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Factors Influencing Non-Surgical Root Canal Treatment Outcomes in Mandibular Second Molars: A Retrospective Cone-Beam Computed Tomography Analysis

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Factors Influencing Non-Surgical Root Canal Treatment Outcomes in Mandibular Second Molars: A Retrospective Cone-Beam Computed Tomography Analysis

Da-min Park [1], Woo-Hyun Seok [2] and Ji-Young Yoon [1,*]

[1] Department of conservative dentistry, Section of Dentistry, Seoul National University Bundang Hospital, Seongnam, Korea; 54668@snubh.org (Park); jyyoon20@naver.com (Yoon)
[2] Section of Dentistry, Seoul National University Bundang Hospital, Seongnam, Korea; whseok96@naver.com
* Correspondence: lucia@snubh.org; Tel.: +82-31-787-2780

Abstract: Background/Objectives: This study aims to investigate the influence of root canal morphology and various treatment variables on the outcomes of root canal treatments (RCT) in mandibular second molars, assessed through cone-beam computed tomography (CBCT) imaging. **Methods**: A total of 150 CBCT images were examined, comprising 100 cases of persistent endodontic infections and 50 from previously treated root canals with normal apices in mandibular second molars. CBCT was utilized to evaluate root canal configuration, the radiographic quality of coronal restorations and treated canal systems, and the presence of periapical lesions. Statistical analyses were performed to explore correlations between these factors. **Results:** The presence of a C-shaped root canal configuration did not demonstrate a significant correlation with periapical lesions (p=0.05). Factors influencing endodontic treatment outcomes included the presence of missing canals (p=0.018), underfilling or overfilling (p=0.045), and inadequate coronal restoration (p=0.006). The presence of a missing canal was identified as the variable most significantly associated with periapical lesions (OR=3.103). Leaky canals were more commonly observed in C-shaped root canals (p<0.001). **Conclusions:** Regardless of the root canal morphology of mandibular second molars, successful RCT depends on thorough disinfection to eliminate any untreated canals, precise three-dimensional filling of the canals at the correct working length, and a securely sealed coronal restoration to prevent leakage.

Keywords: non-surgical endodontics; periapical diseases; cone-beam computed tomography; treatment outcomes

1. Introduction

Root Canal Treatment (RCT) hinges on achieving complete sterilization and sealing of the canal interior [1]. To achieve this, it's essential to ensure proper shaping, irrigation, and three-dimensional filling of the canals. The success of each RCT step is significantly impacted by the anatomical features of the canal, with complexities like isthmi and fins known to decrease success rates [2,3]. Beyond anatomy, intra- and post-operative factors related to treatment quality are crucial determinants of RCT success [4]. The presence of missing canals, the state of canal obturation, and the quality of coronal restoration have been widely recognized as crucial factors influencing the success or failure of RCT [5,6].

The mandibular second molar is notorious for its anatomical complexity and variability in root canal morphology [7]. Among these variations, the C-shaped canal, where the buccal aspect of the canal systems is fused, is known to have a relatively high occurrence rate [8]. Treating C-shaped canals is difficult due to their complicated anatomical features [9]. The presence of isthmi in C-shaped canals can serve as reservoirs for bacteria and debris, which may not be effectively reached or cleaned using traditional shaping and cleaning techniques [10]. Additionally, sealing the root canal in three

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dimensions is challenging, making the mandibular second molar one of the most difficult teeth for RCT. Persistent endodontic infection leads to the failure of RCT [11].

Numerous studies have aimed to uncover factors contributing to the failure of RCT by investigating the anatomical features, pre-operative pulpal status, and treatment variables of teeth displaying persistent endodontic infection [12]. These investigations aid in comprehending the complexity of RCT and considering various factors to enhance clinical outcomes. Prior research on C-shaped root canal studies predominantly focused on anatomical features through the analysis of extracted teeth [8,13–15]. However, to explore the correlation between post-RCT clinical symptoms and anatomical structure, cone-beam computed tomography (CBCT) emerges as a valuable tool [6]. CBCT allows for evaluating root canal configurations and treatment quality without the need for tooth extraction [16]. The insights gained from CBCT offer clues to pinpoint the underlying causes of patient discomfort.

The aim of this study is to assess the influence of root canal morphology and treatment quality on the outcomes of RCT in mandibular second molars, through a retrospective analysis conducted using CBCT imaging. Additionally, this study examines any potential relationship between C-shaped canals and the quality of RCT.

2. Materials and Methods

2.1. Case Selection

The study was approved by the Institutional Review Board (IRB no. B-2308-849-103) of the Seoul National University Bundang Hospital. The case group for this study comprised 100 patients who visited Department of Conservative Dentistry from July of 2020 to June of 2023 with complaints of consultation for endodontic retreatment in mandibular second molar that showed periapical radiolucency and persistent discomfort. They were diagnosed as either symptomatic apical periodontitis or periapical abscess and have been taken CBCT for further evaluation with their consent.

The control group consisted of 50 patients who visited Department of Oral and Maxillofacial Surgery in a same period. These individuals had undergone CBCT for the extraction of the mandibular third molar and had an adjacent second molar that had previously undergone RCT with currently normal periapical status, presenting no clinical symptoms.

- Inclusion criteria: Endodontically treated mandibular molar with its root growth completed, has to be fully included in CBCT's imaging range, while its clear and complete images available.
- Exclusion criteria: Presence of periodontitis at least in a moderate stage. Diagnosis of conditions other than pulpal or periapical lesions (such as fibro-osseous lesions, benign neoplasms, oral cancer, etc.). Difficulty in radiographic interpretation due to metal artifacts associated with the tooth.

2.2. CBCT analysis

CBCT image was taken with Kodak 9500 3D system (Carestream Health, Rochester, NY, USA) at a tube voltage of 80kV, a tube current of 15mA, and an exposure time of 10.8 seconds. The resulting image consisted of axial cross-sectional slices with a thickness of 0.2mm, parallel to the occlusal plane.

Every image of axial, sagittal, and coronal sliced samples of each scan was analyzed by 2 examiners using On Demand3D app (Cybermed, Seoul, Korea). Multiple host and treatment variables were recorded from the patients' records. According to the study design, the following analysis was conducted (Figure 1).

2.2.1. An Anatomical Factor: Root Canal Morphology Classification

C-shaped canal generally means that a transverse section of root canal is in a shape of letter "C" [8]. Root canal shows various types of shape as it repeats dividing into few branches and getting back through anastomosis, following long axis of root. Usually, C-shaped canal is not completely connected from canal orifice to apical foramen. Therefore in this study, C-shaped canal was defined if a tooth shows forementioned C-shape at least once in entire root canal section when it was observed in axial view of CBCT [9]. The subtypes of C-shaped canals were further classified into C1 to C5 based

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on the shape observed in the axial view of the middle 1/3 of the root, following the classification proposed by Fan [7] (Figure 2).

2.2.2. Treatment Factors: Intra- and Post-Operative Factors

The following treatment factors were chosen as criteria for assessing the quality of RCT (Table 1). Obturation density, missed canal, obturation level, and iatrogenic problems are intra-operative factors, while coronal restoration is a post-operative factor.

Table 1. Treatment variable examined through CBCT imaging.

factors	description	
Obturation density [1]	Good	Homogeneous radiopaque material and no visible space. No more than 2 small voids (<1mm)
	Poor	Non-uniform radiodensity, with the canal space visible laterally and apically. Isthmus area that had not been treated (Figure 3-a)
Missed canal [17]	Unfilled canals appearing from cemento-enamel junction to apex including canals splitting from a main canal at coronal, mid, or apical third (Figure 3-b)	
Obturation level [1]	Obturation level of a filling material was measured in millimeters relative to the radiographic apex	
	Normal	Fillings within 2mm short of the radiographic apex
	improper	Fillings more than 2mm short of the radiographic apex / Excess root filling, Sealer extrusion
Iatrogenic problem	File separation, Perforation (present/absent) (Figure 3-c, d).	
Coronal restoration [17]	Adequate	Any permanent restoration that appeared intact radiographically and had no comment on the clinical examination record
	Inadequate	Any permanent restoration with detectable radiographic sings of overhangs, open margins, or recurrent caries or comments such as “ill-fitting margin” or “secondary dental caries” on the clinical examination record.

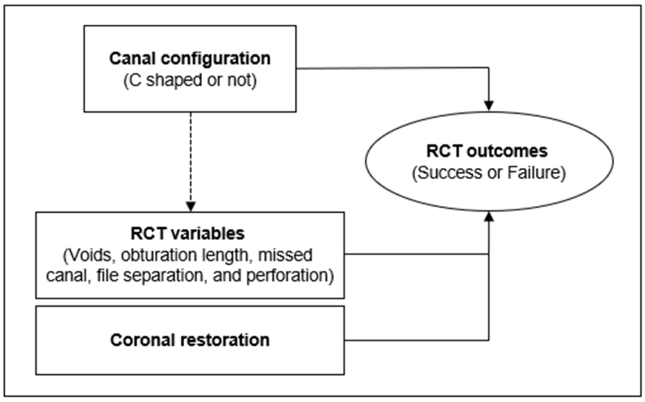

Figure 1. Study design. The impact of root canal features and the treatment variables on the outcome of root canal treatment was individually investigated. Additionally, the correlation between C-shape presence and the treatment quality was explored.

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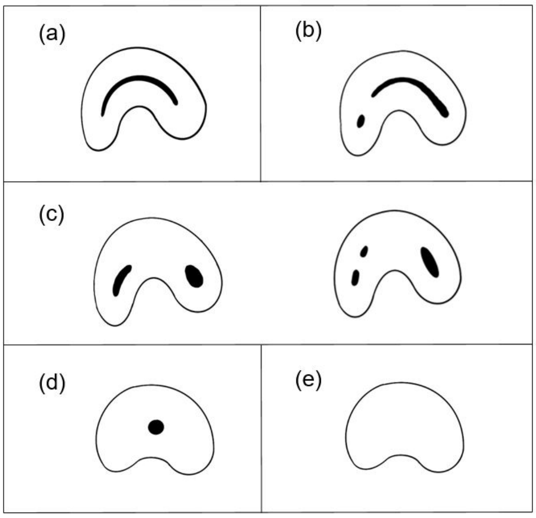

Figure 2. Classification of C-shaped canal. (a) C1, Uninterrupted 'C' with no separation or division. (b) C2, Canal shape resembled a semicolon. (c) C3, Two or three separate canals. (d) C4, Only one round or oval canal. (e) C5, No canal lumen (usually seen near the apex only).

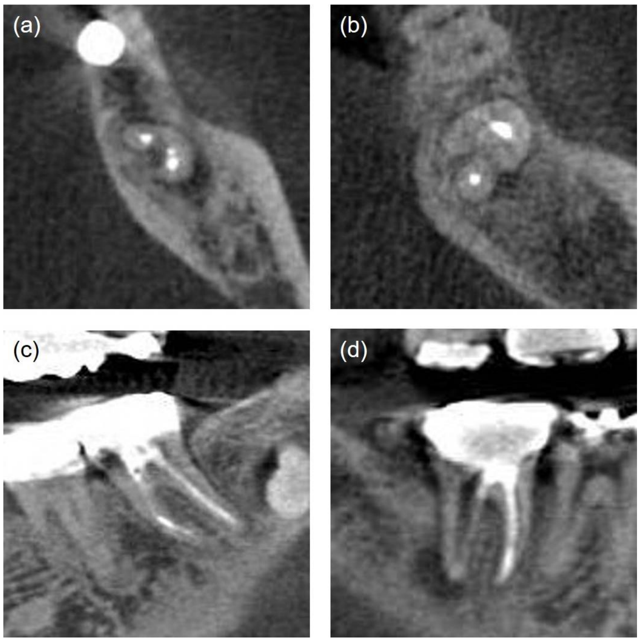

Figure 3. The quality of root canal treatment was evaluated by analyzing CBCT cross-sectional images. (a) The untreated isthmus area of the C-shaped canal in the mandibular right second molar, axial view. (b) The missed mesio-lingual canal in the mandibular right second molar, axial view. (c) Instrument fracture in the mesial root canal of the mandibular left second molar, coronal view. (d) Perforation in the furcation area of the mandibular right second molar, coronal view.

2.3. Statistical Analysis

Chi-square tests were applied to examine the relationship between the outcome of RCT and the canal shape of the mandibular second molar. Additionally, multiple logistic regression analysis was conducted to assess how anatomical and various treatment factors influenced the failure of root canal treatment. A significance level (*p*-value) of 0.05 was chosen for all analyses. Statistical analyses were performed using SPSS ver28.0 (SPSS Inc., Illinois, USA).

3. Results

3.1. An Anatomical Factor: The Root Canal Morphology

To assess the anatomical complexity of the root canal, we evaluated whether it exhibited a C-shaped configuration or not, and examined the impact of this configuration on the success rate of root canal treatment. As seen in Table 2, the results from the examination using CBCT revealed that out of the total 150 teeth, 77 (51.3%) had a C-shaped canal configuration. The success rate for C-type canals was 26%, compared to 41.1% for non-C-type canals. The C-shaped canal configuration does not significantly influence the success rate of root canal treatment *(p=0.05)*. Among the subtypes of C-shaped canals, C1 (uninterrupted 'C' with no separation or division) was the most prevalent, accounting for 55% of the total, followed by C2 (canal shape resembled a semicolon), which constituted 26% (Figure 4).

Table 2. Endodontic treatment outcome relative to anatomical factor.

	C-shape N=77 (100%)	**Non C-shape N=73 (100%)**	**Total N=150**
Success	20 (26%)	30 (41.1%)	50
Failure	57 (74%)	43 (58.9%)	100
$\chi^2(p)$		3.856 (p=0.05)	

* Significant P value at 0.05 level.

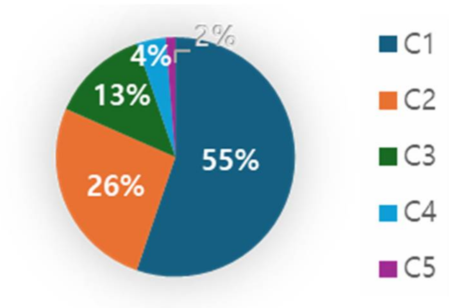

Figure 4. The subtype distribution of C-shaped canal.

3.2. Intra- and Post-Operative Treatment Factors: Missing Canals, Obturation Length, Leaky Canals, Iatrogenic Problems, and Coronal Restoration

We investigated the influence of missing canals, obturation length, leaky canals, iatrogenic events, and coronal leakage on the failure of root canal treatment (Table 3). In cases of missing or untreated canals, failure rate was 82.6%, whereas it was 59.6% when all canals were treated. Analysis on obturation length correlation with success rate showed lower success rate of 14.3% with inappropriate length, compared to 41.1% with appropriate length. Presence of voids in the root canal on CBCT imaging, resulting in leaky canals, led to a failure rate of 77.5%, compared to 54.3% with adequately filled canal. Iatrogenic problems like file separation or perforation were detected in 9 teeth. Coronal restoration status was analyzed in 146 teeth, excluding those with previously removed restorations. Failure rate of RCT was higher at 78.9% when coronal restoration was inappropriate, compared to 53.3% with well-done restoration. As seen in Table 4, according to logistic regression analysis, missing canal, improper obturation length, and coronal leakage were significant variables influencing the success or failure of root canal treatment. If a missing canal exists, the likelihood of endodontic failure is 3.103 times higher, improper obturation length increases the failure rate by 2.909 times, and the presence of coronal leakage raises it by 3.057 times. According to these findings, the presence of a missing canal emerges as the most significant factor influencing the failure of RCT.

Table 3. Endodontic treatment outcome according to treatment factors.

Treatment factors	N	Endodontic outcome	
		Success (N=50)	Failure (N=100)

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Missing canal			
Present	46	8 (17.4%)	38 (82.6%)
Absent	104	42 (40.4%)	62 (59.6%)
Obturation length			
Adequate	107	44 (41.1%)	63 (58.9%)
Inadequate	42	6 (14.3%)	36 (85.7%)
Obturation density			
Poor	80	18 (22.5%)	62 (77.5%)
Good	70	32 (45.7%)	38 (54.3%)
Iatrogenic problem			
Present	9	3 (33.3%)	6 (66.7%)
Absent	141	47 (33.3%)	94 (66.7%)
Coronal restoration			
Adequate	75	35 (46.7%)	40 (53.3%)
Inadequate	71	15 (21.1%)	56 (78.9%)

Table 4. Endodontic treatment outcome according to anatomical and treatment factors. Logistic regression analysis.

	Endodontic Failure				
	B	S.E.	Wald	*p*	Exp (B)
C-configuration	0.115	0.504	0.053	0.819	1.122
Missing canal	1.132	0.478	5.606	0.018*	3.103
Obturation length	1.068	0.533	4.019	0.045*	2.909
Obturation density	0.572	0.508	1.267	0.260	1.772
Iatrogenic events	-0.110	0.819	0.018	0.893	0.896
Coronal leakage	1.117	0.405	7.619	0.006*	3.057

B, coefficient for the constant; S.E., standard error; Exp (B), the exponentiation of the B constant, which is an odds ratio. *Indicates significant differences ($p < 0.05$).

3.3. The Correlation between an Anatomical Factor and Treatment Factors

To investigate the influence of anatomical canal morphology on the quality of en-dodontic treatment, the treatment factors according to canal configurations were compared. The incidence of inhomogenous obturation density was significantly higher in C-type canals compared to non-C-type canals (P<0.001). There was no significant difference in the prevalence of missing canals, inadequate obturation length, or iatrogenic problems between C-type and non-C-type canals (Table 5).

Table 5. Treatment quality according to canal configuration.

	C-shape	Non C-shape	X^2	*p* value
Missing canal (N=46)	25 (54.3%)	21 (45.7%)	0.241	0.623

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Inadequate obturation length (N=42)	26 (61.9%)	16 (38.1%)	2.450	0.118
Poor obturation density (N=80)	65 (81.3%)	15 (18.7%)	61.416	<0.001*
Iatrogenic problem (N=9)	3 (33.3%)	6 (66.7%)		0.318 †

* Significant *p* value at 0.05 level. †Fisher's exact test.

4. Discussion

When identifying the causes of RCT failure, it is essential to consider both anatomical factors and treatment factors together. The root canal complexity increases the difficulty of RCT and makes proper canal cleaning and filling more challenging. As a result, remaining bacteria and their biofilms can lead to the failure of RCT and subsequently progress to apical periodontitis or apical abscess [18,19]. The mandibular second molar is known to have the most complicated canal system of all teeth [20]. Therefore, this study aimed to investigate the impact of anatomical and treatment factors on RCT outcomes of the mandibular second molars.

Whether the root canal is a "C shape" or not is not a significant factor influencing the success or failure of RCT. According to another study comparing healing outcomes of C-shaped mandibular second molars, the success rate for teeth with a "C shape" was 70.9%, while the success rate for teeth without a "C shape" was 66.6%, with no significant difference observed [21]. There are studies suggesting a lower success rate of RCT in mandibular molars [22]. However, there are also studies indicating no significant difference in success rates among teeth. Another study concluded that the success rate of treatment was not adversely affected by tooth type or anatomical complexity [4]. It is true that the complexity of root canal morphology can impact the complete disinfection of the root canal. However, the C shape form is a part of root canal complexity. In addition to the C shape, other factors determining complexity include lateral canals, apical ramifications, isthmuses, curvatures, and so on. It is believed that these factors collectively influence the shaping and obturation of the root canal [23–26].

Other than root canal anatomy, when looking at the effect of treatment quality on outcomes of RCT, obturation level and the presence of missing canal, and coronal leakage act as significant factors. Working length and obturation level are known to significantly affect the result of RCT. It is reported that if canal fillings are 2mm short from root apex then the success rate of RCT drops down to 68~77%, and if it is over-filled through the apex then the RCT shows about 75% of success rate [1,27]. This study also shows significant decrease in success rate of RCT as root canal gets over-filled or under-filled. In addition, the presence of missing canals emerged as a significant factor contributing to the failure of RCT in this study as well. Here, in cases where a canal is missed, the failure rate of RCT was 82.6%. This aligns with the findings of previous studies examining the impact of missed canals on periapical lesions [6]. From aetiologic point of view, it seems reasonable that infected and untreated root canal could possibly be a trigger of apical lesion. Many case studies claim that missed canal has a close relationship with apical lesion, with odds ratios ranging from about 4.4 to 6.25 [6,16,28].

On the other hand, obturation density and iatrogenic problems were not identified as significant factors influencing the outcome of RCT in this study. There are conflicting findings about the effect of intracanal instrument fracture on the prognosis of RCT [29,30] . In this regard, McGuigan[31] claims that remaining of fractured instrument depends on presence of apical disease before RCT. However, since there is no available information on the apical status before RCT in this study, it becomes challenging to analyze the relationship between instrument fracture and the success or failure of RCT. In addition, the low incidence of iatrogenic problems (such as file separation and perforation) in this study poses a challenge when attempting to accurately assess their low correlation with the success rate of root canal treatment. In terms of obturation density, the quality of the coronal restoration played a more significant role in determining endodontic success than the quality of the

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root filling [32,33]. These results are consistent with our study findings, which suggest that coronal leakage significantly influences the failure of root canal treatment.

When examining differences in treatment factors based on canal configuration, it appears that a C-shaped morphology may significantly affect the attainment of inhomogeneous obturation density. C-shaped canals are characterized by canals interconnected by fins and isthmuses, making it challenging to achieve three-dimensional sealing of the root canal system with conventional endodontic materials. Therefore, in cases of C-shaped canals, it is necessary to consider various techniques for achieving three-dimensional canal filling after adequate debridement and irrigation have been completed [34].

In this study, 51.3% of the subjects exhibited C-shaped canal in the mandibular second molar. Previous studies have reported that the occurrence of C-shaped canal has a wide range of distribution of 3 to 39.2% worldwide and is significantly more common in Asian populations. In South Korea, especially, C-shaped canal occurrence rate in mandibular second molar is reported to be around 30 to 40% [35]. The higher prevalence of C-shaped root canals, compared to other studies, is presumed to be attributed to the patient groups composed of individuals referred from local dental clinics due to root canal treatment failure. Among subtypes of C shaped canal, C1, which refers to uninterrupted C-shaped root canal, was the most common, aligning with findings from previous research [36,37]. Each canal subtypes made no significant difference in occurrence of persistent endodontic infection.

This study analyzed CBCT images of root canal-treated teeth. After the introduction of computed tomography (CT) into endodontics by Tachibana and Matsumoto in 1990, CBCT, capable of capturing images with low radiation, has been used to assess the anatomical form and pathological elements of root canals [38]. CBCT enables three-dimensional cross-sectional evaluation without the need for tooth extraction [39]. Furthermore, according to a study comparing the accuracy of various radiographic methods, CBCT demonstrated the highest accuracy in determining root canal configuration. In terms of accuracy, it is comparable to the modified canal staining and clearing technique performed on extracted teeth [40]. Consequently, in endodontic practice, it serves as a valuable diagnostic aid for formulating treatment plans or assessing treatment outcomes, especially when significant anatomical deviations in root canal anatomy are suspected in 2D images [41]. However, it's not feasible to perform CBCT for every endodontic treatment. In cases where patients continue to complain of discomfort after RCT or when anomalies or pathological issues within the root canal are suspected based on 2D radiographs, CBCT imaging should be considered.

Studies report that the success rate of primary root canal treatment ranges from 92% to 96% when there is no presence of apical periodontitis before the procedure. However, if apical periodontitis is present, the success rate drops to 62% to 83% [42]. Hence, it is hard to separate the success or failure of RCT from the apical status before the treatment. However, this study focuses on teeth for which the RCT has already been completed. There is a limitation as the preoperative condition of the pulp and apex of the targeted teeth was not included.

In conclusion, based on the evaluation of the impact of root canal morphology and treatment quality on persistent endodontic infection using CBCT imaging, successful RCT for mandibular second molars necessitates thorough disinfection to address any untreated canals, precise three-dimensional canal obturation at the correct working length, and a securely sealed coronal restoration to prevent leakage, irrespective of the root canal morphology.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of Seoul National University Bundang Hospital (IRB no. B-2308-849-103). Approval date: 08/17/2023.

Informed Consent Statement: Not applicable

Data Availability Statement: Data supporting reported results are not provided due to ethical restrictions, but can be provided upon request.

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Conflicts of Interest: The authors declare no conflicts of interest.

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