Original Study

RETROSPECTIVE ASSESSMENT OF DENTAL IMPLANT-RELATED ANATOMICAL STRUCTURE PERFORATIONS USING CONE BEAM COMPUTED TOMOGRAPHY

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ABSTRACT

This retrospective study assessed the prevalence of dental implant-related perforations of adjacent anatomical structures using cone-beam computed tomography (CBCT). Retrospective assessments of CBCT scans of dental implants were evaluated for the presence of relevant anatomical structure perforations. The data collection included demographic and implant information. The implants were further categorized according to the implants' type, location, length, diameter, mesial and distal spacing, thread exposure, and the presence or absence of a radiographic guide. Univariate and bivariate analyses were conducted to assess the prevalence of dental implant-related anatomical perforations and to evaluate their distribution across several factors. A total of 441 implants met the inclusion criteria; 14.5% were associated with anatomical structure perforation. The inferior alveolar canal was most frequently perforated, followed by the maxillary sinus. Around half of the implants had cortical plate perforations (210 implants; 47%). Perforation of adjacent anatomical structures was more prevalent posteriorly than anteriorly (P=0.03). Mesial and distal spacing were significantly inadequate when the adjacent structure was an implant rather than a tooth (P<.0001). Dental implant-related anatomical perforations are relatively prevalent and occur more frequently posteriorly than anteriorly. This study alerts dental practitioners to avoid these perforations and emphasizes the importance of presurgical planning using CBCT and implant planning software to achieve the desired clinical outcome.

Key words: Dental implants, Cone-beam computed tomography, CBCT, Implant failure.

Introduction

Dental implants, a safe, durable treatment option widely used worldwide to replace missing teeth, have a 98.8% survival rate and a 97.0% success rate [1]. To achieve an ideal result and to avoid future peri-implant disease, dental implant treatment planning during the planning phase should include careful consideration of all possible factors that can contribute to implant failure [2].

Dental implant complications can arise from several contributing risk factors that affect implant success. These factors include smoking; systemic diseases or medications; the persistent presence of bacteria due to poor oral hygiene; infections; inadequate bone volume at the site of implant surgery; and operator-related causes, such as lack of experience, inadequate equipment, or neglect during implant selection, or complications during implant surgical placement [3, 4].

An additional concern associated with insufficient surgical planning and surgical errors is the possible violation of normal anatomical structures, such as the inferior alveolar canal, incisive canal, and mental foramen, which may cause neurosensory changes due to nerve injury from osteotomy or bone compression [5]. Improper implant angulation can negatively affect the neighboring tooth's vascular supply, leading to devitalization of the adjacent tooth and bone necrosis.

Advanced cases with severe infection can provoke mobility and loss of the dental implant [6]. Therefore, the clinician must thoroughly understand the bone anatomy at the implant site and its adjacent anatomical structures before surgery to avoid any possible violations of the anatomical structures.

The use of three-dimensional imaging, such as cone beam computed tomography (CBCT), is recommended before dental implant placement for pre-surgical diagnosis and treatment planning [7]. These images should be of good diagnostic quality, allowing proper visualization of the adjacent anatomical structures and the desired area of bone to receive the dental implant. The volumetric evaluation of the desired area helps to examine the dimension and morphology of the alveolar bone, the density, and the trabecular bone pattern, as well as the surrounding anatomical structures more accurately [8].

For post-surgical implant evaluation, a periapical or panoramic radiograph is needed to confirm the location of the implant. However, the European Association for Osseointegration recommends using CBCT for post-surgical evaluation in cases with complications, such as sinonasal infection, altered sensation, or neural disturbance due to dental implant proximity to the inferior alveolar nerve [9]. CBCT is also recommended in cases of dental implant mobility in which implant retrieval is expected. However, it is crucial to understand that CBCT imaging is not indicated for the periodic evaluation of clinically asymptomatic patients [10].

A cross-sectional study conducted in Brazil reported that anatomical perforation occurred in 33.3% of implants, with more perforations in the maxilla than in the mandible [11, 12]. Another study in Romania reported that only 6.89% of implants showed positioning complications, with the maxillary sinus being the most involved structure [13].

Very few studies have reported dental implant-related anatomical perforations, with no studies being conducted in Saudi Arabia or other countries in the Middle East. Thus, the objectives of this study were to assess the prevalence of dental implant-related perforations of relevant anatomical structures using CBCT. Moreover, examine the association between dental implant-related perforations and other factors, including different dental specialties, dentist's experience level, preoperative CBCT scan with the radiographic stent, dental implant location, diameter, type, and thread exposure.

Materials and Methods

This research was reviewed and approved by the Research Ethics Committee of King Abdulaziz University, Faculty of Dentistry (KAUFD), Jeddah, Saudi Arabia (Protocol number 135-12-20) and was conducted in accordance with the Helsinki Declaration of 1975, as revised in 2013. As this retrospective study involved only reviewing the dental record with no human risk or harm to participants. Thus, signed written consent was waived by the Committee.

Study Sample

This retrospective cross-sectional study assessed CBCT images from the database of a university-based oral and maxillofacial radiology clinic. All CBCT images were obtained using an iCAT scanner (Imaging Sciences International, Hatfield, PA, USA). Inclusion criteria included CBCT scans with single or multiple dental implants of good diagnostic quality. CBCT scans with a voxel size of 0.3-0.4 mm were included in the study. CBCT scans containing artifacts or partially imaged dental implants were excluded. The sample size calculation was determined according to Krejcie and Morgan's sample size table [14]. The minimum sample size required was 364 implants.

Image Assessment

Two calibrated examiners carried out data collection using OnDemand 3D Imaging Software (Cybermed, Seoul, South Korea). The reconstructions were reoriented in three dimensions (coronal, axial, and sagittal). The retrieved data included the patient's age, gender, dentist's specialty (implant dentistry, periodontics, oral surgery, and prosthodontics), dentist's experience level (faculty or resident), and whether the implant was placed at KAUFD or outside the institution.

The implants were classified according to the following: [11]

- Implant location: maxilla or mandible, and anterior or posterior.
- Diameter: <3.0 mm, ≥3.0 mm to <3.75 mm, ≥3.75 to <5 mm, and ≥5 mm.
- Length: ≤6 mm, >6 mm to -10 mm, ≥10 mm to <13 mm, and ≥13 mm.
- Implant type: Straumann, Nobel, Astra, Zimmer, Prima, and Biohorizon.
- Prosthetic loading: present or absent.
- Type of prosthesis: single implant, implant/implant FDP, and implant/tooth FDP, or not applicable (NA) in cases with absent prosthetic loading.
- Angulation of implant/abutment: normal or abnormal (>30°), or NA in cases with absent prosthetic loading.
- Cortical plate perforation: absent, present – buccal/labial, present – palatal/lingual, present – buccal/labial + palatal/lingual.
- Perforation of adjacent anatomical structures: absent, incisive canal, nasal cavity, maxillary sinus, mental foramen, inferior alveolar canal, and adjacent tooth root.
- Thread exposure (≥1 mm): present or absent.
- The spacing between the implant and the adjacent implant/tooth (both mesial and distal): adequate (implant to tooth ≥1.5 mm) (implant to implant ≥3 mm), inadequate (implant to tooth <1.5 mm) (implant to implant <3 mm), or NA (in cases of adjacent edentulous area).
- CBCT before implant placed with radiographic guide: present, absent, NA (if the implant was placed outside KAUFD).

Statistical Analysis

All statistical analyses were performed using Statistical Analysis System (SAS) version 9.4 software. Inter-examiner and intra-examiner reliability were evaluated using kappa statistics (1.0 $P<0.001$ and 0.7 $P<0.001$, respectively). Univariate analysis was performed to describe the characteristics of the sample. A Chi-squared test and a Fisher's exact test with Monte Carlo simulation were conducted to assess the distribution of dental implant-related perforation. Statistical significance was set at P-value <0.05.

Results and Discussion

A total of 1102 CBCT scans acquired at KAUFD were randomly selected and evaluated. Of these scans, 152 CBCT had a total of 441 dental implants, which met the inclusion criteria (301 females and 140 males, ages 21 to 80 years; mean age was 49.3 ± 13.1 years).

According to the anatomical location, 34 implants (7.71%) were in the anterior mandible, 168 (38.1%) were in the posterior mandible, 73 (16.55%) were in the anterior maxilla, and 166 (37.64%) were in the posterior maxilla. There were more implants in the maxilla than in the mandible (n=237, 53.7% vs. n = 204, 46.3%, respectively). Out of these 441 implants, only 171 (38.8%) had the prosthetic component present. Out of these 171 (38.8%) implants, only 13 (3%) had abnormal implant-abutment angulation (>30°).

Overall, the prevalence of dental implant-related anatomical perforations was 14.5%, with the inferior alveolar canal being the most commonly perforated anatomical structure, followed by the maxillary sinus. A detailed distribution of the perforated anatomical structures is shown in **(Table 1)** with no additional anatomical structures perforated other than those listed in the table. Cortical plate perforation was present in about half of the dental implants (210 implants, 47.6%), with the majority of cortical plate perforations involving both buccal and palatal cortical plates of the same implant (96 implants, 21.8%), followed by buccal plate perforation, with palatal/lingual plate perforation being the least frequent **(Table 1)**.

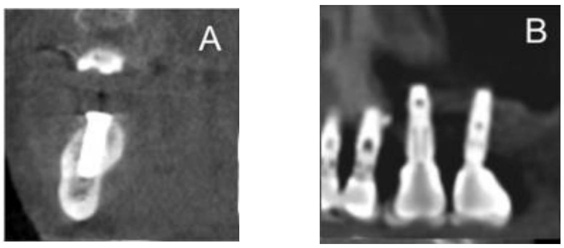
Table 1. Sample characteristics

Characteristics	**Total implants n=441 n(%)**
Gender	
Male	140 (31.8)
Female	301 (68.3)
Nationality	
Saudi	385 (87.3)
Non-Saudi	56 (12.7)
Placed at KAUFD	
Yes	305 (69.2)
No	136 (30.8)
Anatomical structure perforation	
Yes	64 (14.5)
No	377 (85.5)
Perforated anatomical structure	
Absent	377 (85.5)
Nasal Cavity	1 (0.2)
Maxillary Sinus	21 (4.8)
Mental Foramen	7 (1.6)
Inferior Alveolar Canal	27 (6.1)
Adjacent Tooth Root	8 (1.8)
Cortical plate perforation	
Absent	231 (52.4)
Present – Buccal	88 (19.9)
Present – Palatal/Lingual	26 (5.9)
Present – Buccal + Palatal/Lingual	96 (21.8)
Perforation	
Absent	193 (43.76)
Both cortical plate and adjacent structure	27 (6.12)
Cortical plate without adjacent structure	183 (41.5)
Adjacent structure without cortical plate	38 (8.62)
Angulation of implant/abutment	
Abnormal (>30°)	13 (3.0)
Normal	159 (36.0)
N/A	269 (61.0)
Prosthetic loading	
Yes	171 (38.8)
No	270 (61.2)

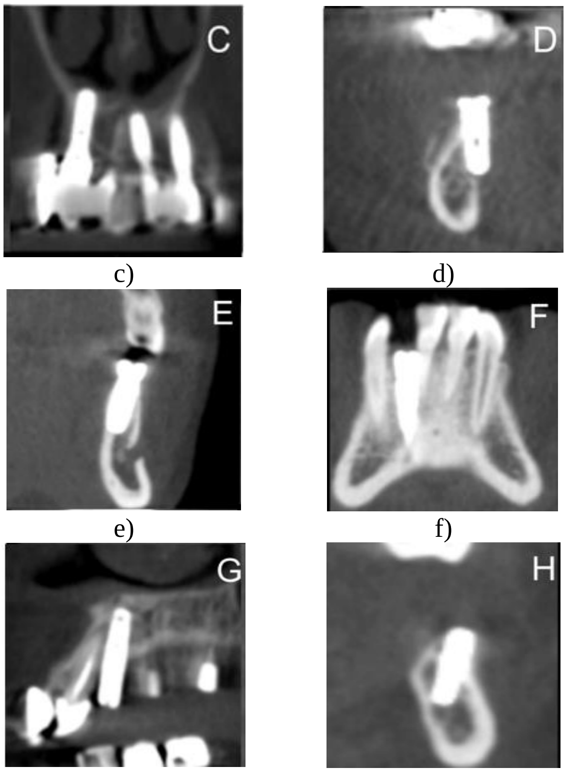
Type of prosthesis	
Single implant	88 (20.0)
Implant/implant FDP	77 (17.5)
Implant/tooth FDP	9 (2.0)
N/A	267 (60.5)
Thread exposure	
Yes (≥1mm)	210 (47.6)
No	231 (53.4)
Implant's radiographic guide present in CBCT	
Yes	119 (27.0)
No	186 (42.2)
N/A	136 (30.8)
Mesial spacing	
Inadequate spacing	63 (14.3)
Adequate spacing	270 (61.2)
N/A- edentulous area	108 (24.5)
Distal spacing	
Inadequate spacing	55 (12.5)
Adequate spacing	215 (48.8)
N/A- edentulous area	171 (38.8)
Implants length	
≤ 6 mm	2 (0.5)
> 6 mm to < 10 mm	72 (16.3)
≥10 mm to < 13 mm	279 (63.3)
≥ 13 mm	88 (19.9)
Implants diameter	
< 3.0 mm	3 (0.7)
≥ 3.0 mm to < 3.75 mm	86 (19.5)
≥ 3.75 mm to < 5 mm	243 (55.1)
≥ 5 mm	109 (24.7)

N/A: not applicable

Implant cases with cortical plate perforation and/or perforations of different anatomical structures are shown in **(Figure 1)**. A presurgical CBCT with a radiographic stent was acquired for 119 implants only (27%). Only 193 implants (43.76%) were in an adequate position with no perforation of either the cortical plate or any adjacent anatomical structure, while 27 implants (6.12%) had both cortical plate perforation and perforation of the adjacent anatomical structure **(Table 1)**. Adjacent anatomical structure perforation was more frequent posteriorly than anteriorly (*P=0.03*), but there was no significant association when comparing the maxilla and mandible. Detailed perforation information in relation to the anatomical location is shown in **(Table 2)**.



a) b)



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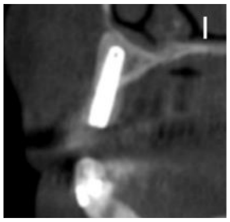

i)

Figure 1. CBCTs showing different implant cases with cortical plate perforation and/or perforation of different anatomical structures (a) Inferior alveolar nerve canal. (b) Maxillary sinus. (c) Nasal fossa. (d, e) Cortical plate. (f, g) Adjacent tooth root. (h) Inferior alveolar nerve canal with cortical plate perforation and thread exposure. (i) Buccal and palatal cortical plate perforation and thread exposure.

Table 2. Dental implants related anatomical perforations in relation to the anatomical location.

	Arch			**Anatomical Location**		
	Maxilla n (%)	**Mandible n (%)**	***P*-value**	**Anterior n (%)**	**Posterior n (%)**	***P*-value**
Cortical plate perforation						
Absent	122(51.5)	109(53.7)		56 (51.4)	175(52.9)	
Present: Buccal	46 (19.4)	41 (20.2)	0.9	27 (24.8)	60 (18.1)	0.4
Present: Palatal/Lingual	14 (5.9)	12 (5.9)		5 (5.0)	21 (6.3)	
Present: Buccal + Palatal/Lingual	55 (23.2)	41 (20.2)		21 (19.3)	75 (22.6)	
Adjacent structure perforation						
Yes	115(48.5)	95 (46.6)	0.7	9 (8.3)	55 (16.6)	0.03*
No	122(51.5)	109(53.4)		100(91.7)	277(83.4)	
Thread exposure						
Yes (≥1mm)	115(48.5)	95 (46.6)	0.7	53 (48.6)	157(47.3)	0.8
No	122(51.5)	109(53.4)		56 (51.4)	175(52.7)	

*Statistically significant

Our sample consisted of different types of dental implants: 79 Straumann, 48 Nobel Biocare, 13 Astra Tech, 9 Zimmer Biomet, 44 Prima, and 4 Biohorizons. Based on our sample, Straumann implants were likelier to have cortical plate perforation followed by Nobel Biocare, and Prima. Regarding the perforation of adjacent anatomical structures, Straumann implants were more prevalent, followed by Nobel Biocare.

The distribution of different implant lengths showed that more than one-third (63.3%) had a length of 10 mm to less than 13 mm, while only 0.5% had a length of less than 6 mm. Over half of the implants (55.1%) had a diameter of 3.75 mm to less than 5 mm, while only 0.7% of the implants had a diameter below 3 mm **(Table 1)**. Regarding cortical plate perforation, implant lengths≥10 mm to <13 mm were likelier to have a perforated cortical plate than other implant lengths (P=0.002), while no significant association was found related to different diameters **(Table 3)**.

Table 3. Dental implants related anatomical perforations in relation to different dental implant categories.

	Cortical plate perforation		***P*-value**	**Adjacent structure perforation**		***P*-value**
	Yes n (%)	**No n (%)**		**Yes n (%)**	**No n (%)**	
Placed at KAUFD						
Yes	111 (36.5)	193 (63.5)	<0.0001*	50 (16.4)	255 (83.6)	0.09
No	98 (72.1)	38 (27.9)		14 (10.3)	122 (89.7)	
Gender						
Male	67 (32.1)	73 (31.6)	0.9	23 (35.9)	117 (31.0)	0.4
Female	142 (68.0)	158 (68.4)		41 (64.1)	260 (67.0)	
Dentist's Specialty						
Implant Dentistry	37 (30.1)	46 (26.9)		18 (36.7)	65 (26.5)	
Periodontics	54 (43.9)	76 (44.4)	0.1	26 (53.1)	104 (42.5)	0.03*
Oral surgery	24 (19.5)	46 (26.9)		5 (10.2)	65 (26.5)	
Prosthodontics	8 (6.5)	3 (1.75)		0 (0.0)	11 (4.5)	
Dentist's experience						
Consultant/specialist	45 (34.9)	84 (65.1)	0.03*	29 (22.5)	100 (77.5)	0.01*
Resident	78 (47.3)	87 (52.7)		20 (12.1)	145 (87.9)	

Implant Type						
Straumann	22 (31.0)	57 (45.2)	0.08	19 (40.4)	60 (40.0)	0.08
Nobel	17 (23.9)	31 (24.6)		18 (38.3)	30 (20.0)	
Astra	9 (12.7)	4 (3.2)		2 (4.3)	11 (7.3)	
Zimmer	5 (7.1)	4 (3.2)		3 (6.4)	6 (4.0)	
Prima	16 (22.5)	28 (22.2)		5 (10.6)	39 (26.0)	
Biohorizon	2 (2.8)	2 (1.6)		0 (0.0)	4 (2.7)	
Radiographic guide						
Yes	25 (12.0)	93 (40.3)	<0.0001*	31 (48.4)	88 (23.3)	0.0002*
No	86 (41.2)	100 (43.3)		19 (29.7)	167 (44.3)	
N/A	98 (46.9)	38 (16.5)		14 (21.9)	122 (32.4)	
Thread exposure						
Yes	209 (100.0)	0 (0.0)	<0.0001*	26 (40.6)	184 (48.8)	0.2
No	0 (0.0)	231 (100.0)		38 (59.4)	193 (51.2)	
Mesial spacing						
Inadequate	28 (13.4)	35 (15.2)	0.02*	11 (17.2)	52 (13.8)	0.8
Adequate	141 (67.5)	128 (55.4)		38 (59.4)	232 (61.5)	
N/A	40 (19.1)	68 (29.4)		15 (23.4)	93 (24.7)	
Distal Spacing						
Inadequate	30 (14.4)	25 (10.8)	0.5	10 (15.6)	45 (11.9)	0.7
Adequate	98 (46.9)	116 (50.2)		31 (48.4)	184 (48.8)	
N/A	81 (38.8)	90 (38.7)		23 (35.9)	148 (39.3)	
Implants length						
≤ 6 mm	1 (0.5)	1 (0.4)	0.002*	0 (0.0)	2 (0.5)	0.5
> 6 mm to < 10 mm	24 (11.5)	48 (20.8)		14 (21.9)	58 (15.4)	
≥10 mm to < 13 mm	129 (61.7)	149 (64.5)		40 (62.5)	239 (63.4)	
≥ 13 mm	55 (26.3)	33 (14.3)		10 (15.6)	78 (20.7)	
Implants diameter						
< 3.0 mm	3 (1.4)	0 (0.0)	0.3	0 (0.0)	3 (0.8)	0.6
≥ 3.0 mm to < 3.75 mm	38 (18.2)	48 (20.8)		13 (20.3)	73 (19.4)	
≥ 3.75 mm to < 5 mm	118 (56.5)	124 (53.7)		39 (60.9)	204 (54.1)	
≥ 5 mm	50 (23.9)	59 (25.5)		12 (18.8)	97 (25.7)	

N/A: not applicable, *statistically significant

Regarding the experience level of the practitioners, dental residents were associated with more cortical plate perforations (*P=0.03*), while perforation of adjacent anatomical structures was reported more among the faculty (*P=0.01*). According to the specialty, it was found that both cortical plate perforation and perforation of adjacent anatomical structures were more prevalent when implants were placed by periodontists followed by implant specialists (*P*=0.1 and *P=0.03* respectively) **(Table 3)**.

Of the 441 implants, 136 (30.8%) were placed outside KAUFD. When comparing implants placed at KAUFD vs. implants placed outside, cortical plate perforation was more frequent among implants placed outside KAUFD compared to implants placed in KAUFD (72.1% vs. 36.5%, respectively), while for adjacent structure perforation, the opposite was true (10.3% vs. 16.4%, respectively) **(Table 3)**. More than half of the implants had thread exposure. Moreover, all dental implants with cortical plate perforation had thread exposure **(Table 3)**.

When evaluating the horizontal distance between the implant and the adjacent tooth or implant, most implants exhibited adequate spacing with the adjacent structure, whether that was an implant or a tooth (both mesially and distally). Only 63 (14.3%) implants had inadequate mesial spacing, while 55 (12.5%) implants had inadequate distal spacing. Mesial and distal spacing were significantly inadequate when the adjacent was an implant rather than a tooth (73.0% and 90.9% respectively; *P*<.0001) **(Table 4)**.

Table 4. Detailed distribution of the horizontal distancing related to dental implants.

	Mesial spacing		***P*-value**	**Distal spacing**		***P*-value**
	Adequate	**Inadequate**		**Adequate**	**Inadequate**	
Tooth	169 (62.8)	17 (27.0)	<.0001*	133 (62.1)	5 (9.1)	<.0001*
Implant	100 (37.2)	46 (73.0)		81 (37.9)	50 (90.9)	

Edentulous area	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)

*Statistically significant

This study revealed that about one-seventh of the assessed dental implants (14.5%) involved perforation of the adjacent anatomical structures. The perforations in the dental implants occurred posteriorly more than anteriorly; a similar result was found in another study [11], which reported that the maxilla was associated with more anatomical perforations than the mandible; however, in our study, the results for the maxilla and mandible were similar. Our results reported that the inferior alveolar canal was the most common perforated anatomical structure, followed by the maxillary sinus. This is in contrast to previous studies that reported the maxillary sinus was the most perforated anatomical structure [11, 13].

Inferior alveolar canal perforation was reportedly associated with 14% of dental implants in one study [13], and 1.1% in another [11]. Perforation of the inferior alveolar canal is reportedly associated with a wide variety of consequences, ranging from paresthesia, or altered sensation to serious pain in the involved area [15]. This impaired sensation can lead to altered aesthetics as a result of lip ptosis and saliva drooling [16]. A treatment protocol has been proposed for the management of such perforation after dental implant placement based on the extent of the associated damage [15].

In our study, maxillary sinus perforation was less than that reported in other studies (34% and 13.3 %) [11, 13]. Complications of maxillary sinus perforation can range from mild sinusitis [17] to active localized infections involving the affected sinus [18]. Very extensive forms of infections can involve viable anatomical structures, such as the orbital cavity, cranial fossae, and paranasal sinuses [19-21]. An experimental study assessing the effect of maxillary sinus perforation by dental implants showed that this perforation did not show any undesirable effect [22]. Controversially, a systematic review and meta-analysis concluded that maxillary sinus perforation could contribute to dental implant failure [23].

Only one implant showed nasal cavity perforation. In contrast, nasal cavity perforation has reportedly been associated with 31% of dental implants in one study [13] and 4.4% in another [11]. Patient complaints from nasal cavity perforation reportedly appear later as impaired breathing and pain [24].

Cortical plate perforation was more frequent in our study than in other studies. A study revealed that 11.1% of the dental implants involved had buccal cortical plate perforation, while 2.3% of these dental implants had lingual cortical plate perforation [11]. The prevalence of lingual cortical plate perforation in dental implants upon assessing the CBCT scan was 21% in another study [13].

Perforation of the cortical plate can result in altered aesthetics, as it can lead to loss of the supporting gingival tissue around the implants due to bone loss and subsequently peri-implantitis [25]. Moreover, lingual cortical plate perforation in the mandible at the area of the submandibular fossa can cause severe life-threatening consequences, including breathing difficulties due to hematoma and profound bleeding as a result of injury to the submandibular and sublingual arteries [26, 27].

Dental implant failure can be significantly associated with narrow and short dental implants [28, 29]. Controversially, further studies showed that dental implant survival is not related to different dimensions [30, 31]. The literature lacks studies on the effect of different dental implant lengths and diameters on adjacent structures, as most studies only assessed dental implant survival or failure.

A study assessed the association of different dental implant lengths in relation to anatomical structure perforation stated that the combination of short and extra-short (≤6 mm) dental implants had a lower prevalence of perforations compared to standard (≥10 mm to <13 mm) and long (≥13 mm) implants combined [11]. Our results were consistent with the reported findings, as shorter dental implants were associated with fewer perforations of the adjacent anatomical structures.

Previous studies have linked the dental surgeon's level of experience with the final dental implant success and failure outcomes, rather than the prevalence of adjacent anatomical perforations [32-35]. Indeed, some studies have shown that the more experienced the surgeon, the lower the risk of dental implant failure [32]. In contrast, other studies have contradicted this finding [34]. Our study investigated the prevalence of adjacent anatomical perforations among different experienced clinicians. Our sample showed that cortical plate perforation was more frequent among patients treated by dental residents; however, perforation of the adjacent anatomical structures was more prevalent among specialists/consultants. No previous studies have assessed the prevalence of anatomical perforations among different specialties. Our results revealed that anatomical perforations were more prevalent among periodontists followed by implant specialists; this could be attributed to the large number of implant cases they performed compared to other specialties, as shown in our sample.

Our results showed that more than half of the dental implants had thread exposure associated with cortical plate perforation. This finding was consistent with another study that reported a similar association in which dental implants perforating adjacent anatomical structures had a high prevalence of thread exposure [11].

Regarding horizontal distancing, a study showed that most dental implants displayed adequate distancing from the adjacent tooth or implant [11]. This is consistent with our results, which showed that horizontal distancing is likelier to be inadequate when the adjacent structure is a dental implant rather than a tooth. The proximity of dental implants can result in considerable bone loss, which can contribute to peri-implant disease and poor aesthetics. A study investigating the effect of different inter-implant distances on bone loss reported that when the inter-implant distance was ≤3 mm, an average bone loss of 1.04 mm was noted in comparison to only 0.45 mm loss of bone when the inter-implant distance was >3 mm. Their study concluded that a minimum of 3 mm of horizontal distancing between adjacent implants is recommended to prevent bone loss and maintain peri-implant health [36].

This study has a few limitations. Since the reasons for the CBCT examinations were not recorded, those CBCT examinations were likely acquired for clinical indications other than post-surgical dental implant assessment. Thus, some of the reported dental implant-related anatomical perforations could be considered incidental findings. Furthermore, the interpretation of our findings is limited due to the lack of clinical information regarding the patient's signs and symptoms, surgical complications during dental implants, and the use of bone augmentation procedures. Moreover, some patients possibly had presurgical CBCT for implant planning outside KAUFD. In addition, our results might be subjected to sample bias due to the over-representation of some implant categories compared to others.

Despite these limitations, our findings demonstrate the importance of a thorough assessment of the anatomical structures of the implant site, its variations, and any potential risk factors using CBCT. Additionally, our study highlights the significance of utilizing recent advances in digital implant treatment planning, such as virtual implant planning and fully guided implant surgery, as these may result in more precise placement of the dental implant in the desired location [37].

Conclusion

Dental implant-related anatomical structure perforations occur more frequently in the posterior area, with the inferior alveolar nerve canal being the most involved anatomical structure, followed by the maxillary sinus. In our study, cortical plate perforation was common. Thorough preoperative implant planning using CBCT is crucial to ensure proper assessment and planning and to properly guide the surgical implant placement while considering prosthetic and anatomic factors.

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Ethics statement: The study was approved by the Research Ethics Committee of King Abdulaziz University, Faculty of Dentistry (KAUFD), Jeddah, Saudi Arabia (Protocol number 135-12-20) and was conducted in accordance with the Helsinki Declaration of 1975, as revised in 2013. Verbal informed consent was obtained via phone calls with all participants as this retrospective study involved only reviewing the dental record with no human risk or harm to participants. Thus, signed written consent was waived by the Committee.

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