Risk factors for external root resorption of maxillary second molars due to impacted third molars as evaluated using cone beam computed tomography

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Abstract. The purpose of this retrospective study was to evaluate risk factors for external root resorption (ERR) on maxillary second molars (MxM2) in association with impacted third molars (MxM3) using cone beam computed tomography (CBCT) scans. The angles between the axes of MxM2/MxM3 (inclination) were measured. Further, ERR on MxM2 was classified as absent, slight, moderate, or severe. Contact location between MxM3 and MxM2, the size of the dental follicle, type of impaction, root formation, and patient demographic characteristics were also assessed. Half of the 84 MxM2 showed ERR (slight 36.9%, moderate 6.0%, severe 7.1%). Patient age was a significant factor for the presence of ERR ($P=0.03$). The inclination was also a relevant factor, with transverse MxM3 exhibiting the highest risk of ERR ($P=0.02$). The cervical third (28.6%) showed a significantly lower risk percentage of ERR compared to the apical (73.7%) and middle thirds (60.6%) of the root ($P=0.004$). Based on these findings, clinicians assessing the need for surgical removal should be able to selectively identify impacted MxM3 at risk of causing ERR on MxM2 early on, especially when the MxM3 is located in close contact with the apical and middle thirds of the MxM2 roots and has a transverse inclination.

Key words: root resorption; cone beam computed tomography; maxillary third molar; second molar; risk factor.

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Third molar (M3) impaction is the most common among all kinds of tooth impaction^{1–3}. Maxillary M3 (MxM3) and mandibular M3 impaction can cause

various pathological conditions in the M3 or in the adjacent tissue or teeth. Mandibular M3 are found to be more frequently impacted than MxM3, which can be

explained by the anatomy^{4,5}. In contrast, MxM3 commonly erupt without obstruction. Nevertheless, pathologies can be associated with impacted MxM3 and are

reported to develop later in life. These are typically inflammatory conditions such as pericoronitis with or without concomitant periodontal tissue loss, external root resorption (ERR) of the neighbouring teeth, and cystic lesions^{6–8}. ERR and cystic lesions are generally asymptomatic until a late stage, and only then is the affected individual aware of the problematic MxM3.

Panoramic imaging is an accepted and readily available radiographic method for assessing M3 in both jaws^{9,10}. However, the prevalence and severity of ERR on the adjacent second molars (M2) is more frequently observed using three-dimensional (3D) imaging modalities, such as cone beam computed tomography (CBCT)^{11–14}. CBCT has already proven superior to two-dimensional (2D) radiography for the detection of ERR of the neighbouring teeth in studies related to impacted canines^{15–17} and mandibular M3/M2¹¹. However, only a few studies have analysed the predictors and prevalence of ERR on the distal surface of the maxillary M2 (MxM2)^{11,13,14,18–20}. Prevalence rates of 6.4% ($n=5$) to 32.6% ($n=60$) for ERR on MxM2 have been reported, usually with ERR being much less frequent in the maxilla than in the mandible, with ratios of 1:2.3¹¹ and 1:4¹³ reported.

It is clinically important to recognize a potential ERR of MxM2 caused by MxM3. Knowledge of the risk factors associated with ERR on MxM2 is still limited, and the decision to remove MxM3 without the presence of a current pathology remains very much debated⁶. CBCT imaging may provide important information on MxM2/MxM3, allowing the surgeon to establish the correct diagnosis and also to decide whether to remove MxM3 or MxM2 in the case of ERR on MxM2.

The aim of this retrospective study based on CBCT scans was to identify risk factors for ERR (prevalence and severity) on MxM2 due to impacted MxM3. These potential factors include the inclination of MxM3, type of impaction, size of the dental follicle, and location of the direct contact between MxM2 and MxM3, as well as the age and sex of the patient.

Materials and methods

Study design

In this retrospective study, all patients undergoing CBCT examinations for MxM3 analysis between January 2012 and July 2015 in the Section of Dental Radiology and Stomatology, Department of Oral Surgery and Stomatology, University of Bern,

were initially eligible. The images were obtained with a 3D Accuitomo 170 scanner (Morita Corp., Kyoto, Japan) using a full scan rotation (360°) of 17.5 seconds (standard mode) or 10.5 seconds (high-speed mode) and exposure settings of 5.0 mA and 90 kV. The fields of view (FOV) and respective voxel sizes were 4×4 cm/ $80 \mu\text{m}$, 6×6 cm/ $125 \mu\text{m}$, 8×8 cm/ $160 \mu\text{m}$, and 10×10 cm/ $160 \mu\text{m}$. Only the upper M2 and M3 fully visible in the FOV, with no extended caries and no other concomitant pathology such as cysts or odontogenic tumours, were included. All completely erupted MxM3 and MxM3 with root development less than two-thirds were excluded.

The CBCT images were examined on a Dell 380 Precision work station (Dell SA, Geneva, Switzerland) and a 19-inch Eizo Flexscan monitor with a resolution of 1280×1024 pixels (Eizo Nanao AG, Wädenswil, Switzerland) using specialized computer software (i-Dixel version 2.2.1.2; Morita Corp., Kyoto, Japan). The 'zoom box' tool of the software was used to optimize image evaluation quality. CBCTs with reduced image quality caused by artefact formation were excluded. One observer (M.R.) examined and evaluated all images, considering all three planes. The observer was previously trained and calibrated for this specific study by a dentist experienced in oral and maxillofacial radiology (V.S.).

Outcome measures and data collection

The primary outcome was to determine the presence of ERR on MxM2 adjacent to MxM3. The criteria of Ericson and Kurol²¹ were used to classify the severity of ERR, which was graded as follows: (1) no resorption, with an intact root surface (the cementum layer may have been lost), (2) slight resorption, with resorption up to half of the dentine thickness (Fig. 1A, B), (3) moderate resorption, with resorption of the dentine midway to reaching the pulp or further, with the pulp lining unbroken (Fig. 1C, D), and (4) severe resorption, with resorption reaching the pulp (Fig. 1E, F).

For the inclination of MxM3, the following categories were used: horizontal, mesioangular, vertical, distoangular, transverse, and inverted²². Further, the angles between the axes of MxM2 and MxM3 in relation to the occlusal plane were analysed (Fig. 2). Cases showing an MxM2/MxM3 angle of 0° were excluded from this analysis. The type of tooth impaction in relation to the bone was defined as full bony impaction or impaction with

soft tissue coverage. The presence (yes) or absence (no) of proximity between MxM2/M3 was defined by a distance of ≤ 0.5 mm²³. Furthermore, the location of contact of MxM2/M3 in relation to the long axis was classified as cervical, middle, or apical. The root formation of MxM3 was categorized as complete (with closed apical foramen), almost complete (with open apical foramen), or more than two-thirds of the root developed. The dental follicle size of MxM3 was divided into absent (<1 mm), regular (1–3 mm), or enlarged (3–5 mm). Dental follicle sizes of >5 mm were excluded from the present study.

Demographic data collected included sex, age, and the occurrence of the impacted MxM3 on the right or left side. The guidelines of the World Medical Association Declaration of Helsinki were followed during the examination and data collection²⁴. The standing ethics committee of the State of Bern (Ref Nr. KEK-BE: 392/2015) and Swissethics (Basec: 2015-00224) approved the study protocol.

Data analysis

MxM3 in patients with multiple occurrences (right and left) were randomly selected to reduce the observation to one per patient. Descriptive statistics were calculated first. Patients were divided into three age groups (<25 years, 25–35 years, >35 years). To assess the impact of ERR in relation to patient-related and tooth-related variables (sex, inclination of MxM3, contact of MxM2/M3, type of impaction, and size of the dental follicle), Fisher's exact test was performed as the overall and post hoc test. To assess the impact of ERR on the factors age and angle between MxM2 and MxM3, the exact Wilcoxon rank sum test was applied. In the statistical analysis, P -values of ≤ 0.05 were considered statistically significant. All results were calculated using the statistical software package R, version 3.5.0 (The R Project for Statistical Computing, Vienna, Austria).

Results

Population studied

During the observation period, a total of 197 CBCT scans of MxM2/MxM3 were performed. Of these, 82 were excluded for the following reasons: less than two-thirds of the root of the MxM3 developed ($n=46$), impacted MxM2 ($n=16$), missing MxM2 ($n=7$), pathologies in the area of the MxM2/MxM3 ($n=4$), presence of a

Fig. 1. Coronal, sagittal, and axial CBCT images illustrating different severities of external root resorption. A, B: slight resorption (A sagittal, B axial section); C, D: moderate resorption (C sagittal, D axial section); E, F: severe resorption (E sagittal, F coronal section).

supernumerary tooth ($n=4$), MxM2 or MxM3 not fully visible in the FOV ($n=3$), MxM3 displaced in the maxillary sinus ($n=1$), and completely erupted MxM3 ($n=1$). MxM3 from patients with multiple occurrences (right and left) were randomly selected. Thus, the data size was reduced from 115 to 84 MxM3 (in 84 patients); the sample included 37 MxM3 from the left side and 47 MxM3 from the right side. The median age of the patients

was 28 years (mean age 34.6 years). The majority of patients (39.3%) were younger than 25 years, but 36.9% were older than 35 years. The male-to-female ratio was 1.3:1 (Table 1).

Characteristics of MxM2 and MxM3

The majority (95.2%) of MxM3 exhibited a tooth impaction with soft tissue coverage. Most MxM3 (59.5%) had fully

developed roots with a complete, closed apex. In most cases, the MxM3 showed a vertical inclination (41.7%), followed by a distoangular inclination (34.5%) and mesioangular inclination (15.5%). A total of 80 MxM2/MxM3 (95.2%) were found to be in close contact (≤ 0.5 mm), and the contact was most often located in the middle part of the root (39.3%) of MxM2. In the majority of cases, no dental follicle was observed (64.3%). In half of

Fig. 2. Sagittal sections of CBCT images demonstrating angle measurements between maxillary second molars and third molars. The axis was set to be perpendicular to the occlusal plane of each tooth. The teeth were divided into the following groups: A: horizontal/mesioangular/vertical/inverted; B: distoangular.

Table 1. Demographic characteristics of included patients.

Total patients, <i>n</i>	84
Age, years	
Mean	34.6
Median	28.0
Maximum	77.0
Minimum	17.0
Patients in age group, <i>n</i> (%)	
<25 years	33 (39.3)
25–35 years	20 (23.8)
>35 years	31 (36.9)
Sex, <i>n</i> (%)	
Female	36 (42.9)
Male	48 (57.1)

the cases ($n = 42$), ERR was diagnosed on MxM2. This was predominantly slight resorption ($n = 31$, 36.9%) (Fig. 1A, B), followed by severe resorption ($n = 6$,

7.1%) (Fig. 1E, F) and moderate resorption ($n = 5$, 6.0%) (Fig. 1C, D; Table 2).

Root resorption and associated risk factors

Age was a significant risk factor for the presence of ERR ($P = 0.03$). The median age of patients with ERR was 31.5 years, while the median age of patients without ERR was 24.5 years. In the group of severe ERR ($n = 6$), most patients (4/6) were older than 35 years. Another significant risk factor for the presence of ERR on MxM2 was the inclination. In post-hoc tests, the transverse group ($n = 5$, 100%) showed a significantly higher risk percentage of ERR than the vertical group ($P = 0.05$) or the distoangular group ($P = 0.02$).

When considering the angles between MxM2 and MxM3, no significant association with ERR was found. The nine cases

with an angle of 0° were excluded from this evaluation. Concerning contact location, 42 of 80 MxM2/MxM3 showed contact: the apical third of the root had a risk percentage of 73.7% (14/19), the middle third a risk of 60.6% (20/33), and the cervical third a risk of 28.6% (8/28) for ERR ($P = 0.004$). Direct contact between MxM3/MxM2 with a distance of ≤ 0.5 mm was not a factor associated with more frequent ERR. Furthermore, sex, type of impaction, and the size of the dental follicle showed no significant association with ERR (Table 3).

Discussion

The diagnosis and prediction of ERR on MxM2 due to MxM3 remain a clinical challenge. The decision to remove MxM3 or MxM2 when ERR is suspected is often a dilemma for the patient and the dentist. The results of this study serve to help in the clinical judgement by providing evidence for the estimation of the risk of ERR on MxM2 due to MxM3. By understanding the risk factors for ERR on MxM2, the decision to remove the MxM3 rather than to ‘wait and see’ may preserve the MxM2. Timely removal of an MxM2 with a high risk of ERR to allow eruption of MxM3 as its replacement is also a rational treatment option, provided the MxM3 is still developing.

In this study, ERR on MxM2 was observed in half of the cases analysed (50%, $n = 42$), and the extent was predominantly slight (36.9%, $n = 31$). The major risk factors identified for ERR on MxM2 were the inclination of MxM3, the location of the contact between MxM2/M3, and the age of the patient. On the other hand, the type of MxM3 impaction, size of the dental follicle, the exact angle between MxM2/M3, and sex did not exhibit any significant association with ERR.

Only a few studies using CBCT to analyse the severity and prevalence of ERR on MxM2 as a result of impacted MxM3 have been published until now^{11,13,20}. Prevalence rates for ERR in these studies were reported as 6.4% ($n = 5/78$)¹³, 14.3% (13/91)¹¹, and 32.6% (60/184)²⁰. The lower prevalence values in these studies in comparison with the present analysis (50%, 42/84) may be due to differences in inclusion criteria, recruitment strategies for patients, and also sample sizes.

Regarding the severity of ERR, Li and co-workers²⁰ found a similar distribution of ERR on MxM2, with mostly slight (55%), then severe (36.7%) and lastly moderate (8.3%) severity. ERR is still a

Table 2. Characteristics of the maxillary second and third molars included.

Teeth, <i>n</i> (%)	
Overall	84
Right maxillary M3	37 (44.0)
Left maxillary M3	47 (56.0)
Developmental state of M3 roots, <i>n</i> (%)	
Complete, closed apex	50 (59.5)
Almost complete, open apical foramen	28 (33.3)
>Two-thirds root developed	6 (7.1)
Inclination of M3, <i>n</i> (%)	
Vertical	35 (41.7)
Distoangular	29 (34.5)
Mesioangular	13 (15.5)
Transverse	5 (6.0)
Horizontal	1 (1.2)
Inverted	1 (1.2)
Type of M3 impaction, <i>n</i> (%)	
Retention with soft tissue coverage	80 (95.2)
Full bony impaction	4 (4.8)
Size of dental follicle of M3, <i>n</i> (%)	
Absent	54 (64.3)
Regular	27 (32.1)
Enlarged	3 (3.6)
Contact M2/M3, <i>n</i> (%)	
Yes	80 (95.2)
Location cervical	28 (33.3)
Location middle	33 (39.3)
Location apical	19 (22.6)
No	4 (4.8)
M2 resorption and severity, <i>n</i> (%)	
Yes	42 (50.0)
Slight resorption	31 (36.9)
Moderate resorption	5 (6.0)
Severe resorption	6 (7.1)
No	42 (50.0)

M2, second molar; M3, third molar.

poorly understood phenomenon in which the periodontium is mentioned as the principle active biological unit²⁵. As major contributors to ERR, pressure applied directly on the root surface of an adjacent tooth and associated factors deriving from the follicle that activate clastic cells triggering resorption have been described in the literature^{26–30}. This is in line with the present study findings, as the majority of MxM2 with ERR (52%, 42/80) were in contact with MxM3, although this was not statistically significant.

As in this study, Li et al.²⁰ found most of the ERR localized in the apical third of the root (52%). During the eruption process of MxM3, the pressure on the periodontal ligament and thus on MxM2 decreases²⁷, which may explain the findings of this study. Additionally, cementum and dentine vary in density and hardness according to their localization on the root, and higher density and hardness can delay resorption³¹. In an *in vitro* study, Malek et al.³² investigated first premolars and found lower hardness and elasticity on the distal root surface in the apical and middle third than in the cervical area³², which is in line with the results of this

study. In contrast to these findings, Tasoker¹³ reported that the middle and cervical thirds of the root were the regions most affected by ERR on MxM2.

Li and co-workers²⁰ found that MxM3 with mesial inclinations (16–75°) were 9.66 times more likely to cause ERR in MxM2 when compared with those outside this range. This could not be confirmed by the present study data, as no significant association was found between angle measurements and ERR. In other studies, upper and lower M2/M3 were pooled^{11,13} or the transverse angulation group was not defined separately¹³. It appears that only Li et al.²⁰ and the present study have reported separately on the outcomes of ERR on the outcome of ERR of MxM2 caused by MxM3, and also in association with angle measurements. Thus, to gain more detailed knowledge of the range of angles between MxM2 and MxM3 and the possible risk for ERR, angle measurements should also be performed in future studies using CBCT. In addition, a separate analysis of risk factors for ERR in the maxilla and the mandible seems important, as the jaws differ regarding tooth morphologies, eruption mechanisms, bone

densities, and space limitations in the regions of M2/M3.

Age over 25 years has been identified previously as a risk factor for ERR in MxM2²⁰, which is in line with the results of the present study. Furthermore, Li et al.²⁰ observed an increase in severity of ERR in MxM2 with age. A possible explanation for these results may be that MxM3 are often extracted later in life, which favours the later detection of ERR on MxM2.

There are some retrospective studies and case reports analysing root resorption on MxM2 using 2D imaging (panoramic imaging, peri-apical radiographs)^{27,33,34}. In studies using peri-apical radiographs, MxM2 was associated with ERR in 11% of the cases²⁶, and in studies using panoramic imaging, this was 8%³³ and 0.3%³⁴. Thus, ERR in MxM2 is clearly underdiagnosed using 2D imaging, and the superiority of CBCT scans over panoramic imaging for the diagnosis of ERR has been shown in the literature^{11,14}.

CBCT allows a multiplanar analysis of M2 that is very valuable in the assessment of the severity and extent of ERR, especially in the initial stages¹³. In the present study, different voxel sizes (0.08 mm, 0.125 mm, 0.16 mm) were used in relation to the FOVs selected, and all CBCT scans were performed with one device (3D Accuitomo 170 machine; Morita, Kyoto, Japan). Bragatto et al.³⁵ stated that a voxel size of 0.25 mm was enough to ensure 100% accuracy in the detection of ERR in CBCT scans: sensitivity and specificity were severely decreased with a voxel size of 0.40 mm, followed by 0.30 mm.

So far, the presence of ERR as observed in CBCT scans has not been confirmed by clinical correlation studies. The majority of CBCT studies have reported a slight ERR on the maxillary and/or mandibular M2^{13,36,37}, which does not justify the removal of M2 and might explain the absence of such studies. ERR (mild to moderate) not reaching the pulp is usually an incidental finding without clinical symptoms³⁷. An initial diagnosis of mild to moderate ERR on M2 in CBCT scans should allow for a conservative treatment plan (observation or restoration), thus avoiding tooth removal.

So far, there are no guidelines for MxM2/MxM3 that state when to perform a CBCT in addition to a panoramic imaging. Therefore, based on the examination and clinical experience, the clinician will decide whether adjunctive CBCT imaging may provide further important information. Information about the localization and severity of ERR based on CBCT scans

Table 3. Statistical analysis regarding the presence of external root resorption in relation to patient-related and tooth-related variables ($n = 84$).

Variables	P-value
Patient-related variables	
Sex (risk percentage, cases)	1.00
Female (50.0%, 18/36 cases)	
Male (50.0%, 24/38 cases)	
Age (years)	0.03
Tooth-related variables	
Inclination of M3 (risk percentage, cases)	0.02
Vertical (42.9%, 15/35 cases)	
Distoangular (37.9%, 11/29 cases)	
Mesioangular (69.2%, 9/13 cases)	
Transverse (100.0%, 5/5 cases)	
Horizontal (100.0%, only one case)	
Inverted (100.0%, only one case)	
Angle between M2 and M3	
Group horizontal/mesioangular/vertical ^a /inverted ($n = 46$)	0.29
Group distoangular ($n = 29$)	0.80
Contact M2/M3 (risk percentage, cases)	
Contact (52.5%, 42/80 cases) vs. no contact (0.0%, 0/4 cases)	0.12
Location	0.004
Cervical (28.6%, 8/28 cases)	
Middle (60.6%, 20/33 cases)	
Apical (73.7%, 14/19 cases)	
Type of impaction (risk percentage, cases)	1.00
Full bony impaction (50.0%, 2/4 cases)	
Soft tissue coverage (50.0%, 40/80 cases)	
Dental follicle (risk percentage, cases)	0.36
Absent (48.1%, 26/54 cases)	
Regular (48.1%, 13/27 cases)	
Enlarged (100.0%, 3/3 cases)	

M2, second molar; M3, third molar.

^a Only angles $>0^\circ$.

should facilitate the decision-making process, with options being conservative treatment of MxM2, prophylactic removal of MxM3, or removal of MxM2 instead of MxM3^{11,14}. An irreversible pathology, such as severe ERR on MxM2 related to MxM3, is an indication for removal of MxM3 and sometimes MxM2 as well⁶ or instead¹⁴. For clinicians it may be important to identify high-risk patients for ERR on MxM2. Based on the present findings, these are patients with an MxM3 in a transverse position and in close contact to the apical and middle thirds of MxM2. However, these findings have to be interpreted with caution as only a few cases ($n = 5$, but all with ERR, risk percentage 100%) were in this position. If the clinician decides together with the patient for the prophylactic removal of MxM3, it might be advisable to perform the operation before the age of 25 years²⁰. The benefit for the patient is that future CBCT scans can be avoided and ERR on MxM2 by MxM3 may be prevented.

In conclusion, CBCT scans allow the precise detection of ERR, including in the initial stages, and are helpful in cases when the indication for MxM3 removal needs to be verified. Based on the present

study findings, it appears to be of specific clinical relevance to identify and discuss the removal of the transverse MxM3 located in contact with the apical and middle thirds of the MxM2 roots.

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Competing interests

All authors confirm that they do not have any conflict of interest.

Ethical approval

Ethical approval for the study was given by the standing ethics committee of the State of Bern (Ref Nr. KEK-BE: 392/2015) and by Swissethics (Basec: 2015-00224).

Patient consent

Not required.

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References

- Hou R, Kong L, Ao J, Liu G, Zhou H, Qin R, Hu K. Investigation of impacted permanent teeth except the third molar in Chinese patients through an X-ray study. *J Oral Maxillofac Surg* 2010;**68**:762–7. <http://dx.doi.org/10.1016/j.joms.2009.04.137>.
- Tymofiyeva O, Rottner K, Jakob PM, Richter EJ, Proff P. Three-dimensional localization of impacted teeth using magnetic resonance imaging. *Clin Oral Investig* 2010;**14**:169–76. <http://dx.doi.org/10.1007/s00784-009-0277-1>.
- Gisakis IG, Palamidakis FD, Farmakis ET, Kamberos G, Kamberos S. Prevalence of impacted teeth in a Greek population. *J Invest Clin Dent* 2011;**2**:102–9. <http://dx.doi.org/10.1111/j.2041-1626.2010.00041.x>.
- Hashemipour MA, Tahmasbi-Arashlow M, Fahimi-Hanzaee F. Incidence of impacted mandibular and maxillary third molars: a radiographic study in a Southeast Iran population. *Med Oral Patol Oral Cir Bucal* 2013;**18**:e140–5.
- Kumar Pillai A, Thomas S, Paul G, Singh SK, Moghe S. Incidence of impacted third molars: a radiographic study in People's Hospital, Bhopal, India. *J Oral Biol Craniofac Res* 2014;**4**:76–81. <http://dx.doi.org/10.1016/j.jobcr.2014.04.001>.
- National Institute for Health and Care Excellence. *Guidance on the extraction of wisdom teeth*. London, United Kingdom: NICE; 2000.
- Ghaemina H, Perry J, Nienhuijs ME, Toedting V, Tummers M, Hoppenreijts TJ, Van der Sanden WJ, Mettes TG. Surgical removal versus retention for the management of asymptomatic disease-free impacted wisdom teeth. *Cochrane Database Syst Rev* 2016;**8**:CD003879. <http://dx.doi.org/10.1002/14651858.CD003879.pub4>.
- Chou YH, Ho PS, Ho KY, Wang WC, Hu KF. Association between the eruption of the third molar and caries and periodontitis distal to the second molars in elderly patients. *Kaohsiung J Med Sci* 2017;**33**:246–51. <http://dx.doi.org/10.1016/j.kjms.2017.03.001>.
- Matzen LH, Wenzel A. Efficacy of CBCT for assessment of impacted mandibular third molars: a review – based on a hierarchical model of evidence. *Dentomaxillofac Radiol* 2015;**44**:20140189.
- Shoshani-Dror D, Shilo D, Ginini JG, Emodi O, Rachmiel A. Controversy regarding the need for prophylactic removal of impacted

- third molars: an overview. *Quintessence Int* 2018;**49**:653–62. <http://dx.doi.org/10.3290/j.qi.a40784>.
11. Oenning AC, Neves FS, Alencar PN, Prado RF, Groppo FC, Haiter-Neto F. External root resorption of the second molar associated with third molar impaction: comparison of panoramic radiography and cone beam computed tomography. *J Oral Maxillofac Surg* 2014;**72**:1444–55. <http://dx.doi.org/10.1016/j.joms.2014.03.023>.
 12. Matzen LH, Schropp L, Spin-Neto R, Wenzel A. Radiographic signs of pathology determining removal of an impacted mandibular third molar assessed in a panoramic image or CBCT. *Dentomaxillofac Radiol* 2017;**46**:20160330.
 13. Tassoker M. What are the risk factors for external root resorption of second molars associated with impacted third molars? A cone-beam computed tomography study. *J Oral Maxillofac Surg* 2019;**77**:11–7. <http://dx.doi.org/10.1016/j.joms.2018.08.023>.
 14. Hermann L, Wenzel A, Schropp L, Matzen LH. Marginal bone loss and resorption of second molars related to maxillary third molars in panoramic images compared with CBCT. *Dentomaxillofac Radiol* 2019;**12**:20180313. <http://dx.doi.org/10.1259/dmfr.20180313>.
 15. Liu DG, Zhang WL, Zhang ZY, Wu YT, Ma XC. Localization of impacted maxillary canines and observation of adjacent incisor resorption with cone-beam computed tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008;**105**:91–8.
 16. Haney E, Gansky SA, Lee JS, Johnson E, Maki K, Miller AJ, Huang JC. Comparative analysis of traditional radiographs and cone-beam computed tomography volumetric images in the diagnosis and treatment planning of maxillary impacted canines. *Am J Orthod Dentofac Orthop* 2010;**137**:590–7. <http://dx.doi.org/10.1016/j.ajodo.2008.06.035>.
 17. Lai CS, Suter VGA, Katsaros C, Bornstein MM. Localization of impacted maxillary canines and root resorption of neighbouring teeth: a study assessing the diagnostic value of panoramic radiographs in two groups of observers. *Eur J Orthod* 2014;**36**:450–6. <http://dx.doi.org/10.1093/ejo/cjt074>.
 18. Ventä I, Turtola L, Ylipaavalniemi P. Radiographic follow-up of impacted third molars from age 20 to 32 years. *Int J Oral Maxillofac Surg* 2001;**30**:54–7. <http://dx.doi.org/10.1054/ijom.2000.0002>.
 19. Ventä I, Vehkalahti MM, Huuomonen S, Suominen AL. Signs of disease occur in the majority of third molars in an adult population. *Int J Oral Maxillofac Surg* 2017;**46**:1635–40. <http://dx.doi.org/10.1016/j.ijom.2017.06.023>.
 20. Li D, Tao Y, Cui M, Zhang W, Zhang X, Hu X. External root resorption in maxillary and mandibular second molars associated with impacted third molars: a cone-beam computed tomographic study. *Clin Oral Investig* 2019. <http://dx.doi.org/10.1007/s00784-019-02859-3>. [Epub ahead of print].
 21. Ericson S, Kurol PJ. Resorption of incisors after ectopic eruption of maxillary canines: a CT study. *Angle Orthod* 2000;**70**:415.
 22. Andreasen JO, Severin IP. The impacted maxillary third molar. In: Andreasen JO, Kolsen Petersen J, Laskin DM, editors. *Textbook and color atlas of tooth impactions*. Copenhagen, Denmark: Munksgaard; 1997. p. 315–29.
 23. Walker L, Enciso R, Mah J. Three-dimensional localization of maxillary canines with cone-beam computed tomography. *Am J Orthod Dentofac Orthop* 2005;**128**:418–23.
 24. World Medical Association Declaration of Helsinki. Ethical principles for medical research involving human subjects. *JAMA* 2013;**310**:2191–4.
 25. Brezniak N, Wasserstein A. Root resorption after orthodontic treatment: Part I. Literature review. *Am J Orthod Dentofac Orthop* 1993;**103**:62–6.
 26. Nitzan D, Keren T, Marmary Y. Does an impacted tooth cause root resorption of the adjacent one? *Oral Surg Oral Med Oral Pathol* 1981;**51**:221–4.
 27. Nemcovsky CE, Tal H, Pitaru S. Effect of non-erupted third molars on roots of approximal teeth. A radiographic, clinical and histologic study. *J Oral Pathol Med* 1997;**26**:464–9.
 28. Yamaoka M, Furusawa K, Ikeda M, Hasegawa T. Root resorption of mandibular second molar teeth associated with the presence of the third molars. *Aust Dent J* 1999;**44**:112–6.
 29. Fuss Z, Tsesis I, Lin S. Root resorption—diagnosis, classification and treatment choices based on stimulation factors. *Dent Traumatol* 2003;**19**:175–82.
 30. Heithersay GS. Management of tooth resorption. *Aust Dent J* 2007;**52**(1 Suppl):S105–21.
 31. Andreasen JO. Autotransplantation of premolars. In: Andreasen JO, editor. *Atlas of replantation and transplantation of teeth*. Fribourg, Switzerland: Mediglobe; 1992. p. 164–72.
 32. Malek S, Darendeliler MA, Swain MV. Physical properties of root cementum: part I. A new method for 3-dimensional evaluation. *Am J Orthod Dentofac Orthop* 2001;**120**:198–208. <http://dx.doi.org/10.1067/mod.2001.114535>.
 33. Kahl B, Gerlach KL, Hilgers RD. A long-term, follow-up, radiographic evaluation of asymptomatic impacted third molars in orthodontically treated patients. *Int J Oral Maxillofac Surg* 1994;**23**:279–85.
 34. Van der Linden W, Cleaton Jones P, Lownie M. Diseases and lesions associated with third molars: review of 1001 cases. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1995;**79**:142–5.
 35. Bragatto FP, Iwaki Filho L, Kasuya AV, Chiccarelli M, Queiroz AF, Takeshita WM, Iwaki LC. Accuracy in the diagnosis of vertical root fractures, external root resorptions, and root perforations using cone-beam computed tomography with different voxel sizes of acquisition. *J Conserv Dent* 2016;**19**:573–7.
 36. Oenning AC, Melo SL, Groppo FC, Haiter-Neto F. Mesial inclination of impacted third molars and its propensity to stimulate external root resorption in second molars—a cone-beam computed tomographic evaluation. *J Oral Maxillofac Surg* 2015;**73**:379–86. <http://dx.doi.org/10.1016/j.joms.2014.10.008>.
 37. Suter VGA, Rivola M, Schriber M, Leung YY, Bornstein MM. Risk factors for root resorption of second molars associated with impacted mandibular third molars. *Int J Oral Maxillofac Surg* 2019;**48**:801–9. <http://dx.doi.org/10.1016/j.ijom.2018.11.005>.

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