Int. J. Oral Maxillofac. Surg. 2019; xxx: xxx–xxx
https://doi.org/10.1016/j.ijom.2020.09.015, available online at https://www.sciencedirect.com

International Journal of Oral & Maxillofacial Surgery

Research Paper
Oral Surgery

Three-dimensional assessment of root migration and rotation patterns after coronectomy: bone-embedded roots versus soft tissue-covered roots

Z.-Y. Yan[1], F. Wang[1], X.-Y. Yan[2], N. Ge[1], C.-B. Guo[1], K. Liu[1], N.-H. Cui[1]
[1]Department of Oral and Maxillofacial Surgery, Peking University School and Hospital of Stomatology, Beijing, China;
[2]Department of Medical Statistics, Peking University Clinical Research Institute, Beijing, China

Z.-Y. Yan, F. Wang, X.-Y. Yan, N. Ge, C.-B. Guo, K. Liu, N.-H. Cui: Three-dimensional assessment of root migration and rotation patterns after coronectomy: bone-embedded roots versus soft tissue-covered roots. Int. J. Oral Maxillofac. Surg. 2019; xxx: xxx–xxx.

Abstract. In this study, a three-dimensional evaluation was performed to explore differences between bone-embedded and soft tissue-covered roots after mandibular third molar (M3M) coronectomy. Patients were recruited according to the results of cone-beam computed tomography, 6 months after coronectomy. Completely bone-embedded M3Ms were assigned to group B, while completely soft tissue-covered M3Ms were assigned to group S. Data were recorded using digital software. A total of 213 M3Ms in 181 patients were investigated. Age was the primary factor influencing root migration ($P < 0.001$). The smaller the degree of angulation of the M3M, the more likely was the root complex to rotate distally ($r = -0.37$, $P < 0.001$). The depth of the impacted M3M contributed to the regeneration of new bone ($P \leq 0.007$). The length of the root complex (odds ratio 0.82, $P = 0.048$) and distance from the root to the alveolar crest (odds ratio 1.23, $P = 0.026$) were two critical factors influencing whether the root complex was bone-embedded. Ensuring that the length of the root complex is <7.6 mm and the distance between the root and alveolar crest is ≥5 mm were both found to be critical to the remaining root being completely bone-embedded and thus preventing eruption and the need for secondary surgery.

Key words: third molar; cone-beam computed tomography; three-dimensional imaging; coronectomy; root migration; bone regeneration.

Accepted for publication 16 September 2020

Inferior alveolar nerve (IAN) injury is one of the most serious and undesirable complications of impacted mandibular third molar (M3M) extraction. An inferior alveolar canal perforation >3 mm is said to increase the risk of IAN injury by 20%[1]. Pogrel et al. proposed the coronectomy as an alternative option in 2004[2], and the efficiency of coronectomy in reducing IAN injury has been well established over the years[3–7]. However, factors contributing

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to the remaining root complex being bone-embedded are still not clear; therefore, the assessment of possible further root exposure is very limited, necessitating long-term follow-up[2,4]. Furthermore, limitations of previous radiographic assessment methods could also account for this lack of clarity. Most studies have used peri-apical or panoramic radiographs to conduct further analyses[3,5,8]. However, it cannot be determined whether the root complex is completely bone-embedded in two-dimensional (2D) radiographs with overlapping images[9]. Further studies using cone-beam computed tomography (CBCT) with three-dimensional (3D) data are therefore required.

In recent years, the combination of 3D CBCT data and digital software has enabled the reconstruction and registration of digital models of tooth and bone. Typically, 3D data have high reproducibility and their accuracy has been widely accepted[10,11]. The aim of this study was to combine CBCT and a digital technique to explore factors affecting bony coverage of the root section, as well as 3D migration and rotation of the root complex after coronectomy.

Patients and methods

Study design

This study was a prospective single-blind controlled trial and was performed as part of an ongoing study on the long-term changes of M3Ms after coronectomy[6]. The study was conducted in accordance with the Declaration of Helsinki of 1975, as revised in 2013, and was registered in the Chinese Clinical Trial Registry (ChiCTR1800014862). The Biomedical Ethics Committee of Peking University School of Stomatology approved this study (PKUSSIRB-201736080).

Eligible patients

From 2018 to 2019, patients who underwent coronectomy of impacted M3Ms were recruited from the Department of Oral and Maxillofacial Surgery of Peking University School and Hospital of Stomatology, China. The following inclusion criteria were applied: (1) age 18–40 years, and (2) patient with at least one root of the M3M in direct contact with the IAN, as proven by preoperative CBCT. The exclusion criteria were as follows: (1) local risk factors such as caries or periodontitis of the third molar, and cystic or neoplastic conditions around the M3M, and (2) the presence of a general systemic disease state such as diabetes or an immunodeficiency contributing to infection, or a history of radiotherapy or chemotherapy[6].

Grouping and sample size

Two typical postoperative statuses of the root complex were investigated: completely bone-embedded and completely soft tissue-covered. In this study, the M3Ms were grouped according to the postoperative status of the root complex on CBCT. M3Ms with completely bone-embedded roots were assigned to group B, while those with a completely soft tissue-covered root section were assigned to group S. Further details of the groups are provided below in the section headed ‘Variables assessed’.

The study sample size was calculated using SAS software version 8.3 (SAS Institute Inc., Cary, NC, USA). The maximum and minimum previously reported values of root migration are <2 mm[12] and 3.06 ± 1.67 mm[13], respectively. With a

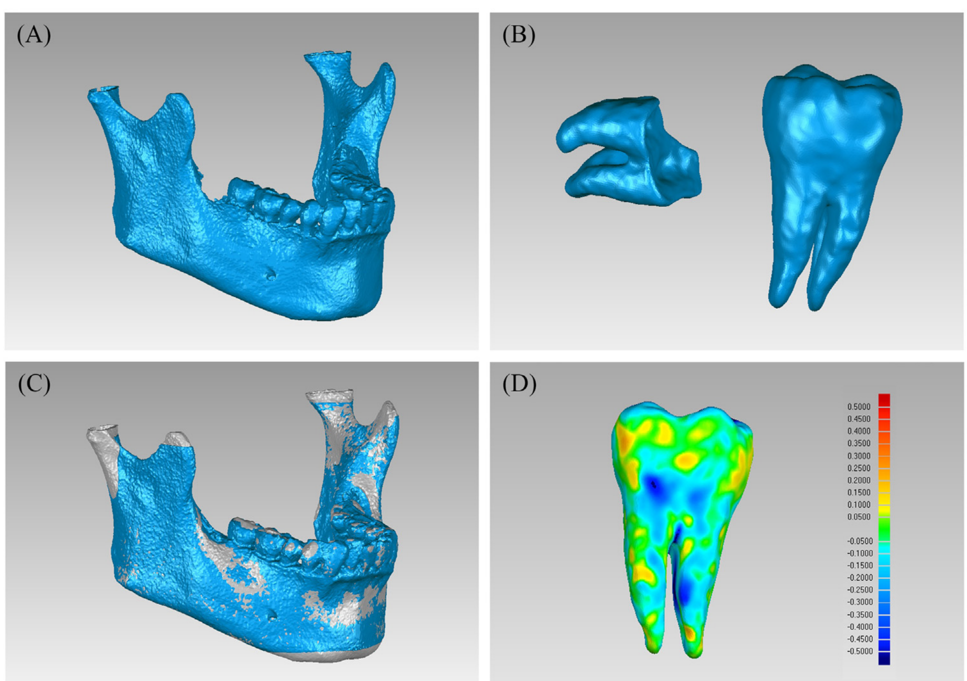

Fig. 1. Registration of the digital models and the measurement of bone regeneration. (A) Construction of the M2M and retained root. (B) Mandible bone model: the model from the day of surgery (baseline, in grey) and the model from 6 months after surgery (6 months postoperative, in blue) were registered according to the best-fit alignment algorithm. (C) 3D colour map of the geometric deviation of the M2M at different times: the range of the comparison deviation error was set between −0.5 mm and 0.5 mm. The map goes from blue (negative error area), passing through green (near no-error area), to red (positive error area). (D) The new bone formed in the extraction socket at 6 months postoperative (blue) was calculated using the Boolean algorithm to subtract the extraction socket model from the different time point. It was assumed that there was no change in hard tissue surrounding the extraction socket during the 6 months following surgery, so that the difference between the two ‘extraction socket’ models was regarded as the volume of bone regeneration in the tooth socket. (M2M, mandibular second molar).

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power of 90% at the 5% significance level, the expected sample size for each group was 54 subjects. Leung reported that the incidence of bone-embedded coronectomies was less than that of partly or completely soft tissue-covered ones (38.6% vs 61.4%)[14]. Considering a drop-out rate of 20%, the sample size was required to be at least 175 in total.

All surgical procedures were performed by the same senior oral surgeon. An experienced resident not participating in the operation or follow-up divided all M3Ms into the two groups (group B and group S). To reduce measurement bias, all study variables were measured and recorded by another resident. The data were then transferred to other co-authors for independent statistical analysis.

Operation and imaging examination

All included patients signed the informed consent before surgery. During coronectomy, a crown section was applied 1–2 mm below the cemento-enamel junction[15]. The surface of the root was trimmed to at least 3 mm below the alveolar crest[2]. Unsuccessful coronectomies were excluded[2,5,16]. After routine root planing of the mandibular second molar (M2M), debridement, and irrigation, the wound was sutured primarily. No antibiotics or analgesic medications were prescribed.

The CBCT examination was performed twice, as reported previously in the literature[14,17,18]: on the day after coronectomy (baseline) and at 6 months postoperative. A NewTom CBCT system (NewTom VG, Quantitative Radiology, Verona, Italy) was used to scan the region of interest. The scanning parameters were 110 kVp with a voxel size of 0.2 mm and field of view (FOV) of 8 × 12 cm. The mA value was automatically regulated according to the head size of each patient. The exposure time was 18 s in each case.

Construction and measurement of the digital model

Registration and measurement of bone regeneration

CBCT data stored in Digital Imaging and Communications in Medicine (DICOM) format were imported into Materialise Mimics 18.0 (Mimics Innovation Suite 18.0; Materialise Dental, Leuven, Belgium). Digital models of the mandibular bone, extraction socket (a digital model of the hard tissue containing the entire extraction socket), M2M, and remaining root of the M3M after coronectomy (baseline and 6 months postoperative) were segmented and saved in stereolithography (STL) format for further analysis in Geomagic Studio 12 (3D Systems, Rock Hill, SC, USA)[11]. According to the best-fit alignment algorithm[19], the relative migration and variation from baseline to 6 months postoperative could be visualized directly. The mean and standard deviation were presented on a graphical colour map[11] (Fig. 1).

Construction of the coordinate system and investigation of root migration

To ensure the reproducibility and comparability of results among different participants, a standard coordinate system was constructed in Geomagic, in which the *X*, *Y*, and *Z* axes were identified to represent

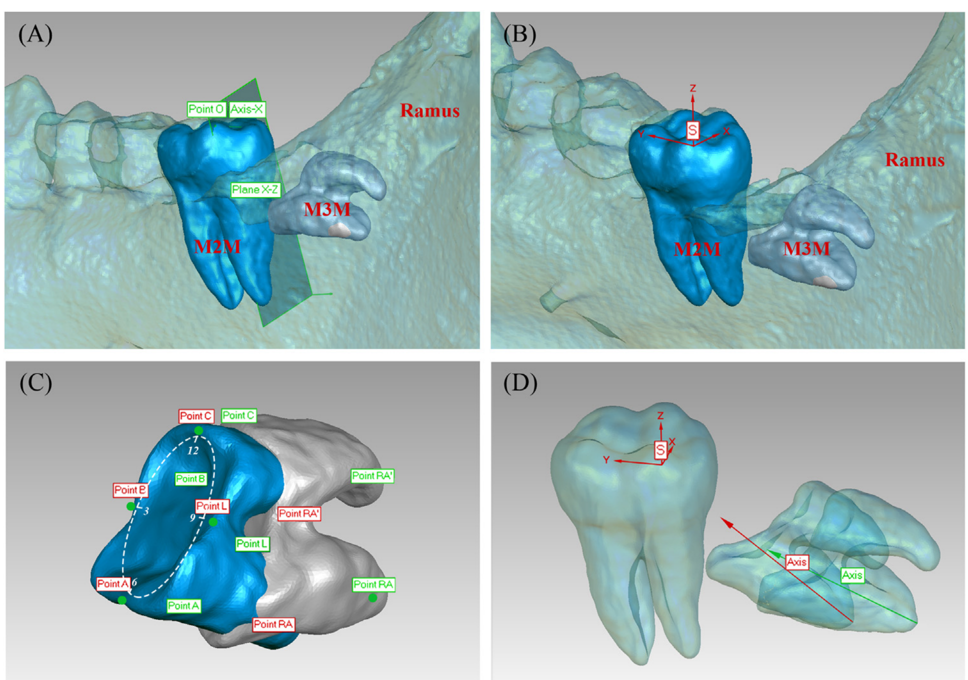

Fig. 2. Construction of the coordinate system and measurement of root migration. (A) Point O: the distolingual cusp of M2M, the origin of the coordinate system. The *X*-axis line represents the distolingual direction, located on the occlusal plate, drawn from point O to another point near the distobuccal cusp of M2M. Point Z: a point near the apical point of M2M. Plane *X*–*Z* is the plane perpendicular to the occlusal plate, determined by the *X*-axis line and point Z. (B) Establishment of the coordinate system 'S'. Positive direction of the axes: *X*-axis, from lingual to buccal direction; *Y*-axis, from distal to mesial direction; *Z*-axis, from apex to crown. (C) Creation of the markable features for measurement. The relative migration and rotation from baseline (blue model with red labels) to 6 months postoperative (grey model with green labels) could be visualized directly. Points 'B' (buccal), 'L' (lingual), 'C' (crown), and 'A' (apical) are at the edge of the fragment section. Point RA represents the root apex point. (D) The axis lines represent the long axis of M3M. The migration (*M*) of the root in the different directions (*X*, *Y*, *Z*) was calculated as the mean value of migration of two points on the corresponding axis: $M_X = (\triangle X_{\text{point B}} + \triangle X_{\text{point L}})/2$; $M_Y = (\triangle Y_{\text{point A}} + \triangle Y_{\text{point RA}})/2$; and $M_Z = (\triangle Z_{\text{point C}} + \triangle Z_{\text{point A}})/2$. Similarly, root rotation was calculated as the variation in the axis line. (M2M, mandibular second molar; M3M, mandibular third molar).

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the clinical buccolingual direction, mesiodistal direction, and crown–apical direction, respectively. Further measurements could be applied through the coordinates of points and lines. Points at the edge of the root complex were established to describe root migration, while the long axis of the root complex was identified to describe root rotation (Fig. 2).

Variables assessed

The pre- and intraoperative variables were as follows: (1) demographic characteristics, including age and sex; (2) M3M condition, i.e. Pell and Gregory depth of impaction, angulation of the M3M (the longitudinal axis intersection angle of M2M and M3M), and retromolar space[20]; (3) relationship between the M3M and IAN, i.e. the size of the cortical perforation of the inferior alveolar canal seen on CBCT (in millimetres)[6]; and (4) surgery-related factors, including (a) the distance between the M3M root surface and alveolar crest assessed with a periodontal probe during the operation, (b) length of the root complex determined as the length of the mesial edge of the root complex (Fig. 3A), which was measured in the digital software, from the apex of the mesial root to a point at the edge of the root section (in the direction of 6 o'clock), (c) volume of the root complex, (d) area of the periodontal membrane, (e) area of the root complex, (f) area of the cross-section of the root complex, and (g) enamel remnants.

The postoperative variables were as follows: (1) eruption status of the root complex (as determined on a quasi-sagittal plane (*Y–Z* plane) in the digital software). For group B, the M3M was completely bone-embedded (section of root completely covered with bone). For group S, the M3M was completely covered with soft tissue; complete soft tissue coverage was defined as ≥90% section of the root covered with soft tissue. (2) Migration and rotation of the root complex: these factors were calculated in Geomagic Studio 12 as discussed above. (3) New bone formation: the thickness of the calcification bridge (radio-resistant bone-like structure above the root section), which was measured at the centre of the root fragment and was only recorded in group B, and the volume of bone regeneration in the extraction socket.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics version 21.0 (IBM Corp., Armonk, NY, USA). All samples were included to assess the general prognosis of coronectomy. When exploring factors affecting whether the root complex was completely bone-embedded or soft tissue-covered, only samples in group B and group S were included.

In the univariate analysis to determine the differences between group B and group S, all variables were compared with the independent samples *t*-test, non-parametric tests, and the χ^2 test. To study the general prognosis of the root complex, the effects of pre- and intraoperative variables on postoperative continuous variables were analysed using Kendall's tau-b correlation coefficient.

In the multivariate analysis, the eruption status of the root complex was selected as the outcome for further binary logistic regression analysis. The thickness of the calcification bridge, only measured in group B, was analysed using multiple linear regression. Relevant pre- and intraoperative variables with $P < 0.1$ in the

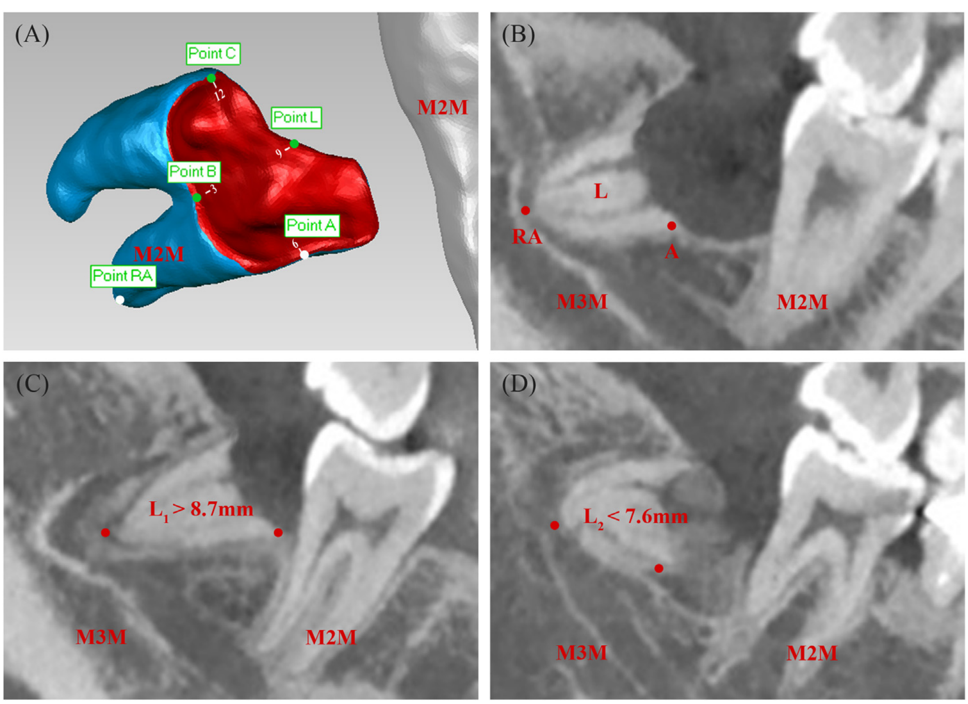

Fig. 3. Measurement of the length of the root complex. (A) Measurement using the digital software. As shown in Fig. 2C, point A is located at the edge of the fragment section, in the direction of 6 o'clock. Point RA represents the apex point of the mesial root. We defined the line segment RA–A to represent the length of the root complex (L) and calculated this in the coordinate system above. (B) Measurement on CBCT: as shown in the quasi-sagittal plane, using the example of an M3M in group S, the long axis of M3M was approximately perpendicular to the fragment section. L was determined as the distance between points RA and A. (C) Example image of an M3M in group S, with L = 12.8 mm (i.e., >8.7 mm, the mean value in the soft tissue retention group, group S), showing the tooth completely covered with soft tissue after coronectomy (6 months postoperative). (D) Example of an M3M in group B, with L = 7.4 mm (<7.6 mm, the mean value in the bony impaction group, group B), showing complete bony impaction after coronectomy (6 months postoperative).

Table 1. Preoperative, intraoperative, and postoperative variables for 213 impacted mandibular third molar coronectomies.

	Group B (Completely bone-embedded roots, $n = 89$) Mean ± SD or %	Group S (Completely soft tissue-covered roots, $n = 81$) Mean ± SD or %	P-value
Demographic characteristics			
Age (years)	27.13 ± 5.06	27.49 ± 4.58	0.601
Sex			0.570
Male	43.8%	39.5%	
Female	56.2%	60.5%	
M3M condition			
Angulation of M3M (°)	61.82 ± 21.28	59.63 ± 28.55	0.821
Retromolar space (mm)	8.82 ± 2.22	9.06 ± 2.96	0.861
Perforation size of IAC (mm)	5.93 ± 3.74	6.94 ± 3.73	0.138
Surgery-related factors			
Volume of root complex (mm^3)	237.00 ± 85.73	275.16 ± 111.22	0.045
Area of periodontal membrane (mm^2)	207.40 ± 60.85	230.25 ± 72.93	0.032
Length of root complex (mm)	7.58 ± 2.03	8.72 ± 2.16	0.001
Root section to alveolar crest (mm)	7.12 ± 1.60	6.63 ± 1.58	0.034
Enamel remnants present	4.5%	14.8%	0.021
Prognosis of root complex			
Root migration in 3D (mm)	3.33 ± 1.20	4.79 ± 2.64	0.000
Root rotation in 3D (°)	13.19 ± 7.27	13.83 ± 7.44	0.455
Volume of new bone in socket (mm^3)	305.32 ± 219.62	296.12 ± 176.45	0.809

3D, three-dimensional; IAC, inferior alveolar canal; M3M, mandibular third molar; SD, standard deviation.

previous univariate analysis and factors of clinical interest were included as the covariates.

Regarding the cut-off points for the root complex being completely bone-embedded, to prevent migration and promote the root complex being completely bone-embedded, the previous literature was reviewed and the results combined with those of the present study, following which the most likely significant variables were selected and their values assigned as cut-off points.

Results

In total, 213 M3Ms of 181 patients (72 male and 109 female; mean age 27.03 ± 4.84 years) who completed the 6-month follow-up were included in this study. Of these 213 M2Ms, 89 were assigned to group B and 81 were assigned to group S (41.8% vs 38.0%). The overall mean deviation of digital registration was 0.01 ± 0.25 mm. No root complex erupted or required a secondary surgery.

Results of the univariate analysis

Table 1 shows that the volume of the root complex ($P = 0.045$), area of the periodontal membrane ($P = 0.032$), and length of the root complex ($P = 0.001$) differed significantly between the two groups. Examples of the clinical measurement of the length of the root complex and the prognosis in different cases are shown in Fig. 3. The length of the root in group B was significantly shorter than that in group S (7.58 ± 2.03 mm vs 8.72 ± 2.16 mm; $P = 0.001$). In addition, significantly more enamel remnants were found in group S than in group B ($P \leq 0.001$).

There was no significant difference between the volume of the root complex on the day of surgery and the volume measured at 6 months after surgery (baseline: 251.96 ± 103.34 mm^3 vs 6 months postoperative: 251.25 ± 99.50 mm^3; $P = 0.841$). The results of the correlation analysis between pre- and intraoperative variables and postoperative variables are summarized in Table 2. The total root migration in 3D was 4.05 ± 1.98 mm, and age was the only factor significantly affecting this (correlation coefficient, $r = -0.33$, $P < 0.001$). However, all factors related to the preoperative condition of the M3M, i.e. depth of impaction ($P = 0.011$), retromolar space ($P < 0.001$), and angulation of M3M ($P < 0.001$), were found to influence root migration from apex to crown.

The total rotation of the root in 3D was 13.24 ± 7.21°. Root rotation in the quasi-sagittal plane was also studied. The angulation of M3M before surgery was the primary factor significantly influencing the direction of root rotation. The smaller the angulation, the more the root complex rotated distally after surgery ($r = -0.37$, $P < 0.001$). The angulation of M3M before surgery was 66.83 ± 18.20° in the mesially rotated group and 49.07 ± 30.28° in the distally rotated group. The patient's sex and the number of roots of the M3M had no significant influence on migration or rotation of the root complex ($P \geq 0.190$).

The volume of bone regenerated in the extraction socket showed no significant correlation with age ($P = 0.452$). The preoperative condition of the M3M appeared to significantly affect new bone volume: a deeper impacted M3M ($r = 0.18$, $P = 0.008$), M3M with a larger angulation ($r = 0.26$, $P < 0.001$), and M3M with a smaller retromolar space ($r = -0.19$, $P = 0.004$) showed more bony regeneration. Regarding the thickness of the calcification bridge, i.e. the part of the bone superior to the root complex system, both the depth of impaction ($r = 0.22$, $P = 0.001$) and the distance between the root and the alveolar crest ($r = 0.19$, $P = 0.005$) showed a significant positive correlation.

Results of the multivariate analysis

As shown in Table 3, for every 1-mm decrease in the length of the root complex, the possibility of further complete bony coverage increased by 18% (odds ratio (OR) 0.82, $P = 0.048$). For every 1-mm increase in the distance between the root and the alveolar crest on the lingual side, the possibility of further complete bony coverage increased by 23% (OR 1.23, $P = 0.026$) and could significantly contribute to the remaining root being completely bone-embedded. Furthermore, preoperative deeply impacted M3M could also result in more bone being formed superior

Table 2. Analysis of the correlation between pre- and intraoperative variables and postoperative continuous variables.

Pre- and intraoperative		Postoperative	Root complex migration		Root complex rotation		Bone regeneration	
			Apex to crown	Total in 3D	Quasi-sagittal plane	Total in 3D	Thickness of the calcification bridge[a]	Volume of the new bone in the socket
Age		Correlation coefficient	−0.21	−0.33	−0.02	−0.21	0.04	−0.05
		P-value	0.002	0.000	0.808	0.002	0.565	0.452
M3M condition	Pell and Gregory depth of impaction	Correlation coefficient	−0.18	−0.13	0.02	0.01	0.22	0.18
		P-value	0.011	0.060	0.744	0.907	0.001	0.008
	Retromolar space	Correlation coefficient	0.34	−0.09	0.18	−0.15	−0.06	−0.19
		P-value	0.000	0.172	0.008	0.033	0.355	0.004
	Angulation of M3M	Correlation coefficient	−0.50	0.11	−0.37	0.21	0.05	0.26
		P-value	0.000	0.108	0.000	0.002	0.510	0.000
Surgery-related factors	Distance between the root and alveolar crest	Correlation coefficient	0.23	−0.08	0.08	0.00	0.19	−0.09
		P-value	0.001	0.227	0.235	0.953	0.005	0.208
	Volume of the root complex	Correlation coefficient	−0.02	−0.07	−0.02	−0.11	−0.07	0.18
		P-value	0.755	0.332	0.800	0.125	0.302	0.008

3D, three-dimensional; M3M, mandibular third molar.
[a] The thickness of the calcification bridge was measured only in group B.

to the root complex (standardized coefficient 0.29, $P = 0.007$).

Cut-off points for the root complex being completely bone-embedded

Several cut-off points were estimated. M3Ms with a length of the root complex <7.6 mm (mean value in group B) were more likely to be bone-embedded than those measuring ≥7.6 mm ($P < 0.001$). More bone-embedded root complexes were found in M3Ms with a distance between the root and alveolar crest ≥ 5 mm (it should be larger than root migration in group S, 4.79 ± 2.64 mm) than in those <5 mm ($P = 0.015$). The extent of root migration (6 months postoperative) was significantly lower in patients aged ≥24 years (eruption of most M3Ms would be complete by then) than in younger patients (3.86 ± 2.15 mm vs 4.64 ± 1.15 mm, $P \leq 0.041$). However, only slightly more bone-embedded M3Ms were found in patients aged ≥24 years than in younger patients (57.3% vs 42.7%, $P = 0.946$).

Discussion

This study applied digital 3D technology, thereby eliminating the error caused by the overlap of 2D radiography[9], to evaluate root migration and rotation patterns in 3D and explore factors affecting the root complex being completely bone-embedded. The key findings were that age, angulation of the M3M, and the depth of the root complex were critical factors influencing root migration, root rotation, and bone regeneration, respectively. Ensuring that the length of the root complex is <7.6 mm and the distance between the root and alveolar crest is ≥5 mm were both found to be critical to prevent eruption and the need for secondary surgery after coronectomy.

General migration of the root complex

It has been reported that many factors such as age, sex, and the morphology of the root complex can affect root migration[5,14,18,21]. However, with more accurate measurement in 3D in the present study, it was found that age was the most important factor significantly affecting the total distance moved ($r = -0.33$).

Changes in other factors may influence certain components of the total migration distance, such as movement in the crown–apical direction, but these factors did not significantly affect the migration in 3D. For example, factors that could influence

Table 3. Results of the multivariate analysis.

	Variable	OR	95% CI	*P*-value
Logistic regression	Postoperative eruption status (bony impaction)			
	Distance between the root and bony margin (lingual side)	1.23	1.03–1.48	0.026
	Length of the root complex	0.82	0.67–1.00	0.048
	Variable	B	Coefficient	*P*-value
Multiple linear regression	Thickness of the calcification bridge[a], adjusted $R^2 = 0.272$			
	Preoperative depth of the impaction	0.98	0.29	0.007
	Distance between the root and bony margin (lingual side)	0.23	0.30	0.007

CI, confidence interval; OR, odds ratio.

[a] The thickness of the calcification bridge was measured only in group B.

the initial position of the root complex, including the preoperative depth of impaction, angulation of the M3M, and distance from the root complex to the alveolar crest, were found only to affect migration in the crown–apical direction ($P \leq 0.011$), but not the total migration in 3D ($P \geq 0.227$).

In the current study, no root complex erupted into the oral cavity even though many of them had reached the alveolar crest. Root exposure has generally been rare in previous long-term studies (0–2.3%)[4,5,22]. It is speculated that the lack of occlusal forces in the retromolar region makes the soft tissue on the alveolar crest resist root eruption. Studies on the root submergence technique in dental prosthetics have shown that an increase in occlusal loading forces can effectively promote root exposure[23]. Hence, complete bony coverage of the root complex is more reliable than soft tissue coverage.

Rotation of the root complex is a frequent occurrence after coronectomy[22]. However, the exact mechanisms behind the direction of root rotation are still unknown[14]. In the present study, it was found that the larger the angulation of M3M before surgery, the more the root complex rotated to the mesial side after surgery ($r = -0.37$). According to the mean values in the different groups, it is speculated that M3Ms with an angulation <49° are more likely to rotate to the distal side, while those with an angulation >67° are more likely to rotate to the mesial side. More attention should be paid to the distally rotated root complex to prevent these M3M roots from erupting postoperatively.

Factors contributing to the root complex being completely bone-embedded

Instead of age, sex, and preoperative M3M conditions, it was found that the volume of the root complex and area of the periodontal membrane of the root complex were key factors for bony coverage. The area of the periodontal membrane in group B was significantly smaller than that in group S ($P \leq 0.045$). It has been reported that the eruption of the root depends on lift or pressure from below, which could come from the periodontal membrane[24]. However, neither the volume of the root nor the area of the periodontal membrane can be applied clinically. As volume is calculated as the bottom area × height, we defined a convenient indicator: the length of the root complex (Fig. 3). It was found that the length of the root complex was significantly negatively correlated with the incidence of the root complex being bone-embedded ($P = 0.048$). This suggests that the length of the root complex is a potential clinical indicator. M3Ms with a length of the root complex <7.6 mm were more likely to be bone-embedded than those with a length ≥ 7.6 mm ($P < 0.001$). We recommend surgical confirmation of the length of the root complex being <7.6 mm to reduce the incidence of further root eruption.

Bony regeneration was another significant influencing factor. Bony coverage of the root complex section is a contest between the speed of root movement and osteogenesis. Deeply impacted M3Ms (small retromolar space, large degree of angulation, and large impaction depth) tended to regenerate more bone after coronectomy than non-deeply impacted M3Ms ($P \leq 0.008$). A greater distance between the root and alveolar crest also contributed to further bony coverage (Table 3). A possible explanation is that the distance between the root and alveolar crest is longer for more deeply impacted roots. This gives more time for new bone regeneration. Bone regenerated from the surrounding socket margin[25] and root section might provide dentin as the osteogenic scaffold for bone regeneration[26]. Most surgeons recommend trimming down the remaining root to at least 3–4 mm below the bone margin, based on previous animal experiments and root migration studies[2,5,21,27]. However, the results of the present study showed that the root complex migrates more in 3D: migration of M3Ms in group S at 6 months postoperative was 4.79 ± 2.64 mm. The root should be located much deeper, at least 5 mm, to prevent eruption.

Tentative recommendations for coronectomy

Although various published studies have focused on coronectomy, the referenced surgical procedures remain unchanged[2,15]. The ideal prognosis for coronectomy cases is not only the prevention of IAN injury, but also the elimination of the risk of complications[17]. Based on prognostic studies, we hoped to identify cut-off points to refine surgical procedures to promote the remaining root complex being completely bone-embedded and thus preventing the need for secondary surgery. The main point is leaving sufficient space and ensuring that it is longer than the root migration distance. In addition, enamel remnants should be completely removed to prevent infection and the need for secondary extraction. However, owing to the limitations of the surgical view and surgeon experience[27], some enamel still remained due to the limited surgical view[16]. In this study, remaining enamel was also found to impair bony coverage on root complex section.

In summary, the results of this study lead to the following tentative recommendations to promote the root complex being completely bone-embedded after coronectomy, thus preventing eruption and the need for secondary surgery: (1) a length of the root complex of <7.6 mm; (2) the root complex should be at least 5 mm below the bone margin; (3) for patients <24 years of age, the root complex should be >5 mm below the bone margin.

Funding

The following grant information is disclosed by the authors: Program for New Clinical Technique Project of the Peking University School and Hospital of Stomatology (PKUSSNCT-18A12).

Competing interests

None to declare.

Ethical approval

Ethical approval was obtained from the Biomedical Ethics Committee of Peking University School of Stomatology (PKUSSIRB-201736080). The research protocol was pre-registered in the Chinese Clinical Trial Registry (ChiCTR1800014862).

Patient consent

All patients provided written informed consent to participate in this study.

Acknowledgements. We are grateful to the assisting staff. The authors thank Yao Tan, a postgraduate majoring in Medical Statistics at the Peking University Clinical Research Institute, for her assistance with the statistical analysis in this study.

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Address:
Nian-Hui Cui
Department of Oral and Maxillofacial Surgery
Peking University School and Hospital of Stomatology
22 South Street
Zhong Guan Cun
Haidian District
Beijing 100081
China
Tel.: +86 185 00153936; Fax: +86 10 62173402
E-mail: drcuinianhui@163.com