Reliability of Two Types of Presurgical Preparation for Implant Dentistry Based on Panoramic Radiography and Cone-Beam Computed Tomography in Cadavers

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Directed by Professor Kyung-Seok Hu, D.D.S., Ph.D.

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대학원 석사과정 동안 학업과 연구에 매진할 수 있도록 아낌없는 격려와 지도를 해주신 지도교수 허경석 교수님과 저를 해부학의 세계로 인도해 주시고 연구의 큰 틀을 잡아 주신 김희진 교수님, 논문 심사에 소중한 충고와 세심한 조언을 해 주셨던 김흥중 교수님께 깊은 감사의 말씀을 올립니다.

그리고 저의 연구와 실험에 큰 도움을 주었던 최다예 선생님을 비롯한 해부학교실 조교 선생님들께도 감사드립니다.

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감사합니다.

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Abstract

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Recent advances in the radiographic techniques used in implant dentistry have increased the accuracy of presurgical planning. Such planning is mostly performed using radiographs, such as panoramic, lateral cephalometric, and periapical radiographs, and computed tomography (CT). Special care is necessary to avoid invading important anatomic structures during surgery when presurgical planning is made based on radiographs. However, none of these types of radiography represents a perfect modality. The purpose of this study was to determine the reliability of presurgical planning based on the use of two types of radiographic image [digital panoramic radiography (DPR) and cone-beam CT (CBCT)] by beginner dentists to place implants, and to quantify differences in measurements between radiographic images and real specimens.

Ten fresh cadavers without posterior teeth were used, and twelve practitioners who had no experience of implant surgery performed implant surgery after 10 hours of basic instruction using conventional surgical guide based on CBCT or DPR. Two types of measurement error were evaluated: (1) the presurgical measurement error, defined as that between the presurgical and postsurgical measurements in each modality of radiographic analysis, and (2) the measurement error between postsurgical radiography and the real specimen.

The mean presurgical measurement error was significantly smaller for CBCT than for DPR in the maxillary region, whereas it did not differ significantly between the two imaging modalities in the mandibular region. The mean measurement error between radiography and real specimens was significantly smaller for CBCT than for DPR in the maxillary region, but did not differ significantly in the mandibular region.

Presurgical planning can be performed safely using DPR in the mandible; however, presurgical planning using CBCT is recommended in the maxilla when a structure in a buccolingual location needs to be evaluated because this imaging modality supplies buccolingual information that cannot be obtained from DPR.

Key words : implant surgery, panoramic radiography, cone-beam CT, complication, anatomic structure

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I . INTRODUCTION

Dental implants have been successfully used in dental clinics for replacing missing teeth with reported success rates of more than 90% in most cases (Albrektsson et al., 1988; Misch et al., 2008). Improvements in the surface and design of dental implants have contributed to their long-term success. Recent advances in the radiographic techniques used in implant dentistry have increased the accuracy of presurgical planning (Spector, 2008; Van de Velde et al., 2008). Nevertheless, there remain the risks of nerve injury and maxillary sinus perforation originating from inappropriate presurgical planning due to innate differences between radiographic measurements and real dimensions. Precise radiographic assessment of the available alveolar bone and bone morphology including important anatomic structures is an indispensible procedure during dental implant placement. When posterior maxillary and mandibular sites are considered, the location of important anatomic structures such as the mandibular canal and maxillary sinus is very important when selecting the length and site for a dental implant. Pain and paresthesia caused by inferior alveolar nerve injury are major complications during implant placement, with such injury inducing sharp pain or electrical shock-like sensations (Bartling et al., 1999; Kraut and Chahal, 2002). Another major complication is perforation of the inferior wall of the maxillary sinus, which is known to be correlated with the incidence of infection followed by eventual failure of a dental implant (Cho-Lee et al., 2010; Hong and Mun, 2011). Therefore, special care should be taken not to invade important anatomic structures during surgery when presurgical planning is made based on radiographs. More precise radiographic techniques that can decrease measurement discrepancies relative to the real dimensions, and the use of computer programs for precisely guiding the surgery would reduce the complication rate (Spector, 2008).

Presurgical planning for a dental implant is mostly performed using radiographs, such as panoramic, lateral cephalometric, and periapical radiographs, and computed tomography (CT) (Scaf et al., 1997; Stella and Tharanon, 1990). However, since none of these types of radiography represents a perfect modality (Reiskin, 1998; Sunden et al., 1995), more accurate radiographic techniques are required, especially for presurgical planning in areas containing important anatomic structures.

Finding an appropriate location and measuring the available bone length based on panoramic radiograph is one of the most frequently used modalities for presurgical planning. A panoramic radiograph displays the body of the mandible and maxilla, mandibular canal, and maxillary sinus on a single image. The length and mesiodistal angulation of an implant are usually determined from a panoramic radiograph. However, especially in the anterior maxillary and mandibular areas where the distortion is greater, the reliability of panoramic radiographs for presurgical planning of an implant remains questionable (Frei et al., 2004; Peker et al., 2008; Tal and Moses, 1991).

The necessity of cross-sectional imaging for a dental implant has been emphasized (Akdeniz et al., 2000; Bolin et al., 1996; Bou Serhal et al., 2001; Lindh et al., 1992; Schropp et al., 2001). According to the recommendation from American Academy of Oral and Maxillofacial radiology (AAOMR) in 2000, some form of cross-sectional imaging including conventional spiral tomography, linear tomography, or CT should be used for presurgical planning (Tyndall and Brooks, 2000). These cross-sectional imaging techniques exhibit varying accuracies. Linear tomography is reported to be significantly less accurate than spiral tomography in detecting mandibular canal (Hanazawa et al., 2004). However, some authors have reported that measuring the available bone volume only using spiral tomography may lead to a dangerous situation because the available vertical bone height is exaggerated in spiral tomography relative to panoramic radiography (Frei et al., 2004).

CT provides a lower magnification distortion than the other types of cross-sectional tomography, with amounts of 3.86% (Peker et al., 2008) and 0% to 4% (Reddy et al., 1994) having been reported. CT scans offer direct volumetric reconstruction and faster and easier data transformation in three-dimensional analysis. In addition, the absence of overlap means that they can be interpreted without difficulty (Hanazawa et al., 2004). While these advantages have led to CT being used for many years, it requires a high radiation dose (Al-Ekrish and Ekram, 2011). Cone-beam CT (CBCT) was developed to overcome the limitations of CT (Hashimoto et al., 2003; Mozzo et al., 1998). CBCT images are of higher quality than CT images, and the radiation dose from CBCT is typically 1/400 of that from CT (Al-Ekrish and Ekram, 2011; Hashimoto et al., 2003).

Each type of radiograph has its own advantages and disadvantages. Therefore, the radiation dose, magnification rate, and specific indications need to be considered carefully when selecting the type of radiographic images to use in presurgical planning. The purpose of this study was to determine the reliability of presurgical planning based on the use of two types of radiographic image [digital panoramic radiography (DPR) and CBCT] by beginner dentists to place implants, and to quantify the differences in measurements between radiographic images and real specimens.

Ⅱ. MATERIALS & METHODS

1. Study design

Ten fresh cadavers without posterior tooth were used to examine the accuracy of CBCT and DPR measurements. The posterior teeth were extracted when there is not any missing posterior tooth. Twelve practitioners who had no experience of implant surgery performed implant surgery after 10 hours of basic instruction. Each participant performed implant surgery using a conventional surgical guide based on CBCT or DPR. The sites for implant surgery were randomly assigned for the two investigated presurgical planning methods: 31 implants were placed with the surgical guide based on DPR and the corresponding computer program (Starpacs, Infinitt, Seoul, Korea), while 32 implants were placed with the surgical guide based on CBCT and the corresponding computer program (Ondemend 3D, Cybermed, Seoul, Korea).

Two types of measurement error were evaluated in this study: (1) the presurgical measurement error, defined as that between the presurgical and postsurgical measurements in each modality of radiographic analysis, and (2) the measurement error between postsurgical radiography and the real specimen.

2. Measurement errors for CBCT

Virtual planning to determine the appropriate length of the implant was first performed using CBCT and the corresponding program. D1 was the difference between the distance from the implant platform to the anatomic structure (e.g., inferior wall of the maxillary sinus or superior border of the mandibular canal) and the distance from the implant platform to the implant apex. D2 was the distance from the implant apex to the anatomic structure in postsurgical CBCT. D3 was the distance from the implant apex to the anatomic structure in the real specimen. The presurgical and postsurgical measurement errors for CBCT were calculated by subtracting D2 from D1 and subtracting D3 from D2, respectively. These measurements are illustrated Figs. 1, 2, and 3.

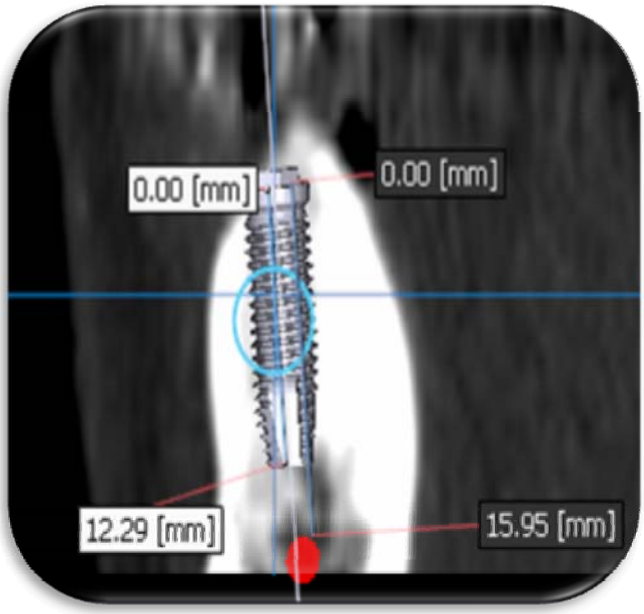

Fig. 1. Measurement of D1. D1 was the difference between the distance from the implant platform to the anatomic structure (e.g., inferior wall of the maxillary sinus or superior border of the mandibular canal) in presurgical CBCT and the distance from the implant platform to the implant apex.

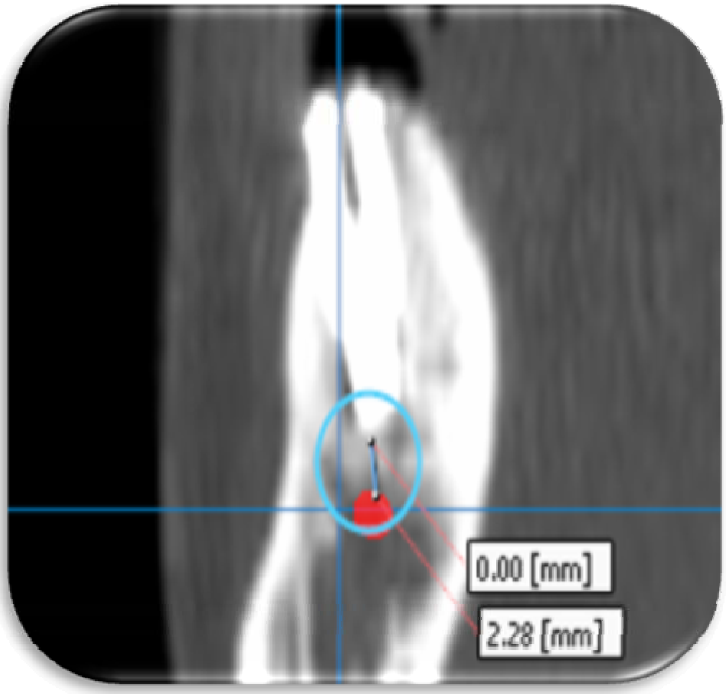

Fig. 2. Measurement of D2. D2 was the distance from the implant apex to the anatomic structure in postsurgical CBCT.

Fig. 3. Measurements of D3 and D6. D3 was the distance from the implant apex to the anatomic structure in the real specimen using CBCT as a guide. D6 was same distance in the real specimen using DPR as a guide.

3. Three-dimensional reconstruction of the mandibular canal

Virtual planning to determine the appropriate length of the implant was performed using DPR and the corresponding program. A presurgical panoramic radiograph was obtained to measure the distance from the implant apex to the anatomic structure (D4), which was the difference between the distance from the alveolar ridge to the anatomic structure and the planned implant length. D5 was the distance from the implant apex to the anatomic structure in postsurgical DPR. D6 was the distance from the implant apex to the anatomic structure in a real cross-sectioned specimen. The presurgical and postsurgical measurement errors for DPR were calculated by subtracting D5 from D4 and subtracting D6 from D5, respectively. These measurements are illustrated Figs. 4 and 5.

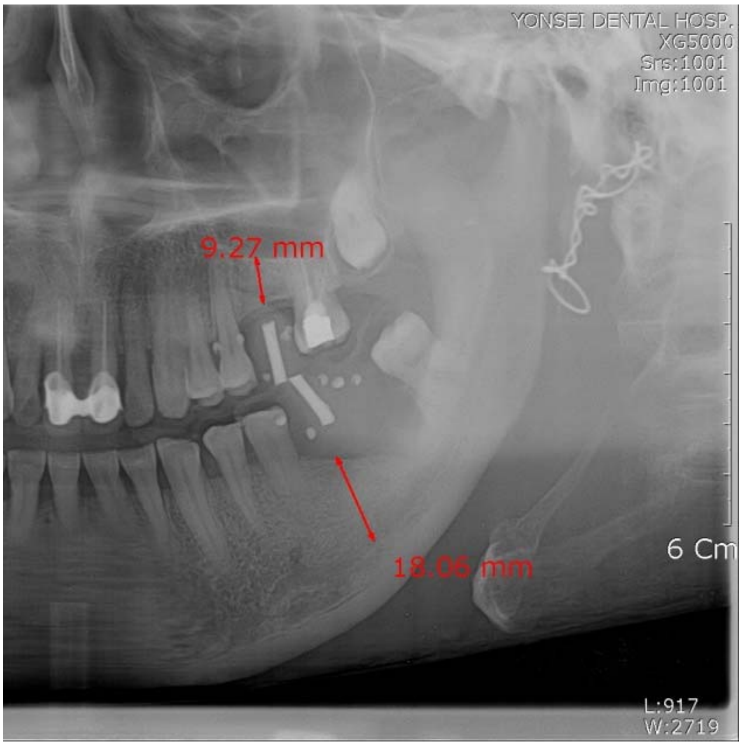

Fig. 4. Measurement of D4. D4 was the difference between the distance from the alveolar ridge to the anatomic structure in presurgical DPR and the planned implant length.

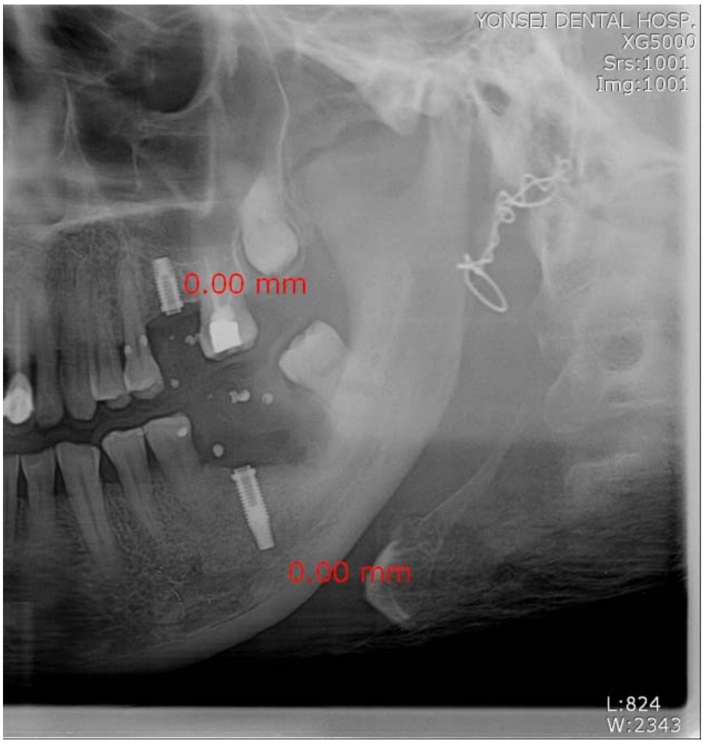

Fig. 5. Measurement of D5. D5 was the distance from the implant apex to the anatomic structure in postsurgical DPR.

4. Statistical analysis

A linear mixed-effects model was applied with the radiographic apparatus as a fixed effect and the participants and cadavers as random effects. SAS 9.2 (SAS Institute, Cary, NC, USA) was used for statistical analysis of the data.

Ⅲ. RESULTS

1. Presurgical measurement errors

Table 1 summarizes the presurgical measurement errors for CBCT and DPR, along with corresponding probability values. The mean presurgical measurement error was significantly smaller for CBCT than for DPR ($p=0.002$). The presurgical measurement error was significantly smaller for CBCT (1.26±1.23 mm) than for DPR (3.32±2.34 mm, $p=0.008$) in the maxillary region, whereas it did not differ significantly between the two imaging modalities in the mandibular region (1.58±1.25 mm vs 2.32±1.81 mm, respectively, $p=0.164$; Table 2).

Table 1. Presurgical measurement errors for cone-beam computed tomography (CBCT) and digital panoramic radiography (DPR).

	N	Mean (mm)	SD (mm)	*p*
CBCT	31	1.42	1.23	0.002*
DPR	32	2.82	2.12	

*Significant difference between errors for CBCT and DPR, $p<0.05$

Table 2. Site-specific presurgical measurement errors.

		N	Mean (mm)	SD (mm)	*p*
Maxilla	CBCT	15	1.26	1.23	0.008*
	DPR	16	3.32	2.34	
Mandible	CBCT	16	1.58	1.25	0.164
	DPR	16	2.32	1.81	

*Significant difference between errors for CBCT and DPR, $p<0.05$

2. Measurement errors between postsurgical radiography and real specimens

The measurement error between postsurgical radiography and real specimens was significantly smaller for CBCT (1.12±1.02 mm) than for DPR (1.85±2.09 mm, p=0.005; Table 3). This difference was statistically significant in the maxillary region (0.67±0.45 mm vs 2.53mm±2.65 mm, respectively, p=0.039) but not in the mandibular region (1.65±1.24 mm vs 1.06±0.55 mm, p=0.098, Table 4).

Table 3. Measurement errors between postsurgical radiography and real specimens for CBCT and DPR.

	N	Mean (mm)	SD (mm)	*p*
CBCT	26	1.12	1.02	0.005*
DPR	24	1.85	2.09	

*Significant difference between errors for CBCT and DPR, $p<0.05$

Table 4. Site-specific measurement errors between postsurgical radiography and real specimens.

		N	Mean (mm)	SD (mm)	*p*
Maxilla	CBCT	14	0.67	0.45	0.039*
	DPR	13	2.53	2.65	
Mandible	CBCT	12	1.65	1.24	0.098
	DPR	11	1.06	0.55	

*Significant difference between errors for CBCT and DPR, $p<0.05$

3. Critical errors

Some specimens experienced critical errors such as maxillary-sinus invasion, mandibular-canal invasion, and lingual-plate perforation (Fig. 6). The error rate in the implant surgery was higher in DPR than in CBCT.

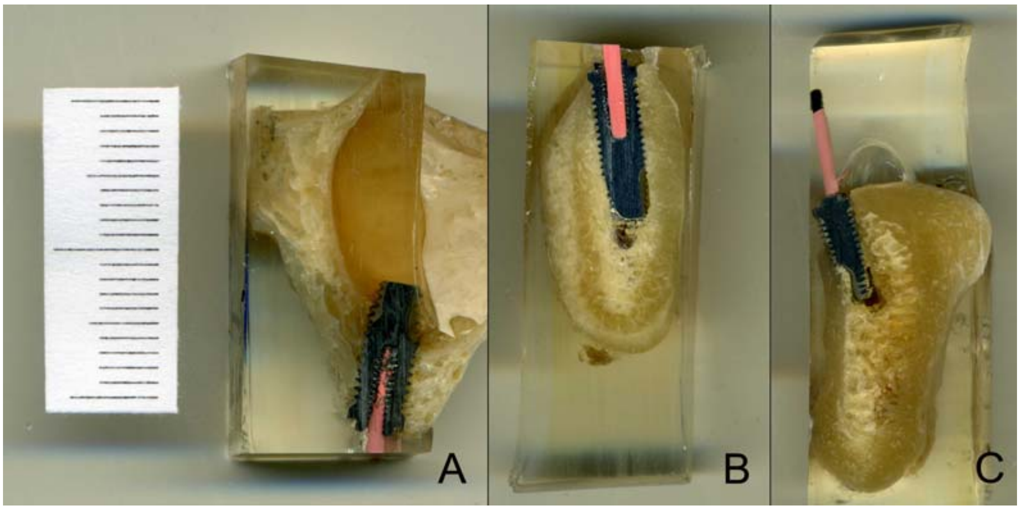

Fig. 6. Some critical errors: A, maxillary-sinus invasion; B, mandibular-canal invasion; and C, lingual-plate perforation.

Ⅳ. DISCUSSION

Statistically significantly differences in measurement errors were found between the two radiographic techniques in this study, which is consistent with the results of previous studies (Kobayashi et al., 2004; Lindh et al., 1995). The errors were greater for DPR than for CBCT because presurgical plans are made on a two-dimensional plane for DPR but in three dimensions for CBCT. The reduced errors in three-dimensional presurgical planning are why CBCT should be used for presurgical planning and postoperative evaluation, especially for dentists with limited experience and skill in implant placement.

The measurement errors in the maxilla were significantly lower for CBCT than for DPR, which can be attributed to the difficulty of identifying the exact location of the inferior wall of the maxillary sinus in presurgical planning when using DPR. Various levels of the inferior border of the maxillary sinus appear overlapped in DPR. In contrast, the exact levels of the inferior border of the maxillary sinus can be identified using CBCT because the view in the specific plane where the implant is to be placed is used for presurgical planning. These data suggest that presurgical planning using DPR for implant placement on the maxillary premolar or molar area is not sufficiently reliable for a dentist to place the implant without complications such as perforation of the sinus membrane. Even though abundant clinical experience can compensate for the limitations of DPR when attempting to identify the location of the inferior border of the maxillary sinus, more accurate and precise methods are recommended in order to prevent unexpected complications.

In contrast to the findings in the maxilla, the measurement error in the mandible did not differ significantly between CBCT and DPR. Peker et al. (Peker et al., 2008) made measurements in the vertical and buccolingual directions of the mandible, and their vertical measurements were similar to those made in the present study. They also did not find any statistically significant differences between vertical measurements on radiographs and direct measurements on real specimens—statistically significant differences were found only for buccolingual measurements. This shows that there will be fewer errors when presurgical plans are made using DPR in the mandible than in the maxilla. Identifying the superior border of the mandibular canal is easier than the inferior border of the maxillary sinus because the mandibular canal is easy to identify in most cases, except those with thick cortical bone or a high proportion of trabecular bone. This convenient detection of the mandibular canal can allow dentists (even those with limited clinical experience) to place implants in the posterior mandibular area without any critical complications as long as the buccolingual width is measured carefully first. Direct measurement using calipers is recommended intraorally or extraorally in a study cast. In summary, presurgical planning in the mandible can be performed safely using DPR by dentists with sufficient experience and skill, whereas presurgical planning using CBCT is strongly recommended when a buccolingual location of the mandibular canal needs to be evaluated.

Radiographic images do not always display anatomic structures accurately. The present study revealed that measurement errors in the maxilla between postsurgical radiographic images and real specimens were lower for CBCT than for DPR. More accurate detection of the inferior wall of the maxillary sinus was possible using CBCT. A measurement error of less than 1 mm is generally required on radiographic images for presurgical planning (Wyatt and Pharoah, 1998). Although the mean measurement errors between postsurgical radiographic images and real specimens were less for CBCT than for DPR in this study, the measurement error did exceed 1 mm in 21.4% of cases using CBCT (Table 5). Therefore, despite CBCT being one of the most reliable radiographic modalities, during presurgical planning the selected implant fixture should be 2 mm shorter than the distance between the cortical bone level and border of an important anatomic structure such as the mandibular canal or maxillary sinus. Selecting the implant length in this way could prevent critical clinical complications.

Table 5. Rates of site-specific measurement errors between postsurgical radiography and real specimens.

		0 mm<Error<1 mm (%)	Error >1 mm (%)
Maxilla	CBCT	78.6	21.4
	DPR	30.8	69.2
Mandible	CBCT	41.7	58.3
	DPR	45.5	54.5

*Significant difference between errors for CBCT and DPR, $p<0.05$

It was also found that the mandibular canal can be located more easily than the inferior border of the maxillary sinus using DPR. Even if CBCT can supply more information about the location of implantation, CBCT is not more accurate than DPR in vertical-direction measurements in the mandible. However, CBCT can supply buccolingual information that cannot be obtained using DPR.

Both positive and negative presurgical measurement errors were obtained, whereas only positive measurement errors were obtained between postsurgical radiographs and real specimens. It appears that the distance from the implant apex to anatomic structures was always greater in a postsurgical radiograph than in the corresponding real specimen.

This study has revealed the best radiographic methods to use in order to reduce errors by beginner dentists during dental implantation. However, adequate education and experience are also very important. Future studies should evaluate the validity of computer-assisted implant surgery with a surgical guide fabricated based on CBCT. In addition, it is necessary to evaluate the measurement errors when experienced dentists are placing implants.

V. CONCLUSION

The conclusions of this study are as follows.

1. In the maxillary region, the presurgical measurement error was significantly smaller for CBCT than for DPR.
2. In the mandibular region, the presurgical measurement error did not differ significantly.
3. In the maxillary region, the measurement error between postsurgical radiography and real specimens was significantly smaller for CBCT than for DPR.
4. In the mandibular region, the measurement error between postsurgical radiography and real specimens did not differ significantly.

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Abstract (in korean)

파노라마 방사선 사진 촬영법과 CBCT를 이용한 임플란트 수술 전 계획의 신뢰도 평가

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이 원 재

최근 방사선 촬영 기술의 발전으로 정확한 임플란트 식립이 가능하게 되었다. 수술 전 계획을 세울때 파노라마 방사선 촬영법, CBCT등을 이용해 임플란트 고정체의 길이와 식립 각도를 결정하며, 방사선 사진에 기반한 surgical guide를 이용하기도 한다. 그러나 임플란트 시술에 따른 합병증도 많이 나타나는데, 아래이틀신경의 손상이나 위턱굴천공이 대표적인 것이다. 이러한 합병증을 예방하기 위해 수술 전 방사선 사진 상에서 주요 해부학적 구조물의 위치를 정확히 파악해야 할 필요가 있다. 따라서 이 연구의 목적은 초보 치과의사가 두 종류의 방사선촬영방법을 기반으로 세운 술전 계획의 신뢰도를 평가하고, 방사선 사진과 실체 표본에서의 계측 값의 차이를 명확히 하는 것이다.

연구 재료로는 10구의 해부용 시신을 이용하였다. 임플란트 식립 경험이 없는 12명의 술자에게 10시간의 기초 교육 후, 파노라마 방사선 촬영법과 CBCT를 이용해 임플란트를 식립하게 하였다. 본 연구에서는 두 가지 오차를 계측하였다. (1) 술전 방사선 사진과 술후 방사선 사진에서의 계측 값 차이, (2) 술후 방사선 사진과 실제 표본에서의 계측 값의 차이

술전 방사선 사진과 술후 방사선 사진에서의 계측값의 차이는 CBCT를 이용해 수술 한 표본이 파노라마 방사선 촬영법을 이용한 것 보다 오차가 적었지만, 이것은 위턱에서만 유의하였다. 실제 표본에서의 계측값은 술후 방사선 사진에서의 계측값보다 언제나 작게 나타났으며, 이 차이 역시 위턱에서만 유의하였다.

이러한 결과를 종합해 볼때, 해부학적 구조물의 수직적 위치 파악에서는 파노라마 방사선 사진을 이용하는 것이 안전하지만, 볼혀쪽 위치관계 파악이 필요할 때는 CBCT를 이용할 것이 권장된다.

핵심되는 말 : 임플란트 수술, 파노라마 방사선사진 촬영법, CBCT, 합병증, 해부학적 구조물