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Clinical and Radiographic Analysis of Primary Tooth Extractions: Indications, Dental Maturation Percentiles, and Space Maintainer Requirements

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Abstract

Objectives

To investigate primary tooth extraction indications, dental maturation percentiles, and clinical and radiographic factors associated with space maintainer requirements in children.

Materials and Methods

This retrospective study evaluated 481 primary tooth extraction sites in 200 children. Dental maturation was assessed using the Demirjian method and age- and sex-specific percentile references, while permanent successor development was evaluated using Nolla stages. Space maintainer requirements were classified as required, follow-up sufficient, or not required. Associations were examined using chi-square tests and multivariable logistic regression with patient-clustered standard errors.

Results

Dental caries and its complications were the most common extraction indications (39.3%), followed by physiological mobility/ectopic eruption (36.8%). Space maintainers were considered necessary at 223 extraction sites (46.4%). Children below the 50th dental maturation percentile showed a higher patient-level requirement than those at or above this percentile (65.0% vs. 48.3%; $p = 0.021$). Thick alveolar bone coverage was strongly associated with space maintainer requirement (adjusted odds ratio [aOR] = 42.33; 95% confidence interval [CI]: 11.76–152.41; $p < 0.001$). Increasing chronological age was associated with lower odds (aOR = 0.70; 95% CI: 0.51–0.98; $p = 0.037$). Dental maturation percentile was not independently associated with the outcome after adjustment ($p = 0.281$).

Conclusions

Space maintainer requirements were strongly associated with local radiographic characteristics, particularly alveolar bone coverage, whereas dental maturation percentiles showed no independent association after adjustment.

Clinical Relevance

Integrating dental maturation assessment with local radiographic findings may support individualized clinical decision-making following primary tooth extraction.

INTRODUCTION

Primary teeth play an important role in maintaining arch integrity and guiding the eruption of permanent teeth, in addition to essential functions such as mastication, phonation, and aesthetics in children [1, 2]. However, despite preventive and restorative treatments, premature loss of primary teeth remains an important clinical and public health problem [3, 4]. Dental caries and associated uncontrolled periapical pathologies have been reported as the leading causes of primary tooth extraction, with rates ranging

from 51.6% to 58.6% [5, 6]. These are followed by physiological mobility, trauma, and orthodontic indications [2, 4, 7].

Loss of primary teeth before physiological exfoliation may lead to undesirable changes in the dental arch. During this process, tipping of adjacent teeth into the extraction space and malocclusions associated with reduced arch length may necessitate the use of space maintainers [2, 8]. However, space maintainer requirements should not be determined solely by chronological age, as chronological and biological development do not always progress in parallel [9, 10]. Recent meta-analyses emphasize that the Demirjian method generally tends to overestimate dental age, whereas the Nolla method tends to underestimate it. Therefore, more detailed assessment approaches that account for individual developmental differences are recommended [10, 11].

Evaluating dental maturation not only for age estimation but also through maturation percentiles may contribute to a more detailed interpretation of individual developmental differences in pediatric dentistry [9]. Maturation percentiles position a child's dental development within the distribution of peers, allowing a more precise assessment of the correlation between developmental rate and skeletal maturity [9, 12]. This approach may provide an additional decision-support tool, particularly in assessing the risk of post-extraction space loss and interpreting space maintainer requirements clinically and radiographically [8, 9].

Currently, these percentile assessments are performed using automated dental age estimation applications developed to overcome the complexity of manual calculations [13, 14]. Recently developed digital dental age assessment applications have been reported to enable faster and more standardized evaluations using the Demirjian method [13]. These applications may support clinical assessment by facilitating faster and more standardized interpretation of developmental scores obtained from panoramic radiographs [13, 15].

Previous studies have examined extraction reasons or dental age separately [4, 5]. Studies jointly evaluating primary tooth extraction reasons, dental maturation percentiles, and space maintainer requirements remain limited. This study aimed to evaluate the reasons for early primary tooth loss, affected tooth groups, and age and sex distributions using panoramic radiographs and clinical records of pediatric patients, and to investigate the potential contribution of dental maturation percentiles to determining space maintainer requirements following extraction.

MATERIALS AND METHODS

Study Design and Ethical Approval

This study was approved by the Yozgat Bozok University Non-Interventional Clinical Research Ethics Committee (2026-GOKAEK-2617_345). The study was conducted in accordance with the principles of the Declaration of Helsinki and all applicable ethical guidelines and regulations. In this single-center, retrospective observational study, clinical records and digital panoramic radiographs of pediatric

patients were examined. All panoramic radiographs were obtained using the same digital panoramic device under standardized imaging parameters. No additional radiographic examinations or clinical interventions were performed, and existing archival data were anonymized before analysis.

Sample Selection and Criteria

The sample size was calculated using a prevalence-based sample size formula. As the rate of primary tooth extraction due to caries was reported as 55.1% in the literature, the expected prevalence was set at p = 0.551. With a 95% confidence level and a 7% margin of error, the minimum sample size was calculated as 194. Considering potential data loss, 200 pediatric patients were planned for inclusion.

Systemically healthy children aged 4–14 years with clearly documented primary tooth extraction indications and panoramic radiographs suitable for clinical and radiographic assessment were included. Patients with systemic diseases or syndromes affecting dental development, generalized developmental dental disorders, insufficient image quality preventing evaluation of the relevant region, or incomplete clinical records were excluded.

Clinical Data Collection

Digital treatment files and medical history records of the included patients were retrospectively reviewed. Each patient's chronological age at extraction, sex, location of extracted primary teeth, and extraction indications were recorded on a standardized data collection form. Only cases with extraction indications documented by pediatric dental specialists and sufficient clinical and radiographic data were evaluated. When multiple primary teeth had been extracted from the same patient, each extraction site was considered a separate unit of assessment. Clinical data were verified by comparing digital patient records with medical history forms.

Radiographic Evaluation

Digital panoramic radiographs were retrospectively evaluated on a high-resolution monitor under standardized viewing conditions. Extracted primary teeth were classified according to jaw (maxilla/mandible), side (right/left), and tooth group (central incisor, lateral incisor, canine, first primary molar, and second primary molar). Extraction indications were classified into five categories: dental caries and pulpal/periapical complications, traumatic injuries, failed endodontic treatments, physiological mobility/ectopic eruption, and orthodontic indications [2, 4, 5].

The developmental stage of the permanent successor and the overlying alveolar bone coverage were examined at each extraction site. Alveolar bone coverage was visually assessed on panoramic radiographs and classified as absent, thin, or thick. Extraction space status (fully maintained, partially closed, or completely closed) and adjacent tooth position (normal, mild tipping, or marked

tipping/migration) were also evaluated. All clinical and radiographic data were transferred to a standardized digital data collection form.

Demirjian Method and Dental Age Analysis

Dental maturation was assessed using the Demirjian method, based on the calcification stages of the seven left mandibular permanent teeth (31–37) on panoramic radiographs. The developmental stage of each tooth was manually determined by the researcher according to stages A–H. These stages were entered into the digital Dental Age application to calculate sex-specific total maturation scores and estimated dental ages [13].

If a permanent tooth in the left mandibular region was congenitally absent or could not be evaluated radiographically, the developmental stage of the corresponding homologous tooth in the right mandibular region was used. The resulting total maturation scores were used to assess dental development.

Nolla Method for Permanent Successor Evaluation

The Nolla method was used to evaluate the developmental stages of the permanent successors of extracted primary teeth. Mineralization and root development of each permanent successor were assessed on panoramic radiographs according to Nolla's developmental stages ranging from 0 to 10. For statistical analyses, Nolla stages were grouped into three categories: ≤6, 7–8, and 9–10. Three extraction sites without permanent successors were recorded separately and excluded from Nolla stage analyses.

Other Current Approaches: Dental Maturation Percentiles

Total Demirjian maturation scores were classified using age- and sex-specific dental maturation percentile values reported by Ong et al. [9]. Each individual's maturation score was compared with the P5, P16, P50, P84, and P95 thresholds for the corresponding age and sex group. Accordingly, individuals were classified into six percentile groups: <P5, P5–P16, P16–P50, P50–P84, P84–P95, and >P95.

For the analysis of the association between space maintainer requirement and dental maturation, a simpler clinical classification was used. Individuals below P50 were classified as “below P50/delayed dental maturation,” while those at or above P50 were classified as “P50 and above/advanced dental maturation.”

Assessment of Space Maintainer Requirements

Space maintainer requirements following primary tooth extraction were determined by evaluating clinical and radiographic findings together. The following criteria were considered:

Radiographic Bone Coverage

The presence and thickness of alveolar bone coverage over the permanent successor were evaluated in relation to eruption timing.

Dental Maturation

Patients' dental developmental levels were assessed considering the maturation percentiles reported by Ong et al. [9].

Local Dental Development

The Nolla developmental stage of the permanent successor, extraction space status, and risk of adjacent tooth migration were evaluated.

Based on these criteria, each extraction site was classified into one of three categories: space maintainer required, clinical follow-up sufficient, or space maintainer not required.

Statistical Analysis

SPSS and Python software were used for statistical analyses. Patients' demographic characteristics, primary tooth extraction indications, dental maturation status, and space maintainer requirements were presented as frequencies (n), percentages (%), means, and standard deviations. Associations between categorical variables were evaluated using the chi-square test, and effect sizes were expressed using Cramér's V coefficient.

Multivariable binary logistic regression analysis was performed to evaluate clinical and radiographic variables associated with space maintainer requirements. The dependent variable was dichotomized as space maintainer required versus space maintainer not required/clinical follow-up sufficient. Because multiple extraction sites were present in some patients, standard errors were clustered at the patient level. Regression results were presented as adjusted odds ratios (aORs) with 95% confidence intervals. Three sites without permanent successors and one tooth extracted due to traumatic injury were excluded from the regression analysis.

To assess intraobserver reliability, radiographic evaluations of 20 patients (10% of the sample) were repeated, and the intraclass correlation coefficient (ICC) was calculated. A p-value < 0.05 was considered statistically significant.

RESULTS

A total of 200 pediatric patients were included in the study. Intraobserver reliability was assessed by repeating the radiographic evaluations in 20 randomly selected patients (10% of the sample). The intraclass correlation coefficient (ICC) was 0.89, indicating good intraobserver reliability. Of these, 94

(47.0%) were girls and 106 (53.0%) were boys. The chronological ages of the patients ranged from 4.5 to 13.9 years, with a mean age of 9.22 ± 2.00 years. The mean dental age calculated using the Demirjian method was 9.31 ± 2.26 years.

A total of 481 primary teeth were extracted from the 200 patients. The mean number of extracted primary teeth per patient was 2.41 ± 1.57, ranging from 1 to 7 teeth. The distribution of extracted primary teeth according to the number of teeth extracted per patient, tooth group, and jaw is presented in Table 1.

Table 1
Distribution of extracted primary teeth according to the number of teeth extracted per patient, jaw, and tooth group

Variable	**n**	**%**
Number of extracted primary teeth per patient		
1 tooth	76	38.0
2 teeth	52	26.0
3 teeth	28	14.0
4 teeth	19	9.5
5 teeth	12	6.0
6 teeth	10	5.0
7 teeth	3	1.5
Distribution by jaw		
Maxilla	273	56.8
Mandible	208	43.2
Distribution by tooth group		
Primary central incisor	17	3.5
Primary lateral incisor	20	4.2
Primary canine	94	19.5
First primary molar	173	36.0
Second primary molar	177	36.8

The distribution of dental maturation scores according to chronological age, sex, and maturation status is presented in Fig. 1. Of the patients, 140 (70.0%) were below P50, while 60 (30.0%) were at or above P50.

When space maintainer requirements were evaluated at the patient level, 120 patients (60.0%) were recorded as requiring a space maintainer for at least one extraction site. In 50 patients (25.0%), clinical follow-up alone was considered sufficient, while in 30 patients (15.0%), space maintainers were classified as unnecessary at all evaluated sites.

The distribution of the primary reasons for extraction and the main factors influencing space maintainer decisions is presented in Table 2. The most common reason for extraction was dental caries and pulpal/periapical complications (39.3%), followed by physiological mobility/ectopic eruption (36.8%) and orthodontic indications (18.7%).

At the extraction-site level, space maintainers were considered necessary at 223 of 481 sites (46.4%), clinical follow-up was sufficient at 121 sites (25.2%), and space maintainers were not required at 137 sites (28.5%). The most common factors influencing space maintainer decisions were extraction close to the physiological exfoliation period (38.0%), premature primary tooth loss (23.1%), and extraction as part of an orthodontic treatment plan (15.2%).

Table 2
Distribution of primary tooth extraction reasons and main factors influencing space maintainer decisions

Variable	**N**	**%**
Primary reason for extraction		
Dental caries and pulpal/periapical complications	189	39.3
Physiologic mobility / ectopic eruption	177	36.8
Orthodontic indication	90	18.7
Failed endodontic treatment	24	5.0
Traumatic injury	1	0.2
Main factor influencing the space maintainer decision		
Extraction close to the physiologic exfoliation period	183	38.0
Premature loss of a primary tooth	111	23.1
Extraction as part of an orthodontic treatment plan	73	15.2
Permanent successor distant from eruption	51	10.6
Suspected arch-length loss	36	7.5
Migration of adjacent teeth	22	4.6
Delayed dental maturation*	5	1.0

Three extraction sites (0.6%) were excluded from Nolla developmental stage analyses because permanent successors were absent. Among sites with permanent successors, the most common stages were Nolla stage 8 (n = 136; 28.3%), stage 7 (n = 122; 25.4%), and stage 9 (n = 87; 18.1%). Bone coverage over the permanent successor was classified as thick at 193 sites (40.1%) and thin at 137 sites (28.5%), while no bone coverage was observed at 151 sites (31.4%).

The extraction space was fully maintained at 361 sites (75.1%), partially closed at 100 sites (20.8%), and completely closed at 20 sites (4.2%). Adjacent tooth position was normal at 359 sites (74.6%), showed mild tipping at 100 sites (20.8%), and marked tipping/migration at 22 sites (4.6%).

A significant association was found between dental maturation and space maintainer requirements at the patient level. Among the 140 patients below P50, 91 (65.0%) required a space maintainer for at least one extraction site, compared with 48.3% (n = 29) of the 60 patients at or above P50. Among patients below P50, clinical follow-up alone was sufficient in 24.3%, and space maintainers were not required in 10.7%. The corresponding rates among patients at or above P50 were 26.7% and 25.0%, respectively. The difference between groups was statistically significant (χ^2=7.75; p = 0.021).

Statistically significant associations were found between space maintainer requirements and the Nolla developmental stage of the permanent successor (χ^2=124.50; p < 0.001; Cramer's V = 0.361), bone coverage over the permanent successor (χ^2=311.48; p < 0.001; Cramer's V = 0.569), primary reason for extraction (χ^2=230.13; p < 0.001; Cramer's V = 0.489), extraction space status (χ^2=23.95; p < 0.001; Cramer's V = 0.158), adjacent tooth position (χ^2=23.32; p < 0.001; Cramer's V = 0.156), and primary tooth type (χ^2=59.13; p < 0.001; Cramer's V = 0.248), as presented in Table 3.

In contrast, no statistically significant associations were found between space maintainer requirements and the jaw in which the extracted tooth was located (χ^2=2.06; p = 0.356), right-left side distribution (χ^2=0.42; p = 0.813), or sex (χ^2=2.84; p = 0.241).

Table 3
Associations of clinical and radiographic variables with space maintainer requirement

Variable	Category	Space maintainer required, n (%)	P	Cramer's V
Nolla stage	≤ 6	110 (85.3)	< 0.001	0.361
	7–8	98 (38.0)		
	9–10	13 (14.3)		
Bone coverage	None	10 (6.6)	< 0.001	0.569
	Thin	43 (31.4)		
	Thick	170 (88.1)		
Primary reason for extraction	Dental caries and pulpal/periapical complications	157 (83.1)	< 0.001	0.489
	Failed endodontic treatment	15 (62.5)		
	Physiologic mobility / ectopic eruption	21 (11.9)		
	Orthodontic indication	29 (32.2)		
Extraction-space status	Space maintained	167 (46.3)	< 0.001	0.158
	Partially closed	49 (49.0)		
	Completely closed	7 (35.0)		
Adjacent tooth position	Normal	165 (46.0)	< 0.001	0.156
	Mild tipping	50 (50.0)		
	Marked tipping/migration	8 (36.4)		
Tooth type	Central incisor	1 (5.9)	< 0.001	0.248
	Lateral incisor	1 (5.0)		
	Canine	28 (29.8)		
	First primary molar	89 (51.4)		
	Second primary molar	104 (58.8)		
Traumatic injury was not presented separately because only one extraction was recorded in this category.				

Multivariable binary logistic regression analysis was performed to identify independent predictors of space maintainer requirements. Because multiple extraction sites were present in some patients, standard errors were clustered at the patient level. In the model, thick bone coverage over the permanent successor (aOR = 42.33; 95% CI: 11.76–152.41; p < 0.001) and thin bone coverage (aOR = 4.08; 95% CI: 1.43–11.62; p = 0.008) were identified as independent predictors of space maintainer requirements. Space maintainer requirements were significantly lower following primary central incisor loss compared with second primary molar loss (aOR = 0.06; 95% CI: 0.01–0.58; p = 0.015). Additionally, each one-year increase in chronological age was associated with lower odds of requiring a space maintainer (aOR = 0.70; 95% CI: 0.51–0.98; p = 0.037). Dental maturation below P50 did not remain a statistically significant independent predictor after adjustment for other clinical and radiographic variables (aOR = 1.63; 95% CI: 0.67–3.98; p = 0.281) (Fig. 2).

DISCUSSION

In this study, the extraction indications of 481 primary teeth in 200 children aged 4–14 years were retrospectively evaluated. The most common reason was dental caries and pulpal/periapical complications (39.3%; n = 189), followed by physiological mobility/ectopic eruption (36.8%; n = 177) and orthodontic indications (18.7%; n = 90). Failed endodontic treatment (5.0%; n = 24) and traumatic injury (0.2%; n = 1) were recorded as rare indications. When dental caries and its complications were considered together with failed endodontic treatment due to their common pathological basis, a total of 213 sites (44.3%) were found to be caries-related.

Dental caries is reported as the most common reason for primary tooth extraction in the literature. Özveren et al. identified caries as the leading extraction reason, accounting for 55.1% of cases [4]. Similarly, Çiftçi et al. reported a rate of 80% [2], Demiri et al. 59.64% [16], and Utami et al. 53% [1]. Doğan et al. identified dental caries as the most common extraction reason in their ten-year study [17]. Tatlı and Sarı also stated that caries remains the primary reason for tooth extraction in children despite modern advances [18]. The caries rate of 39.3% observed in our study was at the lower end of the range reported in the literature. The most likely explanation for this difference is that physiological mobility/ectopic eruption and orthodontic indications were defined as separate categories in our study. Indeed, Özveren et al. reported mobility/root resorption as the second most common reason, with a rate of 42.4% [4]. Furthermore, as our sample covered a broad age range of 4.5–13.9 years, the proportion of teeth approaching physiological exfoliation was increased. A study from the Western Mediterranean region also showed that most primary teeth indicated for extraction due to pathological reasons were observed in children aged 6–8 years (54%), indicating that the distribution of extraction indications is associated with age [2].

No significant association was found between space maintainer requirements and sex in our study (χ^2=2.84; p = 0.241). This result is consistent with the literature. In Syrian refugee children and adolescents, caries and pulpal diseases were the most common extraction reasons in both sexes, with no difference between sexes [19]. In an Indonesian study evaluating 1,772 teeth from 529 children,

extraction requirements were significantly associated with age but not with sex [20]. Similarly, no sex-related difference was found in a Turkish study involving 3,076 primary teeth from 1,363 children ($p = 0.489$) [4]. In contrast, some studies have reported sex-related differences. In an Indian study, the association between extraction reason and sex was borderline significant ($\chi^2=12$, $df = 5$, $p = 0.08$), with caries rates of 45.21% in boys and 39.86% in girls; orthodontic extractions were slightly more frequent in girls [21]. In Tetovo, although the total number of extractions was higher in boys, statistical significance was observed only for caries-related extractions [16]. This heterogeneity suggests that sex-related differences may be associated more with oral hygiene habits, parental attitudes, and access to healthcare than with biological tendencies.

The age distribution of extractions was also consistent with the literature. Demiriz and Hazar Bodrumlu reported that the highest proportion of teeth was extracted at age 9 (24%; 583 teeth), followed by ages 10 (22.7%), 7 (19.7%), 8 (18.7%), and 11 (14.9%) [5]. Özveren et al. reported that 42% of extractions were concentrated in children aged 6–9 years [4]. The mean age in our study (9.22 ± 2.00 years) was consistent with the center of this distribution. Furthermore, the association between each one-year increase in chronological age and reduced odds of space maintainer requirement in the logistic regression model (aOR = 0.70; 95% CI: 0.51–0.98; $p = 0.037$) indicates that teeth approach the physiological exfoliation period with increasing age.

Of the 481 extracted primary teeth, 273 (56.8%) were located in the maxilla and 208 (43.2%) in the mandible. By tooth group, second primary molars accounted for 177 (36.8%), first primary molars for 173 (36.0%), canines for 94 (19.5%), lateral incisors for 20 (4.2%), and central incisors for 17 (3.5%). Molars accounted for 72.8% (n = 350) of all extractions. This distribution closely matches the findings of Demiriz and Hazar Bodrumlu, who reported that primary molars accounted for 73.7% of extracted teeth, while primary canines and incisors accounted for 16.3% and 10%, respectively. The predominance of maxillary extractions was also consistent with their findings (maxilla: 55.7%; mandible: 44.3%) [5]. An Indian study also emphasized that maxillary tooth extractions were consistently more frequent across all age groups, attributing this to differences in susceptibility to dental diseases and traumatic injuries between maxillary and mandibular teeth [21].

In our study, the mean dental age calculated using the Demirjian method (9.31 ± 2.26 years) was close to the mean chronological age (9.22 ± 2.00 years), with a difference of only 0.09 years between the two means. This finding alone does not demonstrate the method's accuracy at the individual level or the absence of systematic estimation error. The literature reports considerable population-dependent differences in this regard. Nur et al. reported that the Demirjian method overestimated dental age by 0.89 years in girls and 0.84 years in boys, whereas the Nolla method tended to underestimate age by − 0.54 years overall and provided more accurate results for this population [22]. Recent reviews and meta-analyses support these findings while indicating that the direction of estimation errors may vary. A meta-analysis including 25 studies reported that the Demirjian method overestimated age by an average of 0.5 years, whereas the Nolla method underestimated age by 0.28 years in boys and 0.25 years in girls [11]. In the systematic review by Gupta et al., the Demirjian method consistently overestimated age regardless

of sex, while the Nolla method was found to provide more accurate results [23]. In contrast, Marconi et al. reported that both methods tended to overestimate age. The combined use of the two methods in our study may be considered a deliberate approach to reducing the influence of these methodological estimation errors on clinical decisions.

Interpreting dental maturation through percentile curves, rather than solely for age estimation, allows a child's developmental rate to be positioned within the distribution of peers [9]. In our study, 65.0% (n = 91) of patients below P50 required a space maintainer for at least one extraction site, compared with 48.3% (n = 29) of patients at or above P50, with a statistically significant difference between groups (χ^2=7.75; p = 0.021). This finding indicates that space maintainer requirements were more frequently identified in children with dental maturation below P50. However, the loss of statistical significance in the multivariable analysis suggests that overall dental maturation status may not be sufficient as an independent indicator for space maintainer decisions. Therefore, dental maturation percentiles should preferably be interpreted alongside the local developmental characteristics of the permanent successor and other clinical and radiographic variables. Teo et al. emphasized that Demirjian dental age alone was insufficient to predict spontaneous space closure and that additional factors, such as second molar angulation and the presence of a third molar germ, may also be important [24].

A significant association was found between space maintainer requirements and the Nolla developmental stage of the permanent successor (χ^2=124.50; p < 0.001; Cramer's V = 0.361). Space maintainers were required at 85.3% (n = 110) of sites with Nolla stage ≤ 6, decreasing to 38.0% (n = 98) at stages 7–8 and 14.3% (n = 13) at stages 9–10. This finding directly supports the criterion of two-thirds root development, considered a critical threshold for eruption timing. In the systematic review by Kamki et al., the presence of > 1 mm of bone coverage over the permanent successor and/or formation of less than one-third of the permanent tooth root were identified as key criteria for space maintainer indication [25]. Samal also stated that at least 1 mm of bone coverage was required for space maintainer placement, while its absence constituted a contraindication [26]. Nevertheless, Nolla stage did not remain a statistically significant independent predictor in the multivariable regression analysis. This result may reflect shared variability between Nolla stage and bone coverage, chronological age, and other clinical variables.

One of the notable findings of our study was the strong association between alveolar bone coverage over the permanent successor and space maintainer requirements. In the multivariable analysis, thick bone coverage (aOR = 42.33; 95% CI: 11.76–152.41; p < 0.001) and thin bone coverage (aOR = 4.08; 95% CI: 1.43–11.62; p = 0.008) remained statistically significant. However, the fact that bone coverage was among the clinical criteria used to determine space maintainer requirements should be considered when interpreting this association. Therefore, rather than demonstrating bone coverage as an independently validated prediction tool, these findings support its important role in the current clinical decision-making process [8].

The distribution of the main factors influencing space maintainer decisions reflects the multifactorial nature of the decision-making process. The effect sizes of the associations between space maintainer requirements and extraction space status (χ^2=23.95; $p < 0.001$; Cramer's V = 0.158) and adjacent tooth position (χ^2=23.32; $p < 0.001$; Cramer's V = 0.156) were relatively small. The retrospective study design and possible differences in the time elapsed since extraction among patients should be considered when interpreting these findings. The literature indicates that space loss increases over time following premature tooth loss [27]. In particular, the inability to evaluate the time elapsed since extraction in a standardized manner limits conclusions regarding changes in space loss over time.

Observer-dependent variability in radiographic evaluation has increased interest in decision-support systems in pediatric dentistry. Therefore, dental maturation assessment in our study was performed using a digital dental age estimation application with established accuracy and reliability. In a validation study comparing this application with the conventional Demirjian method, a high intraclass correlation coefficient was reported, with no tendency toward overestimation or underestimation [13]. This confirms that digital tools can facilitate standardized and reproducible Demirjian assessments.

Limitations

Several limitations should be considered when interpreting the results of this study. First, the study had a single-center, retrospective design, and extraction indications were based on clinical notes in archival records; therefore, variations in record quality may affect data reliability. Second, age- and sex-specific reference values reported by Ong et al. were used to evaluate dental maturation percentiles. As dental maturation may vary across populations, validation of these percentile classifications in different populations would be beneficial in future studies. Third, Nolla staging was limited to sites with permanent successors; three sites (0.6%) were excluded from the analysis because permanent successors were absent. Fourth, traumatic injury was recorded at only one site (0.2%), preventing statistical inference for this category. Fifth, long-term follow-up data after space maintainer placement were unavailable; therefore, the effectiveness of space maintainer decisions in preserving arch length could not be evaluated with this study design.

CONCLUSION

This study comprehensively evaluated the combined effects of extraction indications, dental maturation status, and radiographic characteristics on space maintainer requirements following early primary tooth loss. Our findings indicate that dental caries and its complications remain the most common reason for extraction, although physiological mobility/ectopic eruption accounts for a nearly equal proportion, and that extractions predominantly involve molars and maxillary teeth. Bone coverage over the permanent successor was the strongest independent determinant of space maintainer requirements, whereas dental maturation percentiles gain significance when considered alongside the local developmental stage of the permanent successor rather than independently. These findings indicate that space maintainer decisions following early primary tooth loss should not be based solely on chronological age

or a single parameter, and that radiographic bone coverage and the developmental stage of the permanent successor should be systematically integrated into clinical decision-making.

DECLARATIONS

Authors' contributions: Study conception and design: İ.C. and M.K.H.; data acquisition: İ.C.; data analysis and interpretation: İ.C. and M.K.H.; manuscript drafting: İ.C. and M.K.H.; critical revision of the manuscript: M.K.H. Both authors reviewed and approved the final manuscript.

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Ethics approval and consent to participate: Ethical approval was obtained from the Yozgat Bozok University Non-Interventional Clinical Research Ethics Committee (Approval No. 2026-GOKAEK-2617_345). The study was conducted in accordance with the principles of the Declaration of Helsinki and applicable institutional and national ethical guidelines and regulations. This retrospective observational study was conducted using existing clinical records and panoramic radiographs. The requirement for informed consent was waived by the ethics committee.

Clinical trial registration: Not applicable. This study was retrospective and observational in design and did not involve prospective assignment of participants to interventions.

Consent for publication: Not applicable. The manuscript contains no identifiable personal information.

Availability of data and materials: The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request, subject to applicable ethical and institutional restrictions.

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Figures

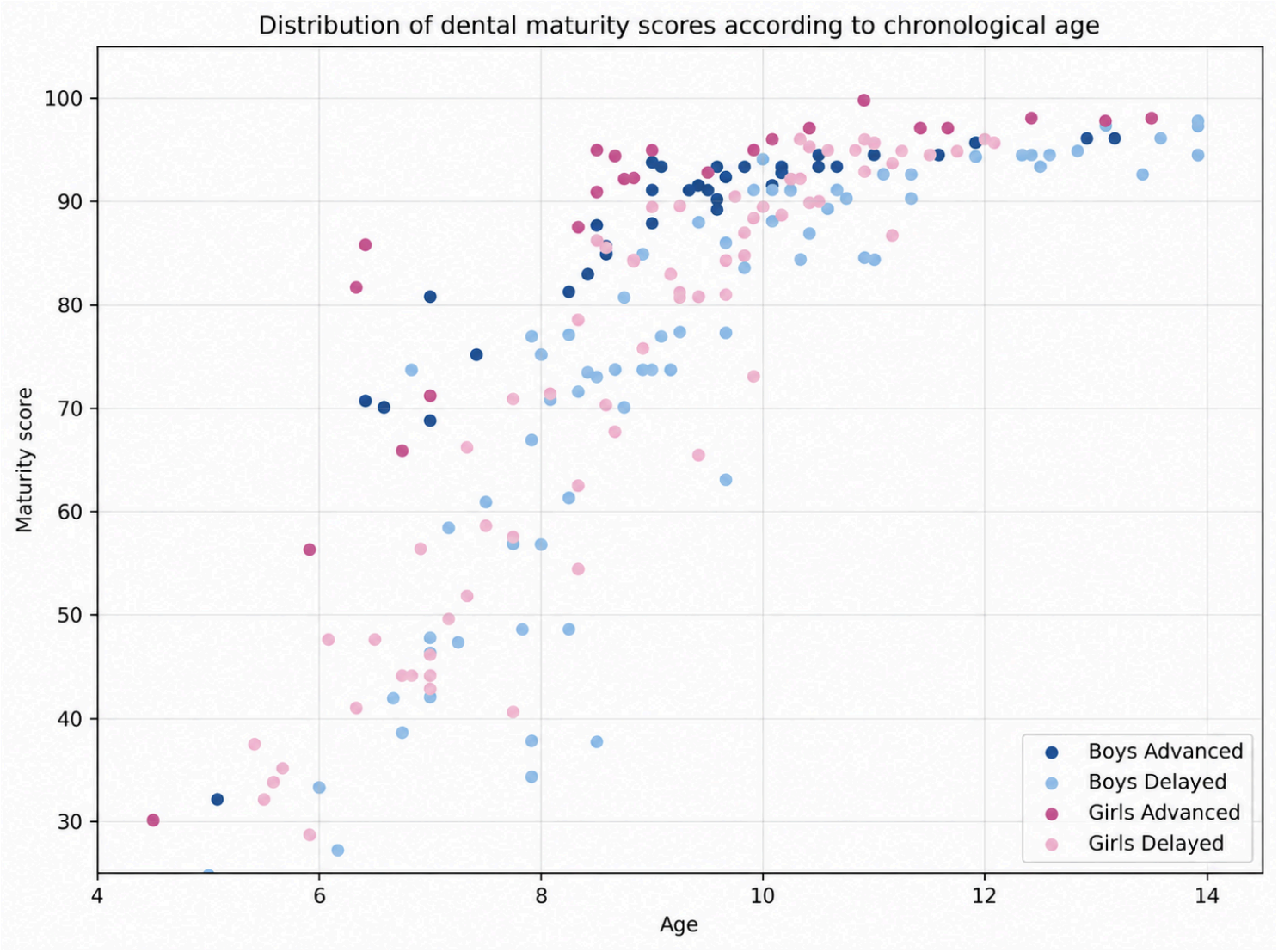


Figure 1

Distribution of dental maturity scores according to chronological age in boys and girls. Darker shades represent advanced dental maturation (≥P50), and lighter shades represent delayed dental maturation (<P50)

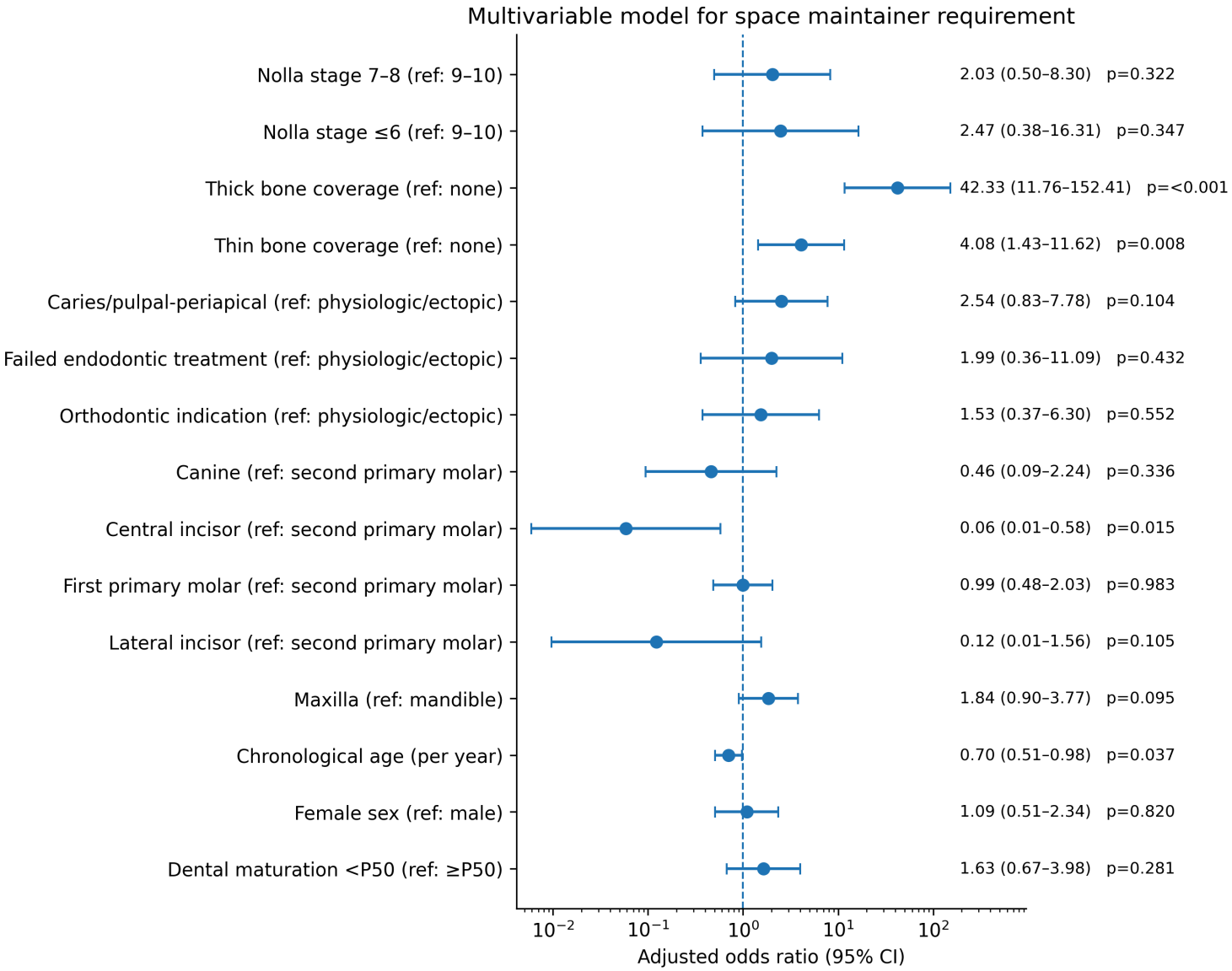


Figure 2

Forest plot showing the independent predictors of space maintainer requirement in the multivariable logistic regression model. Points represent adjusted odds ratios (aORs), and horizontal lines indicate 95% confidence intervals. The vertical dashed line denotes the null value (aOR=1.0).