COHORT STUDY

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Radiographic Evaluation of Permanent Second Molar Substitution After Extraction of Permanent First Molar: Identifying Predictors for Spontaneous Space Closure

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Abstract: ***Purpose:*** *The purpose of this study was to investigate pre-extraction variables associated with spontaneous space closure of the permanent second molar (PSM) following early extraction of the permanent first molar (PFM), and test an existing prediction model for the mandibular arch as the rates of spontaneous space closure are significantly lower in the mandible compared to the maxilla.* ***Methods:*** *Pre-extraction panoramic radiographs of 162 patients (138 maxillary and 168 mandibular quadrants) between five and 15 years old at the time of PFM extraction were evaluated. The prediction model was applied to the mandibular quadrants. Postextraction radiographic evaluation was used for outcome assessment, with success defined as the presence of a visible contact between the second premolar and PSM without marginal ridge discrepancy.* ***Results:*** *Success was observed in 82 percent of maxillary quadrants and 51 percent of mandibular quadrants. Maxillary PFM extraction between eight and 10 years or PSM Demirjian stage D or E demonstrated over 90 percent predictive probability for success. Mandibular PFM extraction at age eight years or PSM Demirjian stage D demonstrated 80 percent success. The prediction model did not add a more predictive value than chronological age or PSM Demirjian stage.* ***Conclusions:*** *The prediction model was not validated in this study population. Chronological age and permanent second molar developmental stage were the primary predictors for successful substitution with the permanent second molar.*
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As the first permanent tooth to erupt, the permanent first molar (**PFM**) is exposed longest to the caries risk factors that exist during the mixed dentition, when oral hygiene tends to be poor and diet is increasingly cariogenic.[1] The PFM experiences the highest incidence of caries in both the mixed and permanent dentitions.[2-4] Not surprisingly, the PFM is the most heavily restored and most commonly extracted permanent tooth due to caries in adolescence and early adulthood.[5-7]

The enamel of the PFM is uniquely susceptible to molar hypomineralization (**MH**). Severely affected PFMs are prone to caries and structural breakdown, requiring complex, early restorative treatment for patients as young as six years of age.[8,9] Hypomineralized molars demonstrate heightened sensitivity upon eruption and are more difficult to anesthetize.[10-12] The difficulty in bonding to the altered enamel structure often results in restorative failure.[10,11,13] The repeat restorative treatment imposes an economic and psychological burden on patients with MH, and the increased behavior management problems result in a greater need for treatment under sedation or general anesthesia.[10]

In cases of severe MH and/or caries, early PFM extraction with spontaneous substitution of the permanent second molar (**PSM**) can be superior to restorative treatment.[13] In 2008, the Faculty of Dental Surgery, Royal College of Surgeons of England (**FDSRCS**), first published national clinical guidelines (**NCGs**) on the extraction of PFMs in children.[14] The NCGs, updated in 2014, state that the unerupted maxillary PSM will achieve an ideal replacement position, with space closure observed in 80 to 90 percent of cases.[14-16] Mandibular PFM extraction requires careful evaluation, as the rates of spontaneous space closure are significantly lower, with a success rate of approximately 50 percent.[15-19] Per the NCGs, the ideal time to extract in the mandibular arch is between eight and 10 years of age and at the earliest sign of bifurcation development of the PSM in the same quadrant.[14]

Recent retrospective studies have demonstrated results conflicting with the NCGs, with the PSM developmental stage failing to be a primary predictor for space closure.[15-17,19] Furthermore, the presence of the permanent third molar (**PTM**) combined with mesial angulation of the PSM are variables demonstrating high predictive value in the mandibular arch.[16,17] Teo et al. assessed the influence of the second premolar developmental stage, PSM angulation and developmental stage, and presence of the PTM; these authors reported an 85 percent success rate in the mandible when mesial angulation of the PSM, presence of the PTM, and PSM at Demirjian stage D, E, or F were observed.[17] Similarly, Patel et al. assessed the influence

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of PSM developmental stage, angulation of both the second premolar and PSM relative to the occlusal plane, dental age, and presence of PTM.[16] Patel et al. reported that the presence of the PTM combined with mesial angulation of the PSM resulted in 89 percent predicted probability for success in the mandibular arch.[16] As a result of their findings, Patel et al. created a toolkit (**toolkit)** to assist the clinician in evaluating angulation of the PSM and predicting success in the mandibular arch (Figure 1).[16]

The purpose of this study was to investigate pre-extraction variables associated with success in both arches and to test the prediction of success of Patel et al.'s toolkit in the mandibular arch.

Methods

To test the toolkit, this study replicated Patel et al.'s retrospective design regarding population, measurement, variables, and statistical methods. Pre-extraction variables and postextraction outcomes were assessed radiographically. The following pre-extraction variables were recorded: PSM developmental stage; presence/absence of the PTM; angle of the mandibular PSM; chronological age at the time of extraction; and gender.

Subjects. The charts of 162 patients were assessed for a total of 138 maxillary quadrants and 168 mandibular quadrants. The charts were reviewed between April 24, 2020, and January 31, 2021, from three university-based pediatric dental residency programs: the University of Minnesota, Minneapolis, Minn., USA; Virginia Commonwealth University, Richmond, Va., USA; and the University of Iowa, Iowa City, Iowa, USA. Institutional Review Board (**IRB**) approval was obtained from each university IRB committee independently. The sample included pediatric patients between five and 15 years of age at the time of extraction of one or more PFMs. A pre-extraction panoramic radiograph and a postextraction radiograph showing the PSM and second premolar after their complete eruption were required for inclusion. Patients were excluded if there was a diagnosis of craniofacial syndrome, anomalies of eruption, extractions or hypodontia of other permanent teeth in the same quadrant as PFM extraction, initiation of orthodontic treatment prior to postextraction radiograph, and lack of requisite radiographs.

Data collection. The following data were obtained from the dental record: gender; date of birth; date of pre-extraction panoramic radiograph (**T1**); date of extraction (**T2**); and date of postextraction radiograph (**T3**). The variable chronological age at T2 was categorized according to the age recommendations per the NCGs: early (younger than eight years); ideal (eight to 10 years); and late (older than 10 years).[14]

If more than one pre-extraction panoramic radiograph was available, the panoramic radiograph taken closest to T2 was used. If more than one postextraction radiograph was available, the radiograph which best demonstrated the complete eruption of both the PSM and second premolar was used.

Dental stage of the PSM was assessed on the pre-extraction panoramic radiograph using Demirjian et al.'s eight-stage

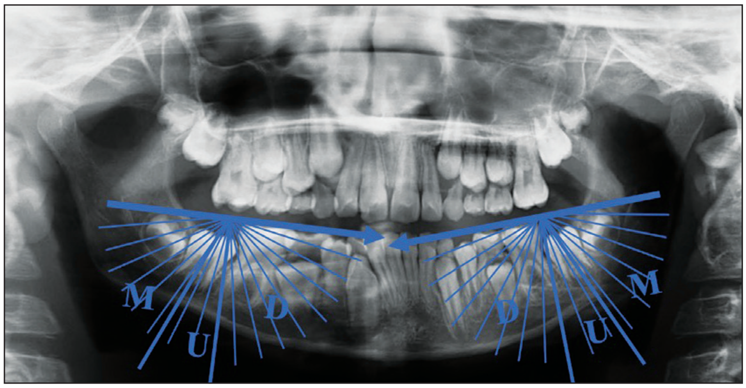

Figure 2. Demonstration of the Patel et al. toolkit applied to a patient in this study to determine angulation of the permanent second molar (PSM) relative to the occlusal plane.[16] The toolkit template was aligned along the occlusal plane first (horizontal arrow) then slid to find the angular sector that most closely matched the long axis of the PSM. The PSM angulation relative to the occlusal plane was recorded as mesial (M), upright (U), or distal (D) as defined by the toolkit boundaries.

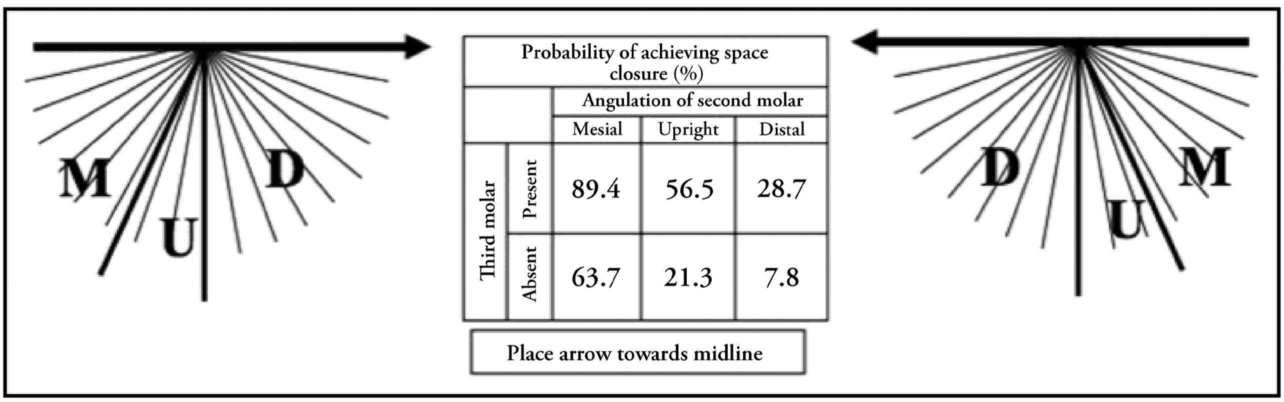

Figure 1. Patel et al. toolkit for the predictive probability of spontaneous space closure in the mandibular arch based on a permanent second molar (PSM) angulation and presence or absence of the permanent third molar (PTM) in the same quadrant. PSM angulation is determined by overlaying the horizontal arrow of the angulation template along the occlusal plane and determining the angular sector, mesial (M), upright (U), or distal (D) that most closely matches the long axis of the PSM.[16]

scale, recorded as A-H (see **Supplemental Electronic Data—sFigure**).[20] Consistent with the methodology in Patel et al., the Demirjian PSM stage was categorized as early (A-D), ideal (E), and late (F-H).[16]

Angulation of the mandibular PSM was determined using the toolkit angulation template, which was traced in Microsoft Powerpoint™ software and superimposed on the pre-extraction panoramic images (Microsoft Inc., Redmond, Wash., USA).[16] The toolkit template was aligned along the occlusal plane first, then slid to find the angular sector that most closely matched the long axis of the PSM. The PSM angulation relative to the occlusal plane was recorded as mesial, upright, or distal as defined by the toolkit (Figure 2).[16]

PTM was marked as present or absent. At a minimum, observation of the PTM crypt was required for it to be marked as present. If no crypt formation was observed, the PTM was marked as absent.

The outcome of spontaneous PSM substitution was determined at T3 using the postextraction radiograph, and it was defined as successful or unsuccessful. Consistent with Patel et al.'s outcome criteria, a successful outcome required the presence of a visible contact between the second premolar and PSM, and without marginal ridge discrepancy to exclude quadrants with crown tipping on space closure.[16]

All data were obtained and recorded by the primary researcher (Nordeen KA). The developmental stage of the PSM, angulation of the mandibular PSM, presence/absence of the PTM, and outcome were reassessed for intrarater reliability in 40 quadrants by the primary researcher after a four-week washout period. The same variables were also assessed in all quadrants by a second examiner (Roham A), a third-year predoctoral dental student, for interrater reliability using deidentified radiographs. The second examiner was trained by the primary researcher to assess and record the variables according to the study protocol and consistent with the methodology in Patel et al.[16]

Statistical analysis. Logistic regression models with generalized estimating equations were conducted to examine the association between the explanatory variables and outcome. Statistical models accounted for correlations among multiple observations (up to four quadrants) in the same patient. Maxillary and mandibular quadrants were analyzed separately. Nonsignificant variables (P>0.05) were removed from the model and rerun. The odds ratio, the 95 percent confidence intervals, and the P-value were reported. Statistical analyses for the outcome assessment were performed using SAS® software version 9.4 (SAS Institute, Inc., Cary, N.C., USA). Kappa statistics were used for intra- and interrater reliability testing.

Results

A total of 162 patients were included: 52 percent females and 48 percent males. In all, 306 quadrants were assessed, with 168 mandibular quadrants and 138 maxillary quadrants. The maxillary quadrants demonstrated an overall success rate of 82 percent. The mandibular quadrants demonstrated an overall success rate of 51 percent. Most patients had only one PFM extracted (53 percent), 24 percent had two PFMs extracted, four percent had three PFMs extracted, and 19 percent had all four PFMs extracted.

The mean age at T1 for all study patients was 10.6 years. The mean age at T2 for all study patients was 10.7 years, with a range of 6.7 to 14.9 years. Thirty-three percent were between eight and 10 years of age at the time of extraction, seven percent were younger than eight years, and 60 percent were older than 10 years. The mean time between T1 and T2 was 71 days; the mean time between T2 and T3 was 4.1 years.

Demirjian stages A and B were not observed at T1 in any patients. PTMs were observed in 64 percent of maxillary and 82 percent of mandibular quadrants. The right and left quadrants were evenly represented with 50 percent per side.

Intra- and interrater reliability testing demonstrated substantial to almost perfect kappa agreement for all variables except mandibular PSM angulation (Table 1).

Maxillary quadrants. Demirjian stage category was the only variable that correlated significantly with outcome in the maxillary multilevel model. Early-stage PSMs were 7.2 times more likely to be successful than late-stage PSMs (odds ratio [**OR**] equals 7.2; 95 percent confidence interval [**95% CI**] equals 1.9 to 27.6; P=0.004). Ideal-stage PSMs were 6.8 times more likely to be successful than late-stage PSMs (OR equals 6.8; 95% CI equals 1.7 to 27.3; P=0.007).

The chronological age category was significant in a unilevel model; extraction between eight and 10 years of age was significantly more likely to be successful than extraction at older than 10 years of age (OR equals 3.3; 95% CI equals 1.1 to 9.3; P=0.03). Although the success rate for extractions at younger than eight years of age was 89 percent (eight out of nine), this was not statistically significant due to the low number of quadrants in this age group (P=0.39).

Mandibular quadrants. The chronological age category was the only variable that correlated significantly with outcome in the mandibular multilevel model. Extraction at less than eight years of age was 5.7 times more likely to be successful than extraction occurring at older than 10 years of age (OR equals 5.7; 95% CI equals 1.5 to 21.8; P=0.01). Extraction between eight and 10 years of age demonstrated 3.9 times higher odds of success compared to extraction at older than 10 years of age (OR equals 3.9; 95% CI equals 1.7 to 8.8; P=0.001).

Table 1. RELIABILITY TESTING FOR CATEGORICAL VARIABLES

Categorical variable	Kappa statistics	95% CI*	Agreement**
Intrarater agreement			
Mandibular PSM angulation †	0.90	0.71-1	Almost perfect agreement
PSM Demirjian stage ‡	0.86	0.75-0.96	Almost perfect agreement
PTM §	0.79	0.57-1	Substantial agreement
Outcome ‖	0.91	0.73-1	Almost perfect agreement
Interrater agreement			
Mandibular PSM angulation †	0.59	0.48-0.70	Moderate agreement
PSM Demirjian stage ‡	0.81	0.77-0.85	Almost perfect agreement
PTM §	0.85	0.78-0.91	Almost perfect agreement
Outcome ‖	0.78	0.71-0.85	Substantial agreement

* Abbreviation in this table: CI=confidence interval.

** Interpretation of kappa statistics for strength of agreement: <0=poor; 0.01-0.20=slight; 0.21-0.40=fair; 0.41-0.60=moderate; 0.61-0.80=substantial; 0.81-1.00=almost perfect.

† Mandibular permanent second molar (PSM) angulation (mesial, upright, or distal, as determined by the toolkit template[16]).

‡ PSM Demirjian stage[20] (C-H). § Permanent third molar ([PTM]; present, absent).

‖ Outcome (successful, unsuccessful as determined by visible contact between PSM and second premolar on postextraction radiograph).

Demirjian stage category was significant in a unilevel model; early-stage PSMs were 3.9 times more likely to erupt successfully than late-stage PSMs (OR equals 3.9; 95% CI equals 1.3 to 12.0; P=0.02). Ideal-stage PSMs were 3.3 times more likely to be successful than late-stage PSMs (OR equals 3.3; 95% CI equals 1.4 to 7.8; P=0.006).

Table 2. PREDICTED PROBABILITY FOR SUCCESS BY PERMANENT SECOND MOLAR DEMIRJIAN STAGE[20]

PSM Demirjian stage*	N	Predicted probability for success**	Standard deviation	Lower 95% CI*	Upper 95% CI
Mandibular quadrants					
D	27	0.775	0.124	0.726	0.824
E	43	0.689	0.127	0.649	0.728
F	37	0.706	0.169	0.650	0.762
G	26	0.247	0.125	0.197	0.298
H	32	0.057	0.040	0.043	0.072
Maxillary quadrants					
D	41	0.923	0.047	0.908	0.937
E	52	0.924	0.034	0.915	0.934
F	20	0.801	0.102	0.753	0.849
G	16	0.417	0.140	0.342	0.491
H	8	0.375	0.124	0.272	0.478

* PSM=permanent second molar; CI=confidence interval.
** Logistic regression models with generalized estimating equations.

Table 3. PREDICTED PROBABILITY FOR SUCCESS BY CHRONOLOGICAL AGE AT T2*

Chronological age (years) at T2	N	Predicted probability for success**	Standard deviation	Lower 95% CI †	Upper 95% CI †
Mandibular quadrants					
8	18	0.798	0.113	0.741	0.854
9	35	0.743	0.113	0.704	0.782
10	31	0.665	0.220	0.584	0.746
11	26	0.530	0.242	0.432	0.627
12	22	0.279	0.207	0.187	0.371
13	17	0.175	0.200	0.072	0.277
14	10	0.082	0.108	0.004	0.159
15	6	0.043	0.030	0.011	0.074
Maxillary quadrants					
8	14	0.942	0.022	0.930	0.955
9	36	0.926	0.063	0.905	0.948
10	31	0.910	0.053	0.891	0.930
11	24	0.832	0.112	0.784	0.879
12	20	0.613	0.234	0.504	0.723
13	7	0.450	0.201	0.264	0.636
14	3	0.312	0.091	0.084	0.539
15	2	0.250	0.073	-0.410	0.910

* Chronological age (years) at T2=age at date of extraction, rounded to nearest whole integer year.
** Logistic regression models with generalized estimating equations.
† CI=confidence interval.

Toolkit testing. According to the toolkit, the combination of a mesially-angulated PSM with PTM should yield the highest predicted probability for success in the mandibular arch.[16] Predicted probability for this combination was 63 percent (95% CI equals 58 to 69 percent), whereas predicted probability was highest for a mesially-angulated PSM without a PTM (71 percent; 95% CI equals 62 to 81 percent).

Individual Demirjian stages and outcome. Since the Demirjian stage and chronological age categories were the only significant variables, unilevel regression analysis was performed to investigate the relationship between these variables and the outcome beyond the categories. For convergence of the regression model, the four patients in the study with PSM Demirjian stage C were excluded. The predicted probability for success based on the individual Demirjian stage was highest for both stages D and E at 92 percent in the maxillary arch and highest at stage D in the mandibular arch at 78 percent (Table 2). There was a trend that probability for success decreased in both arches with increasing developmental stage for stages D to H.

Chronological age at T2 and outcome. Unilevel regression analysis was performed for chronological age and outcome by rounding age at T2 to the nearest integer year, resulting in a range of seven to 15 years. For convergence of the regression model, the three patients in the study with a rounded age of seven years were excluded. For ages eight to 10, the predicted probability for success in the maxillary arch was highest at 91 to 94 percent. In the mandibular arch, age eight had the highest predictive probability at 80 percent (Table 3). Like the Demirjian stage variable, success decreased with increasing chronological age.

Figure 3 demonstrates the distribution data for the PSM Demirjian stages observed at each chronological age, rounded to nearest integer year at T2.

Discussion

The results of this study did not validate the toolkit, as the combination of PTM and mesially-angulated PSM did not result in the highest predicted probability for success in the mandibular arch. The results demonstrated the primary importance of chronological age and the PSM Demirjian stage in predicting success. Findings from this study did not support the NCGs' recommendations to delay extraction in the mandible until the PSM has reached stage E nor did they support the recommendation to extract between a window of eight to 10 years. The predicted probability for success in the mandible dropped considerably after eight years and after Demirjian stage D.

Although it is well-established that chronological age and the dental developmental stage are correlated, significant variation is observed in dental development at various chronological ages. Understandably, a clinician would not base the irreversible treatment decision of PFM extraction on chronological age alone.[20-22] Furthermore, the relationship between PSM developmental stage and chronological age is changing, with dental developmental maturation occurring at earlier chronological ages.[23,24] Generally, patients requiring extraction of a PFM have a panoramic radiograph; therefore, PSM developmental stage information would be

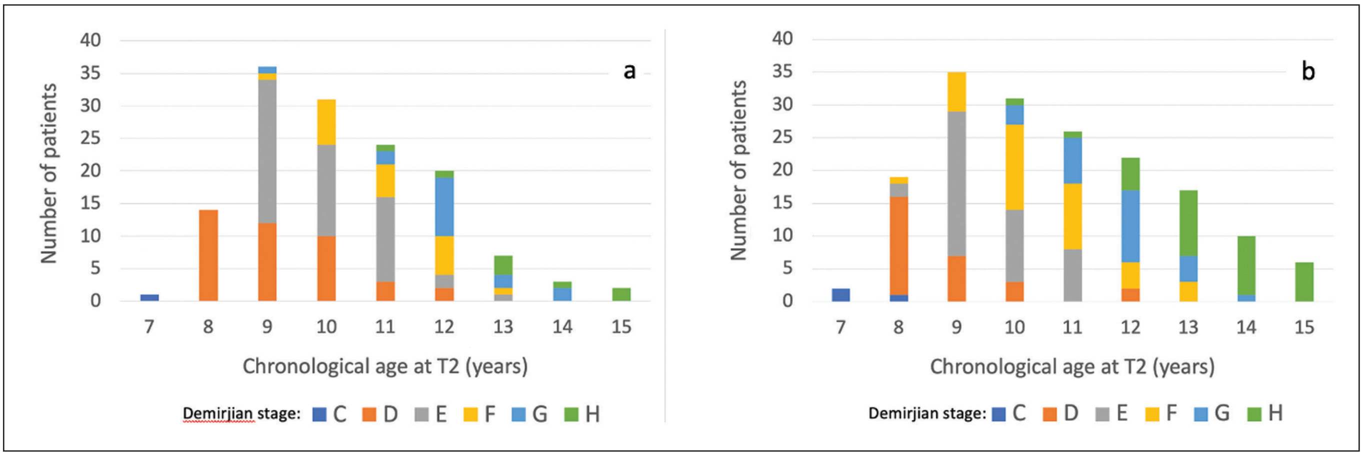

Figure 3. Demirjian stage distribution at each chronological age rounded to the nearest whole integer year at the time of extraction (T2) in maxillary quadrants (panel a) and mandibular quadrants (panel b).

readily available in addition to age. Distribution data for this study demonstrated that certain Demirjian stages predominated at specific chronological ages, but variation was observed. The trend was that patients with PFM extractions at the youngest ages and Demirjian stages had the highest predictive probability for success.

The overall results for a successful outcome by arch were similar to the results from other retrospective studies: the maxillary arch success rate was 82 percent and the mandibular arch success rate was 51 percent. Patel et al. observed a 90 percent success rate in the maxillary arch and a 49 percent success rate in the mandibular arch.[16] Similarly, Teo et al. observed a 92 percent success rate in the maxillary arch and a 61 percent success rate in the mandibular arch, and Ciftci et al. reported a 53 percent success rate in the mandibular arch.[15,19] However, the variables predictive of success differed.

This study found that neither the presence of the PTM nor mesial angulation of the PSM significantly influenced success in the mandibular arch, refuting findings of previous retrospective studies.[16,17,19] However, Teo et al. also required a PSM stage D, E, or F in addition to mesial angulation of the PSM and presence of the PTM, whereas Patel et al. only found mesial angulation and PTM to be significant.[16,17] One possible explanation for the discrepancy is that Patel et al. reported PSM Demirjian stage by category: early (A to D); ideal (E); and late (F to H).[16] The grouping of PSM stages likely affected the significance of this variable in the multilevel modeling in Patel et al., given that Teo et al. found that the individual stages D to F were associated with success along with mesial angulation of the PSM and PTM but stage G was not.[16,17] The same discrepancy in the significance of the Demirjian stage versus the Demirjian stage by category was observed in this study. Since there is evidence that stage F behaves differently than stage G or H, the Demirjian categories described by Patel et al. and used initially in this study do not accurately reflect the success when the Demirjian stages are observed individually.[16] Ciftci et al., in contrast, reported that only the presence of PTM was associated with success among the variables studied: PSM developmental stage; PSM angulation; chronological age; and presence of PTM.[19]

The failure to validate the toolkit may be explained by the difference in mean chronological age of the populations studied. The mean age at T1 for the present study was 10.6 years compared to 9.2 years for Patel et al.[16] The mean age for crypt formation of the PTM is reportedly 9.8 years; therefore, the population in Patel et al. encompassed more patients in whom PTM development was not initiated.[16,25] In this study, 82 percent of mandibular quadrants had developing PTMs, whereas Patel et al. reported 75 percent.[16] Patel et al. acknowledged that the influence of the PTM in their study population may be attributed to early PTM development rather than its ultimate presence or absence, thus reducing the applicability of the toolkit in older children.[16]

There were several limitations to the present study. Due to the multisite nature of the sample, the panoramic images were taken on multiple devices by multiple operators resulting in unknown radiographic variability, which may have introduced errors in the toolkit angulation measurement.[26,27] Patel et al. obtained all panoramic images at one location, and, therefore, likely had less variability in images and possibly more reliable angular measurements compared to the present study.[16]

Identifying the occlusal plane for the toolkit may have been another source of error. Patel et al. did not explicitly define the landmarks; instead, they demonstrated an occlusal plane in one sample panoramic radiograph.[16] The intrarater reliability testing for PSM angulation in the present study demonstrated almost perfect agreement, whereas interrater testing demonstrated only moderate agreement. Although the second examiner was trained to use the toolkit as described by Patel et al., the lack of a defined occlusal plane may leave the PSM angulation measurement prone to error.[16]

The Demirjian staging system is based on shape and relative length criteria rather than angulation measurements or absolute lengths; therefore, it is less sensitive to errors resulting from variability in panoramic machines and patient-positioning techniques.[20] Almost perfect intra- and interrater agreement was observed for the PSM Demirjian stage. The PTM variable was similarly unaffected, as its presence or absence relies on evidence of at least crypt formation or later stages of development.

The definition of a successful outcome required complete space closure between the PSM and second premolar as well as a lack of vertical marginal ridge discrepancy.[16] As noted by Patel et al., the binary nature of this definition excluded some patients who had PSM eruption that was very close to ideal, but did not evaluate for open contact points anterior to the second premolar.[16] Teo et al. accounted for distal movement of the second premolar in their outcome criteria, with success defined as: "complete space closure between the PSM and second premolar, no angulations or rotations and no distal movement of the second premolar."[15] Teo et al. observed 61 percent success in the mandibular quadrants studied, which is higher than the overall success reported in both this study (51 percent) and Patel et al. (49 percent).[15,16] In their follow-up study, Teo et al. assessed all contact points distal to the canine and defined "optimal success" as "only extremely minor contact displacements and malocclusion of less than one mm."[17] Using this definition, their optimal success rate in the mandible was 51 percent.[17] It is of note that Teo et al. evaluated outcomes clinically and Patel et al. evaluated outcomes radiographically or clinically, whereas the present study used exclusively radiographs.[15-17] Nevertheless, the similarity among the studies regarding the outcome in the mandibular arch suggests that successful outcomes in both Patel et al. and the present study are not overreported, despite the differences in the assessment of outcome and definition of success.[15-17]

Similar to the previous retrospective studies, the present study did not report on orthodontic characteristics due to a lack of available data.[15-17,19] Future research on PSM substitution should include orthodontic variables as both pretreatment predictors and part of the outcome assessment in order to evaluate the consequences of early PFM extraction on a growing patient.[18,28-31]

Conclusions

Based on this study's results, the following conclusions can be made:

1. The Patel et al. toolkit was not validated by this study.
2. Chronological age and PSM Demirjian stage were significantly associated with success in both arches.
3. The highest predictive probability for success (80 percent) in the mandibular arch was observed at age eight years or PSM Demirjian stage D.
4. The highest predictive probability for success (91 percent) in the maxillary arch was observed between eight to 10 years or PSM Demirjian stages D and E.
5. Future research should include pre-extraction dentofacial variables, and outcome criteria should include an orthodontic assessment.

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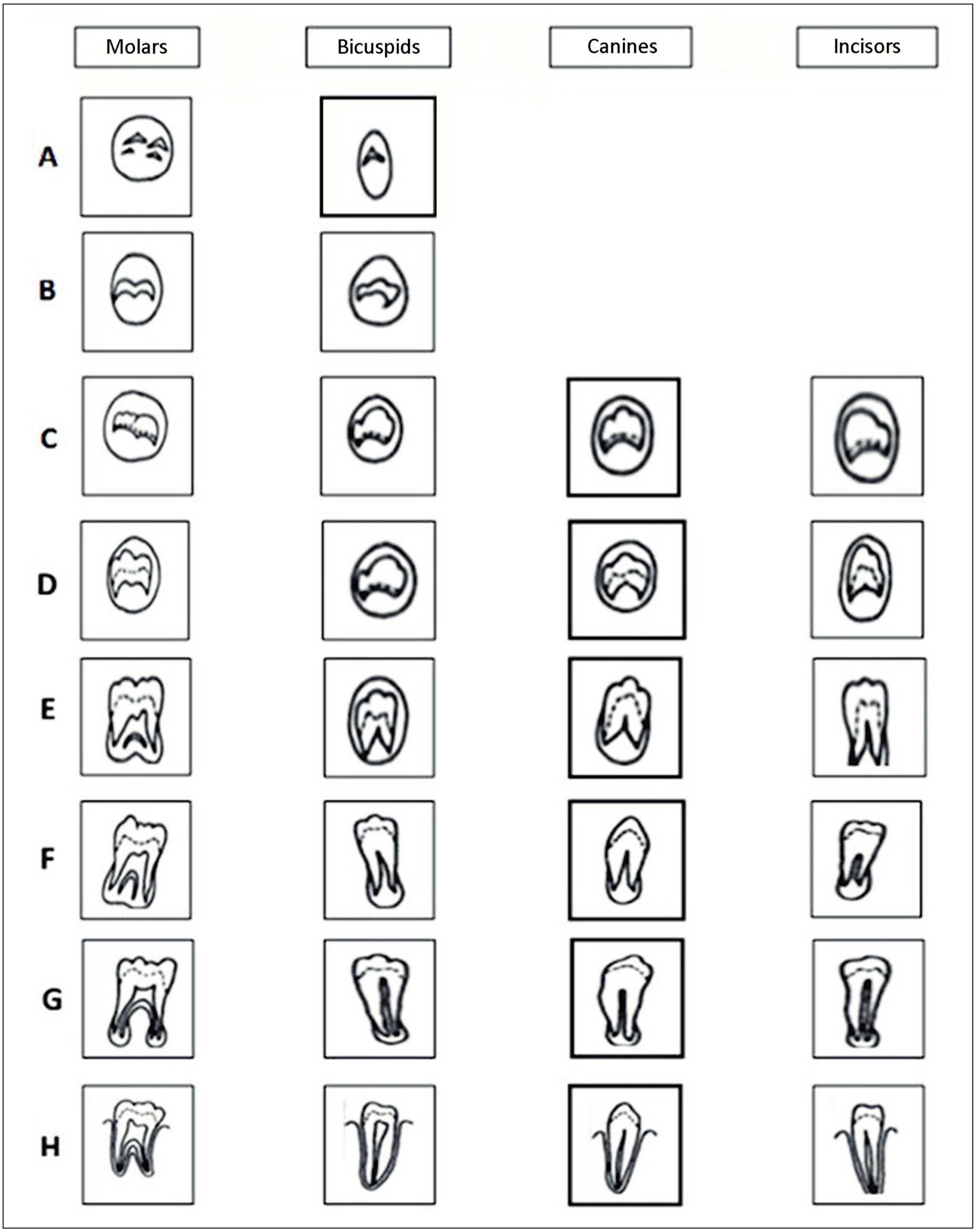
Supplemental Electronic Data—Figure



sFigure. Demirjian staging of tooth development based on shape and relative length criteria as depicted radiographically.[20]

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