual identification. The online platform was designed to be intuitive, allowing the input of a significant amount of information.

The data aggregated through the online platform were managed using a web-based clinical research management system (i-CReaT) maintained by a reputable national agency. This system ensures the objectivity and transparency of the clinical research process and enables efficient management of the clinical research process.

KAP criteria: Prosthesis evaluation form (for implant)

Examination date: _______Y / ___M / ____D

Institution			Patient ID		Examiner				
Patient information	Name		Date of birth		Gender	M		F	
Chief complaint									

Treated location																
	8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8
	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
	8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8
	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□

[Notation] ○: Abutment ═: Pontic or connector of splinted crown

Are there any other prostheses inside the oral cavity? □ Yes □ No

Type of prosthesis		□ Single unit FDP type □ FDP type □ RDP type
Type of clinic		□ Dental hospital □ Local clinic □ Non-licensed □ Unknown
Date of treatment		_________ Y (Please write the exact year, not a range)
Type of antagonist		□ Natural teeth or FDP □ RDP □ Implant prosthesis
Plaque index		□ 0 □ 1 □ 2 □ 3
Grade of prosthesis		□ A □ B □ C □ D
Reason for failure	Biologic	□ Osseointegration failure □ Peri-implantitis
	Mechanical	□ Abutment fracture □ Fixture fracture □ Food impaction □ Prosthesis fracture □ Inappropriate proximal contact □ Loss of retention
	Esthetic	□ Gingival recession □ Discoloration
	[Multiple selection allowed]	

[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 doesn't harmful to surrounded 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]

Figure1. Implant prosthesis evaluation form (KAP criteria).

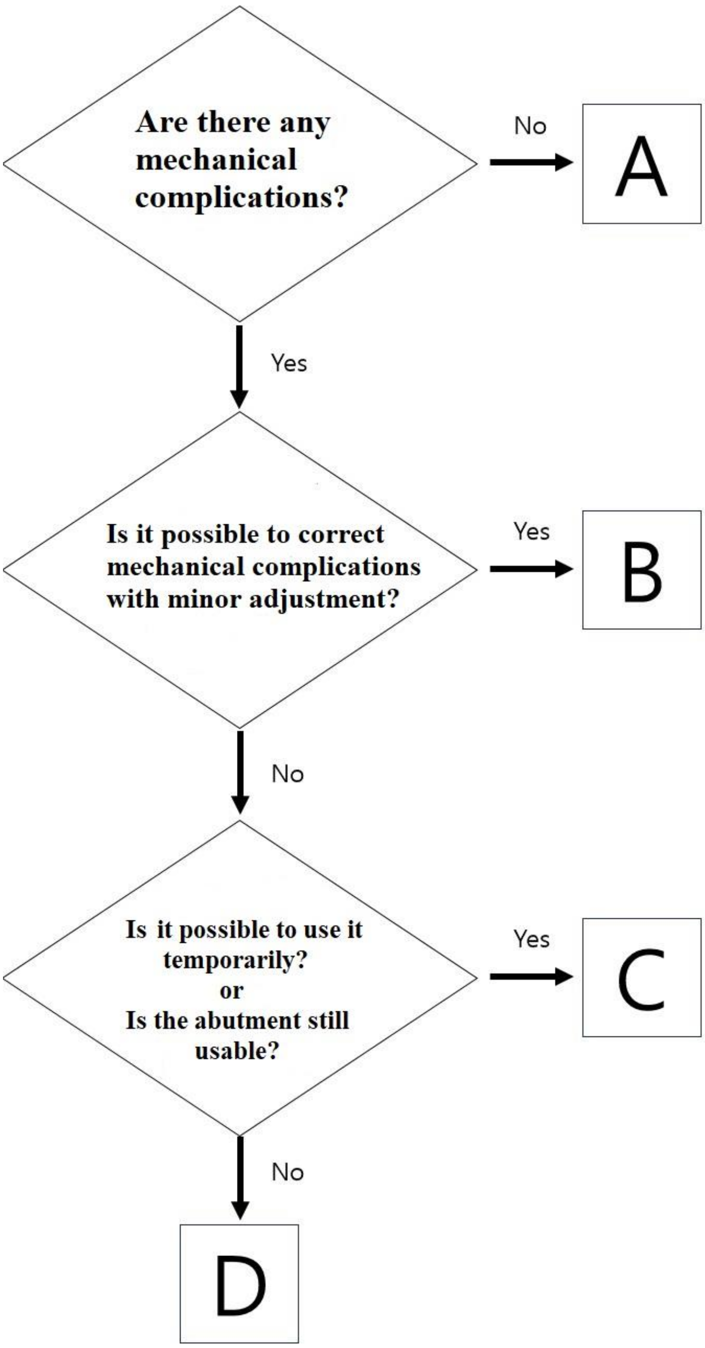


Figure 2. Flowchart for implant prosthesis assessment (KAP criteria).

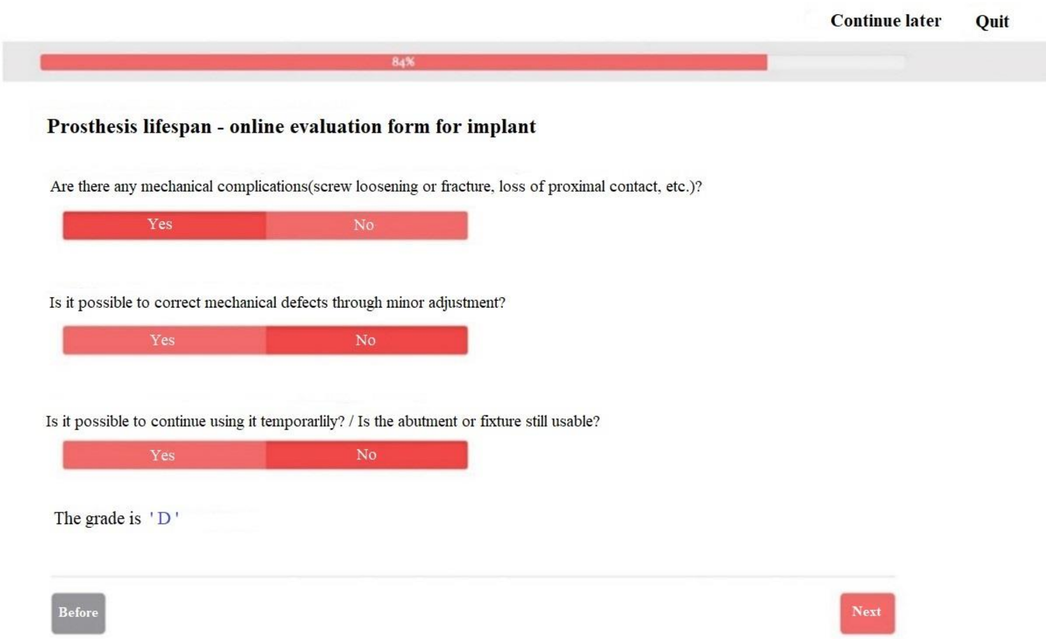


Figure 3. Evaluation procedure for implant prostheses with an online evaluation system.

2.3. Statistical analysis

Statistical analyses were performed using R version 3.4 (The R Foundation for Statistical Computing, Vienna, Austria), and P values < 0.05 were considered statistically significant.

2.3.1. Analysis of factors influencing the success and failure

A Cox proportional hazard model was used to assess the risk factors for success or failure. This model is represented as follows:

$$h(t|Z) = h_0(t) \exp(\beta_1 Z_1 + \beta_2 Z_2 + \dots + \beta_p Z_p)$$

$h(t|Z)$ is the hazard function at time t for a given set of covariates (Z), meaning the probability of an event (implant prosthesis failure) occurring at time t. $h_0(t)$ is the baseline hazard function (all covariate values are zero). This means that the fundamental level of risk, with all the explanatory variables, has no impact. β is a regression coefficient corresponding to each covariate Z. β indicates how each covariate influences the hazard function.

The Cox proportional hazard model assumes that the values of the covariates do not change over time, following the proportional hazards assumption. The model evaluates the impact of each covariate through the log-hazard ratio, where a hazard ratio (HR) > 1 indicates a higher risk associated with that covariate, whereas a HR < 1 indicates a lower risk[18, 19].

2.3.2. Visualization of survival probability: Kaplan-Meier analysis

Kaplan-Meier analysis was conducted to assess the survival probabilities for each risk factor. Kaplan-Meier analysis is a statistical technique used to analyze time-to-event data. This allows one to estimate and visualize how many individuals survive within specific time intervals, as events such as implant failure occur over time.

2.3.3. Visualization of survival probability: Nomogram

A nomogram is a statistical tool that facilitates the visualization of factors influencing the risk of events, such as implant failure, and the prediction of probabilities. It presents point probabilities, with corresponding scores for each factor, allowing for a straightforward comparison of the importance of risk factors. Furthermore, the nomogram provides a simplified scoring system that eliminate the need for complex formulae. This scoring system allows for the easy evaluation of survival probability at a specific time for each case.

First, the linear predictor was calculated using the regression coefficients for each risk factor in the model. Points were assigned based on this linear predictor. In other words, when converting the relative measure, HR, to an absolute scale, the factor with the most substantial impact became the top-ranked factor and was assigned a maximum of 100 points. Points for the second-ranked significant factor were assigned based on the following formula: (absolute value of the coefficient for the second-ranked factor / absolute value of the coefficient for the top-ranked factor) x 100. This formula was consistently applied to the subsequent factors in the ranking[19].

As a result, all points fell within the range of 0 - 100. These points were then summed, and the sum was used to calculate the survival probabilities for each case. This scoring system simplifies the interpretation of the Cox proportional hazards model and allows for a more intuitive assessment of the impact of various factors on survival.

To facilitate the understanding of the nomogram, we provide an example of the actual nomogram used in this study along with a case (Figure 4): a 40-year-old female patient treated at local clinic (LC) without insurance coverage; antagonist dentition, FDP; plaque index 3, ratio of prosthesis units to implant body, 1. The scores for each item were as follows: age (13), sex (0), type of clinic (29), insurance coverage (0), type of antagonist dentition (2), plaque index (53), and ratio of prosthesis units to implant body (18). The total cumulative score is 115 points, and based on this, when evaluating the 5-year, 10-year, and 20-year survival probabilities, it approximates to ~0.89 for 5 years and ~0.58 for 10 years, and it is not possible to assess the score for 20 years.

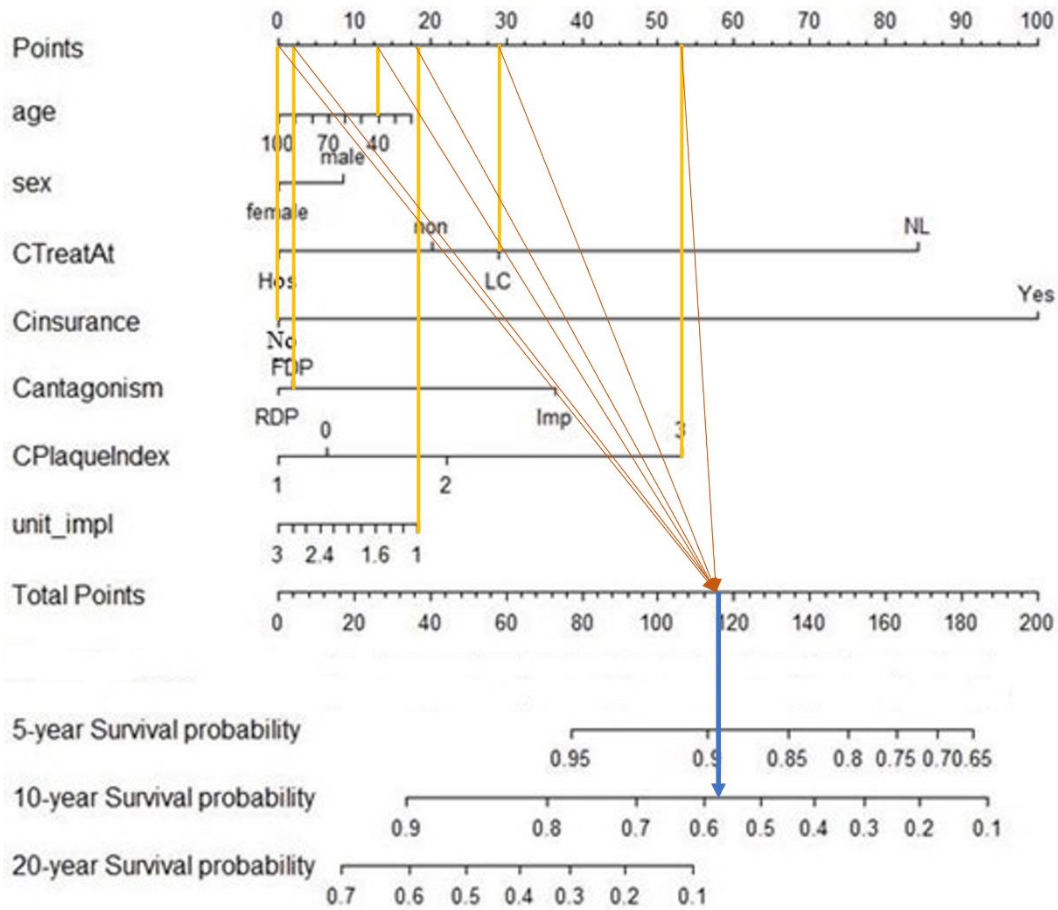


Figure 4. An example of utilizing the nomogram.

Case information: A 40-year-old female patient was treated at LC, without insurance coverage. Antagonist dentition was FDP, plaque index was 3, and ratio of prosthesis units to implant body was 1. Total score is 115. Survival probability was 0.89 for 5 years and 0.58 for 10 years.

2.3.4. Prediction of lifespan: Principal component analysis

Multiple linear regression (MLR) is commonly used to estimate lifespan. However, when independent variables fail to exhibit perfect linear independence, they can have a negative impact on data analysis. In this study, because of the diverse factors influencing the lifespan of implant prostheses and the need to consider the interrelationships among these factors, an extended concept called principal component analysis (PCA) was employed instead of MLR.

In the PCA process to reduce the dimension of variables, eigenvalues, which represent the total variance of the parameters, were determined as principal components if they exceeded 1.0. The component with the highest eigenvalue was designated as the first principal component. Through this process, the linearly transformed principal component, selected as a biomarker for lifespan, was used to calculate the biological age score (BAS).

$$\mathrm{BAS} = a(X_1 - \mathrm{mean}_1)/\mathrm{SD}_1 + b(X_2 - \mathrm{mean}_2)/\mathrm{SD}_2 + cX3 + \cdot\cdot\cdot\ n(X_n - \mathrm{mean}_n)/\mathrm{SD}_n.$$

Here n is the number of selected parameters, X_n is the biomarker, which is the lifespan parameter selected by the PCA method, and mean_n and SD_n are the mean and standard deviation of X_n.

Similarly, we estimated the biological age and compared it with the actual chronological age to assess the level of disparity. Furthermore, to evaluate how well this predictive model fits the actual data intuitively, we created a scatter plot with a regression line for visualization[19].

3. RESULT

A total of 841 cases, including implant-supported crowns and implant supported dentures were identified. The median survival time was 16 years with a 95% confidence interval.

3.1. Risk factor for implant prosthesis failure

In the multivariate Cox proportional hazards model, we identified statistically significant factors associated with prosthesis failure, including the type of clinic, type of antagonist dentition, and plaque index ($P < 0.05$) (Table 1). Specifically, compared to patients treated at a dental hospital, those receiving treatment from a non-licensed practitioner had a higher hazard ratio (HR=5.5 (1.216-24.630), p=0.03). The risk of failure was 1.9 times higher with implants that made occlusal contact with other implants (HR=1.9 (1.152-3.334), p=0.01) than with implants that made occlusal contact with natural teeth (or FDP with natural teeth abutment). The risk of failure was 2.5 times higher when the plaque index was 3 than when it was 0 (HR=2.5(1.207-5.249), p=0.01).

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

		Univariate		Multivariate	
		HR (95% CI)	*P*-value	HR (95% CI)	*P*-value
Age		0.9(0.982-1.011)	0.60	0.9(0.980-1.011)	0.57
Sex	Male	1		1	
	Female	0.8(0.590-1.201)	0.34	0.8(0.581-1.211)	0.35
Type	Single	1			
	FDP	0.8(0.570-1.155)	0.24		
	RDP	1.1(0.456-2.527)	0.87		
Type of clinic	Hos	1			
	LC	1.5(0.882-2.664)	0.13	1.8(0.999-3.170)	0.05
	NL	4.4(0.999-19.197)	0.05	5.5(1.216-24.630)	0.03*
	Unknown	1.3(0.726-2.472)	0.35	1.5(0.783-2.782)	0.23
Insurance	Yes	1		1	
	No	0.1(0.027-0.480)	0.01	0.1(0.018-1.059)	0.06
Antagonist	FDP	1		1	
	RDP	1.0(0.632-1.739)	0.85	0.9(0.564-1.637)	0.88
	Implant	1.7(1.026-2.820)	0.04	1.9(1.152-3.334)	0.01*
Plaque Index	0	1			
	1	0.8(0.556-1.340)	0.51	0.9(0.560-1.414)	0.62
	2	1.4(0.809-2.456)	0.22	1.4(0.777-2.490)	0.27
	3	2.3(1.168-4.801)	0.01	2.5(1.207-5.249)	0.01*
Unit/Implant		1.0(0.534-2.020)	0.91		

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

3.2. Survival probability

3.2.1. Kaplan-Meier analysis

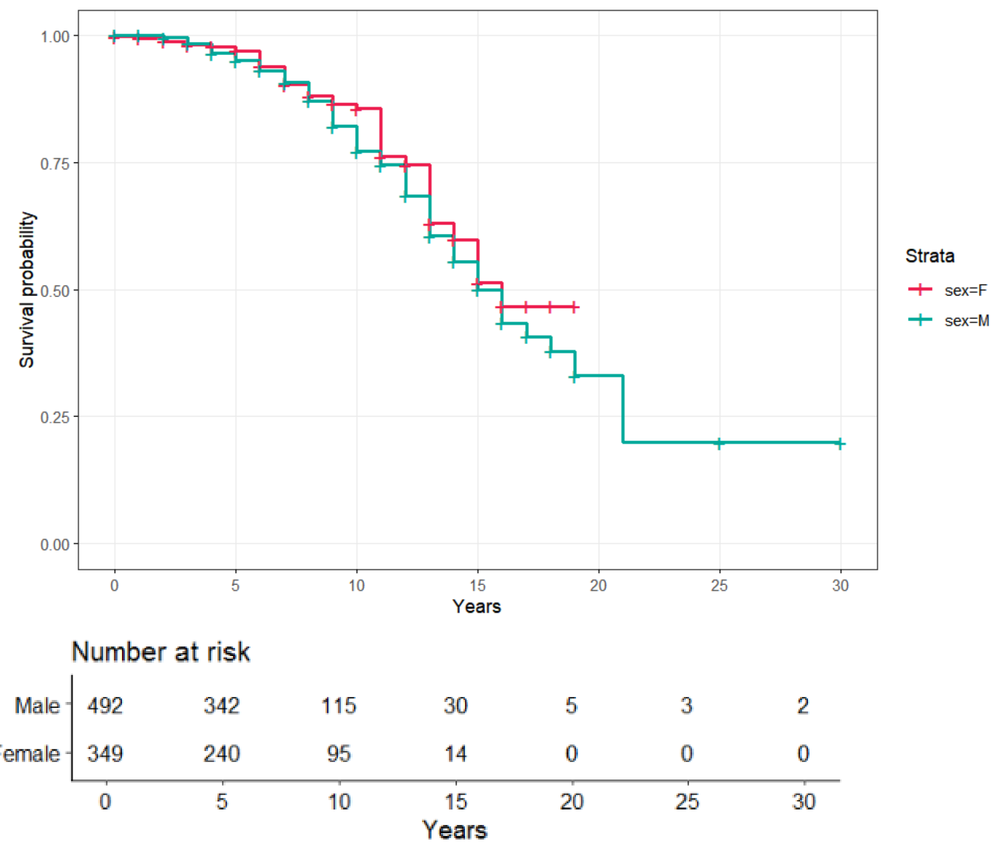


Figure 5. Evaluation of survival probability by gender.

Both males and females showed similar patterns, with a median survival of 15 years. Estimating survival curves beyond 20 years was not statistically significant owing to the small sample size.

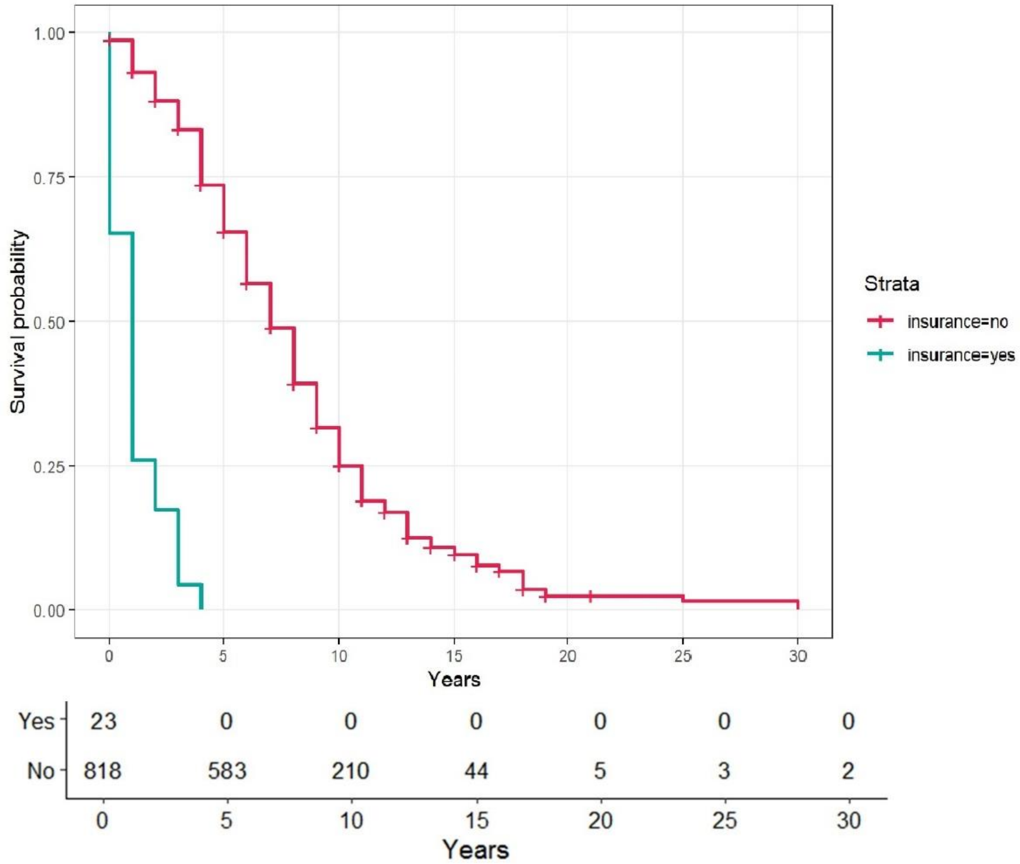


Figure 6. Evaluation of survival probability by insurance coverage.

The estimation was statistically insignificant because the number of cases with insurance covered prostheses was too small.

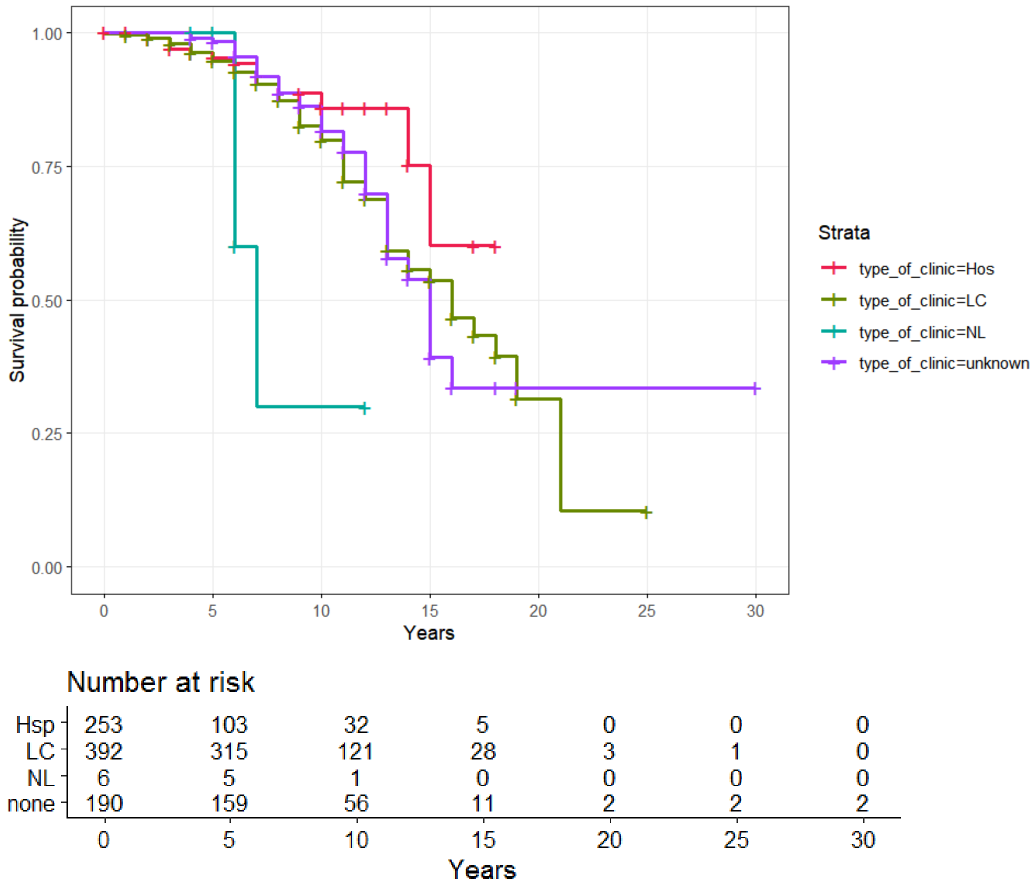
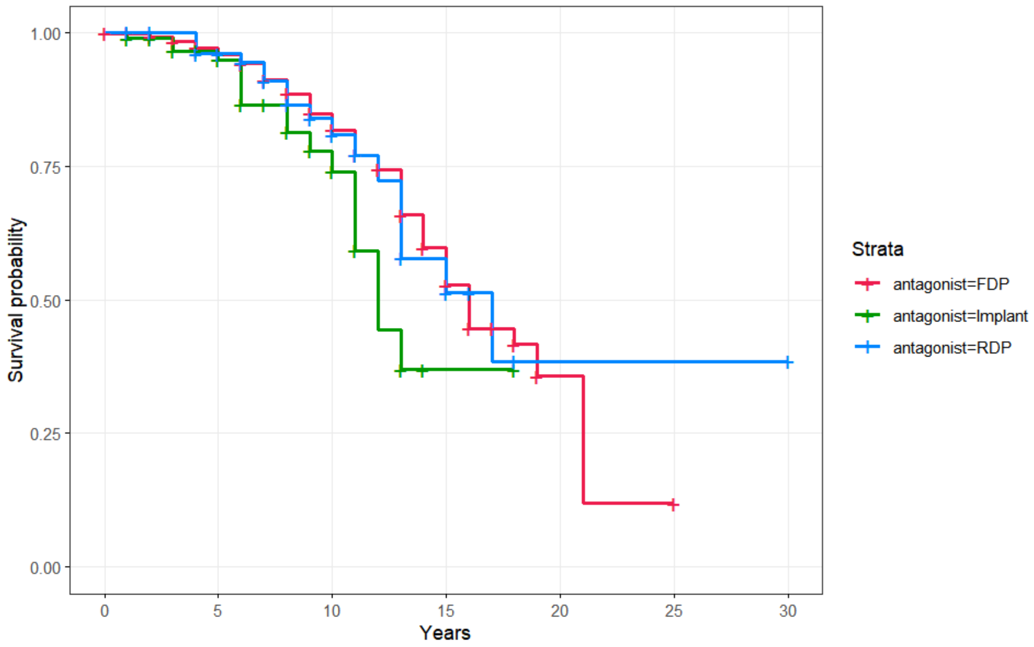


Figure 7. Evaluation of survival probability by type of clinic.

Prostheses treated at dental hospitals (Hos) seemed to have the most favorable prognosis. The median survival for local clinics (LC) was estimated to be 16 years, whereas for dental hospitals, it was not available, and estimating the survival curve beyond 15 years was considered unreliable owing to the small number of surviving prostheses. Non-licensed practitioners (NL) had an estimated median survival of 7 years, and for the 'unknown' category, it was estimated to be 15 years.



Number at risk

	0	5	10	15	20	25	30
FDP	668	456	163	34	3	1	0
RDP	79	66	27	9	2	2	2
Imp	94	60	20	1	0	0	0

Years

Figure 8. Evaluation of survival probability by type of antagonist dentition.

The graph indicates that when the antagonist dentition was an FDP or RDP, a similar trend was observed; however, when the antagonist dentition was an implant, a relatively declining trend was observed. The median survival was estimated to be 16 years for antagonist dentition with FDP, 17 years for antagonist dentition with RDP, and 12 years for antagonist dentition with implants.

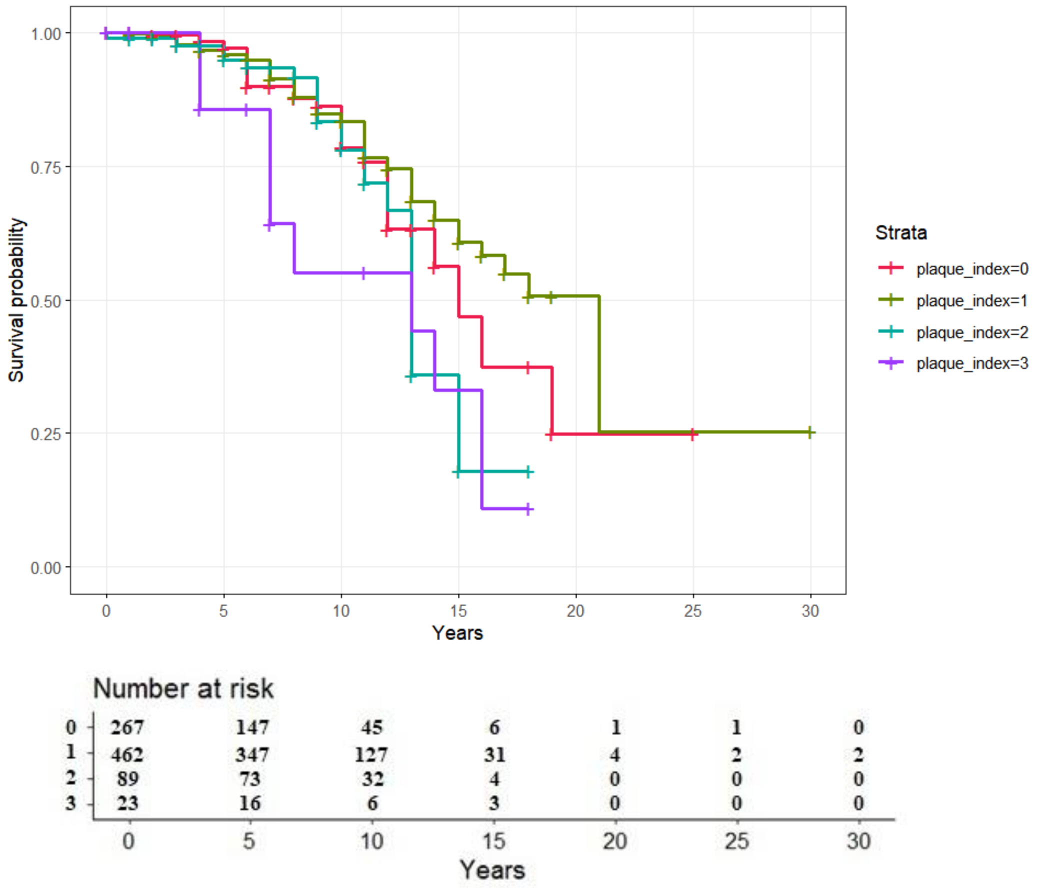
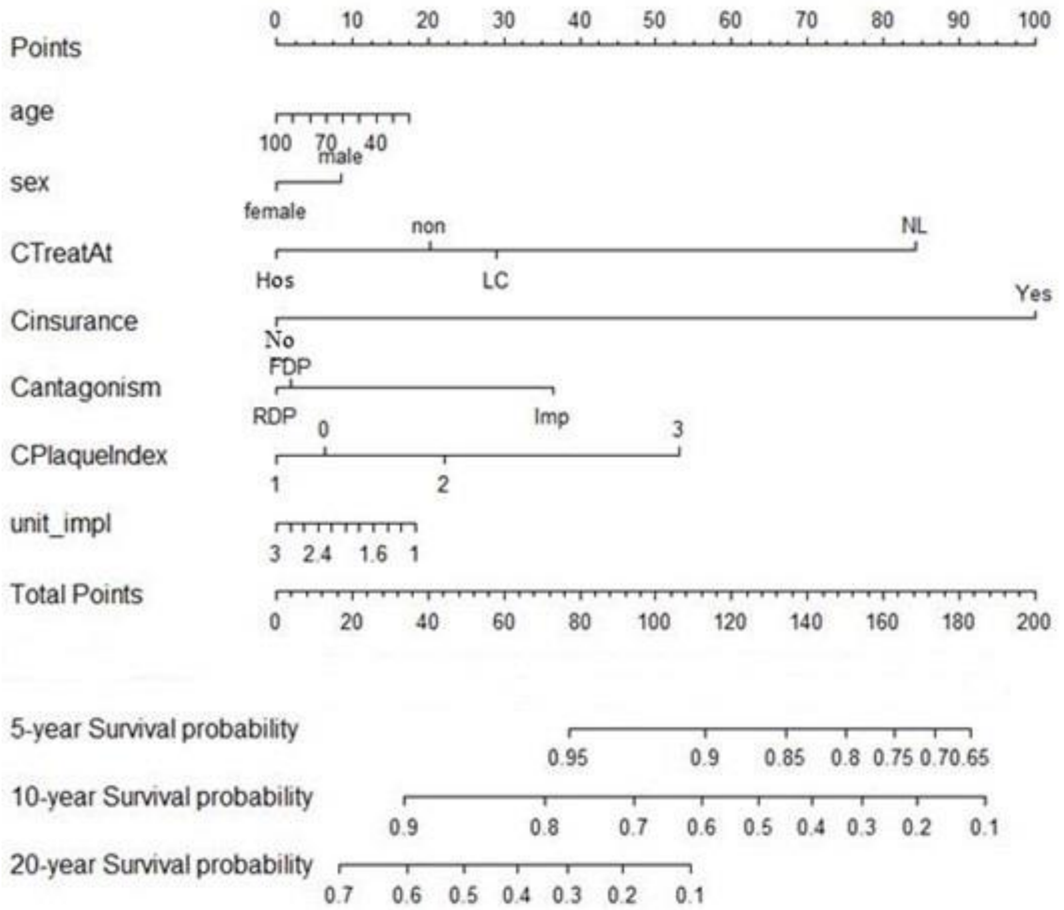


Figure 9. Evaluation of survival probability by plaque index.

There was an observable trend of decreasing survival rates when the plaque index was 3. The estimated median survival was 13 years for plaque index 2 and 3, which was lower than 15 years for plaque index 0, and 18 years for plaque index 1.

3.2.2. Nomogram



CTreatAt: type of clinic, Cinsurance: insurance coverage,
Cantagonism: type of antagonist dentition, unit_impl: ratio of prosthesis units to implant body

Figure 10. A nomogram representing the 5, 10, and 20-year survival probability of implant prostheses.

In the evaluation of the model development process, the statistically significant factors appeared in the following order: insurance coverage, type of clinic, plaque index, type of antagonist dentition, ratio of prosthesis units to implant body, age, gender.

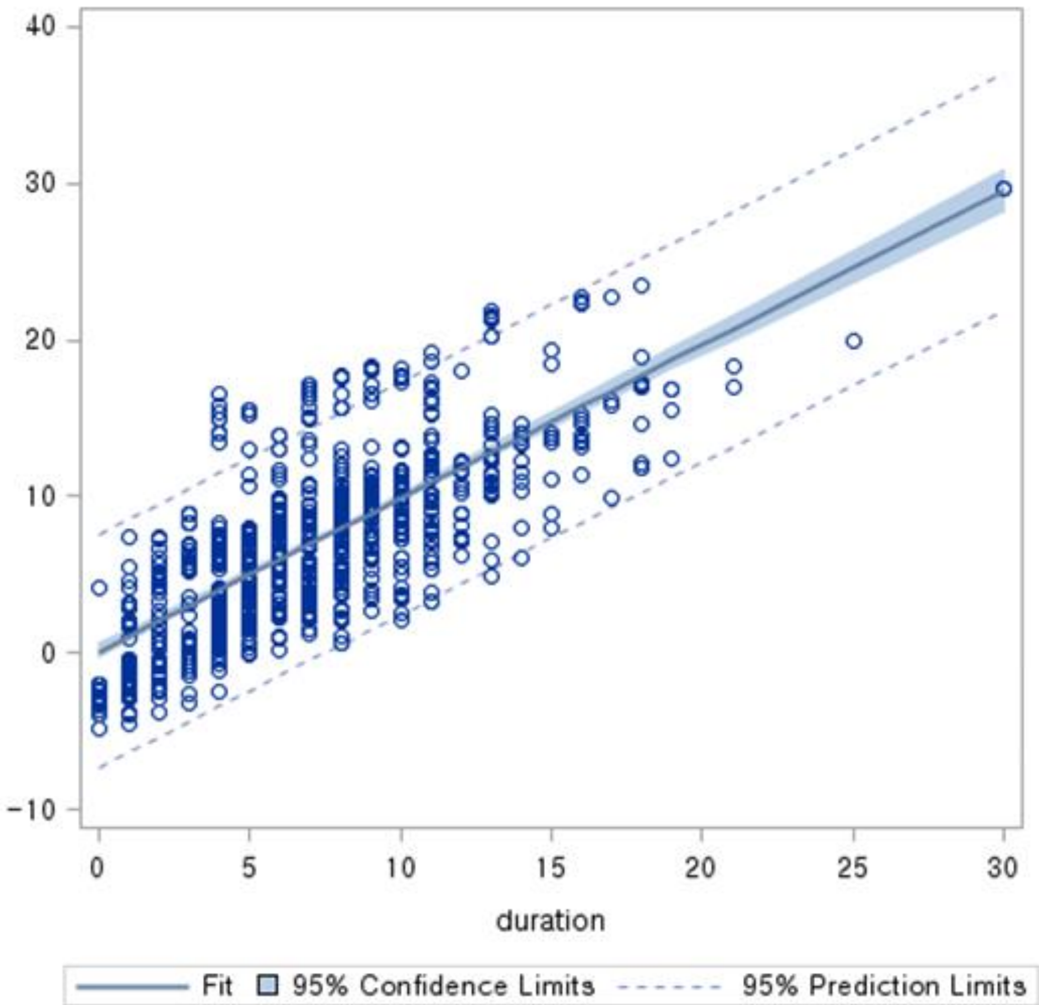
The survival probability corresponding to the total points was determined by summing the points assigned to each item.

3.3. Prediction of lifespan

We assigned a biological age score based on the linearly transformed principal components obtained through PCA and visually evaluated the estimation results (Figure 11, Table 2).

In Figure 11, the data points are relatively evenly distributed around the fit line that passes through the center of the scatter plot, and they generally exhibit a trend similar to that of the fit line. Most of the points were within the 95% prediction limit.

However, it can be observed that there are more data points located below the fit line, indicating that the estimated values are generally underestimated compared to the actual values.



Horizontal axis: actual prosthesis usage duration, Vertical axis: estimated prosthesis lifespan

Figure 11. Estimation of implant prosthesis lifespan.

Such an underestimation of the estimated values compared with the actual values can also be observed in Table 2.

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

	N	Mean	S. D	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

S. D: standard deviation, Min: minimum, Max: maximum

For prosthesis failure, the difference between the estimated and actual values generally tends to approach zero, indicating that the estimates are, for the most part, close to the actual values.

However, for prostheses that have not failed, the mean of the difference between estimated values and actual values is close to -1.3. This implies that these prostheses can be used for approximately 1.3 years longer than the estimated lifespan, indicating an underestimation.

4. DISCUSSION

4.1. Risk factors for implant prosthesis failure

The success and failure of dental implants are influenced by various factors, including the structural characteristics of the implant, anatomical considerations, occlusal forces and loading, the patient's systemic condition, biological factors, and more[12, 20]. These factors include elements that can be controlled by the dentist, such as the choice of implant system or prosthesis design, and factors that can be influenced by the patient, such as smoking habits and dietary choices. However, there are also factors beyond the control of both the patient and dentist, such as the quality of the bone where the implant is placed, the patient's endocrine disorders, or infection of the peri-implant tissue. In other words, dental implants can fail for exceedingly complex and multifactorial reasons[12, 20].

Even when considered solely from the perspective of implant prostheses, they tend to exhibit a wider variety of complications than conventional FDP and RDP. In addition to common complications such as prosthesis detachment or fracture, implant prostheses often present various complications related to screws and abutments, with screw loosening and screw or abutment fractures being prominent examples[10].

Various risk factors contribute to prosthodontic complications and failures. For implant-supported fixed prostheses, these factors include the three-dimensional position and angulation of the implant, screw torque value, structural differences in the implant body, and prosthesis material. Similarly, for implant-retained removable prostheses, the three-dimensional implant positioning and angulation, prosthesis material, and opposing dentition have been reported[11].

In contrast to the findings of previous studies, this study did not identify any differences in the risk of failure based on the type of implant prosthesis. However, it was confirmed that the risk of failure was influenced by the maintenance of oral hygiene and opposing dentition, as in previous studies. This study showed a statistically significant increase HR when the opposing dentition was implant-supported, and the plaque index was 3. In addition, cases treated by non-licensed practitioners showed a higher hazard ratio and statistically significant results. However, the sample size of these cases was extremely small (six of the total 841 cases); therefore, statistical interpretation should be approached with caution.

Studies on risk factors are meaningful not only in the context of patient care, but also in practitioner education. In a review by Paquette et al.[20], the emphasis was placed on the evaluation of risk factors for successful implant treatment and the importance of improving controllable factors. Patients should improve their lifestyle habits (especially smoking) and practitioners should focus on understanding the characteristics, design, site preparation, and appropriate loading strategies for implants. Additionally, it is essential for patients and practitioners to maintain good oral hygiene management over the long term. These results were also found to be applicable and meaningful to the present study. As mentioned earlier, for major risk factors, such as a high plaque index, both patients and practitioners should endeavor to maintain good oral hygiene. In addition, practitioners should provide an appropriate occlusal scheme depending on the type of opposing dentition. When the opposing dentition is composed of implants, the absence of the periodontal ligament, which is a characteristic of dental implants, may result in reduced proprioception. This can lead to delayed perception of overload or occlusal interference[21-23]. When occlusal contact occurs between implants, failure to adequately address parafunction can lead to a significant increase in mechanical complications of implant prostheses[24]. This can lead to the failure of implant prostheses, and practitioners need to be especially cautious.

Furthermore, unlike previous studies[25-27], this study did not consider detailed factors that could increase the risk of failure, such as systemic disorders, implant location, or patient habits. In future follow-up studies, by reevaluating the survey form and obtaining a larger sample size, a more detailed analysis can be conducted by appropriately extracting information.

4.2. Survival probability

Survival analysis models typically use data that are influenced by time and do not follow a normal distribution. In other words, survival data may exhibit asymmetric skewness, and in extreme cases, the presence of highly skewed outliers could prevent the central tendency of the data from being properly reflected[23, 28, 29]. In this case, 'median' is more suitable as the representative statistic than 'mean', so we used median survival in this study.

The insurance coverage variable (Figure 6) showed statistically significant results in the univariate analysis (Table 1). However, the sample size of 23 was quite small, and most cases experienced failure or censoring before the 5-year mark. Since the coverage of dental implants by the South Korean National Health Insurance only began in 2014, accumulating a sufficient sample size may have been challenging. Therefore, this variable is likely to require reevaluation in follow-up studies with larger sample sizes and additional validation.

Similarly, the type of clinic variable (Figure 7) showed statistically significant results in the multivariate analysis (Table 1). However, the overall sample size of six was very small, and most cases experienced failure or censoring around the 10-year mark. These results may change in subsequent studies with larger sample sizes. However, considering that dental implant procedures are relatively new compared to the traditional FDP and RDP options, they require specialized training. Moreover, patient awareness and access to dental clinics have improved compared to the past, leading to a decrease in demand for non-licensed practitioners. Considering these variables, the results may not change significantly in subsequent studies.

A nomogram was created to visualize and provide a simple way to understand the results (Figures 4 and 10). The factors that received high scores on the nomogram are ordered as follows: insurance coverage, type of clinic, plaque index, type of antagonist dentition, the ratio of prosthesis units to implant body, age, gender.

In the previously mentioned Cox proportional hazards model, the risk factors that had a statistically significant impact on implant failure were the type of clinic, type of antagonist dentition, and plaque index. However, in the nomogram, insurance coverage emerged as the factor with the greatest influence. This discrepancy may be attributed to the process of converting the HR to an absolute scale during the construction of the nomogram, where the insurance coverage factor appears to have been assigned a higher value. However, it is crucial to note that this factor, like 'non-licensed practitioners,' is represented by a very small number of cases in the entire study (23 out of 841 cases). Therefore, this variable should be interpreted with caution, and re-evaluation may be necessary in future follow-up studies with larger overall sample sizes.

Nomograms allow researchers to easily compare survival probabilities from their own perspective. In the field of medicine, nomograms are actively used to evaluate patient's survival probabilities and are versatile diagnostic and predictive models for various diseases[30, 31]. Moreover, because of their intuitive format, they can serve as educational materials for patient counseling. This could allow for not only a post-assessment of the prostheses but also prediction of the expected survival rate of prostheses under the current conditions before initiating treatment. This allows patients to intuitively understand the aspects that require improvement for the successful maintenance of implant prostheses both before and after treatment.

4.3. Prediction of lifespan

When predicting the lifespan of implant prostheses, using traditional MLR can lead to multicollinearity issues that may adversely affect data analysis. In this study, a multitude of factors influenced lifespan, and we needed to consider their interrelationships. Most importantly, determining the criteria for the 'actual duration of prosthesis usage' corresponding to the prosthesis lifespan is ambiguous. In survival analysis targeting 'patients,' the 'time of death' is clearly identifiable. However, in research focusing on 'implant prostheses,' there is no way to determine the exact moment of 'failure.' If the prosthesis has already reached a state of 'failure,' but the patient was unaware or delayed seeking treatment for other reasons, the recorded 'duration of the prosthesis' can be significantly longer than the 'actual time.' The incorporation of ambiguous and unstable factors as important considerations in the lifespan estimation process can be challenging[32-34]. In such situations, the extended concept of MLR, also known as PCA, is a viable approach.

The process included analyzing the correlations between the prosthesis duration and related parameters, conducting redundancy analysis, and utilizing the variables obtained to create a PCA model. Based on this, a BAS was calculated, and the estimated prosthesis lifespan and actual duration were compared and visualized (Figure 11, Table 2).

As mentioned earlier, in Figure 11, the data appears to be evenly distributed around the fit line, with relatively small deviations. However, there was a noticeable tendency for more data points to be estimated below the fit line, indicating shorter estimated durations than actual durations. This can be more clearly observed in Table 2, where the average difference between the estimated values and the actual duration for non-failed prostheses was -1.34.

This result may be attributed to the fact that the prostheses were labeled ‘success’ when they were in sufficiently good condition for future use. However, ‘the duration of prostheses,’ which is ‘the lifespan of the prostheses,’ was measured based on the time when the prostheses were evaluated, and therefore, it appears to be underestimated under the conditions controlled by PCA.

4.4. Large sample and multicenter study

This study is highly significant for collecting a large sample in accordance with standardized assessment criteria and for efficiently gathering and analyzing data from various institutions scattered over long distances using an online platform. However, there are clear limitations that require further improvement.

First, the strength of inter-examiner reliability was not determined. As multiple examiners from 16 independent institutions participated, an evaluation of inter-examiner variability is necessary. Typically, this is evaluated by calculating the Cohen's kappa coefficient, which assesses the strength of agreement on a scale from poor to almost perfect, depending on the value[35]. Each institution's examiners received thorough training for this study; however, if we cannot provide numerical values for such inter-examiner calibration, concerns about the reliability of the data collection process may become significant.

Second, compared to recent big data studies, the sample size in this study was relatively small. Many recent big data studies related to implants[36, 37] have relied on dental insurance declarations or data from health management organizations, resulting in considerably larger sample sizes. However, although the sample size was larger in these big data studies, the information that could be extracted was limited by the pre-existing data pool. In contrast, this study involved well-trained prosthodontists who directly interviewed patients and conducted clinical and radiological assessments, which provided a broader range of information for analysis. Additionally, with the ease of access and intuitive data input through the online platform across multiple institutions, collecting a substantial amount of data should be achievable without difficulty.

We expect that future research directions will involve large-scale big data studies using extensive samples. However, it is important to be cautious, as in such cases, errors that may arise during the sampling and study design processes can be magnified, potentially leading to bias associated with these errors. The continuous reduction of errors through thorough validation and improvement processes can lead to more reliable research outcomes. This approach can also enable the effective handling of rare events and simplify research protocols, leading to time and cost savings and contributing to the overall qualitative growth in research[38, 39].

5. CONCLUSION

1. Factors influencing the success and failure of implant prostheses include the type of antagonist dentition and plaque index. Clinic type was also considered; however, the sample size was too small.

2. According to the survival analysis results, the median survival of the implant prostheses was 16 years, with a 95% confidence interval.

3. Thus, the estimated lifespan of implant prostheses tends to be underestimated. Prostheses that have not failed are expected to be used for approximately 1.34 years longer than the estimated lifespan.

4. A visualization tool such as a nomogram is effective not only for the intuitive evaluation of prostheses but also for predicting their prognosis under specific conditions. This provides significant benefits to patients, practitioners, and researchers.

5. The use of an online platform enables efficient large-sample studies across multiple institutions, with the potential for overall improvement in the quality of research.

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ABSTRACT (KOREAN)

다기관의 다수 데이터를 활용한 임플란트 보철물의 위험인자 평가 및 수명 예측

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김 정 훈

치아 결손에 대해 치과 임플란트는 효과적인 치료방법으로 자리잡고 많은 환자의 구강재건에 활용되고 있지만 구조적 특성으로 인해 여러 합병증이 발생하고 실패에 기여하는 원인도 다양하다. 합병증과 실패에 대응하기 위해 정기적인 검진과 환자 교육은 필수적이다. 이를 위한 객관적 데이터를 제시하기위해 실패한 보철물의 사용 연한을 평가하거나 특정 기간 동안 임플란트의 생존율을 분석하는 연구가 지속적으로 이루어졌다. 하지만 대부분의 선행연구는 조사기관이 단독 혹은 소수로 제한적이거나 표본의 수가 충분치 못하다는 한계점을 보였다.

이에 본 연구에서는 임플란트 보철물의 분석에 필요한 다량의 데이터를 표준화된 기준에 맞춰, 다기관에서 원격으로 효율적으로 수집하고자 한다. 수집한 데이터를 통해 임플란트 보철물의 성공과 실패에 영향을 미치는 요인에 대해 평가하고 보철물의 수명 예측과 관련된 분석을 해보려 한다.

선행연구에서 확립한 표준화된 평가 기준에 따라 16개 기관에서 환자의 문진과 임상 및 방사선학적 평가를 하여 정보를 수집하였다. 이는 온라인 플랫폼을 통해 한 기관으로 수합되고 이에 대한 통계적인 분석을 하였다. 통계적 분석은 Cox proportional hazard model, Kaplan-Meier analysis, nomogram, Principal component analysis를 활용하였다.

생존분석에서의 중간값은 95% 신뢰구간에서 16년으로 추정되었다. 통계적으로 유의미하게 임플란트 보철물의 실패에 영향을 준 요인으로는 진료받은 의원의 종류, 대합치의 종류, 치태지수였으며 각각 무자격자에게 진료를 받았을 때, 대합치가 임플란트였을 때, 치태지수가 3인 경우다. 보철물의 수명에 대한 추정을 하였을 때 해당시점에 아직 실패하지 않은 보철물의 경우 평균적으로 1.34년 이상 더 사용할 수 있을 것으로 기대된다.

성공적인 임플란트 보철치료를 위해선 환자와 치과의사 모두 구강위생 관리에 힘써야 한다. 보철물의 수명 추정은 다소 과소 추정되는 경향을 보인다. 노모그램과 같은 시각화 도구는 술자, 연구자, 환자 모두에게 유용한 직관적인 정보를 제공한다. 표준화된 양식과 온라인 플랫폼을 활용하니 많은 수의 표본도 효율적으로 수집하고 분석할 수 있었으며 이를 후속 연구에도 활용한다면 보다 큰 표본의 빅데이터 연구도 수월하게 가능할 것으로 기대한다.

핵심 되는 말: 치과 임플란트, 임플란트 보철물 실패, 보철물의 생존분석, 보철물의 수명 예측, 빅데이터, 다기관 연구