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RESEARCH

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Is cone beam computed tomography accurate in predicting inferior alveolar nerve exposure during mandibular third molar extraction?

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Abstract

Objectives This study aims to evaluate the accuracy of cone beam computed tomography (CBCT) in predicting the exposure of inferior alveolar nerve (IAN) during complicated mandibular third molars (M3M) extraction.

Methods 115 M3Ms with canal cortical defect signs on preoperative CBCT were extracted. Candidate variables included sex, age, types of CBCT machine, the Winter classification of M3Ms, the size of root entering the canal on CBCT, the size of cortical defect on CBCT. The primary outcome was the exposure of IAN and the exposed neurovascular bundle size which was recorded measured under endoscope. The independent sample t-test, Bland-Altman analysis was performed to assess the agreement between the CBCT and endoscopic measurements. The regression analysis was performed to determine if there was a correlation between the measurements of CBCT and endoscope. The Chi-square test was used to evaluate whether the proportion of IAN exposure in different impacted M3M types were consistent. ANOVA was used to test the correlation between the actual size of exposed IAN and (1) Winter classification types; (2) types of CBCT machine.

Results 85/115 (73.9%) M3Ms with canal cortical defect signs on preoperative CBCT had intraoperative exposure of IAN. The average length and width of the exposed IAN were 5.89 ± 1.72 mm and 2.48 ± 0.79 mm, which were significantly smaller than the size of root entering the canal on CBCT (9.69 ± 3.05 mm and 3.26 ± 0.87 mm, $P < 0.001$) but larger than the cortical defect size (5.06 ± 2.05 mm and 2.10 ± 0.54 mm, $P < 0.05$). The regression analysis showed that IAN exposure was significantly associated with the cortical defect length (0.1 mm) on CBCT (OR = 1.38, $P = 0.001$). The probability of intraoperative IAN exposure was statistically different among different Winter classifications of M3M and the probability of IAN exposure was higher in non-horizontal impacted type according to Chi-square test results. ANOVA showed statistical difference between exposed IAN length and Winter classification types ($p = 0.001$).

Conclusions Not all M3Ms with tooth-IAN contact signs on preoperative CBCT indicated intraoperative IAN exposure. The size of root entering the canal on CBCT were mostly larger than the intraoperative endoscopic measurements. IAN exposure can be accurately predicted by the length of cortical defect on CBCT. Non-horizontal impaction predisposed the M3M to a higher risk of intraoperative IAN exposure.

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Clinical relevance Endoscope provides the possibility to observe and record the IAN exposure directly. IAN exposure can be accurately predicted by the length of cortical defect instead of the size of root entering the canal on CBCT. Non-horizontal impaction predisposed the M3M to a higher risk of intraoperative IAN exposure.

Clinical trial number Not applicable

Keywords CBCT, Endoscopy, Impacted lower third molars, Inferior alveolar nerve

Introduction

Extraction of mandibular third molar (M3M) is the most commonly performed operation in oral and maxillofacial surgery. Inferior alveolar nerve (IAN) exposure may occur during extraction, thus increasing the risk of neurosensory deficit. Study by Gennaro et al. had shown that there was a high incidence of neurosensory disturbance in the lower lip and chin after sagittal split osteotomy surgery and intraoperative quantity of IAN exposure [1]. A prospective study of impacted tooth extraction also showed intraoperative exposure of IAN bundle carried a 20% risk of paresthesia and 70% chance of recovery by 1 year [2]. Exposure of IAN if not treated carefully such as scraping the alveolar fossa may lead to neurosensory deficit [3].

Although the use of cone beam computed tomography (CBCT) may not reduce the frequency of post-operative IAN injury (IANI) after M3Ms extraction compared to panoramic imaging according to recent studies [4–12], CBCT provides operators more information to do preoperative preparations by clear high-contrast images with high isotropic spatial resolution [13] and reducing a lower incidence of temporary IANI [12]. Preoperative CBCT has been widely used to evaluate the relationship between M3M tooth roots and the mandibular canal [14–22]. In clinical practice, CBCT is used to measure the length of the root entering the canal in cases without bone barrier between root and canal on CBCT. Susarla et al. found that loss of cortical integrity had a high sensitivity but low specificity for the prediction of IAN exposure [23]. In this study, we used "cortical bone" to describe bony lining of the mandibular canal in accordance with previous literatures [23]. It should be stressed that the mandibular canal has no cortical lining although it can appear as such in the radiographs [24]. Our previous study also showed that the sign of root entering canal on CBCT did not predict the actual IAN exposure [25]. The accuracy of CBCT in predicting IAN exposure is still controversial in previous studies due to a lack of methods for direct intraoperative measurement and documentation. Moreover, intraoperative IAN exposure is due to incomplete canal cortical bone and it is unknown whether the bone defect size is consistent with the size of root entering the canal on CBCT. Therefore, the relationship between the root entering canal size, the cortical defect size on CBCT and the actual IAN exposure size also remains elusive. The purpose of this retrospective study is to evaluate the accuracy of CBCT in predicting the exposure of IAN and the size of exposed IAN during M3Ms extraction. The specific aims are (1) to observe IAN exposure probability in cases without bone barrier between tooth root and mandibular canal after tooth extraction; (2) to measure the size of root entering canal and the cortical defect size on CBCT and the size of intraoperatively-exposed IAN under endoscope; (3) to identify the relationship between IAN exposure and other variables such as impaction classification and types of CBCT machine.

Methods

Patients

This retrospective study consisted patients who underwent M3M extraction at the Department of Oral and Maxillofacial Surgery from Nov 2020 to Jan 2022. Inclusion criteria were: (1) patients over 18 years of age; (2) completely or partially impacted M3M; (3) preoperative panoramic or intraoral imaging showed "high risk" of IANI (a close relationship between the tooth roots and the canal) and the surgeon believed CBCT was helpful and necessary to extract the roots of M3Ms; (4) CBCT still showed the bone of the canal was discontinuous, or the M3M root compressed or encircled the mandibular canal. The high risk of IANI signs on panoramic or intraoral imaging included darkening of the root, deflection of the root, narrowing of the root, superimposition of the root, bifurcation of the root over the inferior alveolar canal, diversion of the inferior alveolar canal, interruption of the lining of the canal, craniocaudal relation of the roots, the mandibular canal and position of the canal over the roots [26–30]. Patients or the M3M had surgery contraindications were excluded, e.g. pregnant females, M3M with acute inflammation, or with pulp, periodontal and periapical diseases. This study was conducted in accordance with the principles of the Declaration of Helsinki and approved by the institutional biomedical ethics committee. Informed consent was obtained from all participants.

Surgical procedure

Extraction of M3M was performed under local anesthesia by one senior surgeon. Briefly, an incision on the buccal side of the lower second molar at the distal or proximal mesial axial angle and from distal to the lower

Table 1 Winter classification for impacted M3M

Impaction Class	Definition
Horizontal	Long axis of the third molar is horizontal (90°±10°)
Mesioangular	Impacted tooth is tilted toward the second molar in a mesial direction
Vertical	Long axis of the third molar is parallel to the long axis of the second molar (0°±10°)
Distoangular	Long axis of the third molar is angled distally or posteriorly away from the second molar
Inverse	The tooth is reversed and positioned upside down
Buccal/lingual obliquity	The tooth is buccally (tilted toward the cheek) or lingually (tilted toward the tongue) impacted
Transverse	The tooth is horizontally impacted in a cheek–tongue direction

second molar were made. The mucoperiosteum flap was elevated. The crown of M3M was segmented using a contra-angle high-speed rotary handpiece. During the crown segmentation, a 4.0 mm Storz Tricam SL II SCB endoscope (Karl Storz, Tuttlingen, Germany; Cat. No. 20223020-1) and DELON endoscope (Beijing Fanxing Guangdian Medical Treatment Equipment Co., Beijing, China; Cat. No. UHD3840) with 30° or 70° view angle was used to check the medial part of the crown and the distal root surface of lower second molar. M3M roots were segmented and adjacent bone was partially removed by wavy blade piezosurgery under endoscope. Minimally invasive elevator was used to remove the roots. Following copious irrigation, the socket was endoscopically examined. Any IAN exposure was recorded and the size of exposed IAN was measured. The incision was closed and all patients received amoxicillin 500 mg 3 times daily for 3 days.

Variables

Candidate variables included sex, age, manufacturer of CBCT machine and scan parameters, Winter classification of M3Ms, the size of root entering the canal on CBCT, and cortical defect size on CBCT. Winter classification was based on the position of the impacted M3M to the long axis of the second molar as shown in Table 1. We also took Quek's classification system [31] into consideration, using the angle formed between the intersected long axis of second and third molars, and defined vertical as 0°±10°, horizontal as 90°±10°.

Preoperative CBCT scans were taken using one of the following machines and parameters: (1) NewTom VGi (Quantitative Radiology, Verona, Italy) in 110 kV and 3.65 mA (Scanning time, 36 s; field of view, 160 mm×160 mm; slice, 0.3 mm); (2) 3D Accuitomo 170 (J Morita Mfg., Corp., Kyoto, Japan) in 90 kV and 10 mA (Scanning time, 15s; field of view, 60 mm×60 mm; slice, 0.375 mm); (3) iCAT FLX (Imaging Sciences International Inc., Hatfield, PA, USA) in 120 kV and 5 mA (Scanning time, 26.9 s; field of view, 160 mm×130 mm; slice, 0.3 mm). The predictor variables were the perforation length and width in the mandibular canal in the third molar region. These were measured in the picture archiving communication system (Carestream Health, Inc, Rochester, NY). The XYZ axes of the CBCT multiplanar reformation were adjusted to achieve a cross-section with the long axis of the IAN passing along the M3M completely [25]. The cortical defect length and width were defined as the longest exposed distances measured along the long axis and cross section of IAN. The direct contact length and width were defined as the direct line between the point tooth root and the bone was contact along the long axis and across section of IAN. They were measured on CBCT by the same observer who also participated in the surgery as demonstrated in Fig. 1.

The co-primary outcomes were the intraoperative exposure of IAN (yes or no) and the exposed IAN size including length and width. The IAN exposure was defined as direct visualization of the IAN via endoscope. The length and width of any exposed IAN were measured

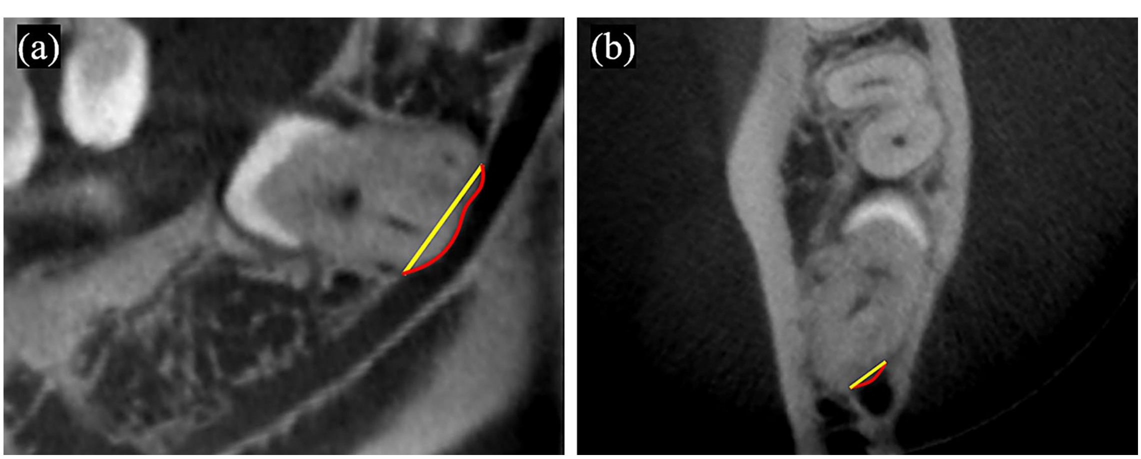

Fig. 1 The length (**a**) and width (**b**) of root entering the canal (red line); the canal cortical defect length (**a**) and width (**b**) (yellow line) on CBCT

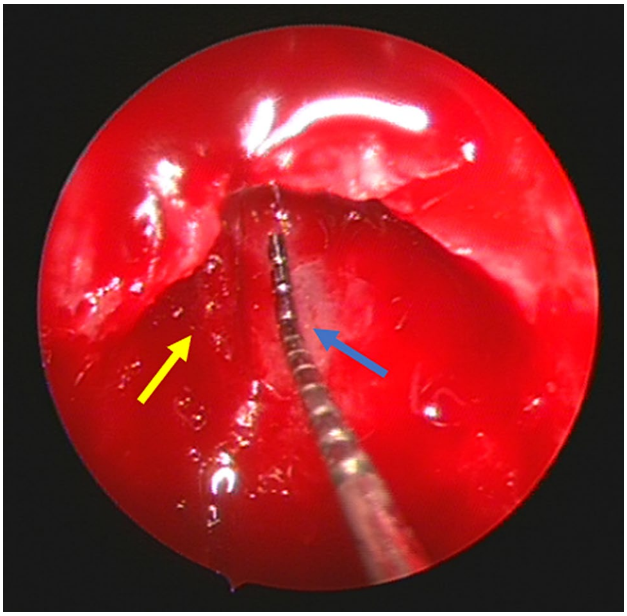

Fig. 2 The exposed IAN under endoscope. Yellow arrow showed the direct visualization of IAN; blue arrow showed the prebent periodontal probe with 1 mm scale as a reference for measurement. The IAN exposed length and width were the distance along and perpendicular to the long axis direction of the part that can be seen under endoscope, which were estimated by probe

using a prebent periodontal probe as a reference. We placed the probe as close to the IAN as possible and parallel to the IAN during the operation, and recorded the photograph and video. We measured the exposed IAN length by reading the probe number, obtained the width by (measured width/ measured length of the probe scale) *1 mm according to the photograph (Fig. 2).

Statistical analysis

The statistical analysis was performed using Stata 15.0 (StataCorp, College Station, Texas, USA). Continuous variables (age, the size of root entering the canal on CBCT, and cortical defect size on CBCT and the exposed IAN) were expressed as the mean standard deviation, or median and range if they were not normally distributed. Categorical (types of CBCT machines, Winter classification) and binary variables (sex, IAN exposure) were reported as proportions or percentages. The independent sample t-test, Bland-Altman analysis were performed to assess the agreement between the CBCT and endoscopic measurements. The regression analysis was performed to determine if there was a correlation between the measurements of CBCT and endoscope. The Chi-square test was used to evaluate whether the proportion of IAN exposure in different groups of Winter classification was consistent. ANOVA was used to test the correlation between the actual size of exposed IAN and (1) Winter classification types; (2) types of CBCT machine. A P-value of <0.05 was considered statistically significant. This study is reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

Table 2 The descriptive statistics and comparison between IAN exposed and unexposed groups

Characteristic	Total ($n=115$)	Exposed ($n=85$)	Unexposed ($n=30$)	*P* value
Types of CBCT machine				
i-CAT FLX	50	40	10	0.174
3D Accuitomo 170	25	15	10	
NewTom VGi	40	30	10	
Winter classification				
Horizontal	50	30	20	0.026
Mesioangular	52	44	8	
Vertical	10	8	2	
Inverted	3	3	0	
Size of root entering the canal on CBCT (mm)				
Length	9.69 ± 3.05	9.92 ± 3.04	9.03 ± 3.03	0.170
Width	3.26 ± 0.87	3.28 ± 0.86	3.21 ± 0.91	0.724
Cortical defect on CBCT (mm)				
Length	5.06 ± 2.05	5.90 ± 1.61	2.66 ± 0.93	<0.001
Width	2.10 ± 0.54	2.26 ± 0.48	1.65 ± 0.42	<0.001
Exposed IAN (mm)				
Length		5.89 ± 1.72	N/A	
Width		1.96 ± 0.84	N/A	

Results

Descriptive statistics and comparison between the exposed and unexposed groups

A total of 105 patients (40 males and 65 females) with an average age of 29 years (from 18 to 55 years) and 115 M3M were included. 85 (73.9%) M3Ms had intraoperative exposure of IAN under endoscope. The descriptive statistics of the 115 M3M and comparison between the exposed and unexposed groups were listed in Table 2.

There were no significant differences in size of root entering the canal on preoperative CBCT between intraoperative IAN exposed and unexposed group. However, the independent sample t-test showed the length and width of exposed IAN were significantly smaller than those of root entering the canal on CBCT in IAN exposed group ($P<0.001$ for both). The Bland-Altman plots showed inconsistency between the size of root entering the canal on CBCT and endoscopic IAN-exposure size (Fig. 3).

As there were significant differences in cortical defect size on preoperative CBCT between IAN exposed and unexposed group in Table 2, we also analyzed the cortical

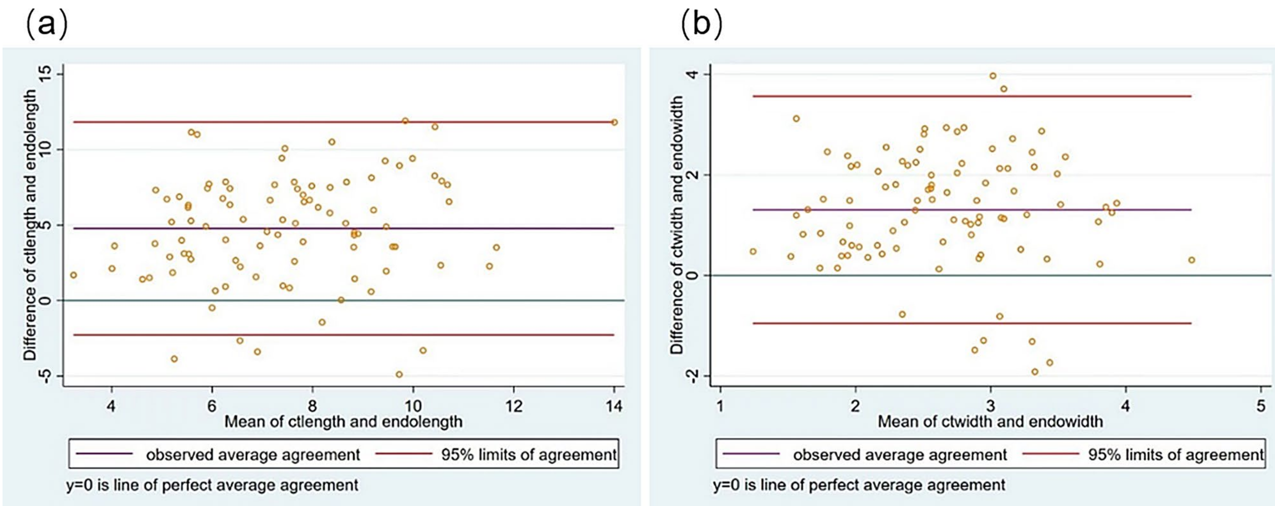

Fig. 3 Bland-Altman plot of the agreement between the length (**a**) and width (**b**) of intraoperatively-exposed IAN under endoscope and the size of root entering the canal on CBCT

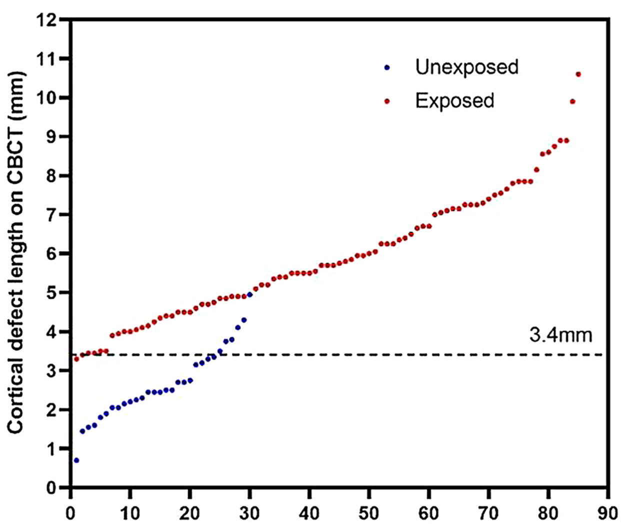

Fig. 4 The scatterplot of cortical defect length on CBCT, based on IAN exposure status. Red points showed the length on CBCT of exposed IAN during operation and blue points showed the unexposed ones

defect size and the exposed IAN size in Fig. 4. Moreover, logistic regression showed that IAN exposure was significantly associated with the cortical defect length (0.1 mm) on CBCT (OR = 1.38, 95% CI 1.14 to 1.67, $P = 0.001$). Linear regression analyses showed that the length and width of exposed IAN were significantly associated with the cortical defect length ($P<0.001$, $P = 0.013$) and width ($P = 0.004$, $P<0.001$).

There was a significant difference between the horizontal and mesioangular impacted type ($p = 0.005$) when Chi-square test was used to evaluate whether the proportion of IAN exposure in different groups of Winter classification was consistent. We also used ANOVA to test the correlation between the actual size of exposed IAN and (1) Winter classification types; (2) types of CBCT machine. A statistical difference was found between exposed IAN length and Winter classification types ($p = 0.001$), but no difference was found in width ($p = 0.679$). There were no statistical differences in correlation analysis between the length and width of exposed IAN and those of root entering the canal on CBCT ($p = 0.549$ and 0.199).

Discussion

Major findings

This study found that (1) not all M3Ms with root entering the canal signs on preoperative CBCT would expose IAN; (2) IAN exposure can be predicted by the size of cortical defect on CBCT, (3) the IAN exposure ratio was different among tooth in different types of Winter classification.

Evaluation of the relationship between the M3M and the IAN before tooth removal is important to the oral and maxillofacial surgeons, because IAN injury is one of the most serious complications of M3M removal. Studies have presented some risk signs of a close relationship between the tooth roots and the canal: darkening of the root; deflection of the root; narrowing of the root; superimposition of the root; bifurcation of the root over the inferior alveolar canal; diversion of the inferior alveolar canal; interruption of the lining of the canal; craniocaudal relation of the roots; the mandibular canal and position of the canal over the roots [26–29]. The inclusion criteria were refereed to risk signs in literatures and our clinical experience. Although the use of CBCT may not reduce the frequency of IAN injury compared to panoramic imaging according to recent studies [4–6], CBCT still can provide more information. CBCT was used as a golden standard for the relationship between the tooth roots and the IAN [3, 18, 20, 21]. There were few standard parameters of CBCT for predicting the IAN exposure. Nakayama et al. have shown an increased risk for IAN exposure when the M3M contacts the canal [16]. However, CBCT may be not a perfect tool to predict IAN exposure. Susarla et al. have questioned the accuracy of CBCT in predicting IAN exposure and studied on 80 M3Ms. They found that loss of cortical bone integrity had a high sensitivity but low specificity as a diagnostic test for IAN visualization, but a defect size ≥ 3 mm was associated with an increased risk for intraoperative IAN visualization with a high sensitivity and specificity (≥ 0.82) [23].

There were some cases with actual-exposed IAN that could be observed under direct vision by naked eyes or under 2-power loupe magnification [2, 16, 32–34]. However, these methods were not ideal for IAN observation, possibly for the following reasons: (1) IAN was deep inside the socket; (2) blood leakage from the socket made it difficult to identify IAN; (3) lack of records such as photographs and videos resulted in poor repeatability. The endoscope with light source and amplification effect, which makes it possible to observe the structures clearly. The process of tooth dislocation would exert force on the surrounding tissues. When the tooth was in direct contact with IAN, the nerve was more likely to be affected by the force during tooth extraction process, and the possibility of IANI was also higher. The IAN exposure indicated the direct contact relationship between IAN and tooth, which had important clinical significance. We chose IAN exposure and the size of IAN exposure as clinical outcomes for the following reasons: first, we were interested in the accuracy of the actual anatomical structure that can be predicted by imaging signs; second, the introduction of endoscopy made it possible to observe the socket and IAN. The focus of this study was to analyze the relationship of CBCT imaging and the direct observation by endoscope. There was no further discussion on IANI which may lead to numbness. Studies on IAN under endoscopy are still in progress and more issues will be explored in the future.

In our previous study, we used endoscope assisting removing M3Ms or residual tooth of M3Ms [35] and found that the size under endoscope was smaller than the direct contact size between IAN and tooth root on CBCT, but no further statistical analysis was conducted due to the small sample size [25]. We found that the root entering the canal on CBCT did not indicate the actual IAN exposure during M3Ms extraction. Therefore, as an auxiliary examination tool, CBCT could reflect the relationship between tooth and surrounding structures in its way but the imaging of CBCT is affected by many factors, which cannot be considered as real.

In this study, the IAN exposure rate was 73.9% (85/115), which confirmed that signs of the root entering the canal on CBCT could not predict IAN exposure. The reason may be that there was a thin layer of bone between IAN and tooth root, which was difficult to be shown on CBCT. Mischkowski et al. studied the geometric accuracy of CBCT and obtained the mean absolute measurement error for linear distances was 0.26 mm [36]. Lascala et al. evaluated the accuracy of the linear measurements obtained in CBCT images using a NewTom compared with caliper measurement on dry skulls and found that the real measurements were always larger than those for the CBCT images [37]. The images presented by different machines may also play a part in measuring in theory, but our study did not show statistical differences between CBCT machines.

The inconsistency between preoperative CBCT and endoscopic measurements may be explained by different state of IAN in pre- and post-operation. The clinical measurement of the direct contact length was the longest distance the root entering the canal. When no bone image can be observed between the canal and the tooth root, it is considered that the root is in direct contact with IAN. Due to the presence of tooth roots, it is often considered that IAN would adapt to the shape of tooth roots which are often curved rather than straight. In this study, the postoperative state of the IANs were directly observed and the size of exposed IANs were measured. IANs were straight in cases with IAN exposure under endoscope, which may indicate that after tooth root removal the compression by natural development was released, the IAN became "non-adaptive state" to hard tissue forms such as the root. Therefore, it is necessary to operate gently, especially pay attention not to scratch the site without bone to protect IAN. Based on the results of this study, the possibility of IAN exposure is not high when the cortical defect size is under 3.4 mm. For cases of IAN exposure, linear regression analyses indicated that the larger size of cortical defect on CBCT, the larger size of IAN exposure may be observed although the length of the defect on CBCT is different from that of the actual size of IAN exposure.

In addition, this study found significant differences in the probability of IAN exposure among different impacted types of Winter classifications. In this study, mesioangular impacted M3Ms (43.5%) were also the most common type [38]. In the case of direct contact between the root and IAN, we need to be more vigilant about the non-horizontal impacted type as they may have a higher probability of intraoperative IAN exposure.

Conclusion

This retrospective study demonstrated that not all M3Ms with IAN and root contacting signs on preoperative CBCT showed IAN exposure intraoperation. The size of IAN in contact with tooth root on CBCT is mostly larger than the actual size of exposed IAN during M3M extraction measured by endoscope directly. IANs turned into straight in cases with IAN exposure after tooth root removal, which was shown under endoscope. IAN exposure can be accurately predicted by the length of cortical defect on CBCT. The non-horizontal impacted type may have a higher probability of intraoperative IAN exposure.

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Author contributions
Kenan. Chen contributes to data acquisition, analysis and manuscript writing; Youbai. Chen contributes to data analysis and manuscript writing/revision; Peng. Chen contributes to data analysis and manuscript revision; Junqi. Jiang contributes to data acquisition; Enbo. Wang contributes to equipment support; Chuanbin. Guo contributes to funding support；Xiangliang. Xu contributes to conception, design, data acquisition and revised the manuscript for important intellectual content and gave final approval.

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Data availability
The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics and consent to participate
This study protocol was developed in accordance with the Declaration of Helsinki and approved by the biomedical ethics committee of Peking University Hospital of Stomatology (PKUSSIRB-2024101135). Informed consent was obtained from all individual participants included in the study.

Consent for publication
Not applicable.

Human ethics and consent to participate
Not applicable

Competing interests
The authors declare no competing interests.

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References

1. Gennaro P, Giovannoni ME, Pini N, Aboh IV, Gabriele G, Iannetti G, Cascino F. Relationship between the quantity of nerve exposure during bilateral sagittal split osteotomy surgery and sensitive recovery. J Craniofac Surg. 2017;28(5):1375–9.
2. Tay AB, Go WS. Effect of exposed inferior alveolar neurovascular bundle during surgical removal of impacted lower third molars. J Oral Maxillofac Surg. 2004;62(5):592–600.
3. Xu GZ, Yang C, Fan XD, Yu CQ, Cai XY, Wang Y, He D. Anatomic relationship between impacted third mandibular molar and the mandibular Canal as the risk factor of inferior alveolar nerve injury. Br J Oral Maxillofac Surg. 2013;51(8):e215–219.
4. Matzen LH, Berkhout E. Cone beam CT imaging of the mandibular third molar: a position paper prepared by the European academy of dentomaxillofacial radiology (EADMFR). Dento Maxillo Fac Radiol. 2019;48(5):20190039.
5. Robbins J, Smalley KR, Ray P, Ali K. Does the addition of cone-beam CT to panoral imaging reduce inferior dental nerve injuries resulting from third molar surgery? A systematic review. BMC Oral Health. 2022;22(1):466.
6. de Telles-Araújo T, Peralta-Mamani G, Caminha M, de Moraes-da-Silva RDG, Rubira A, Honório CMF, Rubira-Bullen HM. CBCT does not reduce neurosensory disturbances after third molar removal compared to panoramic radiography: a systematic review and meta-analysis. Clin Oral Invest. 2020;24(3):1137–49.
7. Guerrero ME, Nackaerts O, Beinsberger J, Horner K, Schoenaers J, Jacobs R. Inferior alveolar nerve sensory disturbance after impacted mandibular third molar evaluation using cone beam computed tomography and panoramic radiography: a pilot study. J Oral Maxillofac Surg. 2012;70(10):2264–70.
8. Guerrero ME, Botetano R, Beltran J, Horner K, Jacobs R. Can preoperative imaging help to predict postoperative outcome after wisdom tooth removal? A randomized controlled trial using panoramic radiography versus cone-beam CT. Clin Oral Invest. 2014;18(1):335–42.
9. Ghaeminia H, Gerlach NL, Hoppenreijs TJ, Kicken M, Dings JP, Borstlap WA, de Haan T, Bergé SJ, Meijer GJ, Maal TJ. Clinical relevance of cone beam computed tomography in mandibular third molar removal: A multicentre, randomised, controlled trial. J Craniomaxillofac Surg. 2015;43(10):2158–67.
10. Clé-Ovejero A, Sánchez-Torres A, Camps-Font O, Gay-Escoda C, Figueiredo R, Valmaseda-Castellón E. Does 3-dimensional imaging of the third molar reduce the risk of experiencing inferior alveolar nerve injury owing to extraction? J Am Dent Association. 2017;148(8):575–83. A meta-analysis.
11. Del Lhano NC, Ribeiro RA, Martins CC, Assis N, Devito KL. Panoramic versus CBCT used to reduce inferior alveolar nerve paresthesia after third molar extractions: a systematic review and meta-analysis. Dento Maxillo Fac Radiol. 2020;49(4):20190265.
12. Korkmaz YT, Kayıpmaz S, Senel FC, Atasoy KT, Gumrukcu Z. Does additional cone beam computed tomography decrease the risk of inferior alveolar nerve injury in high-risk cases undergoing third molar surgery?Does CBCT decrease the risk of IAN injury? Int J Oral Maxillofac Surg. 2017;46(5):628–35.
13. Suomalainen A, Kiljunen T, Käser Y, Peltola J, Kortesniemi M. Dosimetry and image quality of four dental cone beam computed tomography scanners compared with multislice computed tomography scanners. Dento Maxillo Fac Radiol. 2009;38(6):367–78.
14. Reia VCB, de Toledo Telles-Araujo G, Peralta-Mamani M, Biancardi MR, Rubira CMF, Rubira-Bullen IRF. Diagnostic accuracy of CBCT compared to panoramic radiography in predicting IAN exposure: a systematic review and meta-analysis. Clin Oral Invest. 2021;25(8):4721–33.
15. Mahasantipiya PM, Savage NW, Monsour PA, Wilson RJ. Narrowing of the inferior dental Canal in relation to the lower third molars. Dento Maxillo Fac Radiol. 2005;34(3):154–63.
16. Nakayama K, Nonoyama M, Takaki Y, Kagawa T, Yuasa K, Izumi K, Ozeki S, Ikebe T. Assessment of the relationship between impacted mandibular third molars and inferior alveolar nerve with dental 3-dimensional computed tomography. J Oral Maxillofac Surg. 2009;67(12):2587–91.
17. Ueda M, Nakamori K, Shiratori K, Igarashi T, Sasaki T, Anbo N, Kaneko T, Suzuki N, Dehari H, Sonoda T, et al. Clinical significance of computed tomographic assessment and anatomic features of the inferior alveolar Canal as risk factors for injury of the inferior alveolar nerve at third molar surgery. J Oral Maxillofac Surg. 2012;70(3):514–20.
18. Tantanapornkul W, Okouchi K, Fujiwara Y, Yamashiro M, Maruoka Y, Ohbayashi N, Kurabayashi T. A comparative study of cone-beam computed tomography and conventional panoramic radiography in assessing the topographic relationship between the mandibular Canal and impacted third molars. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007;103(2):253–9.

19. Kang F, Sah MK, Fei G. Determining the risk relationship associated with inferior alveolar nerve injury following removal of mandibular third molar teeth: A systematic review. J Stomatol Oral Maxillofac Surg. 2020;121(1):63–9.
20. Neves FS, Souza TC, Almeida SM, Haiter-Neto F, Freitas DQ, Bóscolo FN. Correlation of panoramic radiography and cone beam CT findings in the assessment of the relationship between impacted mandibular third molars and the mandibular Canal. Dento Maxillo Fac Radiol. 2012;41(7):553–7.
21. Atieh MA. Diagnostic accuracy of panoramic radiography in determining relationship between inferior alveolar nerve and mandibular third molar. J Oral Maxillofac Surg. 2010;68(1):74–82.
22. Peixoto LR, Gonzaga AK, Melo SL, Pontual ML, Pontual Ados A, de Melo DP. The effect of two enhancement tools on the assessment of the relationship between third molars and the inferior alveolar Canal. J Craniomaxillofac Surg. 2015;43(5):637–42.
23. Susarla SM, Sidhu HK, Avery LL, Dodson TB. Does computed tomographic assessment of inferior alveolar Canal cortical integrity predict nerve exposure during third molar surgery? J Oral Maxillofac Surg. 2010;68(6):1296–303.
24. Iwanaga J, Katafuchi M, Matsushita Y, Kato T, Horner K, Tubbs RS. Anatomy of the mandibular Canal and surrounding structures: part I: morphology of the superior wall of the mandibular Canal. Annals Anat = Anatomischer Anzeiger: Official Organ Anatomische Gesellschaft. 2020;232:151580.
25. Jiang JQ, Kang YF, Chen KN, Cui NH, Yan ZY, Guo CB, Wang EB, Xu XL. Endoscopic visualization of the inferior alveolar nerve associated with somatosensory changes after impacted mandibular third molar extraction. *Odontology* 2023.
26. Monaco G, Montevecchi M, Bonetti GA, Gatto MR, Checchi L. Reliability of panoramic radiography in evaluating the topographic relationship between the mandibular Canal and impacted third molars. J Am Dent Assoc (1939). 2004;135(3):312–8.
27. Matzen LH, Petersen LB, Schropp L, Hermann L, Wenzel A. Risk factors observed in 2-dimensional radiographs for permanent injury of the inferior alveolar nerve after removal of mandibular third molars: a case-control study. Oral Surg Oral Med Oral Pathol Oral Radiol. 2023;136(4):490–9.
28. Matzen LH, Petersen LB, Schropp L, Wenzel A. Mandibular canal-related parameters interpreted in panoramic images and CBCT of mandibular third molars as risk factors to predict sensory disturbances of the inferior alveolar nerve. Int J Oral Maxillofac Surg. 2019;48(8):1094–101.
29. Harada N, Beloor Vasudeva S, Matsuda Y, Seki K, Kapila R, Ishikawa N, Okano T, Sano T. Characteristic findings on panoramic radiography and cone-beam CT to predict paresthesia after extraction of impacted third molar. Bull Tokyo Dent Coll. 2015;56(1):1–8.
30. Vranckx M, Lauwens L, Moreno Rabie C, Politis C, Jacobs R. Radiological risk indicators for persistent postoperative morbidity after third molar removal. Clin Oral Invest. 2021;25(7):4471–80.
31. Quek SL. Tay Ck Fau - Tay KH, Tay Kh Fau - Toh SL, Toh Sl Fau - Lim KC, Lim KC: Pattern of third molar impaction in a Singapore Chinese population: a retrospective radiographic survey. (0901–5027 (Print)).
32. Sedaghatfar M, August MA, Dodson TB. Panoramic radiographic findings as predictors of inferior alveolar nerve exposure following third molar extraction. J Oral Maxillofac Surg. 2005;63(1):3–7.
33. Ghaeminia H, Meijer GJ, Soehardi A, Borstlap WA, Mulder J, Bergé SJ. Position of the impacted third molar in relation to the mandibular canal. Diagnostic accuracy of cone beam computed tomography compared with panoramic radiography. Int J Oral Maxillofac Surg. 2009;38(9):964–71.
34. Bundy MJ, Cavola CF, Dodson TB. Panoramic radiographic findings as predictors of mandibular nerve exposure following third molar extraction: digital versus conventional radiographic techniques. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;107(3):e36–40.
35. Jiang J, Chen K, Wang E, Duan D, Xu X. Endoscopically-assisted extraction of broken roots or fragments within the mandibular Canal: a retrospective case series study. BMC Oral Health. 2024;24(1):456.
36. Mischkowski RA, Pulsfort R, Ritter L, Neugebauer J, Brochhagen HG, Keeve E, Zöller JE. Geometric accuracy of a newly developed cone-beam device for maxillofacial imaging. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007;104(4):551–9.
37. Lascala CA, Panella J, Marques MM. Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). Dento Maxillo Fac Radiol. 2004;33(5):291–4.
38. Passi D, Singh G, Dutta S, Srivastava D, Chandra L, Mishra S, Srivastava A, Dubey M. Study of pattern and prevalence of mandibular impacted third molar among Delhi-National capital region population with newer proposed classification of mandibular impacted third molar: A retrospective study. Natl J Maxillofacial Surg. 2019;10(1):59–67.

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