Lerdchakorn et al. BMC Oral Health (2024) 24:985
https://doi.org/10.1186/s12903-024-04762-0

BMC Oral Health

RESEARCH

Open Access

Etiologies of non-surgical root canal treatment and its association with risk factors in a selected Thai population

Sirimas Lerdchakorn[1,2], Thantrira Porntaveetus[3], Piyanee Panitvisai[1] and Sirinya Kulvitit[1,3*]

Abstract

Background The aim of this study was to investigate the etiologies of non-surgical root canal treatment (NS-RCT) in a Thai population and examine their association with risk factors.

Methods A cross-sectional observational study was performed to examine the etiologies of NS-RCT and risk factors among Thai-nationality patients treated at a tertiary care dental hospital in Thailand from 2019–2023. Treatment records and radiographs were retrospectively reviewed to identify NS-RCT etiologies, and associated contributing factors were analyzed. Statistical analysis used univariate logistic regression followed by multivariate logistic regression, with a significance level set at $P < 0.05$.

Results The data from 1500 teeth were analyzed, comprising 59.1% females and 40.9% males, with ages ranging from 7–91 years (mean = 48.56 years). The most prevalent age group was 61–70 years-old. Among the treated teeth, the mandibular first molar was the most frequently involved (13.9%), followed by the maxillary first molar (9.9%) and mandibular second premolar (9.7%). The primary etiologies of NS-RCT were dental caries (53.7%), old and large restorations (7.9%), and attrition (5.9%). Analysis of etiology of NS-RCT due to caries revealed that the most commonly affected sites were the occlusal (32.6%), distal (31.6%), and mesial (17.2%) surfaces. In immature teeth requiring NS-RCT, the predominant etiologies were dens evaginatus (32.1%), dental caries (28.6%), and traumatic injury (21.4%). The association between the etiology of NS-RCT and investigated associated factors were identified.

Conclusions The etiologies of NS-RCT in the selected Thai population were mainly attributed to dental caries, with additional factors being old and large restorations and attrition. Notably, due to the aging society, the elderly population experiences a higher demand for NS-RCT, particularly due to attrition, non-carious cervical lesions, and erosion. In contrast, in immature teeth, the most common etiologies leading to NS-RCT comprise dens evaginatus, dental caries, and traumatic injuries. The distinct etiological patterns observed in different age groups emphasize the importance of specific oral health prevention programs to address individual needs.

*Correspondence:
Sirinya Kulvitit
sirinya.ku@chula.ac.th
[1] Department of Operative Dentistry, Faculty of Dentistry, Chulalongkorn University, Bangkok 10330, Thailand
[2] Institute of Dentistry, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand
[3] Center of Excellence in Genomics and Precision Dentistry, Department of Physiology, Faculty of Dentistry, Chulalongkorn University, Bangkok 10330, Thailand

Introduction

Non-surgical root canal treatment (NS-RCT) is a very common dental procedure for managing infectious pulp diseases. Understanding the etiology of NS-RCT holds profound significance for several reasons, encompassing a thorough comprehension of its utilization patterns, including frequency, indications, and outcomes across diverse patient demographics [1]. A deeper understanding of the etiology of NS-RCT notably advances evidence-based practices in preventive treatment by enabling the identification of risk factors and preventive measures, and facilitating the development of predictive models. This knowledge aids in informing public health policies [2].

A previous study emphasized the benefits of understanding risk factors of the disease for developing preventive measures [2]. However, there are few recent studies on the etiology of NS-RCT and its risk factors. This is particularly concerning in the context of understanding the etiology of NS-RCT, because it is essential for designing targeted oral health prevention programs and identifying measures to mitigate the need for invasive and costly procedures, such as NS-RCT [3].

Previous studies found that the most common NS-RCT etiology was dental caries [3–5]. However, several studies on immature teeth found that traumatic injury was the predominant etiology [6–8] Other NS-RCT etiologies varied across different studies. Common NS-RCT etiologies studied in previous research included dental caries, traumatic injury, and dens invaginatus (DI). Cracked tooth, defective restoration, old and large restorations, dens evaginatus (DE), periodontal disease, prosthetic retention, and inadequate seal were also identified as NS-RCT etiologies [3–5, 9, 10].

The patients' chief complaint (CC) was also included in etiological studies, with pain being the most common reason for seeking NS-RCT [3, 4, 11]. Teeth requiring NS-RCT exhibit a wide range of signs and symptoms, including pain, sensitivity, sinus tracts, and swelling [12]. However, some teeth requiring NS-RCT might not exhibit any symptoms.

Previous studies conducted a comprehensive collection of demographic data concerning patients undergoing NS-RCT. This data encompassed variables, e.g., sex, age, and specific details about the treated tooth, including dental arch, tooth type, and pulp and periapical diagnoses. Notably, previous studies identified the permanent mandibular first molar as the most frequently treated tooth [13–19], attributed to its early eruption into the oral cavity, thereby heightening its susceptibility to dental caries [10]. There have been studies on the etiology of NS-RCT revealing diverse causes in various countries, including Germany [9], Jordan [10], Denmark [4], Argentina [5], and Sweden [3], however none in Thailand. Moreover, an in-depth analysis of the association between NS-RCT etiologies and their contributing factors was lacking in these earlier investigations. The use of recall questionnaire methods in most studies has raised concerns about the accuracy of the data due to recall bias. Moreover, previous studies overlooked the collection of specific information, such as caries site and trauma type. A more detailed understanding of these factors is essential for developing effective prevention plans.

Considering the demographic shift towards an aging society in Thailand, which will lead to an increased demand for NS-RCT, the aim of this study was to investigate the prevalence of the NS-RCT etiologies in a Thai population and the association between the NS-RCT etiology and risk factors.

Materials and methods

The study was approved by The Human Research Ethics Committee of the Faculty of Dentistry Chulalongkorn University, Thailand (#HREC-DCU 2023–025). The manuscript was prepared according to the STROBE checklist and statement.

The sample size calculation was performed using G*power (Version 3.1.9.2; Universität Kiel, Kiel, Germany) and estimated based on a previous study [4]. Using an alpha = 0.05 and 80% power, we added a 20% compensation for error, resulting in an estimated 1500 samples.

This cross-sectional observational study examined the NS-RCT etiologies and contributing factors using radiographs and patient dental records. This retrospective study's data were collected from the census. The inclusion criteria were Thai-nationality patients who received NS-RCT from 2019–2023 at the undergraduate and postgraduate Endodontics clinics at the Faculty of Dentistry, Chulalongkorn University, Thailand. The types of NS-RCT in this study comprised conventional root canal treatment, vital pulp therapy, regenerative endodontics, and apexification [20, 21]. Each patient was assigned a unique identification number, and the data were manually entered into a Microsoft Excel spreadsheet. Tooth number was assigned according to the FDI World Dental Federation notion [22].

The exclusion criteria were:

- Unavailability of the treatment record or radiograph
- No etiology of pulp injury specified in the treatment record.
- The information from the treatment record and radiograph were not relevant.

Two examiners, a 10-years experienced endodontist and a postgraduate endodontic student, simultaneously reviewed the same treatment records and radiographs. Each patient was registered and multiple variables: sex, age, tooth number, arch, chief complaints, pulp and periapical diagnosis, treatment causes, and type of treatment were recorded. The information of the specific tooth: caries site, type of restoration, restoration site, type of trauma, periodontal condition, stage of root development [23] and periapical lesion were also examined. Intra-observer agreement was tested one month after data collection was completed by two examiners who simultaneously reviewed 100 randomly selected treatment records and radiographs.

The radiographs were displayed on a Dell OptiPlex 7490 All-in-One 23.8-inch Full High Definition 16:9 ratio monitor with a screen resolution set at 1920 × 1080 pixels, and the periapical lesion size was measured using the ruler tool in the INFINIT PACS program (INFINIT Healthcare, Seoul, South Korea), by recording the largest diameter of each lesion.

A flow chart of the recruitment procedure is presented in Fig. 1. The etiological terms used for data collection in this study were the tooth conditions that cause pulp disease, including irreversible pulpitis and pulp necrosis, except for intentional RCT. The etiological terms for data collection were:

- **Non-carious cervical lesions (NCCLs):**
  - Deep cervical lesions on the root surface without the presence of caries or bacterial association, including abrasion and abfraction [24] that caused irreversible pulpitis and pulp necrosis.
- **Old and large restoration:**
  - An extensive dental restoration reaching the inner 1/3 of dentine [25], which includes fillings, onlays, and inlays that exhibit good clinical quality with possible microleakage or a thin layer of dentin overlying the pulp that caused irreversible pulpitis and pulp necrosis.
- **Defective restoration:**
  - A restored tooth with identifiable flaws in the dental restoration that caused irreversible pulpitis and pulp necrosis.
- **Iatrogenic Pulpitis:**
  - Pulpitis resulting from tooth preparation for crown placement, where factors, such as mechanical or chemical stress, during the preparation and other clinical procedures led to inflammation of the dental pulp. The restoration is in good condition.
- **Iatrogenic exposed pulp:**
  - An iatrogenic event occurring unintentionally during tooth preparation or caries removal, resulting in a dental pulp exposure.
- **Periodontal disease:**
  - A tooth with periodontal disease and normal tooth structure, that caused irreversible pulpitis and pulp necrosis without other historical associations with pulp diseases, such as traumatic injuries.
- **Autotransplantation:**
  - A donor tooth in autotransplantation, where pulp disease was expected or occurred after extraction from the donor site.
- **Intentional RCT**:
  - Normal pulp, or doubtful pulp health prior to restorative procedures, with the possibility of pulp disease after restoring a tooth.

Other etiologies of NS-RCT, such as dental caries, attrition, traumatic injury, traumatic occlusion, cracked tooth, fractured cusp, DE, DI, erosion, external cervical root resorption, and external root resorption in this study were conditions that caused pulp disease, including irreversible pulpitis and pulp necrosis.

Statistical methods

The analyses were performed using IBM SPSS Statistics version 22.0(IBM). Cohen's Kappa coefficient was computed to assess intra-rater reliability for qualitative data, and the Intraclass Correlation Coefficient (ICC) was computed to assess the intra-rater reliability for the quantitative data. The intra-reliability rates were 0.922 for qualitative data, demonstrating almost perfect agreement and 1 for quantitative data, demonstrating absolute agreement [26].

To analyze the association between the NS-RCT etiologies and patients and tooth-related dependent variables, statistical analysis was performed using univariate logistic regression followed by multivariate logistic regression. The factors with a *P-value* less than 0.05 in the univariate model were included in the multiple logistic regression. A *P- value* < 0.05 was considered a significant difference.

Results

Out of 1694 inspected teeth, 1500 teeth met the inclusion criteria. Seventy-nine cases were excluded due to unavailable treatment records, 112 cases were unable to determine NS-RCT etiologies, and 3 cases with irrelevant information (Fig. 1). The demographic and clinical data were analyzed. The sample predominantly consisted of female patients (59.1%) compared with male patients (40.9%). The age range of cases was 7–91 years, with a calculated mean age of 48.56 years. The most common age group for NS-RCT was 61–70 years (24.5%) (Table 1).

NS-RCT of the maxillary teeth accounted for 52% of cases, while that of the mandibular teeth comprised 48%. Regarding specific tooth type, the mandibular first molar was the most frequently treated tooth (13.9%), followed by the maxillary first molar (9.9%) and mandibular second premolar (9.7%) (Table 2). Notably, tooth number 46 (7.1%), 36 (6.8%), and 35 (5.4%) were the most treated in descending order.

The chief complaints for patients seeking NS-RCT were pain (41.8%), followed by instances where dental examination precipitated the need for NS-RCT (27.3%) and sensitivity (7.1%).

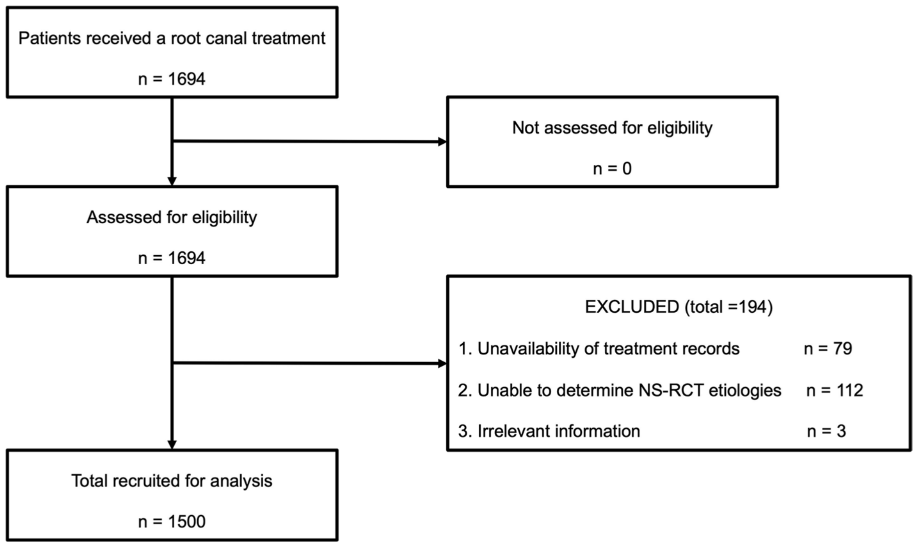

Fig. 1 Study flow chart

The pulpal and periapical diagnoses of NS-RCT teeth were identified. Pulp necrosis was the predominant diagnosis (56.6%), followed by asymptomatic irreversible pulpitis (16.2%), and symptomatic irreversible pulpitis (15.3%). For periapical diagnosis, asymptomatic apical periodontitis was the most prevalent (39.5%), followed by symptomatic apical periodontitis (27.4%), and normal apical tissues (15.6%).

The size of periapical lesions in teeth requiring NS-RCT ranged from 0–20 mm, with a mean size of 5.38 mm. However, most of the teeth requiring NS-RCT exhibited no periapical lesions (18.1%) (Table 3).

The primary etiology leading to the need for NS-RCT was dental caries (53.7%). Other significant causes included old and large restorations (7.9%), attrition (5.9%), intentional NS-RCT (5.4%), and traumatic injury (5.3%). Conversely, external root resorption was the least common cause, comprising 0.1% of cases (Table 1).

When examining the caries location, the most frequently affected site was occlusal (32.6%), distal (31.6%) and mesial (17.2%) surfaces (Table 4).

The most common type of trauma identified was unknown (31.3%), followed by uncomplicated crown fracture (17.5%), complicated crown fracture (16.3%), and subluxation (11.3%) (Table 5). The causes of traumatic injuries were identified in 41.3% of the trauma cases, comprising falls (46.9%), motorcycle accidents (40.6%), sports-related incidents (boxing and skateboarding) (6.3%), and trauma resulting from surgical treatment (6.3%).

In cases requiring NS-RCT, most teeth exhibited mature roots, comprising 98.1% of the cases. Conversely, teeth with immature roots were relatively rare, accounting for only 1.9% of the cases. The leading cause of NS-RCT in mature teeth was dental caries (54.1%), old and large restorations (8%), attrition (6%), intentional root canal treatment (5.5%), and traumatic injury (5%). Conversely, when examining immature teeth, the NS-RCT causes were different from the overall cases. The predominant NS-RCT etiologies in immature teeth were DE (32.1%), dental caries (28.6%), traumatic injury (21.4%), and DI (14.3%). This revealed a distinct pattern of etiologies in immature teeth compared with mature teeth.

Association between etiology and tooth type

The tooth type that most commonly required NS-RCT was the mandibular first molar, with dental caries as the predominant etiology (67.5%), particularly affecting the occlusal (45.5%), distal (30.9%), and mesial (10.8%) surfaces. Additional etiologies of NS-RCT in mandibular first molar included old and large restorations (11%) and the presence of a cracked tooth (6.2%). The second most common tooth for NS-RCT was found in the maxillary first molar, where dental caries was also the primary etiological factor for NS-RCT (66.2%), particularly affecting the occlusal (42.9%), mesial (24.9%), and distal surfaces (21.7%). Old and large restorations (11.5%) and iatrogenic pulpitis (7.4%) were subsequent etiologies. For the mandibular second premolar, ranking third in NS-RCT frequency, dental caries (48.6%) remained the primary cause, particularly affecting the occlusal (34.4%), distal (30.8%), and mesial (18.1%) surfaces. DE on the mandibular second premolar contributed to the etiology of NS-RCT at 11.6% of cases and iatrogenic pulpitis at 8.9% (Table 2).

Table 1 Distribution of the number of root canal treated teeth in relation to the age of the patient and the etiology of the root canal treatment. (The percentage of NS-RCT etiology in each age group)

Age(years)/ Cause %(n)	1. caries	2.Old/ large R	3. Attri	4. Inten	5.Inj	6.Iatro pulpitis	7.Occ	8. Crack	9.Fx cusp	10. NCCL	11. DE	12. Defect R	13. Perio	14.DI	15. Eros	16. Autotrans	17.Iatro exposed	18. ECR	19. ERR	Total	% Age
7–12	65.9 (29)	0	0	0	20.5 (9)	0	0	0	0	0	11.4 (5)	0	0	2.3 (1)	0	0	0	0	0	44	2.9
13–20	73.6 (92)	3.2 (4)	0	0	9.6 (12)	0	0.8 (1)	0.8 (1)	0	0	7.2 (9)	0.8 (1)	0	2.4 (3)	0	1.6 (2)	0	0.8 (1)	0	125	8.3
21–30	66.3 (132)	9 (18)	0	0.5 (1)	10.6 (21)	0.5 (1)	1 (2)	1 (2)	0	0	3.5 (7)	0.5 (1)	0	1.5 (3)	0	1.5 (3)	0.5 (1)	0	0	199	13.3
31–40	62.3 (86)	7.2 (10)	0	3.6 (5)	5.8 (8)	0	2.2 (3)	7.2 (10)	0.7 (1)	1.4 (2)	2.2 (3)	0	1.4 (2)	2.2 (3)	0	1.4 (2)	0.7 (1)	0	1.4 (2)	138	9.2
41–50	56.6 (94)	12 (20)	1.8 (3)	0.6 (1)	6.6 (11)	4.8 (8)	3 (5)	4.2 (7)	3 (5)	3 (5)	0	2.4 (4)	1.8 (3)	0	0	0	0.6 (1)	0	0	166	11.1
51–60	44.7 (136)	9.9 (30)	8.6 (26)	7.9 (24)	2.6 (8)	5.3 (16)	5.6 (17)	3 (9)	3.9 (12)	3.6 (11)	0	2.3 (7)	1 (3)	0	1.3 (4)	0	0.3 (1)	0	0	304	20.3
61–70	45.1 (166)	6.3 (23)	10.6 (39)	9 (33)	2.4 (9)	11.7 (43)	4.1 (15)	1.6 (6)	3 (11)	3 (11)	0	1.1 (4)	1.1 (4)	0	1.1 (4)	0	0.8 (3)	0.5 (2)	0	368	24.5
71–80	46.2 (67)	9 (13)	13.8 (20)	9 (13)	1.4 (2)	4.8 (7)	2.8 (4)	2.1 (3)	3.4 (5)	2.1 (3)	0	2.1 (3)	0.7 (1)	0	1.4 (2)	0	0	1.4 (2)	0	145	9.7
81 +	27.3 (3)	9.1 (1)	0	36.4 (4)	0	9.1 (1)	9.1 (1)	0	18.2 (2)	0	0	0	0	0	0	0	0	0	0	11	0.7
Total	805	119	88	81	80	76	48	38	36	32	24	20	13	10	10	7	7	5	2	1500	100%
% Cause	53.7	7.9	5.9	5.4	5.3	5.1	3.2	2.5	2.4	2.1	1.6	1.3	0.9	0.7	0.7	0.5	0.5	0.3	0.1	100%	

Abbreviations: %Age The percentage of NS-RCT teeth in each age group, *Old/large R* Old and large restoration without any defects, *Attri* Attrition, *Inten* Intentional root canal treatment, *Inj* Traumatic injury, *Iatro pulpitis* Iatrogenic pulpitis, *Occ* Traumatic occlusion, *Crack* Cracked tooth , *Fx cusp* Fractured cusp, *NCCL* Non-carious cervical lesion, *DE* Dens evaginatus, *Defect R* Defective restoration, *Perio* Periodontal disease, *DI* Dens invaginatus, *Eros* Erosion, *Autotrans* Autotransplantation, *Iatro exposed* Iatrogenic pulp exposure, *ECR* External cervical resorption

Table 2 Distribution of the number of root canal treated teeth in relation to tooth type and the etiology of the root canal treatment. (The percentage of NS-RCT etiology in each tooth type)

Tooth/ Cause %(n)	1. caries	2.Old/ large R	3.Attri	4. Inten	5.Inj	6.Iatro pulpitis	7.Occ	8. Crack	9.Fx cusp	10. NCCL	11.DE	12. Defect R	13. Perio	14.DI	15. Eros	16. Autotrans	17.Iatro exposed	18. ECR	19. ERR	Total	%Tooth type	Rank
Max Central incisor	36.7 (40)	6.4 (7)	3.7 (4)	0.9 (1)	36.7 (40)	3.7 (4)	4.6 (5)	0	2.8 (3)	0	0	0.9 (1)	0	1.8 (2)	0	0	0	0.9 (1)	0	109	7.3	6
Max Lateral incisor	47.9 (45)	8.5 (8)	2.1 (2)	8.5 (8)	13.8 (13)	4.3 (4)	3.2 (3)	1.1 (1)	1.1 (1)	0	0	1.1 (1)	0	8.5 (8)	0	0	0	0	0	94	6.3	
Max Canine	50 (44)	2.3 (2)	11.4 (10)	5.7 (5)	5.7 (5)	2.3 (2)	10.2 (9)	0	2.3 (2)	3.4 (3)	0	0	1.1 (1)	0	2.3 (2)	0	1.1 (1)	2.3 (2)	0	88	5.9	
Max 1 PM	60.2 (65)	12 (13)	1.9 (2)	3.7 (4)	0	3.7 (4)	1.9 (2)	0.9 (1)	7.4 (8)	5.6 (6)	0	1.9 (2)	0.9 (1)	0	0	1.9 (2)	0	0	0	108	7.2	
Max 2 PM	57.7 (79)	10.2 (14)	0.7 (1)	8 (11)	0.7 (1)	2.9 (4)	1.5 (2)	0.7 (1)	5.8 (8)	5.1 (7)	2.2 (3)	2.2 (3)	0	0	0	0	1.5 (2)	0	0.7 (1)	137	9.1	4
Max 1 M	66.2 (98)	11.5 (17)	0	3.4 (5)	0	7.4 (11)	1.4 (2)	3.4 (5)	2.7 (4)	0.7 (1)	0	0.7 (1)	2.7 (4)	0	0	0	0.7 (1)	0	0	148	9.9	2
Max 2 M	62.5 (60)	9.4 (9)	1 (1)	6.3 (6)	0	8.3 (8)	2.1 (2)	3.1 (3)	2.1 (2)	0	0	0	4.2 (4)	0	0	0	1 (1)	0	0	96	6.4	
Max 3 M	20 (1)	20 (1)	0	0	0	20 (1)	0	0	0	0	0	0	0	0	0	80 (4)	0	0	0	5	0.3	
Mand Central incisor	14.1 (9)	4.7 (3)	34.4 (22)	1.6 (1)	23.4 (15)	1.6 (1)	14.1 (9)	0	3.1 (2)	0	0	0	0	0	0	0	0	0	0	64	4.3	
Mand lateral incisor	19.4 (7)	0	50 (18)	5.6 (2)	16.7 (6)	0	0	0	0	0	0	2.8 (1)	0	0	0	0	0	0	0	36	2.4	
Mand Canine	37.2 (16)	4.7 (2)	25.6 (11)	11.6 (5)	0	2.3 (1)	4.7 (2)	0	2.3 (1)	2.3 (1)	0	0	0	0	4.7 (2)	0	0	2.3 (1)	0	43	2.9	
Mand 1 PM	51.2 (41)	2.5 (2)	3.8 (3)	11.3 (9)	0	7.5 (6)	1.3 (1)	1.3 (1)	1.3 (1)	8.8 (7)	5 (4)	3.8 (3)	1.3 (1)	0	3.8 (3)	0	0	1.3 (1)	0	80	5.3	
Mand 2 PM	48.6 (71)	5.5 (8)	4.8 (7)	8.2 (12)	0	8.9 (13)	2.7 (4)	0.7 (1)	1.4 (2)	4.8 (7)	11.6 (17)	2.1 (3)	0	0	0.7 (1)	0	0.7 (1)	0	0	146	9.7	3
Mand 1 M	67.5 (141)	11 (23)	2.4 (5)	2.4 (5)	0	4.8 (10)	1 (2)	6.2 (13)	1 (2)	0	0	1.9 (4)	0.5 (1)	0	0.5 (1)	0	0.5 (1)	0	0.5 (1)	209	13.9	1
Mand 2 M	64.6 (84)	7.7 (10)	1.5 (2)	4.6 (6)	0	5.4 (7)	3.8 (5)	9.2 (12)	0	0	0	0	0.8 (1)	0	0.8 (1)	0	0	0	0	130	8.7	5
Mand 3 M	57.1 (4)	0	0	14.3 (1)	0	0	0	0	0	0	0	14.3 (1)	0	0	0	14.3 (1)	0	0	0	7	0.5	
Total	805	119	88	81	80	76	48	38	36	32	24	20	13	10	10	7	7	5	2	1500	100%	
% Cause	53.7	7.9	5.9	5.4	5.3	5.1	3.2	2.5	2.4	2.1	1.6	1.3	0.9	0.7	0.7	0.5	0.5	0.3	0.1	100%		

Abbreviations: *%Age* The percentage of NS-RCT teeth in each age group, *Old/large R* Old and large restoration without any defects, *Attri* Attrition, *Inten* Intentional root canal treatment, *Inj* Traumatic injury, *Iatro pulpitis* Iatrogenic pulpitis, *Occ* Traumatic occlusion, *Crack* Cracked tooth , *Fx cusp* Fractured cusp, *NCCL* Non-carious cervical lesion, *DE* Dens evaginatus, *Defect R* Defective restoration, *Perio* Periodontal disease, *DI* Dens invaginatus, *Eros* Erosion, *Autotrans* Autotransplantation, *Iatro exposed* Iatrogenic pulp exposure, *ECR* External cervical resorption

Table 3 Distribution of the periapical lesion sizes

Periapical lesion size (mm)	Frequency (teeth)	Percentage
0	271	18.1
>0–1	244	16.3
>1–2	28	1.9
>2–3	150	10.0
>3–4	216	14.4
>4–5	149	9.9
>5–6	155	10.3
>6–7	80	5.3
>7–8	61	4.1
>8–9	56	3.7
>9–10	27	1.8
>10–11	20	1.3
>11–12	11	0.7
>13–14	10	0.7
>14–15	7	0.5
>15–16	3	0.2
>16–17	6	0.4
>17–18	3	0.2
>18–19	1	0.1
>19–20	2	0.1

Table 4 Distribution of the number of root canal-treated teeth due to dental caries and the affected carious sites

Carious sites	n	%
Occlusal	480	32.6
Distal	465	31.6
Mesial	254	17.2
Lingual	131	8.9
Buccal	106	7.2
Incisal	37	2.5
Total	1473	100

Table 5 Distribution of the number of root canal-treated teeth due to traumatic injuries and the types of traumatic injuries

Trauma types	n	%
Unknown	25	31.3
Uncomplicated crown fracture	14	17.5
Complicated crown fracture	13	16.3
Subluxation	9	11.3
Lateral luxation	8	10
Extrusive luxation	6	7.5
Intrusive luxation	5	6.3
Concussion	2	2.5
Complicated crown-root fracture	1	1.3
Root fracture	1	1.3

Association between etiology and age group

The most common age group for NS-RCT was 61–70 years (24.5%), with the primary etiologies being dental caries (45.1%), iatrogenic pulpitis (11.7%), and attrition (10.6%). The second most common age group for NS-RCT was 51–60 years (20.3%), where dental caries (44.7%), old and large restorations (9.9%), and attrition (8.6%) were the predominant etiologies. In the third most common age group for NS-RCT, 21–30 years (13.3%), dental caries (66.3%), traumatic injury (10.6%), and old and large restoration (9%) were the primary etiologies (Table 1).

Type of treatment

The most frequent type of overall treatment was conventional RCT (95.4%), partial pulpotomy (1%) and apexification (0.9%). When examining the type of treatment for mature teeth, conventional root canal treatment (96.7%) was the most frequently provided, followed by partial pulpotomy (1%) and full pulpotomy (0.6%). However, for immature teeth, the most common treatment procedures were apexification (35.7%), followed by conventional root canal treatment (25%), and regenerative treatment (17.9%). In immature teeth, the choice of treatment varied based on the stage of root development and various patient factors (Table 6).

Univariate logistic regression

The univariate logistic regression analyses revealed the significant risk factors as displayed in Table 7. Following analysis of all factors within each etiology from the univariate analysis, NS-RCT due to caries etiology was significantly associated with various factors, including specific carious lesion sites and specific teeth, such as the mandibular first molar, maxillary first molar, and mandibular second molar, which demonstrated an increased likelihood of requiring NS-RCT due to caries. Furthermore, males and younger age were identified as significant risk factors in caries etiology. Other etiologies with significant associated factors are also presented in Table 7. Further assessment of these factors was conducted using multivariate logistic regression analysis.

Multivariate logistic regression

Following the identification of significant factors related to NS-RCT etiology in the univariate logistic regression, we employed multiple logistic regression to identify the most influential factors and calculate their odds ratios, indicating the strength of their associations (Table 7).

Table 6 Distribution of the stage of root development and the type of treatment

Stage of root development [23]	Apexification	NS-RCT	Regenerative endodontic	VPT	DI/DE prevent	Total (%)
1	-	-	-	-	-	0
2	-	-	-	-	-	0
3	-	-	-	-	-	0
4	3	-	3	-	-	6 (21.4)
5	5	1	2	2		10 (35.7)
6	2	6	-	2	2	12 (42.9)
Total (%)	10 (35.7%)	7 (25%)	5 (17.9%)	4 (14.3)	2 (7.1%)	28 (100%)

Dental caries

Multiple logistic regression indicated that dental caries on the distal (Odds ratio (OR) = 13.16; $P < 0.001$; 95% confidence interval (Cl): 9.31–18.60), mesial (OR = 6.32; $P < 0.001$; 95%Cl: 4.30–9.30), occlusal (OR = 5.28; $P < 0.001$; 95%Cl 3.72–7.01), lingual (OR = 4.30; $P < 0.001$; 95%Cl: 2.47–7.47), buccal (OR = 3.73; $P < 0.001$; 95%Cl: 2.04–6.85), and incisal (OR = 2.86; $P = 0.021$; 95%Cl: 1.17–7.01) surfaces significantly increased the likelihood of requiring NS-RCT due to caries.

Specific teeth were found to be associated with an increased risk for NS-RCT due to caries, with tooth 17 (OR = 3.10; $P = 0.005$; 95%Cl: 1.41–6.82), tooth 26 (OR = 2.56; $P = 0.011$; 95%Cl: 1.24–5.32), and tooth 37 (OR = 2.24; $P = 0.018$; 95%Cl: 1.15–4.37) demonstrating significant associations. Furthermore, our analysis revealed that older age was associated with a 2% lower likelihood of NS-RCT due to caries, suggesting that younger individuals were more susceptible to NS-RCT due to carious lesions (OR = 0.98; $P < 0.001$; 95%Cl: 0.98 to 0.99) (Fig. 2a).

Attrition

Tooth types with a significant risk for NS-RCT due to attrition compared with other types were mandibular lateral incisors (OR = 35.44; $P < 0.001$; 95%Cl: 14.91–84.25), mandibular central incisors (OR = 16.28; $P < 0.001$; 95%Cl: 7.86–33.74), mandibular canines (OR = 9.34; $P < 0.001$; 95%Cl: 3.97–21.98), and maxillary canines (OR = 2.60; $P = 0.024$; 95%Cl: 1.13–6.04). Moreover, males exhibited a 4.03-fold higher risk of developing attrition, leading to RCT compared with females (OR = 4.03; $P < 0.001$; 95%Cl: 2.29–7.08). Additionally, older age was identified as a significant risk factor, with a 1.07-fold elevation in risk (OR = 1.07; $P < 0.001$; 95%Cl: 1.04–1.09) (Fig. 2b).

Intentional NS-RCT

Older age was identified as a significant risk factor for intentional NS-RCT (OR = 1.05; $P < 0.001$; 95%Cl: 1.03–1.07) (Fig. 2c).

Traumatic injuries

Tooth types with a significant risk for NS-RCT due to traumatic injuries compared with others types were mandibular central incisors (OR = 115.98; $P < 0.001$; 95%Cl: 37.98–354.11), maxillary central incisor (OR = 97.12; $P < 0.001$; 95%Cl: 36.72–256.85), mandibular lateral incisors (OR = 71.03; $P < 0.001$; 95%Cl: 19.49–258.91), and maxillary lateral incisors (OR = 29.78; $P < 0.001$; 95%Cl: 10.20–86.91). Furthermore, our analysis revealed that older age was associated with a 4% lower likelihood of NS-RCT due to traumatic injuries, suggesting that younger individuals were more susceptible to NS-RCT due to traumatic injuries (OR = 0.96; $P < 0.001$; 95%Cl: 0.95–0.97).

Iatrogenic pulpitis

Elderly individuals are at higher risk of encountering iatrogenic errors resulting in pulpitis that required NS-RCT (OR = 1.05; $P < 0.001$; 95%Cl: 1.03–1.07).

Traumatic occlusion

Tooth types with a significant risk for NS-RCT due to traumatic occlusion compared with other types were mandibular central incisors (OR = 5.97; $P < 0.001$; 95%Cl: 2.67–13.40) and maxillary canines (OR = 3.95; $P < 0.001$; 95%Cl: 1.78–8.80). Additionally, older age was also identified as a significant risk factor, with a 1.02-fold elevation in risk associated with older age (OR = 1.02; $P = 0.024$; 95%Cl: 1.00–1.04) (Fig. 2d).

Table 7 Univariate and multivariate logistic regression analysis for the association between the etiology of the root canal treatment and other factors

Etiologies	Univariable model			Multivariable model		
Factors	**OR**	**95%CI**	***P* value**	**OR**	**95%CI**	***P* value**
Dental caries						
Caries at distal	12.21	9.19, 16.22	< .001	13.16	9.31, 18.60	< 0.001*
Caries at mesial	5.16	3.79, 7.03	< .001	6.32	4.30, 9.30	< 0.001*
Caries at occlusal	12.78	9.64, 16.94	< .001	5.28	3.72, 7.01	< 0.001*
Caries at lingual	5.00	3.24, 7.72	< .001	4.30	2.47, 7.47	< 0.001*
Caries at buccal	3.90	2.51, 6.07	< .001	3.73	2.04, 6.85	< 0.001*
Caries at incisal	3.00	1.52, 5.92	0.002	2.86	1.17, 7.01	0.021
Mandibular first molar	1.96	1.44, 2.67	< .001	#		#
Maxillary first molar	1.79	1.25, 2.56	0.001	#		#
Mandibular second molar	1.64	1.13, 2.39	0.009	#		#
Mandibular canine	0.50	0.27, 0.94	0.031	#		#
Maxillary central incisor	0.47	0.32, 0.71	< .001	#		#
Mandibular lateral incisor	0.20	0.09, 0.46	< .001	#		#
Mandibular central incisor	0.13	0.07, 0.27	< .001	#		#
Tooth number 17	1.81	1.01,3.27	0.048	3.10	1.41, 6.82	0.005*
Tooth number 26	2.81	1.66, 4.77	< .001	2.56	1.24, 5.32	0.011*
Tooth number 37	1.66	1.01, 2.73	0.045	2.24	1.15, 4.37	0.018*
Tooth number 46	1.85	1.22, 2.81	0.004	1.62	0.89, 2.97	0.118
Tooth number 36	1.88	1.23, 2.89	0.004	1.36	0.74, 2.50	0.318
Male	1.43	1.16, 1.75	< .001	0.78	0.58, 1.06	0.109
Age	0.98	0.97, 0.98	< .001	0.98	0.98, 0.99	< 0.001*
Attrition						
Mandibular lateral incisor	19.91	9.93, 39.94	< 0.001	35.44	14.91, 84.25	< .001*
Mandibular central incisor	10.87	6.14, 19.26	< 0.001	16.28	7.86, 33.74	< .001*
Mandibular canine	6.16	2.99, 12.69	< 0.001	9.34	3.97, 21.98	< .001*
Maxillary canine	0.03	1.09, 4.40	0.027	2.60	1.13, 6.04	0.024*
Mandibular first molar	0.36	0.14, 0.89	0.027	1.54	0.56, 4.27	0.41
Maxillary second premolar	0.11	0.02, 0.78	0.027	0.39	0.05, 2.98	0.362
Male	5.06	3.06, 8.36	< 0.001	4.03	2.29, 7.08	< .001*
Age	1.08	1.06, 1.10	< 0.001	1.07	1.04, 1.09	< .001*
Intentional NS-RCT						
Mandibular first premolar	2.37	1.14, 4.94	0.021	1.68	0.79, 3.55	0.177
Mandibular first molar	0.39	0.16, 0.98	0.045	0.60	0.24, 1.54	0.291
Age	1.05	1.04, 1.07	< 0.001	1.05	1.03, 1.07	< 0.001*
Traumatic injuries						
Mandibular central incisor	6.46	3.44, 12.12	< .001	115.98	37.98, 354.11	< .001*
Maxillary central incisor	19.58	11.87, 32.30	< .001	97.12	36.72, 256.85	< .001*
Mandibular lateral incisor	3.76	1.52, 9.31	0.004	71.03	19.49, 258.91	< .001*
Maxillary lateral incisor	3.21	1.70, 6.05	< .001	29.78	10.20, 86.91	< .001*
Maxillary second premolar	0.12	0.04, 0.87	0.035	1.53	0.18, 13.24	0.70
Age	0.96	0.95, 0.97	< 0.001	0.96	0.95, 0.97	< .001*
Iatrogenic pulpitis						
Mandibular second premolar	2.00	1.07, 3.74	0.029	1.79	0.95, 3.37	0.74
Age	1.05	1.03, 1.07	< 0.001	1.05	1.03, 1.07	< 0.001*
Traumatic occlusion						
Mandibular central incisor	5.86	2.71, 12.70	< .001	5.97	2.67, 13.40	< .001*
Maxillary canine	4.01	1.88, 8.57	< .001	3.95	1.78, 8.80	< .001*
Age	1.03	1.01, 1.05	0.001	1.02	1.00, 1.04	0.024*
Cracked tooth						
Mandibular second molar	5.26	2.59, 10.69	< 0.001	8.98	4.01, 20.13	< 0.001*

Table 7 (continued)

Etiologies	Univariable model			Multivariable model		
Factors	**OR**	**95%CI**	***P* value**	**OR**	**95%CI**	***P* value**
Mandibular first molar	3.36	1.69, 6.68	< 0.001	5.86	2.68. 12.82	< 0.001*
Fractured cusp						
Maxillary second premolar	2.96	1.32, 6.62	0.008	4.40	1.87, 10.35	< 0.001*
Maxillary first premolar	3.90	1.73,8.77	0.001	4.12	1.75, 9.68	0.001*
Age	1.05	1.02, 1.07	< 0.001	1.05	1.02, 1.07	< 0.001*
NCCL						
Maxillary first premolar	3.09	1.24, 7.68	0.015	5.50	2.12, 14.30	< 0.001*
Mandibular first premolar	5.35	2.24, 12.78	< 0.001	4.87	1.78, 13.34	0.002*
Maxillary second premolar	2.88	1.22, 6.79	0.016	1.03	1.01, 1.05	0.19
Age	1.03	1.01, 1.06	0.005	7.55	2.85, 19.99	< 0.001*
Dens evaginatus						
Mandibular first premolar	3.68	1.23, 11.05	0.02	223.38	31.98, 1560.48	< 0.001*
Mandibular second premolar	25.36	10.33, 62.28	< 0.001	207.11	46.78, 917.00	< 0.001*
Age	0.89	0.85, 0.93	< 0.001	0.83	0.77, 0.90	< 0.001*
Defective restoration						
Mandibular third molar	12.93	1.48, 112.66	0.020	10.88	1.11, 106.70	0.040*
Restoration at Buccal	3.22	1.27, 8.17	0.014	2.60	0.99, 6.82	0.053
Restoration at Distal	2.56	1.06, 6.22	0.038	2.20	0.88, 5.49	0.09
Periodontal disease						
Maxillary second molar	6.74	2.04, 22.30	0.002	10.88	2.87, 41.20	< 0.001*
Maxillary first molar	4.15	1.26, 13.63	0.019	6.95	1.85, 26.18	0.004*
Dens invaginatus						
Maxillary lateral incisor	65.30	13.66, 312.23	< .001	1.09	0.33, 3.58	0.893
Age	0.93	0.89, 0.97	0.001	1.03	1.01, 1.05	0.001*
Erosion						
Mandibular canine	8.84	1.82, 42.91	0.007	8.19	1.51, 44.34	0.015*
Mandibular first premolar	7.87	2.00, 31.01	0.003	7.66	1.77, 33.20	0.007*
Age	1.07	1.01, 1.12	0.014	1.06	1.00, 1.12	0.046*
Autotransplantation						
Maxillary third molar	198.67	27.08, 1457.73	< 0.001	599.92	36.63, 9825.72	< 0.001*
Mandibular third molar	41.31	4.29, 397.32	0.001	345.59	14.20, 8409.03	< 0.001*
Tooth number 18	298.20	34.82, 2553.95	< 0.001	##	##	##
Age	0.93	0.89, 0.98	0.008	0.89	0.82, 0.98	0.013*
External cervical resorption						
Maxillary canine	10.92	1.80, 66.24	0.009	N/A	N/A	N/A

This table displays the factors that achieved statistical significance within the univariate model. (*P* value < 0.05)

N/A = The effect of the factors was not analysed because of the small number of cases

* Asterisks indicate significant differences ($p < 0.05$)

In the multivariable model, we specifically calculated the tooth number, while excluding tooth types only in the case of dental caries as the etiology

In the multivariable model, we specifically calculated the tooth types, while excluding tooth number only in the case of autotransplantation as the etiology

Cracked tooth

Tooth types with a significant risk for NS-RCT due to cracked tooth compared with other types were mandibular second molars (OR = 8.98; *P < 0.001*; 95%Cl: 4.01–0.13) and mandibular first molars (OR = 5.86; *P < 0.001*; 95%Cl: 2.68–12.82) (Fig. 2e).

Fractured cusp

Tooth types with a significant risk for NS-RCT due to fractured cusp compared with other types were maxillary second premolars (OR = 4.40; *P < 0.001*; 95%Cl: 1.87–10.35) and maxillary first premolars (OR = 4.12; *P = 0.001*; 95%Cl: 1.75–9.68). Additionally, older age was identified

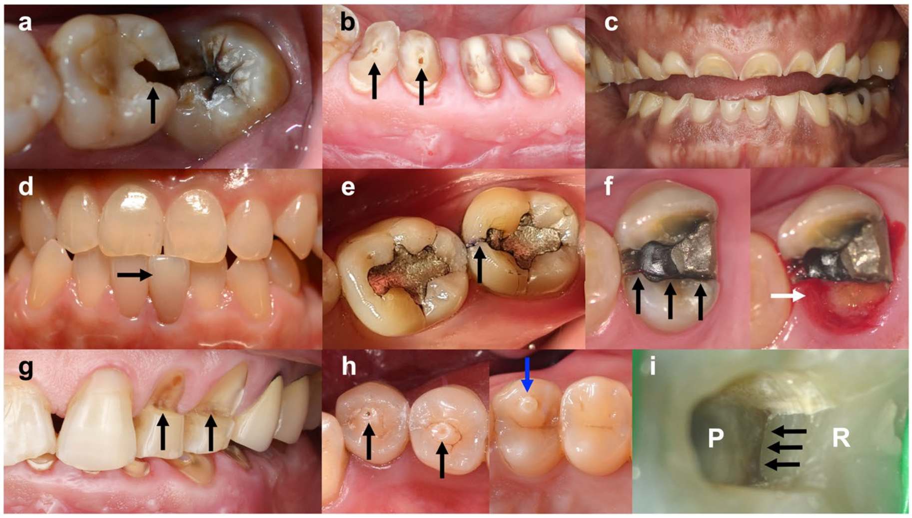

Fig. 2 Representative photographs illustrating different etiologies of NS-RCT. **a**-**e**, **g**, **h** were captured by a digital camera, while Figs. 2(**f**) and (**i**) were captured using an operating microscope (Zeiss Extaro 300) at a magnification of 1.6 (equivalent to 13.6-fold magnification). **a** The arrow indicates D caries on the mandibular second molar due to food impaction from the partially erupted mandibular third molar. **b** Arrows indicate mandibular central and lateral incisors with an attrition exposed pulp. **c** A case of swimmer's erosion with an indication for intentional NS-RCT prior to full mouth rehabilitation. **d** Arrow indicates left mandibular central incisor with pulp necrosis due to traumatic occlusion from maxillary central incisors. **e** Arrow indicates a methylene blue stained M crack line in a mandibular second molar. **f** Black arrows indicate the mesio-distal fracture line of the maxillary first premolar with a palatal cusp fracture, while the white arrow indicates the remaining tooth structure after palatal cusp removal. **g** Arrow indicates pulp exposure from labial abfraction of maxillary lateral incisor and canine. **h** Black arrows indicate DE on mandibular premolars, and the blue arrow indicates DE on the maxillary first premolar. **i** Arrows indicate microleakage at the gingival margin of the resin composite restoration with appropriate margins. P indicates the pulp chamber wall, and R indicates the resin composite restoration

as a significant risk factor, with a 1.05-fold elevation in risk associated with older age (OR = 1.05; *P* < *0.001*; 95%Cl: 1.02–1.07) (Fig. 2f).

Non-Carious Cervical Lesion (NCCL)

Tooth types with a significant risk for NS-RCT due to NCCL, compared with other types were maxillary first premolars (OR = 5.50; *P* < *0.001*; 95%Cl: 2.12–14.30) and mandibular first premolars (OR = 4.87; *P* = *0.002*; 95%Cl: 1.78–13.34). Older age was also identified as a strong significant risk factor, with a 7.55-fold elevation in risk associated with older age (OR = 7.55; *P* < *0.001*; 95%Cl: 2.85–19.99) (Fig. 2g).

DE

Tooth types with a significant risk for NS-RCT due to DE compared with other types were mandibular first premolars (OR = 223.38; *P* < *0.001*; 95%Cl: 31.98–1560.48) and mandibular second premolars (OR = 207.11; *P* < *0.001*; 95%Cl: 46.78–917.00). Furthermore, our analysis revealed that older age was associated with a 17% lower likelihood of NS-RCT due to DE, suggesting that younger individuals were more susceptible to NS-RCT because of DE (OR = 0.83; *p* < 0.001; 95%Cl: 0.77–0.90) (Fig. 2h).

Defective restoration

The mandibular third molars were the only tooth type with a significant risk of NS-RCT due to a defective restoration (OR = 10.88; *P* < *0.001*; 95%Cl: 1.11–106.70).

Periodontal disease

Tooth types with a significant risk for NS-RCT due to periodontal disease compared with other types were maxillary second molars (OR = 10.88; *P* < *0.001*; 95%Cl: 2.87–41.20) and the maxillary first molars (OR = 6.95; *P* = *0.004*; 95%Cl: 1.85–26.18).

DI

Older age was the sole significant risk factor, with a 1.03-fold elevation in risk associated with older age (OR = 1.03; *P* = *0.001*; 95%Cl: 1.01–1.05).

Dental erosion

Tooth types with a significant risk for NS-RCT due to erosion compared with other types were mandibular canines (OR = 8.19; *P* = *0.015*; 95%Cl: 1.51–44.34) and mandibular first premolars (OR = 7.66; *P* = *0.007*; 95%Cl: 1.77–33.20). Furthermore, older age was identified as a significant risk factor, with a 1.06-fold elevation in risk associated with older age (OR = 1.06; *P = 0.046*; 95%Cl: 1.00–1.12).

Autotransplantation

Tooth types with a significant risk for NS-RCT due to autotransplantation compared with other types were maxillary third molars (OR = 599.92; *P < 0.001*; 95%Cl: 36.63–9825.72) and mandibular third molars (OR = 345.59; *P < 0.001*; 95%Cl: 14.20–8409.03). Furthermore, our analysis revealed that older age was associated with an 11% lower likelihood of NS-RCT due to autotransplantation, suggesting that younger individuals were more susceptible to NS-RCT because of autotransplantation (OR = 0.89; *P = 0.013*; 95%Cl: 0.82–0.98).

Discussion

The demographic data revealed a diverse sample. In our research, we observed that more women tended to undergo NS-RCT compared with men, aligning with findings from other studies [3, 5, 10, 14, 27–29].

We observed that the most common age range for NS-RCT was 61–70 years, which differs from several earlier studies. In studies conducted from 2000–2010, the prevalent age range was 50–64 years [16, 18, 27]. In studies from 2010–2020, the most common age range was 40–49 years [3, 5, 19]. These studies found that the age of patients seeking endodontic treatment is higher compared with earlier studies. This may be due to several factors, including improved dental care, increased awareness of endodontic procedures, and the aging population retaining their natural teeth longer.

Our study revealed that the primary chief complaint leading patients to NS-RCT was pain (41.8%). This finding is in accordance with previous research by Wigsten [3], and Abbott [11]. We observed that 27.3% of cases required NS-RCT due to dental inspection without any symptoms. These results emphasize the importance of routine dental check-ups for early detection and prevention of pulp and periapical diseases.

This study found that dental caries was the main cause of RCT (53.7%), in line with previous studies [3–5]. Dental caries accounted for the highest percentage of NS-RCT etiology across all age groups, from 7–80 years. This supports the importance of dental caries prevention strategies, from early childhood caries prevention to oral health promotion in adults and the elderly. Additionally, the slow progression of caries without noticeable symptoms underscores the importance of regular oral examinations, including bitewing radiographs, for early diagnosis and treatment [4, 30].

The mandibular first molar was the most frequently treated tooth, consistent with findings from previous studies [3–5, 13–19]. These findings suggest that this tooth is at higher risk of developing caries due to its anatomy and early eruption [10]. The increased retention of molars through indicated NS-RCT, rather than extraction, may be attributed to heightened awareness among patients [3]. Furthermore, teeth 17, 26, and 37 were identified as significant risk factors for NS-RCT due to caries (OR = 3.10, 2.56, 2.24 respectively), emphasizing the need for precautions in first and second molars.

We also focused on dental caries sites that were not analyzed in previous studies. The most affected caries site was the occlusal surface (OR = 5.28), characterized by irregular pits and fissures that increase susceptibility to food impaction. Placing sealants in deep pits and fissures when patients are young can serve as a preventive strategy, alongside continued monitoring of intact sealants. Regarding the second and third most affected caries sites, proximal surfaces, we noted that the distal surface (OR = 13.16) was more than twice as affected as the mesial surfaces (OR = 6.32), suggesting greater difficulty in accessing and cleaning the teeth on the distal surfaces. Regular oral examinations and x-ray bitewings, as recommended by the American Dental Association [30], are crucial for preventing caries progression.

The second most common cause leading to NS-RCT was old and large restorations. This occurs for several reasons. Microleakage, which cannot be seen with the naked eye, may allow bacteria and their byproducts to cause pulp damage [31] (Fig. 2i). To prevent microleakage, moisture control using a rubber dam and adequate adaptation of the restorative material through an incremental technique to minimize shrinkage are recommended [32]. In contrast, when marginal leakage is visible in the clinic or material breakdown is noticed, it is classified as a defective restoration, with 60% being resin composite and 35% amalgam fillings in our study. Furthermore, caries removal or large cavity preparation might cause pulpal inflammation. This inflammation may not show immediate signs, however, over time, it can lead to pulp necrosis, requiring NS-RCT [33].

Iatrogenic pulpitis caused by mechanical and chemical stresses, such as preparation and luting cements, can occur during crown restoration [34]. If there is a preexisting filling in the tooth, it might indicate that the pulp has been compromised due to previous dental caries and restorative treatments [33]. Elderly individuals have an increased risk of iatrogenic pulpitis leading to the need for NS-RCT because they are likely to have had many previous restorative treatments [35]. Age-related changes in the dental pulp, encompassing aging, defensive responses, and pathologic alterations, were also a risk factor in aged dental pulp [36]. Extensive dental restorations, including those without immediate clinical signs, can conceal underlying issues, such as microleakage or stress on the pulp. Over time, these concealed problems may become apparent and require NS-RCT.

The third most common cause leading to NS-RCT was attrition, with males being approximately fourfold more likely than females to develop attrition (OR = 4.03). This difference might be because men tend to have more occlusal load than females [37]. Older age was also identified as a significant risk factor (OR = 1.07). It is noteworthy that although attrition was absent in patients under 40 years, it became more prevalent in individuals over 51 years, consistent with previous studies [38, 39].

In the case of traumatic injury, younger individuals had a higher susceptibility of NS-RCT with an odds ratio of 0.96. This observation aligns with the findings in a previous study [4]. In individuals under the age of 12, traumatic injuries account for 20% of all cases requiring NS-RCT. We identified the maxillary central incisor as the tooth most frequently prone to trauma (36.7%), consistent with the findings of previous studies [5, 10, 40]. Surprisingly, uncomplicated crown fractures were found to lead to pulp necrosis. This occurrence may be linked to a combination of crown fracture and luxation. Luxation-type injuries can result in ischemic pulp necrosis, causing a reduced pulpal immune response. Furthermore, exposed dentinal tubules are susceptible to microbial infection from saliva [41]. The primary reasons for trauma in our study were falls (46.9%), motorcycle accidents (40.6%), and sports-related incidents (6.3%). This aligns with previous studies that consistently identified falls as the most common cause of traumatic injuries (ranging from 31.7%-64.2%). Other contributing factors included sports activities (40.2%), bicycling accidents (19.5%), traffic accidents (7.8%), and physical violence (6.6%) [42–45]. Based on the prevalence of sports-related incidents contributing to dental trauma, it is highly advisable to recommend the use of mouthguards that act as a cushion, absorbing and dispersing the impact force, during contact sports [46].

Younger individuals (OR = 0.83), especially in the 13–20-year age range, were more susceptible to NS-RCT due to DE. DE is predominantly identified in mandibular and maxillary premolars, especially in mandibular premolars. Preventive measures for DE should be implemented before the completion of root formation, typically between the ages of 12–14 years. This observation aligns with the eruption and root development chronology of permanent premolars. The study findings are consistent with previous research on the occurrence and incidence of DE [47, 48].

In our comprehensive analysis of age-related factors, distinct etiological patterns emerged, leading to the categorization of two specific age groups. Group 1, comprising younger individuals, exhibited significant risk factors, such as caries, trauma, DE, and autotransplantation. In contrast, Group 2, representing older individuals, demonstrated notable risk factors associated with prolonged tooth use and wear, including NCCLs (OR = 7.55), attrition (OR = 1.07), and erosion (OR = 1.06) that are relevant to previous studies [39], fractured cusp (OR = 1.05) and traumatic occlusion (OR = 1.02). Moreover, older individuals were at risk of intentional RCT (OR = 1.05) due to the loss of coronal structure and preparation for definitive prosthetic restorations, consistent with a previous study [3]. Additionally, iatrogenic factors leading to pulpitis (OR = 1.05) emerged as significant contributors in the elderly. These identified factors add depth to our understanding of the diverse etiological landscape in the elderly.

We observed that older patients, particularly those in the 51–70 age range (70.9%), were at a higher risk of experiencing traumatic occlusion. Specifically, mandibular central incisors (OR = 5.97) and maxillary canines (OR = 3.95) were identified as having an elevated risk of traumatic occlusion. The increased incidence of traumatic occlusion in mandibular central incisors among older patients may be explained by the loss of posterior teeth. This implies a potential connection, wherein the absence of posterior teeth may lead patients to rely more on their mandibular central incisors during chewing, potentially contributing to traumatic occlusion in this region [49].

In the case of a cracked tooth, we found that mandibular second molars (OR = 8.98) and mandibular first molars (OR = 5.86) with cracks leading to NS-RCT. One possible factor is an occlusal force. The distribution of occlusal force is greatest in the molar region, followed by premolar, and anterior teeth regions [50]. In contrast, we found that fractured cusp teeth in maxillary second premolars (OR = 4.40) and maxillary first premolars (OR = 4.12) were associated with NS-RCT. Another study stated that the highest occlusal force was at the maxillary premolars [51]. The possible cause of cusp fracture in maxillary premolars might be due to their steep cusp inclines and deep grooves [52].

In the present study, we identified a higher risk of NCCL in the maxillary first premolars (OR = 5.50) and mandibular first premolars (OR = 4.87), consistent with previous research [53–55]. Maxillary teeth may be more susceptible to NCCLs, possibly due to their specific lingual tilt [53]. Various factors contribute to NCCL, depending on the type of NCCL. Abfraction might occur due to high occlusal force and lateral forces, particularly in the first premolar [51]. Abrasion, often caused by tooth-brushing and other possible factors, at the maxillary first premolar area can result in reduced buccal bone. This bone deficiency, combined with the buccal position of these teeth, may increase the risk of gingival recession and cervical abrasion [56].

For autotransplantation cases, the criteria for donor teeth included a non-functional tooth. This study found that the maxillary first premolar and third molar were used as donor teeth. The third molar is non-functional in most patients, and the maxillary first premolar is commonly extracted in some patients undergoing orthodontic treatment. Younger individuals exhibited a higher rate of autotransplantation. This could be due to two main reasons: 1) Patients less than 45 years old were appropriate candidates for autotransplantation due to significantly higher autotransplant tooth survival [57] and the regenerative potential of the periodontal ligament cells [58]. 2) Dental implants are not indicated for patients with ongoing craniofacial bone growth [59]. Craniofacial bone growth is typically completed at ~ 17–18 years old [60]. In cases of tooth loss within this age group, autotransplantation may offer a beneficial treatment option.

The strengths of this study

- Novelty in research area: There has been a lack of studies addressing the causes of NS-RCT and associated factors in Asia. The etiology of NS-RCT often varies in detail across different regions. This understanding is crucial for developing targeted and effective dental prevention programs.
- Large sample size for in-depth analysis: The study employed a large sample size, allowing for a more in-depth examination of the causes, beyond the primary factor of caries (which typically demonstrated significant differences compared with other causes in previous studies). This is crucial for developing comprehensive preventive dental strategies.
- Generalizability: This etiological study collected census data from clinical sources, with two observers demonstrating nearly perfect to absolute agreement in intra-rater reliability calibration. This resulted in high external reliability and enhanced generalizability.
- Detailed data collection: This study excelled in collecting more detailed data compared with previous studies. For example, specific information, e.g., tooth numbers and caries sites were meticulously recorded, providing the most specific data for targeted preventive dental practices in the future.
- Systematic data collection for future studies: The study serves as a guide for future research on the causes and factors related to NS-RCT. The systematic and detailed data collection methodology is designed to facilitate future studies, including the potential for systematic reviews and meta-analyses.

The limitations of this study

- Location specificity: This study was conducted in a dental hospital in the capital city, mainly with patients from urban areas. Their economic status might differ from patients in rural areas, where there is a tendency for a lower rate of NS-RCT due to higher prevalence of tooth extraction. Consequently, the reasons for NS-RCT in rural areas might vary. Our future plan involves studying rural areas to formulate preventive measures tailored to different population groups.
- Selective data: This study exclusively gathered information from patients who had undergone NS-RCT. Consequently, teeth with indications for NS-RCT that were extracted might be absent from the dataset.
- Variability in retrospective studies: Data recording practices in retrospective studies often vary depending on the data collecting habits of the dentists providing the information. In our study, we used standardized endodontic treatment records designed to include all pertinent data. Additionally, we provided guidelines to users to ensure the consistency and reliability of the data.
- Potential data errors: Data recording was based on dentists' input during treatment, introducing the possibility of errors in data entry or diagnosis. To mitigate this, our study included cross-referencing with radiographs for more accurate data.

The clinical implications

- Identifying prognostic factors: This study contributes to our understanding of the significant factors that predict the need for NS-RCT across various etiologies. It provides insights into the extent to which these factors either increase or decrease the risk of requiring NS-RCT.
- Targeted preventive measures: The findings enable the development of precise preventive measures. These measures can effectively reduce the chances of overlooking potential risk factors.

Conclusion

The top five etiologies for NS-RCT are caries, old and large restorations, attrition, intentional NS-RCT, and traumatic injury. Tooth number 36 and 46 are particularly prone to caries, especially in the proximal areas, requiring regular preventive measures, including bitewing radiographs, for all age groups. Teeth requiring NS-RCT might not show symptoms, highlighting the importance of routine check-ups.

Rubber dams should be used to manage microleakage in extensive restorations. Dental trauma from falls, bike accidents, and contact sports can be prevented by raising awareness and encouraging the use of mouthguards and helmets.

Preventive measures for specific age groups depend on their etiology. Immature teeth are at risk of NS-RCT due to DE, dental caries, traumatic injury, and DI. Appropriate DE treatment to prevent the development of pulp disease should be undertaken between ages 12–14, focusing on mandibular premolars. Cracks are prevalent in individuals aged 31–60, constituting 68% of NS-RCT cases attributed to crack-related issues. For the elderly, efforts to maintain oral health should be increased because they are prone to non-caries-based tooth loss, such as attrition, non-carious cervical lesions (NCCL), and erosion.

Abbreviations

NS-RCT	Non-surgical root canal treatment
DI	Dens invaginatus
DE	Dens evaginatus
CC	Chief complaint
ICC	Intraclass correlation coefficient
OR	Odd ratio
CI	Confidence interval
NCCL	Non-carious cervical lesion

Acknowledgements

The authors gratefully acknowledge Assistant Professor Dr. Soranun Chantarangsu for assistance in statistical analysis. We express our gratitude to Dr. Kevin Tompkins for critical review and language revision of our manuscript.

Authors' contributions

All authors contributed to the study conception and design. Data collection was performed by S.L. and S.K. Data analysis was performed by S.L. The first draft of the manuscript was written by S.L. and S.K. T.P. and P.P. critically revised the manuscript for essential intellectual content, and all authors provided comments and approved the final version.

Funding

Not applicable.

Available of data and materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

The study was approved by The Human Research Ethics Committee of the Faculty of Dentistry Chulalongkorn University, Thailand (#HREC-DCU 2023–025). Informed consent to participate was obtained from all participants in the study, and in the case of minors, individuals younger than the age of 16, consent to participate was obtained from their parents or legal guardians.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 23 April 2024 Accepted: 16 August 2024
Published online: 23 August 2024

References

1. MacMahon B, Trichopoulos D: Epidemiology: Principles and Methods: Little, Brown; 1996.
2. Eriksen HM, Kirkevang L-L, Petersson K. Endodontic epidemiology and treatment outcome: general considerations. Endod Top. 2002;2(1):1–9.
3. Wigsten E, Kvist T, Dawson VS, Isberg PE. EndoReCo, Fransson H: Comparative analysis of general dental practitioners' fees and scheduled fees for root canal treatment and coronal restorations in the adult population of Sweden: a 5-year follow-up of data from the Swedish Dental Register. Int Endod J. 2018;51(2):141–7.
4. Bjorndal L, Laustsen MH, Reit C. Root canal treatment in Denmark is most often carried out in carious vital molar teeth and retreatments are rare. Int Endod J. 2006;39(10):785–90.
5. Scavo R, Martinez Lalis R, Zmener O, Dipietro S, Grana D, Pameijer CH. Frequency and distribution of teeth requiring endodontic therapy in an Argentine population attending a specialty clinic in endodontics. Int Dent J. 2011;61(5):257–60.
6. Bücher K, Meier F, Diegritz C, Kaaden C, Hickel R, Kühnisch J. Long-term outcome of MTA apexification in teeth with open apices. Quintessence Int. 2016;47(6):473–82.
7. Kandemir Demirci G, Kaval ME, Güneri P, Çalışkan MK. Treatment of immature teeth with nonvital pulps in adults: a prospective comparative clinical study comparing MTA with Ca(OH)(2). Int Endod J. 2020;53(1):5–18.
8. Ree MH, Schwartz RS. Long-term success of nonvital, immature permanent incisors treated with a mineral trioxide aggregate plug and adhesive restorations: a case series from a private endodontic practice. J Endod. 2017;43(8):1370–7.
9. Weiger R, Hitzler S, Hermle G, Löst C. Periapical status, quality of root canal fillings and estimated endodontic treatment needs in an urban German population. Endod Dent Traumatol. 1997;13(2):69–74.
10. Al-Negrish AR. Incidence and distribution of root canal treatment in the dentition among a Jordanian sub population. Int Dent J. 2002;52(3):125–9.
11. Abbott PV. Analysis of a referral-based endodontic practice: Part 1. Demographic data and reasons for referral. J Endod. 1994;20(2):93–6.
12. Gerald N. Glickman JLS: Endodontic Diagnosis. AAE Endodontics Colleagues for Excellence 2013(Fall 2013):1–5.
13. De Cleen MJ, Schuurs AH, Wesselink PR, Wu MK. Periapical status and prevalence of endodontic treatment in an adult Dutch population. Int Endod J. 1993;26(2):112–9.
14. Buckley M, Spangberg LS. The prevalence and technical quality of endodontic treatment in an American subpopulation. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1995;79(1):92–100.
15. Boucher Y, Matossian L, Rilliard F, Machtou P. Radiographic evaluation of the prevalence and technical quality of root canal treatment in a French subpopulation. Int Endod J. 2002;35(3):229–38.
16. Hull TE, Robertson PB, Steiner JC, del Aguila MA. Patterns of endodontic care for a Washington state population. J Endod. 2003;29(9):553–6.
17. Georgopoulou MK, Spanaki-Voreadi AP, Pantazis N, Kontakiotis EG. Frequency and distribution of root filled teeth and apical periodontitis in a Greek population. Int Endod J. 2005;38(2):105–11.
18. Tsuneishi M, Yamamoto T, Yamanaka R, Tamaki N, Sakamoto T, Tsuji K, Watanabe T. Radiographic evaluation of periapical status and prevalence of endodontic treatment in an adult Japanese population. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2005;100(5):631–5.

19. Matijevic J, Cizmekovic Dadic T, Prpic Mehicic G, Ani I, Slaj M, Jukic Krmek S. Prevalence of apical periodontitis and quality of root canal fillings in population of Zagreb, Croatia: a cross-sectional study. Croat Med J. 2011;52(6):679–87.
20. Committee ACP: Guide to Clinical Endodontics. American Association of Endodontists 2013, Sixth Edition.
21. Kahler B, Taha N, Lu J, Saoud T. Vital pulp therapy for permanent teeth with diagnosis of irreversible pulpitis: biological basis and outcome. Aust Dent J. 2023;68(S1):S110–22.
22. FDI Two Digit Notation. http://www.fdiworldental.org.
23. Moorrees CF, Fanning EA, Hunt EE Jr. Age Variation of Formation Stages for Ten Permanent Teeth. J Dent Res. 1963;42:1490–502.
24. Goodacre CJ, Eugene Roberts W, Munoz CA. Noncarious cervical lesions: Morphology and progression, prevalence, etiology, pathophysiology, and clinical guidelines for restoration. J Prosthodont. 2023;32(2):e1–18.
25. Nigel B. Pitts AII, Stefania Martignon,Kim Ekstrand, Gail V. A. Douglas, Christopher Longbottom: ICCMSTM Guide for Practitioners and Educators. 2014.
26. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159–74.
27. Kirkevang LL, Horsted-Bindslev P, Orstavik D, Wenzel A. Frequency and distribution of endodontically treated teeth and apical periodontitis in an urban Danish population. Int Endod J. 2001;34(3):198–205.
28. Sebring D, Dimenäs H, Engstrand S, Kvist T. Characteristics of teeth referred to a public dental specialist clinic in endodontics. Int Endod J. 2017;50(7):629–35.
29. Sunay H, Tanalp J, Dikbas I, Bayirli G. Cross-sectional evaluation of the periapical status and quality of root canal treatment in a selected population of urban Turkish adults. Int Endod J. 2007;40(2):139–45.
30. Dental radiographic examinations: recommendations for patient selection and limiting radiation exposure https://www.ada.org/-/media/project/ada-organization/ada/ada-org/files/resources/research/oral-health-topics/dental_radiographic_examinations_2012.pdf?rev=b074dde4cb0b4cc5a2343feb3f89b66d&hash=AF0BCF8A12C4937B2921177FE650CC54.
31. Cagidiaco MC, Ferrari M, Garberoglio R, Davidson CL. Dentin contamination protection after mechanical preparation for veneering. Am J Dent. 1996;9(2):57–60.
32. Loguercio AD, Reis A, Ballester RY. Polymerization shrinkage: effects of constraint and filling technique in composite restorations. Dent Mater. 2004;20(3):236–43.
33. Cheung GS, Lai SC, Ng RP. Fate of vital pulps beneath a metal-ceramic crown or a bridge retainer. Int Endod J. 2005;38(8):521–30.
34. Olgart L, Bergenholtz G: The dentin-pulp complex: Structures, functions and responses to adverse influences. In., edn.; 2010:11–32.
35. Abou-Rass M. The stressed pulp condition: an endodontic-restorative diagnostic concept. J Prosthet Dent. 1982;48(3):264–7.
36. Morse DR. Age-related changes of the dental pulp complex and their relationship to systemic aging. Oral Surg Oral Med Oral Pathol. 1991;72(6):721–45.
37. Shinogaya T, Bakke M, Thomsen CE, Vilmann A, Matsumoto M. Bite force and occlusal load in healthy young subjects–a methodological study. Eur J Prosthodont Restor Dent. 2000;8(1):11–5.
38. Yadav S. A study on prevalence of dental attrition and its relation to factors of age, gender and to the signs of TMJ dysfunction. J Indian Prosthodont Soc. 2011;11(2):98–105.
39. Hegde MN, Yelapure M, Honap MN, Devadiga D. The prevalence of tooth wear and its associated risk factors in Indian South West Coastal population: an epidemiological study. J Int Clin Dental Res Organ. 2018;10(1):23–6.
40. Borum MK, Andreasen JO. Therapeutic and economic implications of traumatic dental injuries in Denmark: an estimate based on 7549 patients treated at a major trauma centre. Int J Pediatr Dent. 2001;11(4):249–58.
41. Robertson A, Andreasen FM, Andreasen JO, Norén JG. Long-term prognosis of crown-fractured permanent incisors. The effect of stage of root development and associated luxation injury. Int J Paediatr Dent. 2000;10(3):191–9.
42. Faus-Damia M, Alegre-Domingo T, Faus-Matoses I, Faus-Matoses V, Faus-Llacer VJ. Traumatic dental injuries among schoolchildren in Valencia, Spain. Med Oral Patol Oral Cir Bucal. 2011;16(2):e292-295.
43. Taiwo OO, Jalo HP. Dental injuries in 12-year old Nigerian students. Dent Traumatol. 2011;27(3):230–4.
44. Eyuboglu O, Yilmaz Y, Zehir C, Sahin H. A 6-year investigation into types of dental trauma treated in a paediatric dentistry clinic in Eastern Anatolia region. Turkey Dent Traumatol. 2009;25(1):110–4.
45. Hecova H, Tzigkounakis V, Merglova V, Netolicky J. A retrospective study of 889 injured permanent teeth. Dent Traumatol. 2010;26(6):466–75.
46. Ramagoni NK, Singamaneni VK, Rao SR, Karthikeyan J. Sports dentistry: A review. J Int Soc Prev Community Dent. 2014;4(Suppl 3):S139-146.
47. Reichart P, Tantiniran D. Dens evaginatus in the Thai: An evaluation of fifty-one cases. Oral Surg Oral Med Oral Pathol. 1975;39(4):615–21.
48. Lin C-S, Llacer- Martinez M, Sheth CC, Jovani- Sancho M, Martín- Biedma B. Prevalence of premolars with dens evaginatus in a Taiwanese and Spanish population and related complications of the fracture of its tubercle. Eur Endod J. 2018;3(2):118–22.
49. Craddock HL. Occlusal Changes Following Posterior Tooth Loss in Adults. Part 3. A Study of Clinical Parameters Associated with the Presence of Occlusal Interferences Following Posterior Tooth Loss. J Prosthodont. 2008;17(1):25–30.
50. Kumagai H, Suzuki T, Hamada T, Sondang P, Fujitani M, Nikawa H. Occlusal force distribution on the dental arch during various levels of clenching. J Oral Rehabil. 1999;26(12):932–5.
51. Abe Y, Nogami K, Mizumachi W, Tsuka H, Hiasa K. Occlusal-supporting ability of individual maxillary and mandibular teeth. J Oral Rehabil. 2012;39(12):923–30.
52. Khers SC, Carpenter CW, Vetter JD, Staley RN. Anatomy of cusps of posterior teeth and their fracture potential. J Prosthet Dent. 1990;64(2):139–47.
53. Aw TC, Lepe X, Johnson GH, Mancl L. Characteristics of noncarious cervical lesions: a clinical investigation. J Am Dent Assoc. 2002;133(6):725–33.
54. Borcic J, Anic I, Urek MM, Ferreri S. The prevalence of non-carious cervical lesions in permanent dentition. J Oral Rehabil. 2004;31(2):117–23.
55. Takehara J, Takano T, Akhter R, Morita M. Correlations of noncarious cervical lesions and occlusal factors determined by using pressure-detecting sheet. J Dent. 2008;36(10):774–9.
56. Radentz WH, Barnes GP, Cutright DE. A survey of factors possibly associated with cervical abrasion of tooth surfaces. J Periodontol. 1976;47(3):148–54.
57. Jang Y, Choi YJ, Lee S-J, Roh B-D, Park SH, Kim E. Prognostic factors for clinical outcomes in autotransplantation of teeth with complete root formation: survival analysis for up to 12 Years. J Endodont. 2016;42(2):198–205.
58. Zhang J, An Y, Gao LN, Zhang YJ, Jin Y, Chen FM. The effect of aging on the pluripotential capacity and regenerative potential of human periodontal ligament stem cells. Biomaterials. 2012;33(29):6974–86.
59. Malmgren B, Malmgren O. ANDREASEN JO: Alveolar bone development after decoronation of ankylosed teeth. Endod Top. 2006;14(1):35–40.
60. Szemraj-Folmer A, Wojtaszek-Słomińska A, Racka-Pilszak B, Kuc-Michalska M. Duration of the pubertal growth spurt in patients with increased craniofacial growth component in sagittal and vertical planes-retrospective and cross-sectional study. Clin Oral Investig. 2021;25(8):4907–14.

Publisher's Note