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ORIGINAL ARTICLE

Factors affecting the clinical approach to impacted maxillary canines: A Bayesian network analysis

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Introduction: The aim of this study was to apply Bayesian networks to evaluate the relative role and possible causal relationships among various factors affecting the diagnosis and final treatment outcome of impacted maxillary canines. **Methods:** A total of 168 patients with infraosseous impacted maxillary canines had a combined surgical-orthodontic approach aimed to guide the impacted tooth to the center of the alveolar ridge. Demographic, orthodontic, and periodontal variables were recorded and analyzed by means of Bayesian network analysis. **Results:** All 168 impacted canines were successfully moved and aligned in the dental arches with healthy periodontiums. According to the Bayesian network analysis, bilateral impaction was associated with palatal impaction and longer treatment; the pretreatment α-angle was a determinant for the duration of orthodontic traction, also because of the associations between greater angulation of impacted canines with more severe tooth displacement and with greater distance of the impacted canine from the occlusal plane; the posttreatment periodontal outcome was not related to the pretreatment radiographic variables. **Conclusions:** Bayesian network analysis was useful to identify possible relationships among the variables considered for diagnosis and treatment of impacted canines. (Am J Orthod Dentofacial Orthop 2010;137:755-62)

The prevalence of impacted canines was reported to be from 0.2% to 2.8% according to several authors.[1,2] An impacted canine requires a complex therapeutic management, which can be considered successful only if the forced eruption and the subsequent alignment lead the tooth to the correct position in the dental arch with a healthy periodontium. The eruption of the tooth between the alveolar cortical plates prevents bone dehiscence and unfavorable orthodontic and esthetic consequences.[3,4] Therefore, the most appropriate treatment should simulate the physiologic eruption pattern that occurs at the center of the alveolar ridge, as some authors have suggested.[5-8] Orthodontic appliances and techniques specifically designed for this purpose have been proposed.[4,8-15] In case of persistent deciduous canines and unerupted permanent canines, the "tunnel" technique might be indicated to reproduce the physiologic eruption pattern of the canine.[4,13,14,16]

The therapeutic approach to impacted canines is interdisciplinary, with many factors accounting for the final orthodontic and periodontal outcomes. Pretreatment radiographic features of impacted canines—α-angle, d-distance, and sector of impaction according to Ericson and Kurol[17,18]—have been shown to be predictive factors for the durations of orthodontic traction[14] and comprehensive orthodontic treatment to reposition the impacted tooth.[19] The more severely displaced the canine with regard to the adjacent maxillary incisors, the longer the orthodontic treatment.[19] The indicators on pretreatment panoramic films have been studied also as predictors for the outcomes of interceptive treatment of palatally displaced canines by means of extraction of the corresponding deciduous canine and space maintenance in the maxillary dental arch.[20] However, the same radiographic variables had no predictive value for

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Fig 1. Female patient, 18 years old, with a maxillary left deciduous canine.

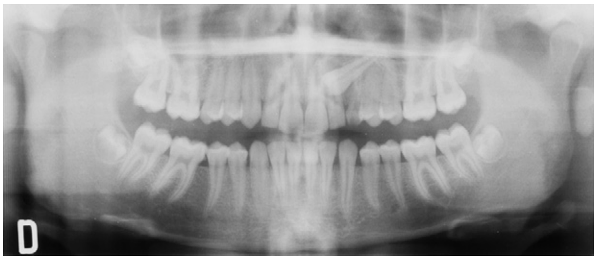

Fig 2. The panoramic radiograph shows the impacted maxillary left canine.

the final periodontal status of the impacted canines after surgical-orthodontic treatment to reposition the canine at the center of the alveolar ridge.[4,14] Most investigations evaluated the relationships between factors accounting for treatment outcomes of impacted canines with descriptive statistics or linear regression on a priori identified variables; more recent studies used multilevel statistics to study associations among factors without determining causal relationships.[4,14]

Bayesian networks (BN) were introduced recently with the goals of generating hypotheses of possible causal relationships among variables and promoting further specific studies (ie, randomized clinical trials).[21,22] BN adopt an intermediate approach between statistics and artificial intelligence. A "network" is composed of a "directed acyclic graph" in which stochastic variables are represented by vertices or nodes of the graph, and oriented lines (arrows) represent the relationships among the variables. The arrows relate the variables in such a way that cycles are not permitted, so that, following the arrows, it is impossible to return to a vertex or starting point. The variables from which the arrows start influence those to which they arrive, possibly through a causal relationship.[21] An example of Bayesian analysis was reported in an oral oncology genomic study,[23] and some aspects of a directed acyclic graph have been elucidated in dental research.[24] Recently, BN have been applied to the analysis of relevant literature in implantology.[25] At the present time, no study applies BN analysis in orthodontics.

The aim of this investigation was to apply BN to comprehensive surgical-orthodontic treatment of maxillary impacted canines to evaluate the relative role and the possible causal relationships among various factors affecting the clinical approach to this condition.

MATERIAL AND METHODS

Our subjects were 168 patients with unilateral or bilateral infraosseous impacted maxillary canines from a previous study.[14] One hundred twenty-five patients had unilateral impaction of the maxillary canine, and 43 had bilateral impactions. A random selection was made of the 86 bilateral impacted canine to evaluate only 1 canine per patient. The final study population consisted of 168 patients (168 impacted canines) (40 male, 128 female; age range, 12.8-52.0 years; mean age, 17.2 $\pm$ 6.0 years).

The following variables before treatment were collected: (1) buccal or palatal site of impaction, left or right side, unilateral or bilateral impaction; (2) radiographic variables on panoramic x-rays: α-angle: angle measured between the long axis of the impacted canine and the midline, d-distance: distance between the canine cusp tip and the occlusal plane (from the first molar to the incisal edge of the central incisor), and s-sector: sector where the cusp of the impacted canine is located (sector 1, between the midline and the axis of the central incisor; sector 2, between the axes of the central incisor and the lateral incisor; or sector 3, between the axes of the lateral incisor and the first premolar).

All patients underwent consecutively a closed-flap surgical approach followed by orthodontic alignment. Treatment was delivered by 1 operator (A.C.) in a time span of 17 years. The teeth were exposed by means of a repositioned flap. Orthodontic traction was

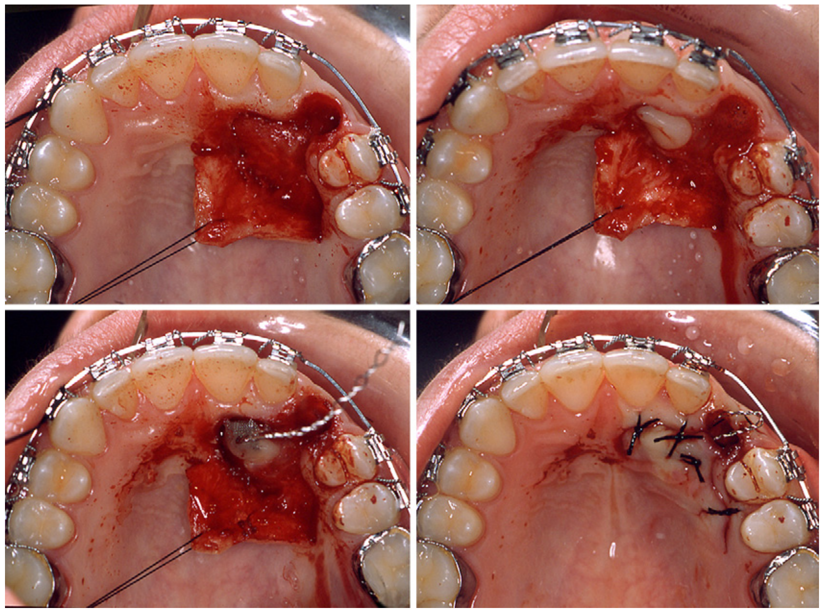

Fig 3. After extraction of the deciduous canine and full-thickness flap elevation, the palatal impacted canine is exposed by means of a gentle ostectomy. A hand-made chain is fixed on the top of the cusp, the flap is repositioned, and the traction is directed toward the center of the ridge.

Fig 4. The maxillary left canine is properly aligned in the arch with healthy periodontal tissues.

Fig 5. The panoramic radiograph shows correct position of the impacted maxillary left canine in the dental arch.

applied to guide the impacted canine directly toward the center of the alveolar ridge. In patients with persistent deciduous canines and unerupted permanent canines ($n = 24$), the "tunnel" technique was used.[4,13,14,16]

The overall combined treatment was divided into 3 phases.

1. Initial orthodontic treatment was aimed at creating space in the maxillary arch with fixed appliance therapy.
2. Surgical exposure and orthodontic traction were used to move the impacted tooth toward the center of the alveolar ridge. A handmade chain was connected to the attaching device on the impacted tooth and to the elastic for orthodontic traction. A rectangular stabilization arch was used to obtain adequate anchorage and maintain sufficient space in the dental arch, and a round arch was used as an attachment for the elastic traction to guide the impacted canine toward the center of the alveolar ridge. The duration of this phase (duration of traction) was calculated as

Fig 6. Male patient, 15 years old, with a maxillary left deciduous canine.

Fig 7. The panoramic radiograph shows the impacted maxillary left canine.

the time between the application of the traction device and the emergence of the cusp of the impacted canine.

3. Final orthodontic treatment aligned the canine in the maxillary arch.

Two patients are shown in Figures 1 to 10.

The treated teeth were evaluated periodontally after the overall orthodontic treatment (phases 1-3).

The following periodontal variables were considered for the treated canines.

1. Probing depth (PD) measurements were made with a Williams offset periodontal probe at 6 sites—mesiobuccal, midbuccal, distobuccal, mesiolingual, midlingual, and distolingual—of each treated tooth. The greatest PD was used in the analysis.
2. Width of keratinized tissue (KT), from the gingival margin to the mucogingival junction, was measured at the medial position of the buccal aspect of the crown.

Statistical analysis

Descriptive statistics were calculated as means and standard deviations for metric variables and as frequencies for nominal variables. An automatic structural learning algorithm of the BN was used as an explorative statistical technique for detecting possible causal relationships among these variables: (1) demographic variables (sex and age); (2) topographic variables (clinical and radiographic): site (buccal or palatal), side (left or right), unilateral or bilateral (patient), α-angle, d-distance, s-sector; treatment technique (tunnel); duration of traction, duration of treatment; KT; and PD.

The metric variables were transformed into binary variables by using the median values as a threshold. For the variable age, the threshold of 20 years was used. The variable s-sector was transformed into a binomial variable by combining sectors 1 and 2. For the generation of the directed acyclic graph, the structural learning algorithm B[26] was used, and the variables were organized in 5 levels. These levels (temporal tiers [TT]) imply a hierarchic order, so that subsequent levels cannot influence previous ones: TT1, sex and age; TT2, site (buccal or palatal), side (left or right), unilateral or bilateral (patient), α-angle, d-distance, and s-sector; TT3, treatment technique (tunnel); TT4, duration of traction; and TT5, duration of treatment, KT, and PD.

To exemplify the concept of the TT, the amount of KT after therapy cannot influence the side of canine impaction. By using these limitations, the graph that illustrates the relationships among the variables was generated.

RESULTS

The study population consisted of 168 patients (40 male, 128 female; age range, 12.8-52.0 years; mean age, 17.2 ± 6.0 years) each having 1 impacted maxillary canine. The clinical and radiographic characteristics are described in the Table. The periodontal evaluation after treatment showed a physiologic sulcus depth (PD, 2.5 ± 0.5 mm) and adequate KT (4.4 ± 1.2 mm). Only 1 patient had a shallow gingival recession (1 mm) on the treated impacted canine.

The means and standard deviations for the pretreatment radiographic variables were 35° ± 13° for the α-angle and 15 ± 4 mm for the d-distance. Duration

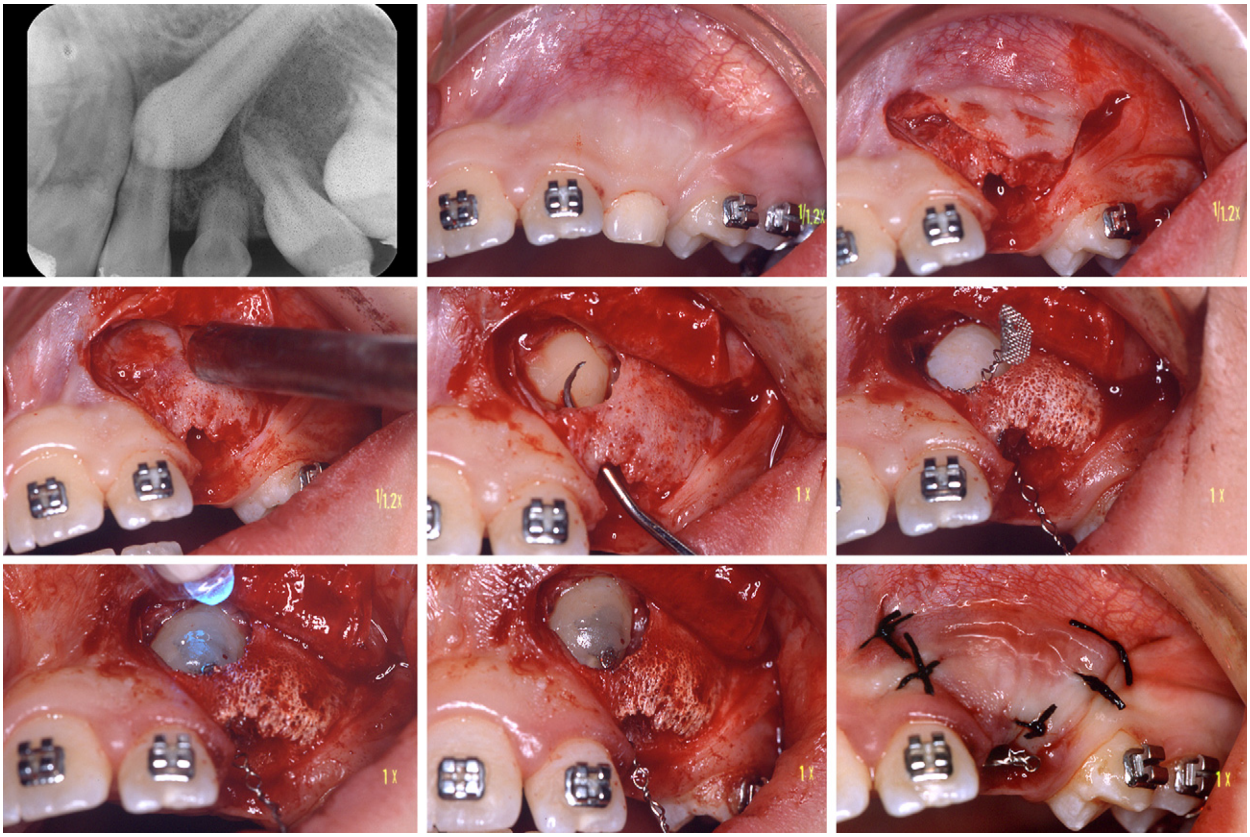

Fig 8. After extraction of the deciduous canine, a buccal full-thickness flap is elevated. The tunnel technique is used, and a hand-made chain is fixed on the top of the cusp passing through the alveolar empty socket. The flap is sutured in its initial position.

Fig 9. The maxillary left canine is properly aligned in the arch with healthy periodontal tissues.

of traction was 8.0 ± 2.3 months, and duration of treatment was 22.0 ± 4.8 months.

BN analysis showed a sequence of relationships among the considered variables, represented in Figure 11, and the relative interpretations are reported as follows.

1. The greater the age at start of treatment (patients older than 20 years), the smaller the d-distance, and the lower the frequency of the tunnel technique.
2. The greater the d-distance, the longer the duration of traction and, consequently, the longer the duration of treatment.
3. The greater the α-angle, the greater the d-distance, the higher the prevalence for s-sectors 1 and 2 (rather than sector 3), the longer the duration of traction, and the higher the frequency of the tunnel technique.
4. The higher the prevalence rate for sectors 1 and 2, the longer the duration of traction.

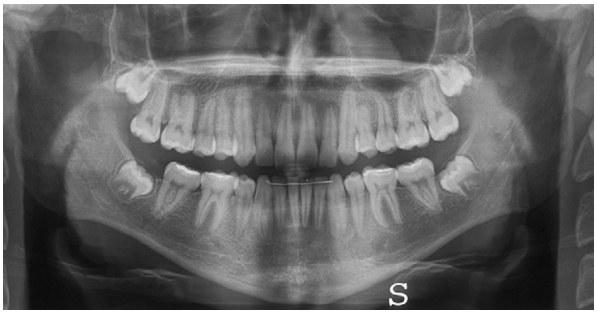

Fig 10. The panoramic radiograph shows the correct position of the impacted maxillary left canine in the dental arch.

5. Male sex led to a higher prevalence rate for sector 3.
6. Bilateral occurrence of impaction determines a longer duration of treatment and more prevalent palatal impaction.
7. The buccal side of impaction led to higher prevalence of sector 3 and greater frequency of the tunnel technique.
8. The palatal side of impaction and more KT led to greater PD at the end of treatment.

Table. Descriptive statistics: binomial variables used for BN analysis

Variable		*Frequency*
Sex	Female	128
	Male	40
Age (y)	<20	144
	≥20	24
Type	Unilateral	125
	Bilateral	43
Side	Left	78
	Right	90
Site	Buccal	50
	Palatal	118
d-distance (mm)	<15	79
	≥15	89
α-angle (°)	≤34	85
	>34	83
s-sector (n)	1-2	103
	3	65
Tunnel technique	No	144
	Yes	24
Duration of traction (mo)	≤8	94
	>8	74
Duration of treatment (mo)	<22	80
	≥22	88
KT (mm)	<4.5	71
	≥4.5	97
PD (mm)	≤2.5	122
	>2.5	46

DISCUSSION

Treatment of impacted canines is a clinical challenge in dentistry, because it is an interdisciplinary therapeutic approach that involves both orthodontic and periodontal operators. The outcome of treatment of impacted canines is successful when the tooth is in a stable position in the dental arch with a healthy periodontium. These goals can be achieved by means of comprehensive surgical-orthodontic treatment aimed to reposition the canine at the center of the alveolar ridge, as shown in previous studies.[4,13,16] This technique is indicated when direct traction to the center of the alveolar ridge on the maxillary arch is feasible, based on diagnostic records.[4,13] The use of multilevel statistics in previous studies was confined to test the role of pretreatment radiographic variables on the final periodontal status of impacted canines after surgical-orthodontic treatment.[14,15] The examined variables (d-distance, α-angle, and s-sector) could not predict the final periodontal outcome, although they were good predictors of the duration of orthodontic traction and comprehensive treatment.

Because of the multifactorial nature of demographic, diagnostic, and therapeutic aspects of impacted canines, our objective was to analyze the possible causal relationships of these variables. To reach this goal, we used BN as an innovative statistical tool to investigate possible causal relationships among the examined variables. In BN analysis, metric variables are transformed into binary variables by using the median values as thresholds. Despite the loss of some information about the distribution of the data, this feature facilitates the interpretation of possible causal relationships among factors. To comment on the results of BN analysis, the hierarchic order of TT, illustrated above, was followed.

Female subjects had a higher prevalence of more severe canine impaction. In the chain of relationships identified by the BN analysis, female sex is associated with a higher prevalence of sectors 1 and 2 vs 3, which in turn is associated with longer durations of treatment and traction. These observations amplify the knowledge on the relationships between sex and canine impaction. The prevalence of canine impaction is significantly higher in female subjects (male:female = 1:3)[1,2]; the same ratio was found in this study. On the other hand, the greater severity of impaction in female patients has not been highlighted yet in the literature. In the multifactorial etiology of canine impaction, the significant sex differences have been used to point to the genetic (sex-linked) basis of the tooth eruption anomaly.[1] Our findings might suggest that the severity of impaction also follows the same genetic pattern.

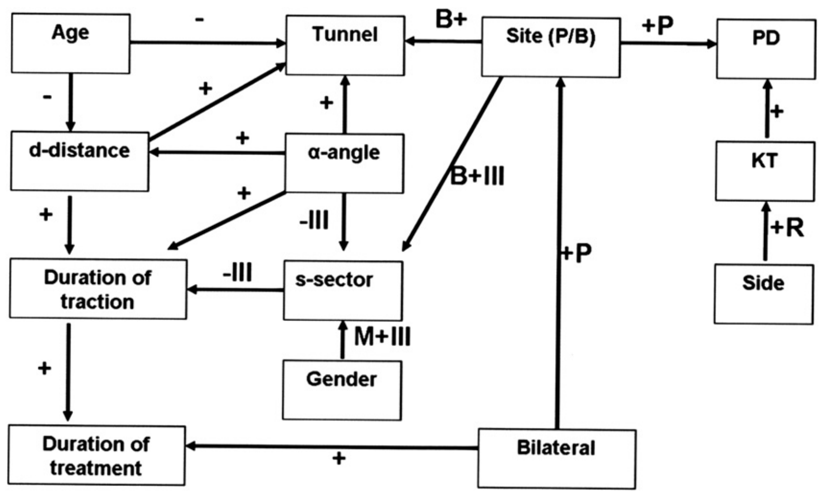

Fig 11. The graph generated by the structural learning algorithm (type B). *P*, Palatal; *B*, buccal; *PD*, probing depth; *KT*, keratinized tissue; *R*, right side; *III*, sector 3; *M*, male; +, the variable at the base of the *arrow* positively influences the variable at the *arrowhead*; −, the variable at the base of the *arrow* negatively influences the variable at the *arrowhead*.

The significant impact of age on the position of the canine (more favorable in older subjects because of a smaller d-distance) appeared to affect treatment duration. This effect might well explain the lack of correlation between age and treatment duration that was reported in previous studies[14,15]: adults with an impacted canine closer to the physiologic position of the dental arch required probably a similar treatment duration than difficult adolescent cases with the impacted canine farther from the alveolar ridge.

A canine impaction in the palatal site was associated with bilateral occurrence. This finding corroborates previous indications that identified palatal impaction of maxillary canines as a genetically based dental disorder.[1,2]

Buccal impaction was associated with a higher prevalence of the tunnel technique, because of the anatomy of the alveolar bone that allows for the tunnel in patients with vestibular impaction more frequently than in those with palatal impaction.[13] Interestingly, buccal impaction was associated also with a higher frequency of sector 3 vs sector 1 and 2 and, consequently, with a shorter duration of treatment. On the other hand, the tunnel technique is indicated when the crown of the impacted canine is close to the deciduous canine—ie, sector 3 at the pretreatment radiographic examination.[13] Additionally, a patient's increased age is inversely related to the frequency of the tunnel approach to an impacted maxillary canine, as assessed by the BN analysis in this study.

The pretreatment α-angle on panoramic radiographs appeared as a determinant for the severity of impaction and, consequently, of the duration of treatment, both directly and indirectly. Directly, the angle influenced the duration of traction, possibly because of the clinical need for therapeutic uprighting of the impacted tooth along with orthodontic traction. Indirectly, the α-angle was associated with a longer treatment through 2 processes: greater angulation of the impacted canine with respect to the midsagittal plane was related to greater distance of the tooth cusp from the occlusal plane, and the more angulated the impacted canine, the more unfavorable the sector of impaction (sectors 1 and 2 vs sector 3). The role of infraosseous pretreatment angulation of the impacted canine on the duration of treatment was described in previous studies.[4,14,19,27] These studies, however, provided no information about the reciprocal relationships between the different radiographic and clinical variables.

The BN approach confirmed the results of previous investigations on the same population in which the final periodontal outcomes after the surgical-orthodontic repositioning of maxillary impacted canines were unrelated to pretreatment diagnostic variables on the panoramic radiographs.[14,15] In this regard, virtually all patients in our sample had healthy periodontiums, with adequate KT, at the end of treatment with the protocol aimed to reposition the impacted canine at the center of the alveolar ridge.

CONCLUSIONS

The application of BN to diagnostic and therapeutic aspects of comprehensive surgical-orthodontic treatment of maxillary impacted canines identified several possible causal relationships among factors affecting the final outcomes of therapy. BN analysis was applied to a sample of 168 patients with specific features allowing for the tunnel traction technique: (1) persistent deciduous canines with impacted canines or space available in the dental arch and (2) feasibility of direct traction of the impacted canine to the center of the alveolar ridge as assessed on the diagnostic radiographic records. In particular, bilateral impaction is associated with palatal impaction and a longer duration of treatment, the pretreatment α-angle is a determinant for the duration of both orthodontic traction and overall treatment, and the posttreatment periodontal outcome is not related to pretreatment radiographic variables that describe the infraosseous position of the impacted canine.

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