Original article

Risk factors for abutment and implant fracture after loading

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Abstract

Purpose: Implant component fractures are one of the most serious complications in implant treatment. With a better understanding of the risk factors for fracture in the preoperative, surgery, superstructure, and post-loading phases of implant treatment, low-risk treatment could reduce implant component fractures, leading to a better prognosis. The aim of this study was to clarify the risk factors for abutment and implant fractures that occur after loading, and to perform a retrospective, approximately 10-year follow-up study to explore the risk factors in each treatment phase.

Methods: Subjects were fitted with an implant prosthesis between January 2008 and December 2009. In total, 1,126 Ankylos implants in 430 patients were included for analysis. Binary logistic regression analysis was performed to extract factors related to non-fracture and fracture of the abutment or implant as a dependent variable.

Results: Gender (OR = 3.466, 95% CI 1.296-9.268, $P = 0.013$), gonial angle (OR = 3.420, 95% CI 1.308-8.945, $P = 0.012$), and splinting status of the superstructure (OR = 4.456, 95% CI 1.861-10.669, $P = 0.001$) were identified as significant risk factors.

Conclusion: The risk of fracture is increased in males, especially those with a mandibular angle of less than 120° on panoramic radiographs, and those with a non-splinted superstructure.

Keywords: gonial angle, implant fracture, retrospective cohort study, risk factors

Introduction

Implant treatment has a stable long-term prognosis with a high chance of achieving osseointegration. However, mechanical and biological complications related to implants have been reported [1-3]. Fracture of the veneering material; loosening or fracture of the abutment screw; and fracture of the framework, abutment, or implant are the worst-case scenarios and have been reported following long-term prosthesis use [4,5]. The fracture rate of implant components, including the implant, abutments, and abutment screws, is 5.6% [6]. Bruxism and the crown-implant ratio (C/I) are possible causes of internal stress that lead to mechanical complications [7]. It has been reported that bruxism is a factor for implant fracture due to the strong force applied [8] and that the strain on the implant body's buccolingual side is directly proportional to an increase in the C/I [9].

Prosthetic problems caused by mechanical complications occur after superstructure installation. Therefore, it is necessary to minimize the occurrence of complications, considering the resulting discomfort to the patient, time needed for repair and remanufacturing, the cost and damage, as well as the distress caused by removal of the fractured implant. It is thus

desirable to predict the case selection, response to risk factors, and prognosis by evaluating risk factors from information obtained prior to surgery.

It is difficult to evaluate risks such as the presence or absence of bruxism by only examining the dentition and skeleton through preoperative oral and X-ray examinations. Therefore, these risks should be evaluated using an established or simple inspection method. Implant treatment is divided into preoperative examination, surgery, superstructure, and post-loading phases. If the risk factors for mechanical complications per phase can be determined, it will be possible to reduce implant treatment failure.

Previous studies [1-10] have examined the risk factors for fracture of the implant component; the incidence of implant and abutment fractures is reportedly low. Possible causes are multifactorial, such as dental implant manufacturing and design failure, bruxism or large occlusal force, superstructure design, implant positioning, implant diameter, metal fatigue, and bone resorption around the implant. However, conflicting reports [11-13] deny the role of the above factors, and no clear cause is stated. Few studies have described the long-term observation of multiple factors from the preoperative to post-loading periods and compared and evaluated cases with and without fractures. By investigating the risk factors for fracture during each phase, it is expected that low-risk implant treatment can reduce the fracture of implant components, leading to a better prognosis. Therefore, the aim of this study was to clarify the risk factors for abutment and implant fracture that occur after loading, and to perform a retrospective, approximately 10-year follow-up study to evaluate these factors in each phase of implant treatment (i.e. preoperative examination, surgery, and superstructure and post-loading phases).

Materials and Methods**Study design**

This was a retrospective cohort study.

Subjects

Subjects underwent insertion of an implant prosthesis between January 2008 and December 2009 at the Oral Implant Clinic, Nihon University Hospital at Matsudo. There were 1,148 implants in 434 patients (129 men, 305 women) with follow-up data until December 2019. Only patients with Ankylos implants (Dentsply Implants Manufacturing GmbH, Hanau, Germany) were included; those with non-Ankylos implants were excluded.

In line with the manufacturer's recommended protocol, all Ankylos implantations were performed in two stages. First, the implant body (commercially pure titanium [cpTi] grade 2) was inserted so that its platform was located at or below the margin of the bone, and the mucosa was sutured. Following a 3-month healing period, a permucosal extension was fashioned during second-stage surgery after taking an impression and prosthesis insertion. All abutments were made of ready-made, formable titanium alloys (Ti-6Al-4V) that correspond to mucosal penetration with different neck lengths. All superstructures were fixed with temporary cement. The occlusal contact applied to the superstructure was adjusted so that the implant and natural tooth parts were in the same occlusal contact state. Maintenance was performed at 1, 3, and 6 months after superstructure installation, and at 6-month intervals thereafter.

The subjects were divided into two groups. Patients with or without

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Fig. 1 Participant flow in this study

fracture of the implant or abutment during the observation period were categorized into the fracture group and non-fracture groups, respectively.

Investigation parameters

Preoperative items

Basic attributes: Age at the time of implant placement and gender were obtained from medical records.

Medical history: The absence or onset of hypertension, heart disease, cerebrovascular disease, diabetes, osteoporosis, hepatic or renal dysfunction, autoimmune disease, psychiatric disorders, and smoking, which are risk factors for implant treatment [14], were obtained from medical records.

Gonial angle: Gonial angle was obtained from a panoramic radiograph. Abe et al. [15] defined the gonial angle as the angle between the ramus and mandibular planes, excluding the mandibular condyle's posterior margin. This angle was expressed as the mean of both sides. It was classified as either greater than 120 degrees or less than 120 degrees, based on a report indicating that the fracture of vital teeth tends to increase when the mandibular angle is less than 120 degrees [15]. Synapse Vincent (Fujifilm Medical Corp., Tokyo, Japan) was used to obtain the measurements.

Miyachi's Index: The relationship between the number of residual teeth and that of occlusal supports preoperatively was acquired from the medical records and panoramic radiographs. It was evaluated in four groups: occlusal miss, occlusal defect, occlusal collapse, and occlusal loss, as per Miyachi's triangular classification [16].

Eichner Index: The occlusal support area of the premolar and molar regions was graded as A, B, or C, as per Eichner's classification [17] based on data from the medical records and panoramic radiographs.

Operative items

The presence or absence of hard tissue management: When normal implant placement was impossible due to insufficient bone mass, hard tissue management (maxillary sinus floor elevation, guided bone regeneration (GBR), bone graft, or split crest) was performed. Its presence or absence was confirmed using the medical records.

Implant body: A relationship between the Ankylos implant diameter and abutment fracture has been reported [18]. Implant diameter and length measurements were obtained from medical records.

Placement position: Because large forces are involved with the last molar [19], whether the implant placement position was at the end of the dental arch or not was evaluated using panoramic radiographs.

Superstructure items

Morphological evaluation: The possibility of mechanical complications depending on the difference in C/I and the superstructure's splinting or non-splinting [9,20] was evaluated, and the following items were acquired: the distance between the platform and crown margin, superstructure length, and distance between the platform and cusp were measured from the medi-

cal records and X-ray photographs. C/I was then calculated.

Splinting or non-splinting: The splinting status of the superstructure was acquired from the medical records and X-ray photographs.

Superstructure material: Differences in the transmission speed and absorption of impact force due to differences in superstructure materials [21,22] have been reported. The use of porcelain, hybrid composite resin, and gold platinum alloy in superstructure materials was acquired from the medical records.

Post-loading items

The presence or absence of fractures of veneering materials or loosening of abutment screws or superstructure falling (mechanical trouble): a previous report [23] suggested that abutment screw fractures preceded implant fractures. The presence or absence of these items was obtained from the medical records.

Presence or absence of fracture of abutment or implant: Presence or absence of this fracture was acquired from the medical records and X-ray photographs.

Marginal bone loss: Marginal bone loss was measured as the distance between the platform and bottom of the marginal bone loss from the X-ray photographs. A report [23] described the relationship between implant fracture and marginal bone loss. The presence or absence of this information was acquired from the medical records and X-ray photographs.

Statistical analysis

Regarding each evaluation item, depending on the fracture and non-fracture groups in relation to abutment and implant, Mann-Whitney *U*-test was performed to examine continuous variables between groups, and chi-square test was conducted to examine categorical variables. Binary logistic regression analysis in forced entry was performed to extract factors related to non-fracture or fracture as dependent variables. The analysis was performed at the implant level, where component fracture occurs, rather than the patient level. Furthermore, the risk ratio was calculated. SPSS version 23.0 for Windows (IBM Corp., Armonk, NY, USA) was used for all statistical analyses. Statistical significance was set at 5%.

Ethical considerations

This study was conducted with the approval of the Ethics Committee of Nihon University School of Dentistry at Matsudo (approval number: EC18-18-15-038-2) and in accordance with the Declaration of Helsinki. All participants provided written informed consent.

Results

Subjects

The participant flow chart is shown in Fig. 1. During the study period, 1,126 Ankylos implants from 430 patients (128 men, 302 women; mean age 55.3 ± 10.6 years) were inserted. There were 1,100 implants in 409

Table 1 Comparison between the non-fracture and fracture group (implant level)

		Non-fracture (<i>n</i> = 1,100)			Fracture (<i>n</i> = 26)			
		Mean ± SD	<i>n</i>	%	Mean ± SD	<i>n</i>	%	<i>P</i> -value
(Preoperative items)								
Age (years)		56.2 ± 9.7			55.7 ± 10.3			0.804 ^a
Gender	men		329	29.9%		19	73.1%	<0.001 ^{b*}
	women		771	70.1%		7	26.9%	
Gonial angle		122.9 ± 7.6			16.4 ± 6.0			<0.001 ^{a*}
Gonial angle	≥120°		751	68.3%		7	26.9%	<0.001 ^{b*}
	<120°		349	31.7%		18	73.1%	
Hypertension	absence		984	89.5%		19	73.1%	0.008 ^{b*}
	onset		116	10.5%		7	26.9%	
Heart disease	absence		1,056	96.0%		23	88.5%	0.057 ^b
	onset		44	4.0%		3	11.5%	
Cerebrovascular disease	absence		1,080	98.2%		25	96.2%	0.450 ^b
	onset		20	1.8%		1	3.8%	
Diabetes	absence		1,036	94.2%		23	88.5%	0.233 ^b
	onset		64	5.8%		3	11.5%	
Osteoporosis	absence		1,092	99.3%		26	100%	0.663 ^b
	onset		8	0.7%		0	0.0%	
Hepatic dysfunction	absence		1,054	95.8%		23	88.5%	0.069 ^b
	onset		46	4.2%		3	11.5%	
Renal dysfunction	absence		1,076	97.8%		23	88.5%	0.002 ^{b*}
	onset		24	2.2%		3	11.5%	
Autoimmune disease	absence		1,076	97.8%		26	100%	0.446 ^b
	onset		24	2.2%		0	0.0%	
Psychiatric disorder	absence		1,085	98.6%		26	100%	0.549 ^b
	onset		15	1.4%		0	0.0%	
Smoking	no		991	90.1%		19	73.1%	0.005 ^{b*}
	yes		109	9.9%		7	26.9%	
Miyachi's index	missing		348	34.9%		12	46.2%	0.391 ^b
	defective		494	44.9%		8	30.8%	
	collapsed		152	13.8%		3	11.5%	
	disappeared		106	9.6%		3	11.5%	
Eichner	A		136	12.4%		3	11.5%	0.988 ^b
	B		832	75.6%		20	77.0%	
	C		132	12.0%		3	11.5%	
(Operative items)								
Hard tissue management	no		880	80.0%		25	96.2%	0.040 ^{b*}
	yes		220	20.0%		1	3.8%	
Placement at the end of arch	no		764	69.5%		17	65.4%	0.083 ^b
	yes		336	30.5%		9	34.6%	
Diameter of implant body		3.6 ± 0.4			3.8 ± 0.5			0.057 ^a
Length of implant body		11.8 ± 2.1			11.6 ± 2.3			0.604 ^a
(Superstructure items)								
Plat-mar		2.4 ± 1.4			2.4 ± 1.0			0.679 ^a
Length of superstructure		9.7 ± 2.9			9.0 ± 3.2			0.505 ^a
Plat-mar + length of superstructure		12.1 ± 3.2			11.4 ± 3.1			0.429 ^a
C/I		1.1 ± 0.3			1.0 ± 0.3			0.818 ^a
Material of superstructure	ceramics		916	83.3%		14	53.8%	0.001 ^{b*}
	hybrid composite resin		120	10.9%		8	30.8%	
	gold platinum alloy		64	5.8%		4	15.4%	
Non-splinting or splinting	non-splinting		340	30.9%		16	61.5%	0.001 ^{b*}
	splinting		760	69.1%		10	38.5%	
(Post loading items)								
Mechanical trouble	no		877	79.7%		19	73.1%	0.406 ^b
	yes		223	20.3%		7	26.9%	
Marginal bone loss		0.7 ± 1.6			1.0 ± 1.6			0.046 ^{a*}

^aMann-Whitney *U*-test; ^bχ²-test; ^{*}*P* < 0.05. Plat-mar: distance between platform and crown margin

patients that did not develop abutment or implant fracture; while 26 components (18 abutments, 8 implants) in 21 patients (abutment: 16 patients, implant: 5 patients) experienced abutment or implant fracture.

Comparison of the non-fracture and fracture groups at the implant level

As shown in Table 1, the average gonial angle was 122.9 ± 7.6 degrees in the non-fracture group and 116.4 ± 6.0 degrees in the fracture group, which was significantly different (*P* < 0.001). The marginal bone loss was 0.7 ± 1.6 mm in the non-fracture group and 1.0 ± 1.6 mm in the fracture group, with the bone loss in the fracture group being significantly higher than that observed in the non-fracture group (*P* = 0.046). There were also significant differences in the gender distribution between the fracture and non-fracture groups (*P* < 0.001), in the proportion of individuals with a gonial angle

more or less than 120 degrees (*P* = 0.001), the presence of a history of hypertension (*P* = 0.008), renal dysfunction (*P* = 0.002), smoking status (*P* = 0.005), use of hard tissue management (*P* = 0.040), splinting status (*P* = 0.002), and the material used in the superstructure (*P* < 0.001).

Examination between various items and fracture of the implant components

Results of binomial logistic regression analysis using forced entry identified that gender (odds ratio (OR) = 3.5, 95% confidence interval (CI) 1.30-9.27, *P* = 0.013), gonial angle (OR = 3.4, 95% CI 1.31-8.95, *P* = 0.012), and splinting status of the superstructure (OR = 4.46, 95% CI 1.86-10.67, *P* = 0.001) were important factors relating to the fracture of an abutment or implant (Table 2).

Table 2 Examination between various items and fracture of the implant component

	Cut-off	OR	95% CI	P-value
Age		0.981	0.936-1.029	0.432
Gender	men	3.466	1.296-9.268	0.013*
	women	—	—	—
Gonial angle	$\geq 120^\circ$	—	—	—
	$< 120^\circ$	3.420	1.308-8.945	0.012*
Hypertension	absence	—	—	—
	onset	0.409	0.140-1.192	0.101
Renal dysfunction	absence	—	—	—
	onset	0.406	0.061-2.694	0.544
Smoking	no	—	—	—
	yes	0.849	0.279-2.579	0.772
Hard tissue management	no	7.556	0.928-61.491	0.059
	yes	—	—	—
Material of superstructure	gold platinum alloy	—	—	0.153
	ceramics	0.381	0.111-1.308	0.125
	hybrid composite resin	0.894	0.203-3.930	0.882
Non-splinting or splinting	non-splinting	4.456	1.861-10.669	0.001*
	splinting	—	—	—
Marginal bone loss		1.069	0.828-1.380	0.608

Forced binary logistic regression analysis. OR, odds ratio; CI, confidence interval; * $P < 0.05$

Fig. 2 Risk ratio and confidence interval of extracted items

Risk ratio

The risk ratio and confidence interval of the extracted items are shown in Fig. 2. Upon calculating the risk ratios of the three extracted items, gender (risk ratio (RR) = 6.4, 95% CI 2.69-15.28), gonial angle (RR = 5.5, 95% CI 2.29-13.37), and splinting status (RR = 3.6, 95% CI 1.61-7.96) were identified as important fracture-related factors.

Discussion

This study is the first to focus on the worst mechanical complications of implant treatment, i.e. fracture of the abutment and implant, by observing multiple long-term factors from before surgery to after loading, and comparing cases with and without implant component fracture. The aim of this study was to clarify the risk factors for fracture to improve the prognosis of patients undergoing implant treatment. A retrospective follow-up study spanning approximately 10 years was also conducted. The results indicate that gender, gonial angle, and splinting status of the superstructure were factors related to fracture development.

This study only assessed patients receiving Ankylos implants because most of the implants used during the study period were of this brand. This eliminated any fracture rate differences possibly attributable to differences in implant morphology and abutment-implant connection methods [6]. The Ankylos implant body is made of pure titanium grade 2, easier to process than grade 4 and reported to show higher shear contact strength when in contact with bone [24]. As a result, the implant body can achieve precise, tight taper abutment joints and reliable osseointegration.

The Ankylos implant has a conical internal connection, with the conical interface being tightly joined by friction (in lieu of a screw) between the implant and abutment. This joint is biomechanically superior to external and internal hexagonal connections [25]. Moreover, because it has a platform switch structure and abutment narrower than the attached implant's diameter, the implant-abutment gap is away from the implant shoulder. As a result, it is possible to maintain the height of the bone around the implant

and reduce the resorption of alveolar bone [26]. It has been shown that the Ankylos implant has good long-term stability with few mechanical or biological complications [27].

In this study, the abutment fracture rate was 1.6%, and implant fracture rate was 0.7%. Previous studies with a follow-up duration of approximately 10 years have reported the rate of abutment fracture to be 3.3-5.5% [6,28], and that of implant fracture as 0.2-2.8% [23,28]. In the case of the Ankylos implant only, the literature suggests an implant fracture rate of 0.23% and abutment fracture rate of 2.2% [18,27], which is slightly different from the values in this study. It has also been reported that a large implant diameter is associated with a high incidence of abutment neck fractures [18]. Ankylos implants have the same abutment diameter of approximately 2.4 mm at the platform, regardless of the implant diameter. When stress exceeds the mechanical strength in the mouth if the implant diameter is large, it is considered as an abutment fracture. On the other hand, if the implant diameter is small, the implant may be fractured. It has also been reported that 92% of fractured implants are associated with marginal bone resorption. It is only possible to speculate whether implants with lost bone support are prone to fracture or whether internal stress causes flexion and deformation of the implant body, resulting in increased fatigue, embrittlement, and crack propagation [4]. Fractures are influenced by the joint style of the implant and abutment, detailed design of the implant components, and relationship with bone resorption. Hence, the difference in fracture rates to other implant systems needs to be examined in detail in future studies.

In this study, gender was identified as an important factor for fractures of the abutment and implant (OR = 3.5, 95% CI 1.30-9.27, $P = 0.027$; RR = 6.4, 95% CI 2.64-15.25), and men were at a higher risk of fracture. Fracture occurs when force is transmitted from the superstructure to the implant component due to occlusal loading; internal stress is also generated in the marginal bone. This internal stress exceeds the mechanical strength of the component [7]. Occlusal force is reportedly significantly stronger in men than in women [29]. In the past, implant fractures were also reported to be more common in men than in women [30]. The results of this study support those of previous studies.

The gonial angle has rarely been mentioned as a factor for abutment and implant fractures in previous studies. In this study, based on Abe et al.'s report [15], the mandibular angle was measured on a panoramic radiograph and used as an occlusal force index, which is the source of internal stress that causes a fracture [7]. When evaluating defective dentition during a preoperative implant treatment examination, in the case of a dentition with multiple missing teeth, it may be difficult to measure the occlusal force of the natural tooth. The gonial angle's evaluation in the panoramic radiograph was as accurate as that of the cephalometric radiograph, and there was no difference in the value of this angle irrespective of the imaging conditions [31].

In addition, the occlusal force of healthy adults and gonial angle on panoramic radiograph were measured; it was reported that the gonial angle

and maximum occlusal force were negatively correlated [29]. Bruxism is a factor that induces internal stress. Bruxers reportedly have a stronger maximum occlusal force than non-bruxers and occlusal force and tooth wear are correlated [32]. However, there is no difference in maximum occlusal force between bruxers and non-bruxers [33], and the relationship between bruxism and occlusal forces is not clear. Because it is not easy to determine clinically whether a subject is a bruxer, it was exempted from inclusion as an evaluation item in this study. From these facts, it can be concluded that the gonial angle measured on a panoramic radiograph, widely used in dentistry, can be more objectively and easily applied in a clinical setting. Therefore, the gonial angle was deemed to be suitable as an occlusal force index and was thus chosen as an evaluation item.

The gonial angle was also established as an important factor (OR = 3.4, 95% CI 1.31-8.95, $P = 0.019$; RR = 5.5, 95% CI 2.29-13.37). The fracture group's mean gonial angle was 116.4 degrees, smaller than that of the non-fracture group's (122.9 degrees). It is speculated that a relatively large occlusal force was applied to the fracture group. The cut-off value was set to 120 degrees, referring to the report that fractures of vital teeth tended to increase when the gonial angle on the panoramic radiographs was less than 120 degrees [15]. Fracture risk for gonial angles less than 120 degrees was also higher than that of angles exceeding 120 degrees. The potential occlusal force was presumably exerted more via restoration of the posterior part's occlusal support by the bone-anchored bridge than by tissue-borne dentures. Therefore, although the gonial angle is a simple index, it may be used as a preoperative risk factor of fracture. However, the occlusal force is affected not only by the gonial angle but also by the shape of the entire mandible [34] and thickness of the masseter muscles [35]. It follows that further studies need to evaluate the relationship between the manifestation of occlusal force affected by the gonial angle and abutment and implant fractures.

Splinting status of the superstructure was also extracted as an important factor for fractures of the abutment or implant (OR = 4.46, 95% CI 1.86-10.67, $P = 0.001$; RR = 3.6, 95% CI 1.61-7.96). Non-splinted patients were at higher risk of fractures than splinted patients. There are almost no published reports on the relationship between abutment or implant fracture and the superstructure's splinting status. Based on past studies, splinted restorations were associated with decreased loosening of screws and ceramic veneer fractures [36]. These biological and mechanical complications were not related to the splinting status of the superstructure [12]. The Ankylos implant supposedly results in several fractures of the abutment neck [18], and its thin morphological characteristics make it well-adapted to surrounding tissues yet mechanically fragile. Therefore, there is a possibility that one can easily avoid the risk of fracture by splinting the abutment with a superstructure.

Ceramic veneer fractures and the loosening of screws also may lead to mechanical complications such as fractures [4,23]. However, these complications were not related to abutment or implant fractures in this study. Because the Ankylos implant is joined by friction between the abutment and implant, the abutment often remains fixed even with a loose screw. It is difficult to investigate the relationship between the looseness of the screw and fracture of the abutment or implant. Furthermore, neither slight veneer fractures or all minor fractures may be recorded in the patient's medical record. Therefore, it is a challenge to accurately investigate the relationship between veneer fractures and implant or abutment fractures.

A higher C/I is also said to cause internal stress and mechanical complications. Still, no relationship between fracture of the abutment or implant and C/I, including the superstructure length, was found ($P = 0.818$) in this study. There is also a report that mechanical complications are more likely to occur when the C/I increases or the superstructure becomes longer [9], but this was opposed by another report stating that a relationship between fracture and C/I cannot be confirmed [13]. C/I increases when a short implant is placed in the absorbed ridge and a long superstructure is attached, but the success rate is similar to that of a long implant [37]. These reports may have promoted the recent increase in the use of short implants.

Three findings were noted on univariate analysis. First, it showed that hypertension ($P = 0.017$), renal dysfunction ($P = 0.022$), and smoking ($P = 0.005$) were associated with fracture of the abutment or implant. Although these diseases are sometimes considered risk factors during implant surgery, there have been no reports showing their direct relationship with fracture. Similarly, no association with fracture was found in our analysis

after adjusting for related factors.

Second, a relationship between the absence of hard tissue management and fracture of the abutment or implant was also found on univariate analysis ($P = 0.040$). Implants at the bone grafting sites reportedly have a low risk of fracture [38]. Because several factors are interrelated, it is considered that no association was found on multivariate analysis after adjusting for confounders.

Last, marginal bone loss resorption was associated with fracture of the abutment or implant on univariate analysis ($P = 0.046$). Similar to this study, fractured implants reportedly have marginal bone loss [4]. However, it is not clear whether the cause of the fracture is bone resorption or overload.

This study had some limitations. Given that this was a retrospective study, it was difficult to accurately investigate all risk factors involved in the fracture of abutments or implants. In addition to the survey conducted, other evaluation items are thought to be related to such fractures. In particular, internal stress enhancement factors [39], such as incorrect mandibular position, occlusal plane disorder, and occlusal interference caused by poor occlusal morphology, may be important. However, it is very difficult to judge whether the mandibular position and occlusion are correct or not and whether there is an occlusal abnormality. In the statistical analysis, both the odds and risk ratios were calculated, and the relationship between the extracted factor and fracture was examined. Because the odds ratio is an approximate value, and the risk ratio was not adjusted to account for other related factors, there is a possibility that the results' accuracy was affected. In addition, while the bias due to difference in manufacturer was eliminated because only Ankylos implants were investigated, the characteristics of the Ankylos implants may have influenced the results. Collecting data to identify the cause of a fracture is tedious due to the rarity of a fracture. Furthermore, many factors can cause a fracture, and the interaction between these factors makes it more challenging to pinpoint the causative factor. Long-term studies involving more cases are required to corroborate these results in the future. In spite of the above limitations, this study was able to investigate the factors related to fractures, the most serious complication associated with implant treatment, with an approximately 10-year follow-up period. The risk factors were evaluated in the preoperative examination and superstructure phases. This information is considered meaningful for patients who will have implant treatment, as it will help avoid complications and improve the prognosis.

In conclusion, this study investigated the risk factors related to abutment and implant fractures in Ankylos implants during preoperative examination, surgery, superstructure, and post-loading phases. Gender, gonial angle, and splinting status of the superstructure were identified as factors related to their occurrence. This suggests that fracture risk is increased in males, especially those with a mandibular angle of less than 120° on panoramic radiographs and non-splinted superstructures.

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Conflict of interest

The authors declare no conflict of interest in relation to this study.

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