Ph.D. Thesis

Evaluation of tooth sectioning and root migration during coronectomy of impacted mandibular third molars

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I. Introduction

Impaction is defined as a failure of tooth eruption due to a physical obstruction. The mandibular third molars are the most frequently affected teeth, with a reported prevalence ranging between 16.7% and 73%. During development, the angulation of the third molar changes; however, in many cases the tooth fails to reach a vertical position and remains in a mesioangular impaction. The development of impaction may be influenced by a discrepancy between tooth size and arch length, insufficient retromolar space, evolutionary reduction in jaw size, and decreased masticatory forces associated with the modern diet.

In clinical practice, the position of impacted third molars is most commonly described using the Winter and the Pell-Gregory classification systems. The Winter classification characterizes the angulation of the third molar in relation to the second molar, whereas the Pell-Gregory classification evaluates the available space for eruption and the vertical depth of impaction. Both systems are based on panoramic radiographs and therefore provide only two-dimensional information, which limits the precise assessment of the relationship between the tooth and surrounding anatomical structures.

Mandibular third molars are among the most frequently removed teeth, accounting for approximately 19% of all tooth extractions. Although an impacted tooth may remain asymptomatic for a long time, it can serve as a source of various pathological conditions. The most common indication for removal is pericoronitis, which typically develops around partially erupted teeth. Other frequent indications include periodontitis or its prevention. Extraction may also be indicated for orthodontic reasons, due to caries or root resorption, in the presence of cyst formation, during prosthetic treatment planning, or as part of the preparation for orthognathic surgery. While the removal of symptomatic third molars is widely accepted, the necessity of prophylactic extraction remains controversial.

As with any surgical procedure, tooth extraction may be associated with complications. Common postoperative events include bleeding, swelling, trismus, and pain, which are usually temporary. Alveolitis, less frequently severe cervicofacial infections, and hard-tissue injuries may also occur. However, nerve injuries have the greatest clinical significance. During removal of mandibular third molars, the inferior alveolar nerve is most commonly affected. In most cases the resulting sensory disturbance is temporary, but permanent deficits may rarely occur. Injuries may be indirect, caused by compression or traction, or direct, when surgical instruments come into contact with the nerve. In addition, injury to the lingual nerve may occur, particularly in cases of thin lingual cortical bone or cortical fenestration.

The risk of inferior alveolar nerve injury is influenced by several factors; however, the most important risk factor is the presence of a close anatomical relationship between the tooth root and the mandibular canal. In such cases, the probability of nerve injury may increase substantially, reaching up to 23–60% according to some reports. Identification of high-risk cases is primarily based on panoramic radiography, where so-called specific radiographic signs are evaluated. These include darkening of the root, root deflection or narrowing, interruption of the superior cortical border of the mandibular canal, and diversion or narrowing of the canal. According to the observations of Rood and Shehab, root darkening, canal diversion, and cortical interruption are particularly indicative of a close relationship between the tooth and the nerve canal. When one or more of these signs are present, three-dimensional imaging with cone-beam computed tomography (CBCT) is recommended to determine the spatial relationship between the tooth and the canal more precisely, although the use of CBCT alone does not reduce the incidence of nerve injury.

Several alternative techniques have been proposed for the management of third molars with a high risk of nerve injury, aiming to reduce the likelihood of nerve damage. These include staged extraction, orthodontic extrusion, and pericoronal ostectomy, which generally require multiple treatment sessions. One of the most widely used alternative methods is coronectomy. The principle of the procedure is to section and remove the crown of the third molar at the cemento-enamel junction while leaving the roots in the alveolus, positioned below the level of the surrounding bone. The procedure is considered successful if the roots remain immobile during crown removal; otherwise, complete extraction becomes necessary. Removal of healthy pulp tissue or root canal treatment is generally not indicated, and radiographic control is performed intraoperatively or postoperatively to exclude residual enamel fragments.

Numerous studies have demonstrated that coronectomy may significantly reduce the risk of inferior alveolar nerve injury compared with complete tooth extraction; therefore, it is particularly recommended in cases where the roots are in close proximity to the mandibular canal. The most common intraoperative complication of coronectomy is root mobilization, which may lead to failure of the procedure; however, the incidence of nerve injury remains considerably lower than after conventional extraction. Injury to the lingual nerve may rarely occur, especially in cases of excessively deep crown sectioning, therefore careful protection of the surrounding anatomical structures is essential. Today, coronectomy has become one of the most important and increasingly widely used surgical alternatives in the management of mandibular third molars associated with a high risk of nerve injury.

II. Objectives

II/1. Evaluation of the applicability of the drill-sleeve

The aim of our study was to design and perform a comprehensive in vitro experiment in which the efficiency of tooth sectioning performed with a 3D-printed drill sleeve could be compared with that of freehand sectioning performed during coronectomy. The primary focus of the investigation was to evaluate the effectiveness and precision of the drill-sleeve technique, with particular attention to its influence on the duration of tooth sectioning and on the accuracy of buccolingual depth control during the procedure.

In addition, we aimed to analyze the potential advantages and possible disadvantages of using the drill sleeve for dentoalveolar and maxillofacial surgeons with different levels of surgical experience. Our objective was to objectively assess to what extent the drill sleeve facilitates the procedure and whether its use may reduce the occurrence of surgical errors or theoretical complications at different levels of operator experience.

II/2. Temporal pattern of root migration following coronectomy

In the second part of our research, a retrospective clinical study was conducted to evaluate the temporal pattern of root migration following coronectomy and its radiographic–anatomical characteristics. Our aim was to identify the clinical and anatomical factors influencing the extent of root migration, with particular regard to patient age, the type of impaction, and the presence of specific radiographic risk signs detectable on panoramic radiographs. A further objective was to investigate the relationship between the level of training of the operating surgeon and the clinical outcomes, including the need for subsequent removal of retained roots and the occurrence of postoperative complications. Based on these analyses, our goal was to identify statistically significant correlations that may contribute to the development of predictive models for root migration after coronectomy and to the objective evaluation of the long-term outcomes of the procedure.

III. Materials and Methods

III/1. Evaluation of the applicability of the drill sleeve

In our investigations, a previously designed and 3D-printed mandibular model was used, based on a CBCT scan obtained from a patient who had presented for third molar removal at the Department of Dentistry and Oral and Maxillofacial Surgery, Clinical Centre, University of Pécs. The use of patient data, as well as the results of clinical and imaging examinations, was approved by the relevant ethics committee (RKEB: 7920/PTE/2019).

III/1.a. Design of the 3D model

The CBCT scans used in the study were acquired with a GXDP-800 3D device (KaVo-Gendex, Charlotte, NC, USA) [90 kVp; 3.2–10 mA; 6.1–8.5 s; field of view: 61 × 78 mm or 78 × 150 mm; focal spot: 0.5 mm; scan time: 10–20 s; slice thickness: 0.5 mm; voxel size: 0.2 mm]. The DICOM data were imported into 3D Slicer software (version 5.0.3), where segmentation was performed and a three-dimensional volumetric reconstruction was generated, after which the data were exported in STereoLithography (.stl) format. The resulting .stl files were further processed in Meshmixer (Autodesk, San Rafael, CA, USA), where a minimal smoothing algorithm was applied to reduce noise while preserving the anatomical structures. The model was then imported into Blender (version 3.2), where it was divided along the median sagittal plane in object mode, and the right side was used for further processing. The shape of the teeth and the occlusal surfaces were minimally corrected in sculpt mode to improve anatomical fidelity.

The buccal bone around the third molar was reduced to 2 mm below the cemento-enamel junction, thereby simulating the intraoperative condition after bone removal and the surgical situation characteristic of the crown sectioning phase. In order to reduce 3D-printing costs, the second and third molar region was designed as a separate, replaceable bone segment. For this purpose, the teeth and surrounding bone were isolated, and a rail-based T-shaped fixation structure was created that connected the segment to the base of the model.

By mirroring the right-sided model, the complete experimental mandibular model was created, containing impacted third molars on both sides in separate replaceable segments. The base of the model was designed using 3D scans (Artec Space Spider, Artec3D, Luxembourg) obtained from a DRSK jaw model (DRSK Restorative Jaw, DRSK, Sweden), in order to ensure compatibility with the standard phantom heads used in the clinic (G40 Jaw Simulator with standard facial mask, KaVo, Biberach, Germany). The design of the model was based on a previous publication describing a mandibular model developed for third molar extraction training.

III/1.b. Fabrication of the 3D model

For the mandibular model, we aimed to select a material that would realistically represent the conditions encountered during tooth sectioning. The model was fabricated from resin (White Resin V4, Formlabs, Boston, MA, USA), which is hard (Shore D hardness = 82) and drillable, thereby providing good tactile feedback for the operator. In addition, it has favorable imaging properties, making it suitable for CBCT scanning.

The models were produced with a stereolithography (SLA) desktop printer (Form 2, Formlabs, Boston, MA, USA) using a layer thickness of 0.1 mm. Print orientation and support generation were configured using PreForm software (Formlabs, Boston, MA, USA). The mandibular model was covered with red silicone (Rebound 25, Smooth-On, Texas, USA) to simulate soft tissues. On the replaceable segment, this was combined with a layer of impression silicone material, thereby making real mucoperiosteal flap elevation and flap retraction necessary during the model surgery. In addition, a tongue was fabricated from silicone impression material (ZA 22 Thixo Body, Zhermack, Badia Polesine, Italy), with the aim of reproducing the difficult visualization of the lingual surface under in vivo-like conditions.

III/1.c. The drill sleeve

In a previous study conducted at the Department of Dentistry and Oral and Maxillofacial Surgery, Clinical Centre, University of Pécs, an individually adaptable, 3D-printed drill sleeve was developed to function as a depth stop during coronectomy sectioning.

This previously developed drill sleeve was used in our model surgery. Its 3D CAD (three-dimensional computer-aided design) model was designed in Autodesk Inventor (Autodesk, San Francisco, CA, USA) on the basis of the measured parameters. The drill sleeve was manufactured using a Stratasys PolyJet J750 3D printer (Stratasys Ltd., Eden Prairie, MN, USA). It was printed from a UV-curable photopolymer blend (Stratasys MED670 VeroDent) with a layer thickness (“Z” resolution) of 16 μm. The material is approved for medical and dental use and is widely applied in these fields.

III/1.d. Model surgery

The simulated surgery was designed to reproduce real clinical situations. The phantom head was fixed into the headrest of a dental chair (Primus 1058 Life, KaVo, Biberach, Germany) using double-sided adhesive tape (3M Heavy Duty Molding Tape, 3M Hungária Kft., Budapest, Hungary).

The surgical physiodispenser (MASTERsurg, KaVo, Biberach, Germany) was coupled with a surgical 45° contra-angle speed-increasing handpiece (1:3 speed-increasing ratio; TiMax Z-SG45L, NSK-Nakanishi, Eschborn, Germany). For the sectioning procedures, irrigation was standardized at 50 mL/min and drilling speed at 120,000 rpm. Crown sectioning was performed using a tungsten carbide fissure bur (HM21L, Hager & Meisinger GmbH, Neuss, Germany). The selection of the bur was based on the results of another previous study conducted at our clinic. The drill sleeve was placed onto the shaft of the bur, where fixation was ensured by friction.

Before the intervention, participants were allowed to review the original CBCT scan on which the model had been based. For image analysis, they used InvivoViewer software (version 2.0.0, KaVo, Biberach, Germany) on a desktop computer equipped with a 32-inch Quad HD monitor (2560 × 1440 resolution; Q32P2, AOC, Taipei, Taiwan). They were informed about the length of the drill sleeve and the maximum buccolingual diameter of the tooth at the planned sectioning site, which they could also verify on the CBCT scan. Thus, they were aware that when the drill sleeve was used and the bur was advanced to the maximum permitted depth, 1.0 mm of lingual tooth structure would remain intact.

Sectioning was performed on one side with the drill sleeve and on the contralateral side without the drill sleeve. The starting side and the allocation of technique to each side were determined by coin toss. Operative time was recorded on both sides using a stopwatch.

III/1.e. Study groups

A total of 36 colleagues from our department participated in the experiment, including residents and specialists in dentoalveolar surgery and oral and maxillofacial surgery. As a first step, groups were established according to the participants' surgical experience. Group allocation was based on the number of impacted third molar removals and coronectomies previously performed.

The less experienced participants were mainly residents who had performed between 30 and 100 impacted third molar removals and between 3 and 10 coronectomies during their careers. The experienced participants were mainly specialists or residents approaching specialist qualification who had performed at least 500 impacted third molar removals and on average 50 coronectomies over the previous 5 years.

III/1.f. Data collection and evaluation

After the procedures, the replaceable segments were labeled with unique identification numbers and rescanned using CBCT.

The DICOM files obtained from the CBCT scans were imported into 3D Slicer software, where segmentation was performed using a threshold range of 1.78–489. Irrelevant structures were removed, and the models were exported in .stl format to Blender software. In Blender, the sectioned segments were compared with the intact segments. A sphere was created to fit exactly into the defect area of the tooth, and the Boolean function was used to determine the dimensions of the cut, leaving only the region corresponding to the sectioned area within the sphere. In this way, the exact extent of the cut was obtained as a three-dimensional object, which could then be analyzed in Blender.

Buccolingual cutting depth was measured at three standardized locations: in a vertical section corresponding to the mesial cusp, in a vertical section along the central fissure, and in a vertical section corresponding to the distal cusp. These measurements were used to characterize the sectioning procedure in terms of mesial, central, and distal cut depth. All cutting-depth measurements were performed in parallel with another investigator participating in the study, and the mean of the obtained values was used for analysis. In addition, both intraobserver and interobserver reliability were calculated.

III/1.g. Determination of optimal cutting depth

A reference (zero) point was established 1.0 mm from the lingual surface of the third molar in each of the three buccolingual sectional planes described above. If the cuts extended at least 2.0 mm deeper than the reference point, they were classified as “too deep” in order to protect the lingual structures. If the cuts were at least 3.0 mm shallower than the reference point, they were classified as “too shallow.” In such cases, at least 4.0 mm of tooth structure remained intact lingually, corresponding to approximately 40% of the buccolingual dimension of the tooth.

III/1.h. Statistical analysis

Statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA) and MedCalc statistical software (Ostend, Belgium).

Inter-rater reliability and agreement were assessed using Cohen's kappa test (values < 0.40 were considered poor, 0.40–0.59 fair, 0.60–0.75 good, and > 0.75 excellent).

The required sample size was calculated using data from a previous pilot drilling series, which included 10 freehand (FH) and 10 drill-sleeve (DS) coronectomies, according to Padam's method. The mean cutting depth was calculated as 7.6 mm in the freehand group and 8.8 mm in the drill-sleeve group, while the standard deviations were 2.0 mm and 1.0 mm, respectively. Assuming a significance level of 0.05 and a statistical power of 80%, the required sample size was estimated to be 36 participants per group.

Associations between "too shallow" and "too deep" cuts and the applied techniques (DS vs. FH) or study groups (experienced vs. inexperienced) were analyzed using Fisher's exact test or the chi-square test, and odds ratios were calculated. The difference between the planned and actually achieved cutting depths was compared using an independent-samples t-test. Differences in drilling time between the two sides, as well as between the study groups, were analyzed using the Mann–Whitney U test. A p value of ≤ 0.05 was considered statistically significant.

III/2. Temporal pattern of root migration following coronectomy

III/2.a. Study design and data source

Our study was based on retrospective clinical data analysis, in which follow-up data from coronectomies performed between August 2018 and December 2025 at the Dentoalveolar Surgery Unit of the Department of Dentistry and Oral and Maxillofacial Surgery, Clinical Centre, University of Pécs, were evaluated.

III/2.b. Study population and ethical compliance

The target population consisted of patients presenting for removal of mandibular third molars in whom an increased risk of inferior alveolar nerve injury had been identified during the preoperative assessment; therefore, coronectomy was performed instead of complete extraction. The use of patient data and imaging examinations was approved by the Regional Research

Ethics Committee (7613-PTE 2019; PTE-KK/53474/2019), and all phases of the study were conducted in accordance with the principles of the Declaration of Helsinki.

III/2.c. Inclusion and exclusion criteria, follow-up

Cases were selected from all performed coronectomies. Inclusion criteria comprised those cases in which, in addition to the intraoperative or immediate postoperative panoramic radiograph, follow-up radiographs obtained at 1, 3, 6, and 12 months were also available. In most cases, a 24-month follow-up radiograph was likewise available. Our aim was to establish a longitudinally traceable patient cohort that would allow detailed assessment of the temporal course of root migration. Exclusion criteria included any case in which the panoramic radiographs showed substantial positioning errors, distortion, or disturbing artifacts that could have influenced quantitative evaluation.

III/2.d. Methodology for measuring root migration and reference values

The extent of root migration was determined on digital panoramic radiographs using the calibrated distance-measurement function of VistaSoft software (version 3.0.32) (Stanford University, Stanford, CA, USA). Panoramic radiographs were obtained with a GX DP-800 device at 90 kV, 12.5 mA, and 16 s exposure settings (DAP: 75 $mGy\cdot cm^2$) (Gendex Dental Systems, Hatfield, PA, USA). To ensure reliability, all measurements at each follow-up time point (1, 3, 6, 12, and 24 months) were performed independently by two examiners with an accuracy of one-tenth of a millimeter, and the mean of the two values was used for analysis.

In most cases, the reference point was defined as the distance between the distal root apex and the projection of the inferior cortical border of the mandibular canal, since these anatomical structures can be reliably identified on panoramic radiographs, and measurement uncertainty caused by superimposition of buccal and lingual roots is minimal in this region. In a few cases where these landmarks were not suitable for monitoring, the two examiners selected identical alternative reference points by mutual agreement (e.g., the mandibular angle). The aim was to minimize subjective measurement bias and improve the reproducibility of data processing.

III/2.e. Collected clinical and radiological parameters

During data collection, demographic characteristics of the patients were recorded. Specific radiographic risk signs visible on panoramic radiographs, the depth of impaction according to the Pell–Gregory classification, and angulation according to Winter’s classification were also documented. In addition, the level of training of the operating surgeon (resident/specialist) and clinical outcomes were recorded, including the need for later removal of retained roots and the occurrence of postoperative complications.

III/2.f. Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics (version 28.0) (IBM Corp., Armonk, NY, USA), while Microsoft Excel (version 365) (Microsoft Corp., Redmond, WA, USA) was used for data organization and preparation of figures. As a first step, descriptive statistical methods were used to characterize the demographic and clinical parameters of the study population, as well as the temporal pattern of root migration.

The reliability of root migration measurements was assessed on the basis of the results of the two independent examiners using the intraclass correlation coefficient (ICC; two-way random-effects model, absolute agreement). Possible systematic differences in the measurement method and the limits of agreement were evaluated using Bland–Altman analysis, during which the mean difference (bias) and the 95% limits of agreement corresponding to ±1.96 standard deviations of the measurement differences were determined. The aim was to confirm that the applied panoramic radiograph-based measurement protocol was suitable for the reproducible quantitative assessment of root migration.

The distribution of continuous variables was assessed using nonparametric methods. The relationship between age and the extent of root migration was analyzed using Spearman's rank correlation. In order to examine the effect of age on root migration in greater detail, patients were categorized into predefined age groups: 18–24 years, 25–34 years, 35–44 years, and ≥45 years. The extent of root migration was evaluated separately in each age subgroup, and comparisons between the groups were performed using the Kruskal–Wallis test.

The influence of anatomical characteristics of the teeth on migration was evaluated according to the horizontal (Classes I–III) and vertical (Positions A–C) components of the Pell–Gregory classification, as well as the angulation categories of Winter's classification. Differences between the groups were analyzed using the Kruskal–Wallis test. During the combined evaluation of Pell–Gregory subgroups, the entire categorical system was compared using the Kruskal–Wallis test in order to determine the extent to which complex anatomical relationships influenced root migration. The horizontal (I–III) and vertical (A–C) components were analyzed both separately and in combined form, allowing joint evaluation of the depth of impaction and anteroposterior position in relation to the extent of migration.

Associations between categorical variables, such as the training level of the surgeon performing the procedure (resident vs. specialist), the occurrence of pulpitis, and the need for root removal in a second-stage procedure, were analyzed using Fisher's exact test.

Cases showing no root migration were also evaluated as a separate subgroup in order to determine whether they could be distinguished on the basis of age, impaction characteristics, or other clinical parameters.

For all statistical tests, the level of significance was set at $p \leq 0.05$.

IV. Results

IV/1. Evaluation of the applicability of the drill sleeve

In our study, excessively deep cuts were detected in 7 of 36 cases during freehand sectioning, while excessively shallow sectioning was observed in 18 of 36 cases. When the drill sleeve was used, no excessively deep cuts were detected, whereas excessively shallow cuts were found in 8 of 36 cases. Based on these findings, without the use of the drill sleeve, the odds ratio for excessively deep tooth sectioning was 18.56 (95% confidence interval: 1.02–338.5; $p = 0.048$), while the odds ratio for excessively shallow cuts was 3.5 (95% confidence interval: 1.26–9.72; $p = 0.016$). The difference between the virtually planned (i.e. optimal) and the actually achieved cutting depths was significantly greater in the freehand group (1.91 ± 1.62 mm) than in the drill-sleeve group (1.21 ± 0.72 mm) ($p < 0.001$; $t = -4.764$; independent-samples t-test).

Of the 36 colleagues participating in the study, 20 were classified as less experienced and 16 as experienced based on their surgical background. The incidence of excessively deep freehand cuts was similar in the experienced (3/16 cases) and less experienced (4/20 cases) groups ($p = 0.983$; Fisher's exact test). The occurrence of excessively shallow freehand cuts was likewise comparable between the two groups (7/16 in the experienced group and 11/20 in the less experienced group; $p = 0.697$; chi-square test). In the case of drill-sleeve-assisted sectioning, the frequency of excessively shallow cuts also showed no significant difference between the experienced (3/16 cases) and less experienced (5/20 cases) groups ($p = 0.655$; Fisher's exact test).

With regard to the location of the cut (mesial, central, distal), the shortest cut depths were observed distally (odds ratio: 6.76; 95% confidence interval: 1.57–29.07; $p = 0.01$).

Use of the drill sleeve (82.27 ± 80.69 s) significantly reduced the operative time (p = 0.021; Mann–Whitney U test) compared with freehand coronectomy (119.93 ± 106.50 s). When the experience-based groups were analyzed separately, no significant difference in operative time associated with drill-sleeve use was observed in the experienced group; however, the less experienced operators completed coronectomy significantly faster when using the drill sleeve (FH: 158.95 ± 125.61 s; DS: 106.92 ± 100.79 s) (p = 0.038; Mann–Whitney U test). In addition, the experienced colleagues were significantly faster during freehand sectioning (65.31 ± 26.54 s) than the less experienced colleagues (158.95 ± 125.61 s) (p < 0.001; Mann–Whitney U test). Furthermore, the experienced colleagues (79.08 ± 16.98 s) were also faster when using the drill sleeve compared with the less experienced group (106.92 ± 100.79 s) (p = 0.004; Mann–Whitney U test).

According to the results of Cohen's kappa test, both intraobserver reliability (0.97 and 0.95) and interobserver agreement (0.91) were found to be excellent.

IV/2. Temporal pattern of root migration following coronectomy

During the study period, a total of 73 coronectomy cases in 57 patients met the inclusion criteria, of whom 16 underwent bilateral procedures. The study population consisted of 47 women (82.46%) and 10 men (17.54%), with a mean age of 29.58 ± 10.66 years. Of the interventions, 44 were performed by residents and 29 by specialists.

According to the impaction characteristics of the teeth, 19, 51, and 3 teeth were classified as Pell–Gregory Classes I, II, and III, respectively, while according to the vertical component, 17 cases belonged to category A, 46 to category B, and 10 to category C. Based on Winter's classification, 42 teeth were mesioangular, 17 vertical, 9 horizontal, and 5 distoangular.

As radiological indications, root darkening was the most frequently observed finding (54/73 cases), followed by interruption of the cortical border of the mandibular canal (41/73 cases), diversion of the canal (21/73 cases), and narrowing of the canal (12/73 cases). In a substantial proportion of cases, more than one risk sign was present simultaneously, most commonly the combination of root darkening and cortical interruption.

Of the 73 analyzed cases, no measurable root migration was observed in 7 cases (9.59%), whereas migration was detectable in 66 cases (90.41%). The mean extent of migration was 1.5 mm at the 1-month follow-up, 2.4 mm at 3 months, 2.8 mm at 6 months, 3.2 mm at 12 months, and 3.5 mm at 24 months. Based on the dynamics of migration, the most pronounced displacement occurred during the first 6 months after the procedure; thereafter, the rate of increase declined, although a further gradual increase was still observed until the end of the follow-up period.

A significant negative correlation was demonstrated between age and the extent of root migration (Spearman's $\rho = -0.29$; $p = 0.013$), indicating that greater migration was observed at younger age.

Analysis by age subgroup (≤25 years, 26–35 years, 36–45 years, >45 years) also revealed a significant difference in the extent of root migration (Kruskal–Wallis: $H = 8.19$; $df = 3$; $p = 0.042$), confirming the determining role of age.

According to the horizontal component (Classes I–III) of the Pell–Gregory classification, a significant difference was found in the extent of migration ($H(2) = 6.87$; $p = 0.032$), whereas the vertical component (A–C) alone did not show a statistically significant difference ($H(2) = 5.62$; $p = 0.060$), although a trend was observed toward deeper impactions. Combined analysis of the Pell–Gregory subgroups (IA–IIIC) did not yield a significant difference ($H(7) = 11.76$; $p = 0.109$). Likewise, no statistically significant association was found between Winter's angulation categories and the extent of root migration ($H = 1.87$; $p = 0.599$).

Following coronectomy, removal of the retained roots became necessary in 13 cases (17.81%). The most common reason for this was root migration (9 cases, 69.23%), while in two cases pulpitis and in a further two cases a late periapical process necessitated the second intervention. Nerve injury occurred exclusively in association with delayed root removal performed at the second stage (3 cases), whereas no nerve injury was observed during the primary coronectomy. The training level of the operating surgeon showed no significant association either with the occurrence of pulpitis ($p = 0.510$) or with the need for a second intervention ($p = 0.340$).

The reliability of root migration measurements between the two examiners proved to be excellent (ICC (2,1) = 0.974). Bland–Altman analysis demonstrated a negligible mean difference (bias = 0.04 mm) and narrow limits of agreement (95% LoA: -0.76 to 0.85 mm), supporting the good reproducibility of the applied measurement method.

V. Discussion

V/1. Evaluation of the applicability of the drill sleeve

The accuracy of tooth sectioning is crucial for successful coronectomy. Our study demonstrated that the use of the drill sleeve improves the precision of sectioning and reduces operative time. This is of particular importance in the prevention of lingual nerve injury, as the lingual cortical plate in the third molar region is often extremely thin or even fenestrated, placing the nerve in close proximity to the surgical field.

The literature frequently recommends subtotal coronal sectioning followed by fracture of the crown with a hand instrument, although some authors prefer complete coronal sectioning in order to reduce the risk of root mobilization. In cases of complete sectioning, however, protection of the lingual soft tissues is essential, while the use of a lingual flap has been reported in several studies to increase the risk of nerve injury. Our findings showed that without the drill sleeve, the likelihood of excessively deep cuts was significantly higher, whereas freehand sectioning more often resulted in excessive residual tooth structure, which requires greater force for crown fracture and increases the probability of root mobilization.

The thickness of the lingual cortical plate in the molar region is often only approximately 1 mm, which further increases the risk of lingual nerve injury. Freehand coronectomy therefore requires considerable surgical experience; previous studies have shown that more experienced surgeons operate with shorter operative times and fewer complications. Based on our results, the drill sleeve appears to be particularly beneficial for less experienced operators, as its use significantly reduced sectioning time in this group.

A further advantage of the method is its cost-effectiveness, since the sleeves can be manufactured by 3D printing at low material cost and can be customized to the required dimensions. However, in certain clinical situations, such as limited mouth opening or deep, unfavorable impaction, its application may be difficult. A limitation of our study is that it was performed under in vitro conditions on a 3D-printed mandibular model, which cannot fully reproduce the clinical environment. Nevertheless, the model represented the technical difficulties of coronectomy well.

V/2. Temporal pattern of root migration following coronectomy

The aim of our study was to analyze the temporal pattern and influencing factors of root migration following coronectomy, as well as to identify those clinical parameters that may determine long-term outcomes. Based on our findings, root migration proved to be a common phenomenon and showed a well-defined temporal pattern: the greatest displacement occurred during the first six months after surgery, after which the rate gradually slowed. Although the extent of migration became less pronounced later, complete cessation of the process could not be confirmed even during the two-year follow-up period, which supports the need for longer-term radiological follow-up. A notable finding was the significant negative relationship between age and root migration: greater displacement was observed in younger patients. This is consistent with current knowledge of bone biology, as bone turnover and tissue remodeling are more active at a younger age. Accordingly, age may also be a clinically important factor when determining follow-up strategy and the potential need for a second intervention. Among the impaction-related characteristics, the horizontal component of the Pell–Gregory classification was associated with the extent of migration, whereas the vertical component and Winter's angulation were not found to be decisive. This suggests that the amount of available space between the ramus and the second molar may play a greater role in root displacement than the vertical depth of impaction or the angulation of the tooth. The literature reports inconsistent findings in this regard, indicating that root migration is likely the result of a complex interaction of multiple anatomical and biological factors.

When evaluating clinical outcomes, removal of the retained roots became necessary in nearly one-fifth of cases, most commonly as a consequence of migration. An important observation was that nerve injury occurred exclusively during delayed root removal performed as a second-stage procedure, whereas no nerve injury was observed during the primary coronectomy. This confirms that coronectomy represents a safe alternative in cases with a high risk of nerve injury; however, the possibility of a second intervention must also be taken into consideration.

From a methodological perspective, the panoramic radiograph-based measurement protocol showed excellent reproducibility, indicating that with appropriate standardization it is suitable for the longitudinal monitoring of root migration in clinical practice as well. The limitations of the study include its retrospective design, the use of two-dimensional imaging, and the relatively young mean age of the study population.

Overall, it can be concluded that root migration following coronectomy is a multifactorial process influenced primarily by age and anatomical relationships. Our findings confirm that coronectomy is an effective and safe procedure when performed with appropriate indication; however, long-term radiological follow-up is essential for the detection of late complications.

VI. Summary of the novel findings of the dissertation

Based on our study evaluating the applicability of the drill sleeve, the following conclusions can be drawn:

- The use of a patient-specific, 3D-printed drill sleeve significantly reduces the incidence of both excessively deep and excessively shallow coronal sections, thereby improving the accuracy of tooth sectioning compared with the freehand technique.
- The use of the drill sleeve significantly shortens operative time, particularly in the case of less experienced operators.
- Based on the wear observed on the drill sleeve after use, the device should be considered single-use in order to maintain precise control of cutting depth.

Based on our study investigating the temporal pattern and influencing factors of root migration following coronectomy, the following conclusions can be drawn:

- Root migration can be detected in more than 90% of cases after coronectomy; the greatest displacement occurs during the first 6 postoperative months, after which migration continues at a slower rate and may still be observed even after two years.
- A significant negative correlation exists between age and the extent of root migration; greater displacement is observed in younger patients.
- Among the impaction-related characteristics, the horizontal component of the Pell–Gregory classification shows a significant association with the extent of migration, whereas the vertical component and Winter’s angulation alone are not decisive factors.
- The probability of reoperation after coronectomy is below 20%.

VII. List of publications

Publications forming the basis of the dissertation

1. **The effect of individual drilling sleeves on the precision of coronectomy tooth sections. An in vitro 3D-printed jaw model experiment**
   Pacheco A, Soós B, Lempel E, Simon I, Maróti P, Möhlhenrich S, Szalma J
   Clinical Oral Investigations. 2023;27:6769–6780.
   PMID: 37783802
   DOI: 10.1007/s00784-023-05289-4
   Scimago: D1; IF: 3.1

2. **A koronektómiát követő foggyökér-migráció időbeli alakulása - retrospektív vizsgálat (Temporal pattern of root migration following coronectomy - a retrospective study)**
   Pacheco A, Gyulai S, Soós B, Szakács M, Szalma J
   Orvosi Hetilap. 2026.
   Accepted for publication (in press)
   Scimago: Q4; IF: 0.9

Total IF: 4.0

Other publications

1. **Pre-eruptive intracoronal resorption in orthodontic patients: A retrospective analysis of 3,143 patients**
   Gurdán Zs, Balázs D, Pásti D, Fathi M, Maróti P, Kardos K, Pacheco A, Szalma J
   Heliyon. 2023;9(8):e18699.
   PMID: 37560674
   DOI: 10.1016/j.heliyon.2023.e18699
   Scimago: Q1; IF: 3.4

2. **A pre-eruptív intrakoronális lézió előfordulása és jelentőssége bölcsességfogak esetében**
   Janovics K, Soós B, Gurdán Zs, Pacheco A, Lempel E, Bán Á, Szalma J
   Fogorvosi Szemle. 2023;116(3):120–126.
   DOI: 10.33891/FSZ.116.3.120-126

3. **Pre-eruptive intracoronal resorption in "high-risk" impacted third molars: A report of four cases**
   Szalma J, Janovics K, Pacheco A, Kaszás B, Lempel E
   Journal of Cranio-Maxillofacial Surgery. 2022;50(10):798–805.
   PMID: 36224052
   DOI: 10.1016/j.jcms.2022.09.004
   Scimago: Q1; IF: 3.1

Cumulative IF: 10.5