Evaluation of Predictors of Spontaneous Space Closure and Supereruption after the Loss of First Permanent Molars

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Dedication

I dedicate this work to:

The memory of David Verlinich.

Abstract

Aim: To evaluate first permanent molar (FPM) replacements by assessing complete radiographic space closure between the second permanent molar (SPM) and the second premolar. To evaluate the supereruption in compensated and uncompensated maxillary molars in patients with mandibular FPMs extractions. To determine if the odds of complete space closure by second permanent molar (SPM) replacements is influenced by compensating extraction. To validate a tool kit to predict the likelihood of spontaneous space closure after the loss of FPM in the Yup'ik population.

Methods: One hundred and thirty-four patients aged six to thirteen years with extracted FPM(s) were evaluated for space closure between the mandibular second molar and the second pre-molar at follow-up. Initial panoramic radiographs were reviewed for the presence of a third permanent molar (TPM), along with the SPM angulation. Bitewing radiographs of one hundred and fifty-six patients aged six to thirteen years with previous FPM extraction were used to evaluate linear measures of supereruption in compensated and uncompensated extractions. Patients with both FPM extractions and compensated and uncompensated extractions were evaluated for complete mandibular space closure.

Results: The confidence intervals of five of the six space closure categories contained values found within the tool kit. Multivariate logistic regression demonstrated that extraction at age 8 to 10 vs. 11 to 12 ($p=0.04$; OR = 0.29, 95% CI 0.08 – 0.91), TPM presence ($p=0.02$; OR = 2.35, 95% CI 1.16 – 4.9), and follow-up time were statistically significant predictors of space closure. A second model demonstrated that odds of uncompensated FPM supereruption is greater than that of compensated FPMs ($p=0.0001$; OR = 3.55, 95% CI 1.86 – 6.92) and that additional follow-up increases the odds of supereruption ($p=0.0005$; OR = 1.18, 95% CI 1.08 – 1.30). A final model demonstrated that uncompensated extractions did not reduce the odds of spontaneous space closure ($p=0.54$; OR=1.3, 95% CI 0.56 – 3.08).

Conclusion: FPM extraction later than 10 years of age appears to be a negative predictor for space closure, while TPM presence is a positive predictor. Uncompensated maxillary FPMs do not appear to inhibit mandibular SPM space closure; however, uncompensated extractions are more likely to supererupt than compensated

extractions. Length of follow-up is a critical factor for assessing both space closure and supereruption. Additional research is required to make generalizable conclusions about the validity of the tool kit studied.

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Introduction

The majority of Alaska Native Children experience caries by kindergarten.[1,2] Caries is a prevalent chronic disease amongst the Yup'ik people within the Yukon Kuskokwim (YK) Delta: 97% of 6 to 8-year-old children experience caries in their primary dentition and 57% in their permanent dentition.[3] The first permanent molars (FPMs) typically erupt into the oral cavity around age six years,[4] and occlusal and buccal surfaces of these teeth are most susceptible to caries in youth.[5,6] Caries, especially with poor restorability, is the main reason for early tooth loss.[78]

FPM extraction guidelines have focused on chronologic age[9] or developmental stage of the second permanent molar (SPM)[10,11] as indicators for extraction timing to facilitate spontaneous space closure by mesially-erupting second molars without additional clinical intervention. However, a recent study indicated that while the developmental stage of the SPM is a statistically significant predictor, it may not be clinically significant.[12] Clinical guidelines using chronological age as a predictor often indicate the ideal age of extraction ranges from 8 to 10 years of age. However, these guidelines are based on studies with limited numbers of patients younger than 8 years of age.[13–17]

The factors determining optimal extraction timing for spontaneous replacement of non-restorable mandibular FPMs have remained unclear. Recently, a study by Patel et al. proposed a tool kit to predict the likelihood of spontaneous space

closure in these instances.[12] This tool kit, made of acetate, is to be placed on top of a patient's panoramic radiograph and then manipulated to assess the angulation of the SPM. With that tool kit, along with the presence or absence of a third permanent molar (TPM), clinicians can estimate the odds of FPM replacement ranging from 7.8% to 89.4%. This tool kit was validated on patients treated in a single hospital in London, England, and requires validation in different populations.

When extraction of a mandibular FPM is necessary, British national guidelines suggest performing a "compensating extraction" of the maxillary antagonist tooth, even if that tooth has a good prognosis.[18] The reasoning for compensating extractions is to avoid supereruption of an unopposed FPM, which may block the eruption and mesial migration of the SPM or cause occlusal interferences.[13] A clinical trial aimed at evaluating outcomes of compensating extractions was initiated to investigate this issue further. However, the study was terminated for lack of patient recruitment.[19] Textbooks and scientific literature continue to recommend compensating extraction based on expert opinion and theoretical evidence,[14] although clinical evidence indicates that not all molars without antagonists supererupt.[18] Numerous authors call to question compensating extractions or indicate a need for additional research into the risk factors for supereruption.[13,16,19–23]

Understanding extraction timing for non-restorable FPMs would enhance the management of their premature loss in the YK Delta. Optimal planning and timing may also reduce the need for additional future orthodontic treatment. Additionally, if compensating extractions are not needed, avoidance of additional surgery may reduce the patient's psychological trauma and pain. It may also reduce the cost to the patient or insurer for less travel, reduce the need for general anesthesia and the operating room, and enhance the dental providers' diagnostic ability and long-term treatment planning.

Review of the Literature

Caries in the Yukon-Kuskokwim Delta

The Yup'ik people of the YK Delta live across a vast area of 75,000 square miles that spans 58 rural communities connected to rivers, marshes, and mountain ranges. Much of the economy revolves around subsistence, resource extraction, and government. The region faces significant poverty. From 2012 to 2016, approximately 3,600 children under 18 years of age were below the poverty level, comprising 32.7% and 41.8% of all children in the Bethel and Kusilvak census areas respectively.[24,25] Much of the area is under-housed, with 16% to 21% of homes overcrowded and 19% to 33% of homes severely overcrowded.[26] On top of this, few villages operate water fluoridation systems,[27] and many dwellings lack piped water systems.[28] Communities generally have one health clinic providing dental services only when a hygienist, dental health aid therapist, or dentist visits their village.[29]

The Yukon Kuskokwim Health Corporation (YKHC) is the primary tribal health organization (THO) providing healthcare to patients within these communities. Aside from Bethel, the region's hub, the communities range from as small as 25 residents to a little over 1000. Villages are generally not connected by road systems, thus requiring patients to access dental services by airplane, boat, snowmobile, or all-terrain vehicle.[30] THOs such as YKHC have had chronic dental vacancies for years while population and demand for dental services have risen.[31,32] YKHC has been innovative in addressing workforce and access

demands, successfully adding dental health aide therapists (DHATs) to their treatment teams.[33] While DHATs have enhanced access to care in many of the remote communities, their training and scope of services excludes limited and comprehensive orthodontic services.[34,35] Additionally, the Indian Health Service has lacked funding for dental specialists in rural Alaska, and there remains insufficient staffing to allocate orthodontists to remote clinics.[36] As a result, only a small number of YK Delta patients receive orthodontic services annually.

Traditionally, the Yup'ik people heavily subsisted on fresh and dried fish, land and marine mammals, birds, plants, and berries.[25] However, over the last two centuries, the diet has increasingly Westernized,[37–39] with data demonstrating that Yup'ik people report more regularly consuming store-bought foods high in fat and sugar.[40] Additionally, communities consume a significant amount of sugar-sweetened beverages.[41] While caries worldwide have generally decreased over the 19th and 20th centuries due to access to sealants, homecare, and community water fluoridation,[42] this is not the case in Alaska Native communities.[43] As the diet has changed, the prevalence of caries has increased.[39] Poor oral health is a persistent concern in Southwestern Alaska,[31,44] and FPMs are often the first permanent teeth affected by this disease.

The FPMs have been described as the cornerstone of the mouth. Edward Angle first stressed that the first molar was the key to occlusion, creating an occlusal classification system that remains in use today.[45] FPMs typically erupt into the

oral cavity around age 6 to 7,[4] and occlusal and buccal surfaces of these teeth are highly susceptible to caries in youth.[5,6]

Carious lesions begin with the colonization of streptococci mutans and other bacteria within plaque on the tooth surface. Over time, these aciduric bacteria lower the pH around the tooth surface, demineralizing the outer-enamel tooth layer. This layer can remineralize with proper oral hygiene and plaque removal, fluoride use, and dietary modifications. Prolonged exposure to acids will eventually demineralize the tooth structure until cavitation forms.[46]

While caries persists as a preventable disease in children globally[47], it is a severe problem amongst the Yup'ik people: 57% of 6 to 8-year-old children experience caries in their permanent dentition.[3] There appears to be a link between high decayed, missing, filled tooth scores and early loss of the FPMs.[48] The management of early carious enamel breakdown varies amongst practitioners.[49,50] However, as caries severity progresses in the FPMs of youth, both general practitioners and pediatric dentists are more likely to converge on the same treatment decision: extraction.[23] Socioeconomic considerations may further encourage the provider to recommend this treatment.[51] Due to patient age and behavior, these teeth are often extracted under anesthesia in the operating room.[16]

Beyond caries, other conditions such as molar-incisor hypomineralization (MIH) may contribute to early tooth loss. This condition may be relatively common, presenting in 10% to 19% of Scandinavian patients,[52] but the prevalence in Yup'ik patients is unknown. Children with MIH may have as few as one, but potentially all four FPMs affected.[2] Teeth with MIH are more susceptible to caries, and MIH has been given as a reason to consider FPM extraction.[53] Regardless of the cause of early tooth loss, understanding predictors of spontaneous space closure may yield better long-term outcomes while optimizing limited dental resources in Southwest Alaska.

Equilibrium and Tooth Movement

Weinstein is credited for first describing oral equilibrium. He made three key assertions:[54]

1. Forces exerted upon the crown of a tooth by surrounding soft tissue may be sufficient to cause tooth movement in the same manner as produced by an orthodontic appliance.
2. Each element of the dentition may have more than one position of stable equilibrium within the oral environment.
3. Differential forces, even when they are of small magnitude, if applied over a considerable period of time, can cause important changes in tooth position.

From these conclusions, one can understand the impact of the loss of a mandibular FPM within the dental arch. Small changes in tooth position may alter the relative force on the other teeth, and over a short period, results in shifting and movement of teeth.

Years later, Proffit revisited the topic of equilibrium and further defined its primary factors: intrinsic and extrinsic forces, dental occlusion, and the periodontal ligament.[33] He posited that the loss of a mandibular FPM may cause a once-stable maxillary FPM (or any antagonist) to change in vertical position via supereruption.[33] This alteration in maxillary FPM position after antagonist loss is consistent with the findings of Love and Adams[55] and other authors.[15,20,56–59] This suggests that loss of mandibular FPM alters the oral equilibrium, causing adjacent teeth to move towards both a new position and a new state of equilibrium.

Supereruption

Various authors have evaluated changes in tooth position after tooth loss.[55–61] Some authors have found vertical change and supereruption as early as one year post-extraction.[61] A randomly distributed questionnaire to dental officers at widespread dental installations across the United States aimed to evaluate post-extraction changes to teeth missing antagonists. Patients ranged from 13 to 62 years of age, with 97% of the total sample 18 years or older. The results provided evidence that teeth distal to an extraction site tend to drift mesially, and teeth

mesial to the extraction are less likely to drift distally. Vertical changes may occur as teeth enter into edentulous spaces, though Love et al. found that 94% of teeth evaluated had slight to no vertical drift.[55] Love et al. also provided evidence that most drift occurs within the first five years after tooth loss.[55] This is significantly different from the results of Compagnon and Woda, who evaluated supereruption in 18 to 45 year-old patients. They found that after 10 years, all teeth without antagonists supererupted.[56]

Killiardis et al. also evaluated the change in vertical position of FPMs lacking antagonists for 10 years or more in patients ranging from ages 40 to 89 years. They observed patterns of changes in these teeth: molar rotation was more common in the maxillary teeth, while molars in the mandible tended to tip. Again, contrary to Compangnon and Woda, the authors found that 18% of molars had no supereruption. Of those that had erupted, 58% had less than 2 mm, and 24% had greater than 2 mm of supereruption. From this, the authors concluded: "not all molars without antagonist over-erupt, even in a long-term perspective."[57]

Craddock et al. evaluated the supereruption associated with both maxillary and mandibular FPMs in patients over the age of 18. They found significant evidence of supereruption, as 92% of unopposed teeth had a vertical increase coronally. Supereruption was greater in unopposed maxillary teeth than mandibular teeth. On average, supereruption was 1.68 mm, with a range of 0 to 4 mm.[58]

Craddock et al. further evaluated supereruption of posterior teeth with partial antagonist contact. They found that the mean supereruption for fully opposed teeth to be 1.7 mm and partially unopposed to be 1.6 mm. Thus, they concluded that both teeth without antagonists and teeth with partial antagonist contact continue to erupt, though antagonists reduce tipping.[60]

Lindskog-Stokland et al. found that unopposed molars of adult females have an increased likelihood of supereruption, with an average increase of approximately 0.9 mm, compared to teeth with antagonists, which erupted 0.4 mm. On average, unopposed molars erupted a greater amount than opposed teeth.[59]

These studies demonstrate that teeth without antagonists appear to erupt more than those with antagonists. Unopposed teeth may have as little as no eruption, and as great as 4 mm. Supereruption may occur as soon as within one year. These conclusions are primarily drawn from non-growing, adult patients with missing antagonists. Despite the number of studies evaluating supereruption, none have focused their evaluations on growing children.

Noting the lack of good quality evidence of supereruption in children, Innes et al. published a protocol for a clinical trial aimed at evaluating outcomes of both space closure and supereruption in children aged 7 to 11.[19] Though the trial was initiated, it was ultimately terminated for lack of patient recruitment.

Researchers have used estimated lines,[60] curves,[57] or splines[58] to define their reference planes for measurements of supereruption. Additionally, they made linear measurements from various sources, including direct patient exams,[55] casts,[56–58,60] or radiographs[59] using analog or digital measuring instruments. There is currently no clear consensus on the best means of measure for supereruption.

Radiographic Considerations for Intraoral Bitewings

The bitewing radiograph is an intraoral image used to detect caries, evaluate existing restorations, and assess the crest of alveolar bone.[62] A high-quality bitewing displays a superimposition of buccal and lingual cusps, a defined alveolar crest, no horizontal overlap of adjacent teeth, with minimal distortion. The primary cause of distortion in a bitewing is improper angulation of the x-ray beam. Close attention to both the film and x-ray position yields diagnostic image results.[63]

Bitewings can be used to measure regions of interest on traditional film using analog methods, including clear rulers.[64] Equivalent measurement tools are available for digital radiographs.[63] Digital sensors possess a known physical dimension and create images of a known pixel size. These two data points make image calibration and accurate linear measurements possible.[65] Digital radiography permits post-capture enhancements via adjustments of brightness,

contrast, gamma, and custom filters created by the sensor manufacturer to enhance regions of interest.[66] A digital bitewing is as accurate as film.[67]

Radiographic Considerations for Panoramic Images

Panoramic radiographs are a popular type of dental radiograph, as they are easy to acquire and show most craniofacial structures relevant to a general dentist. These radiographs are extraoral 2D representations of both the upper and lower jaws and surrounding structures, as well as the complete dentition.[68] Despite their popularity, it is notoriously challenging to acquire panoramic radiographs without some level of error. A study by Brezden and Brooks showed that of the 500 radiographs in their sample, only one image had no technical errors. Further, over half of the radiographs reviewed had five or more errors present.[69] In the private practice setting, Rushton et al. described the common panoramic errors which frequently related to tongue position, anterior-posterior positioning, orientation, and occlusal and sagittal plane errors.[70] In addition, distortion can occur at varying levels throughout the image if the patient is poorly positioned[71] and linear measurements have been shown to be unreliable.[72] Distortion appears to impact both traditional and digitally captured panoramic images in a similar fasion.[73]

Despite the risk of distortion, Yeo et al. found that angular measurements on panoramic radiographs may vary by as little as 5 degrees.[71] A more recent study by Stramotas et al. found that both angular measurements are clinically reliable

in a well-captured panoramic image. However, angular measurements become unreliable if the occlusal plane is significantly mispositioned upward or downward.[74] Another study by Mckee et al. showed that anterior teeth experience more angular distortion than posterior teeth, as the focal trough is wider posteriorly. Mandibular molar angular distortion ranged from 0.6 degrees to 3.8 degrees.[75] An angulation error of this magnitude is unlikely to hold clinical significance considering the broad angulations covered by each angulation tool kit category.

Radiographic Classification of Molar Development

There are two foundational classification systems of tooth development. Gleiser and Hunt first provided both written and visual depictions of molar development across 15 unique stages.[76] Demirjian et al. simplified the previous staging, introducing a classification system that included eight stages.[77] This classification system has been repeatedly used to describe radiographic SPM development in recent studies assessing spontaneous space closure after FPM extraction.[9,12,78,79]

Demirjian et al. describes molar development as follows: stage A demonstrates the beginning calcification as cones or inverted cones, without fusion, stage B demonstrates the fusion of several cusps to display a developed outline, stage C shows complete enamel formation at the occlusal, with minimal dentin, stage D indicates calcification of the SPM crown, stage E, or the "ideal time" indicates

visible radicular calcification at the bifurcation, stage F indicates the early development of the root, greater than that of the crown, and stage G indicates near-complete development of the root, and finally stage H occurs when the root apex is completely closed with a uniform periodontal ligament.[77] Jung and Cho later added an additional molar stage, stage 0, which includes the initial molar crypt formation (Figure 1).

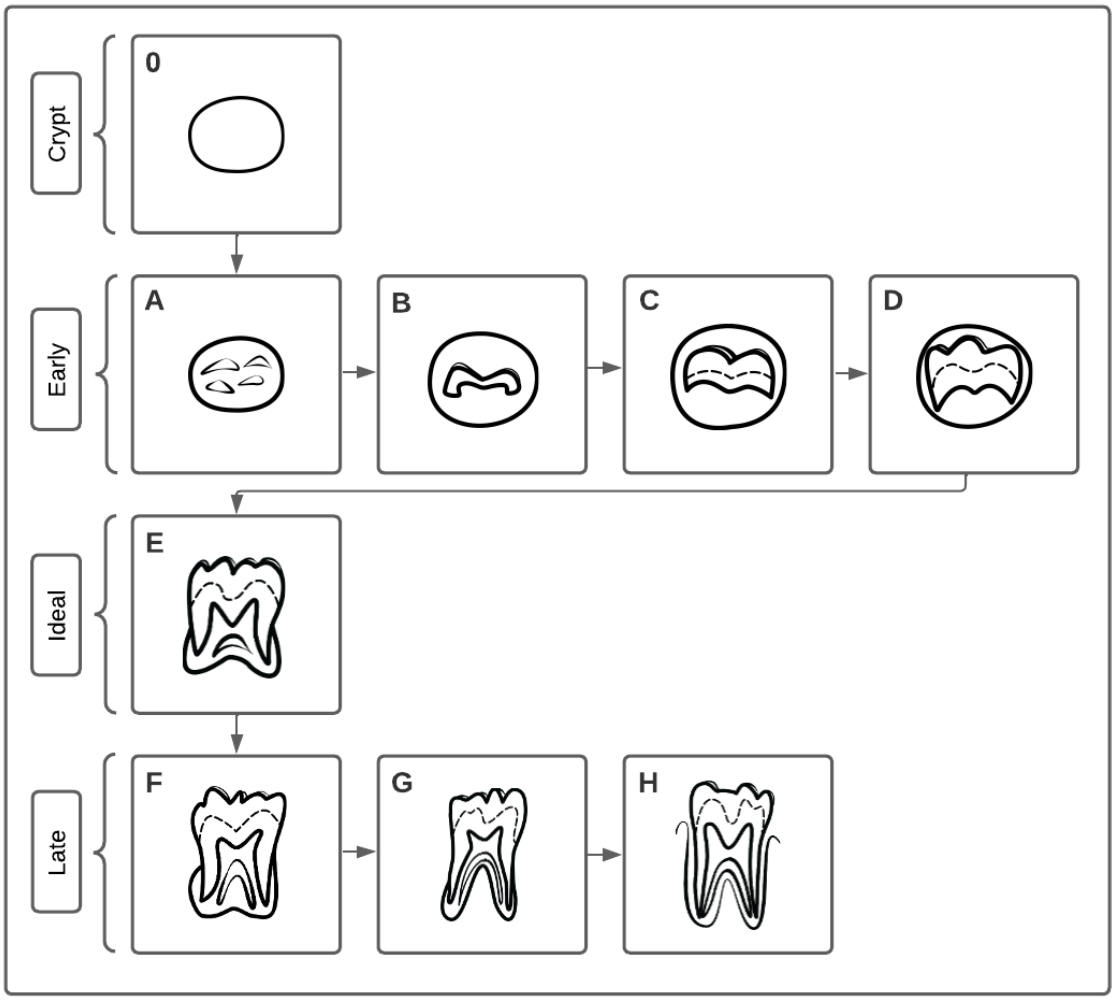

Figure 1: The eight stages of permanent molar development, grouped by theorized optimal staging for spontaneous space closure, adapted from Demirjian et al.[77] and initial molar crypt formation, adapted from Jung and Cho.[80]

Spontaneous Space Closure Predictors

In 1939, Salzman described the concerns and sequelae of FPM loss. He found that when FPMs were lost, patients developed a general malocclusion and had an increased incidence of tooth decay.[81] His comparison of maxillary and mandibular FPM replacements found that maxillary space closes more quickly than mandibular space. In general, space was more likely to close after more time, though not all spaces closed.[81]

In the 1940s, Wilkinson shared his expert opinion on the significance of timing when removing FPMs. He noted the importance of predictors for spontaneous space closure, asserting that the optimal chronologic age for extraction was between 8 and 10.5 years of age, and that the ideal stage of dental development was before significant development of the second molar roots.[82] He asserted that FPM replacement was so predictable that it should be performed routinely on patients.[82] While few today would concur with Wilkinson's statement, a retrospective cohort study suggests that FPM replacement may be generally successful.[21] A systematic review has shown an 81% success rate of favorable space closure after extractions completed at the ideal chronologic age range.[14] A good replacement is generally considered one with space closure, good marginal ridge and contact level, as well as root angulation.[78]

In the early 1960s, Thilander et al. conducted a trial with regular radiographic follow-up, obtaining "Good" and "Acceptable" replacement outcomes 53.6% of

the time in Swedish patients.[83] In their trial, they followed patients every six months post-extraction, capturing new “profile radiographs” and creating models for measurement. They found evidence that dental and chronologic age were significant predictors for FPM replacement.[83] Similar to other authors,[21] Thilander concluded that the optimal time for FPM extraction was after the eruption of the lateral incisors but before the eruption of the second pre-molar or molars.[83] She added a positive predictor for consideration: the presence of a third molar in the replacement quadrants,[83] which has been supported by some authors[15,21,79,84] and disputed by others.[17] Thilander and others have indicated that crowding in the replacement quadrant may improve FPM replacement.[17,83] Similarly, subsequent radiographic and model analysis by Thunold identified missing teeth in a quadrant as a negative predictor for ideal space closure.[17]

Thunold assessed FPM replacements in Norwegian patients. She specifically described the significance of FPM extraction during the 8 to 10 age range,[17] especially for the mandibular FPMs, which has been reiterated similarly in many other publications.[10,14,16,20,21,61,85–87]

Other positive predictors have been proposed: the bifurcation of the second molar roots, with subsequent authors concuring.[10,20] Tooth development is often classified by the Demirjian classification system, and this level of development corresponds with Demirjian stage E.

Teo et al. used a clinical examination to measure space closure after FPM replacement. They conducted follow-up studies and concluded that Demirjian Stage F, or FPM root length equal to or greater than that of the crown, yielded the best replacement outcomes.[9,78] One study demonstrated that the SPM stage of the development may not be significantly associated with space closure.[79]

Teo stressed the difference between the odds of successful FPM replacement in the upper and lower arch, with 92% of maxillary FPM replacements closing successfully regardless of predictors.[78] Extraction and spontaneous replacement of the maxillary FPMs is highly predictable if the tooth is extracted prior to SPM eruption.[12,13,15,17] Conversely, Teo noted that only 66% of FPMs extracted at the ideal SPM Demirjian stage E closed successfully. They also noted no statistical significance in Angle's classification. This finding led to the conclusion that neither SPM Demirjian staging nor Angle's classification are valuable predictors for space closure.[78]

Patel et al. measured space closure via direct clinical examination, study casts, and radiographs. Similar to Teo et al., the authors found higher success rates of space closure in maxillary arches than in mandibular arches, with success rates of 89.9% in the maxillary arch and 49% in the mandibular arch. Based on these findings, Patel et al. concluded that the presence of a TPM was a positive predictor for space closure, though with less overall impact than that of SPM angulation. Patel et al. also found that patients with a mesially angulated SPM

and a TPM present in the same quadrant had an 89.4% chance of space closure while patients with a distally angulated SPM, without a TPM, had only 7.8% chance of space closure.[12] These results were then used as a basis for a novel tool kit designed to predict space closure.

The Patel tool kit[12] was constructed to predict the likelihood of spontaneous space closure after FPM extraction. SPM angulation at the time of extraction and the presence of a TPM as used as predictors of space closure. The tool kit excludes dental and chronologic age, as the authors determined age was not a significant predictor of space closure. The tool kit was tested on 81 participants of whom ethnically were described as 65% White, 20% South Asian, 10% Afro-Caribbean, and 5% other. The authors indicated a need for additional validity testing in other populations.[12]

Using this tool kit, a follow-up study by Çiftçi et al. analyzed the spontaneous space closure after mandibular FPM extraction in patients aged 6 to 10 years.[79] Their sample included 177 mandibular SPMs, which were followed for 3.3 years on average. Space closure was evaluated radiographically or clinically at the end of follow-up. Their sample of mandibular FPM replacements revealed a 52.5% success rate. They also evaluated other predictors discussed in Patel and Teo's study. They concluded that the presence of a TPM was a positive predictor of space closure. Conversely, they found that chronological age and SPM Demirjian stage of the mandibular SPM had no significant predictive value.

To date, the literature provides no methods to reliably predict an optimized occlusion or complete space closure after mandibular FPM extraction.[51] Outcomes appear to be more predictable in the maxilla, but there is a significant variation of success in the mandible. In addition, the literature provides differing methodologies for assessing spontaneous space closure. Techniques to measure space closure outcome ranges from radiographic or model-based assessments, clinical examination, or a combination of the techniques. Chronologic age timing data stem from early studies conducted primarily on European Caucasoid patients, limiting their generalizability. Therefore, a better understanding of the positive and negative predictors of SPM closure in additional populations is needed.

Specific Aims

1. To evaluate the radiographic FPM replacement by assessing a dichotomous "complete space closure" or "incomplete space closure" between SPM and the second pre-molar in association with chronologic age.
2. To validate the tool kit developed by Patel et al.[12] by evaluating categorical radiographic angulation of the SPM and space closure between the SPM and second premolar in patients who have had mandibular or maxillary FPM extractions between 6 and 13 years of age.
3. To evaluate the presence of supereruption in maxillary FPMs in patients with compensated and uncompensated mandibular FPM extractions between 6 and 13 years of age.
4. To evaluate if uncompensated mandibular FPM extraction inhibits complete space closure of mandibular SPMs.

Hypotheses

The following null hypotheses were tested:

1. There is no significant association between radiographic space closure of the SPM and chronologic age.
2. There is no significant predictive value in the tool kit created by Patel et al.[12]
3. There is no significant supereruption of maxillary molars relative to the radiographic occlusal plane when uncompensated FPM extractions are performed.
4. There is no significant difference in replacement space closure between mandibular SPMs with or without maxillary FPM antagonists.

Methods

Study Approval

The following entities approved the protocol for this retrospective cohort study:

- Institutional Review Board at the University of Minnesota (Study ID: #00011616).
- Institutional Review Board for Alaska Area (Study ID: #1675257-1)
- Yukon Kuskokwim Health Corporation Human Studies Committee (Study ID: #20.11.06.)

Subjects and Sample Size

The research aimed to identify all patients treated at YKHC with any FPM extractions between the ages of 6 and 13 years, during the period of January 1st of 2001 until December 31st of 2020, who also had a post-operative bitewing radiograph. Samples evaluated with the Patel tool kit also required an initial panoramic radiograph.

A Structure Query Language (SQL) query was written in Interactive SQL 11.00 (Sybase Systems, Emeryville, CA) and MySQL (Oracle, Redwood Shores, CA) to locate all YKHC dental patients with a comprehensive or periodic dental exam and charting, indicating the loss of one or more FPMs within the Clinical Product Suite (CPS) dental database (Quality Systems, Fullerton, CA).

After testing and query validation, a single flat file was generated. The file included demographic variables relevant to the patient encounters (Table 13 and Table 14). A new study ID was generated to ensure the anonymity of protected health information. The date of birth was used to generate an integer value representing age at initial extraction and follow-up. After data were linked across the tables, patient identifying fields were destroyed.

The initial query identified 5,438 patients (21,752 quadrants) aged 6 to 13 years treated at YKHC during the specified period. A second query identified 586 patients (2,344 quadrants) with at least one missing FPM, as well as an initial panoramic or post-operative bitewing radiograph within the study period. YKHC has maintained an electronic dental record since 1994; however, the corporation did not adopt digital dental radiography until the early 2000s. According to the clinic team, not all early 2000's radiographs were digitized before archival. While some patient records indicated a preoperative panoramic image was taken, they could not be located in the digital system.

Inclusion criteria included:

- Treatment at a YKHC clinic between 01-01-2001 and 12-31-2020 with at least one FPM extraction.
- Age between 6 and 13 years at the time of the extraction.
- Specific to only Mandibular SPMs:
    - At least one panoramic radiograph demonstrating a developing SPM, taken less than 1 year prior to extraction.

Exclusion criteria included:

- Orthodontic treatment prior to radiographic assessment.
- Documented extractions or hypodontia in the same quadrant prior to radiographic assessment.
- Documented craniofacial anomalies and developmental conditions.
- Specific to only Mandibular SPMs:
    - Panoramic radiograph demonstrating significant positioning error.
- Specific to only FPMs evaluated for supereruption:
    - Teeth with significant full cuspal restorations, crowns, or fixed partial dentures.
    - Uncalibrated bitewings radiographs
    - Bitewings radiographs with an indeterminant occlusal plane.

Orthodontic treatment history and medical histories were not documented transactionally in the database. Therefore, a manual review of dental records and medical histories was completed. Radiographs were reviewed using XrayVision DCV (Apteryx Imaging, Akron, OH).

A total of 586 charts with a total of 2844 quadrants, were reviewed for study inclusion. There were 2,087 quadrants excluded for radiographic issues, lack of follow-up, orthodontic treatment prior to re-evaluation, hypodontia, cuspal restorations, or caries. The remaining 257 quadrants qualified for the study. Of these, 51 were excluded from the supereruption group for insufficient maxillary teeth, indeterminant maxillary occlusal plane, or uncalibrated bitewings. Additionally, 75 quadrants were excluded from the space closure group for lack of an initial panoramic radiograph. This left 182 quadrants for evaluation of space closure and 206 maxillary compensated or uncompensated quadrants for evaluation of supereruption. A total of 131 quadrants met the inclusion criteria for analysis of both supereruption and space closure (Figure 2).

Radiographs were downloaded and imported into an "initial" file and a "final" file and labeled with their Study ID and case type. These initial radiographs were separated from final radiographs prior to assessment and data collection for operator blinding.

Two SQL queries were written to randomly select 20 spontaneous space closure quadrants and 20 supereruption quadrants from the final study sample. These were re-assessed by the PI three weeks later to evaluate intra-operator reliability.

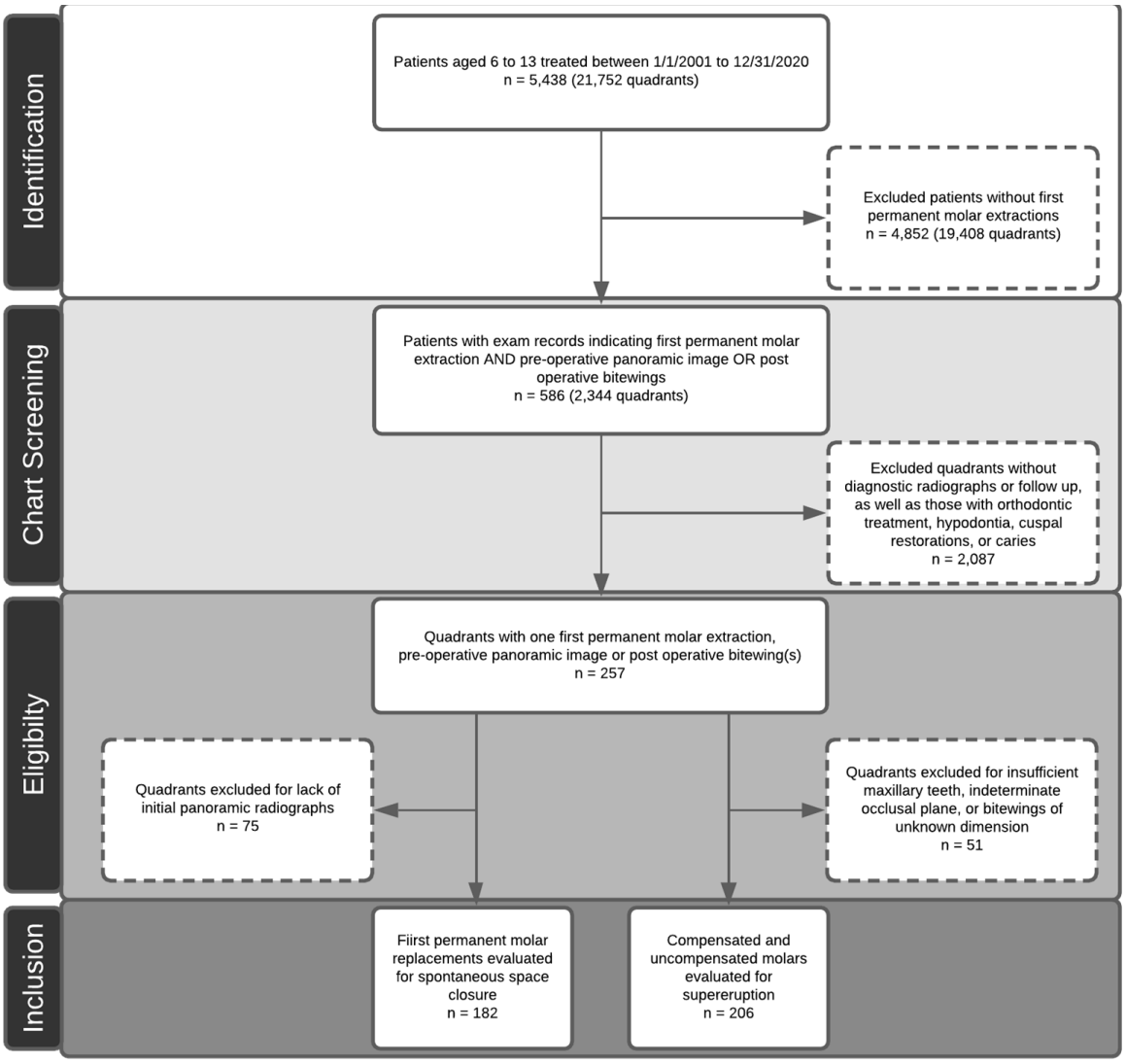

Figure 2: Flowchart demonstrating identification, screening, eligibility, and inclusion for samples within each analysis.

Chronologic Age and Second Permanent Molar Demirjian Staging

For each initial radiograph, chronologic age at the time of extraction was determined. Patients were categorized by age at FPM extraction in accordance with the guidelines established by Cobourne et al.[13] with “early” extraction defined as before age 8 “ideal” at as ages 8-10, and “late” at greater than 10 years old. SPM development stage was assessed using the Demirjian classification system.[77] Each image was evaluated for the presence or absence of a TPM or its crypt. This was recorded as a dichotomous present or absent.

Angulation Assessment and Patel Tool Kit Adaptation

Each mandibular SPM was evaluated categorically for angulation (mesial, upright, or distal) and the presence of a TPM. The original tool kit described by Patel et al.[12] (Figure 3) was tested prior to the initiation of data collection. Patel described the tool as a transparent sheet of acetate, measuring 5 cm x 21 cm, which is placed over a panoramic radiograph of interest, with the arrows pointing toward the midline. Then the existing "protractors" (angulation lines) are used to determine the angulation of the second molar.

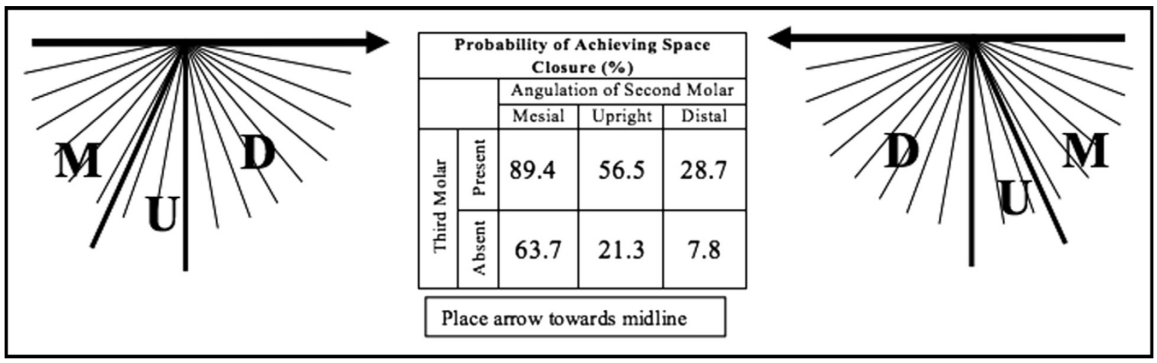

Figure 3: The original Patel et al.[12] tool.

Since no physical radiographs were available for review in this study, the tool was digitized from the portable document file (pdf) of the Patel et al.[12] publication using Greenshot (Braun, Klingen, Krom, Lauf, Germany).

When applied to digital radiographs, the numerous scribe lines of the protractors impaired the operator's ability to assess second molar angulation (Figure 4). Therefore, the protractor lines within the digitized Patel et al. tool kit were

removed, except the demarcation lines between mesial and upright, and upright and distal (Figure 5) using Adobe Photoshop (Adobe Systems, San Jose, CA).

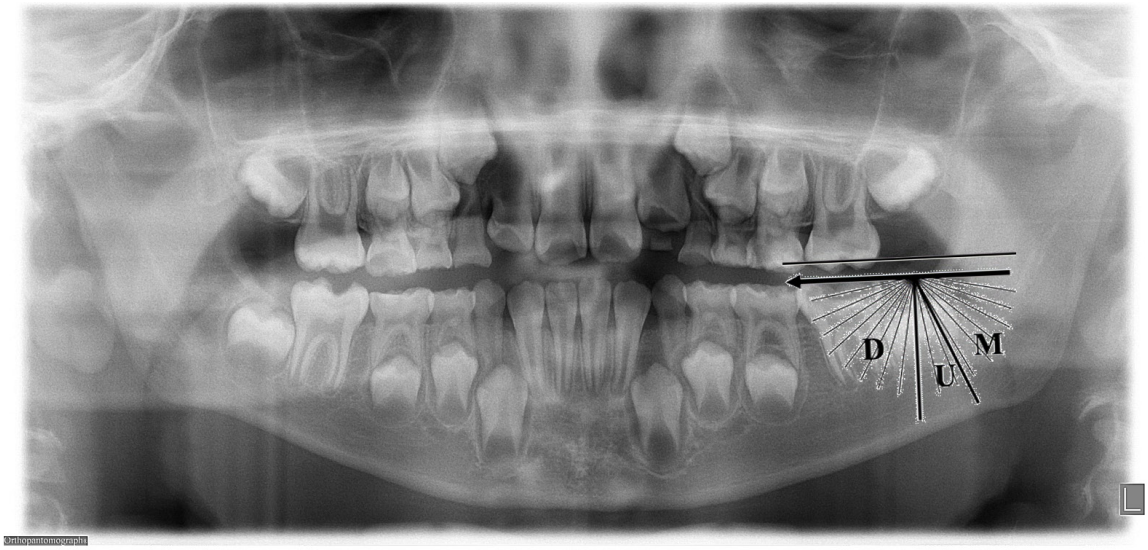

Figure 4: Example of a panoramic image with the Patel et al.[12] tool overlayed on the second permanent molar.

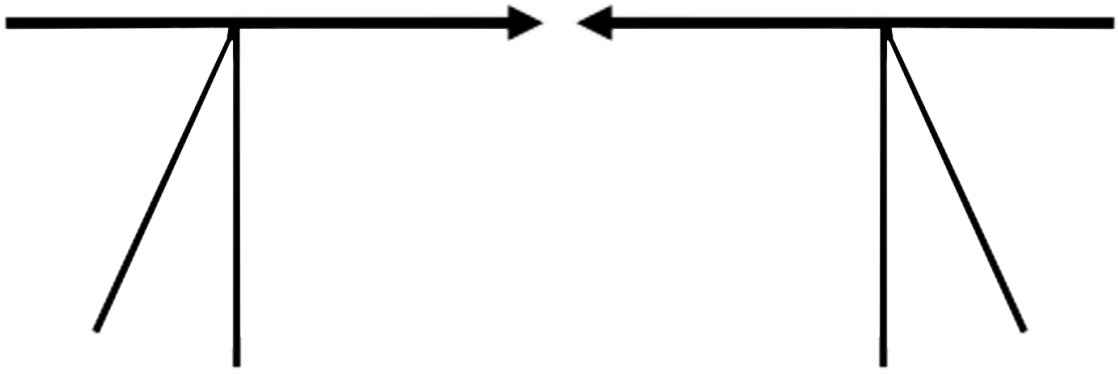

Figure 5: Modified Patel et al.[12] angulation tool. The modification increased the visibility of angulation categories when assessing panoramic radiographs.

Prior to the digital placement of the modified tool, a single straight line was drawn through the long axis of the SPM(s) requiring assessment. This line was drawn in

a widely available vivid orange color (HEX ff6600). The modified tool was then placed over the SPM, and the angulation category was recorded (Figure 6).

Figure 6: Example of the modified Patel et al.[12] angulation tool, showing enhanced clarity for angulation assessment of mandibular first permanent molars.

Assessment of Space Closure

Initial radiographs used to assess SPM angulation using the modified version of the Patel et al. tool kit.[12] If more than one pre-operative panoramic radiograph existed, the image closest to extraction was assessed.

The radiographs used to assess space closure were limited to bitewings, as these have been shown to detect open contacts more accurately than panoramic radiographs.[88] When multiple images of the same site existed, the radiograph with the most parallel view of the contact area between the mandibular second pre-molar and molar was selected.

Consistent with the methodology of Patel et al.,[12] complete or incomplete space closure was recorded. Spontaneous space closure was recorded as complete when the SPM was in contact with the second premolar without clinically significant angulation, even in the presence of other spacing in the quadrant (Figure 7). Spontaneous space closure was considered incomplete when the SPM was not in contact with the second premolar (Figure 8).

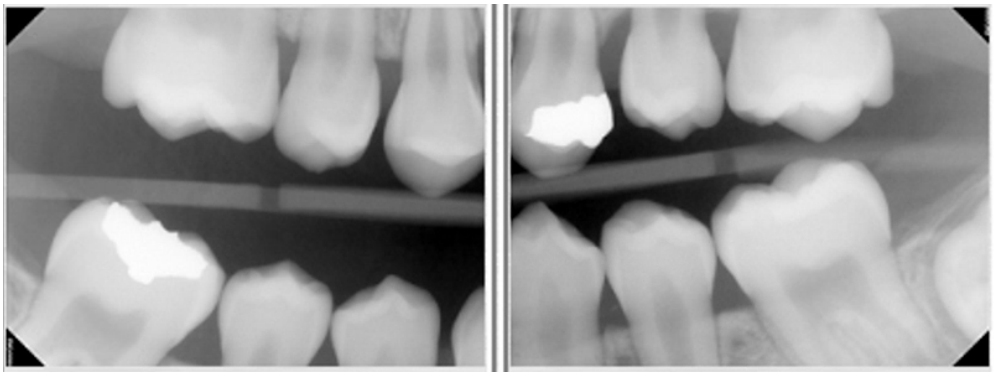

Figure 7*:* Example of complete spontaneous space closure of upper and lower first molar at forty months of follow-up.

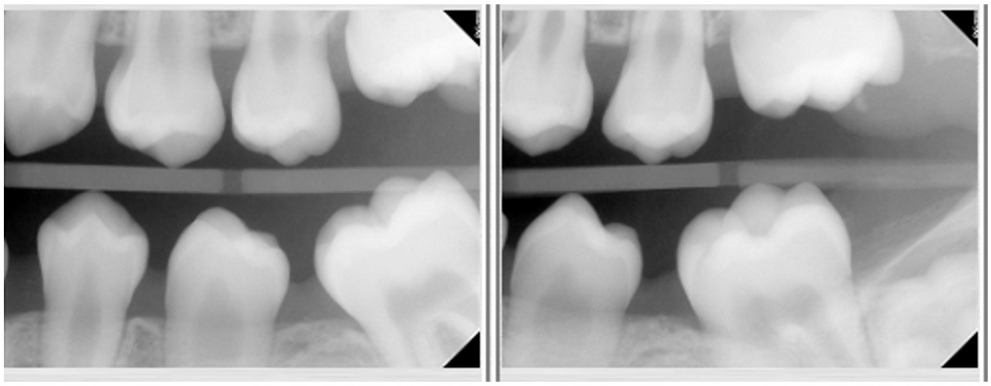

Figure 8*:* Example of incomplete spontaneous space closure of upper and lower first molars at forty-two months of follow-up.

Supereruption

Supereruption of compensated and uncompensated extractions was measured on bitewing radiographs to avoid risk of linear distortion. For each patient, the radiograph with the longest follow-up was measured. The samples comprised 83 compensated and 123 uncompensated extractions from 156 patients.

Radiographs were captured from sensors made by three different manufacturers, depending on the sensor type used at the clinic at the time of imaging. Manufacturer, sensor type, and image pixel size was recorded from the DICOM data associated with each radiograph. The radiographs were calibrated for measurement according to the manufacturer's calibration tables (Table 12) using XrayVision DCV (Apteryx).[65] The best fit line of the maxillary occlusal table was first drawn across the quadrant. Then a second line was drawn vertically from the most coronal part of the occlusal cusp to the first line, and this distance was measured. If the maxillary molar was above or at the occlusal plane, no supereruption was recorded. The amount of supereruption was recorded in millimeters.

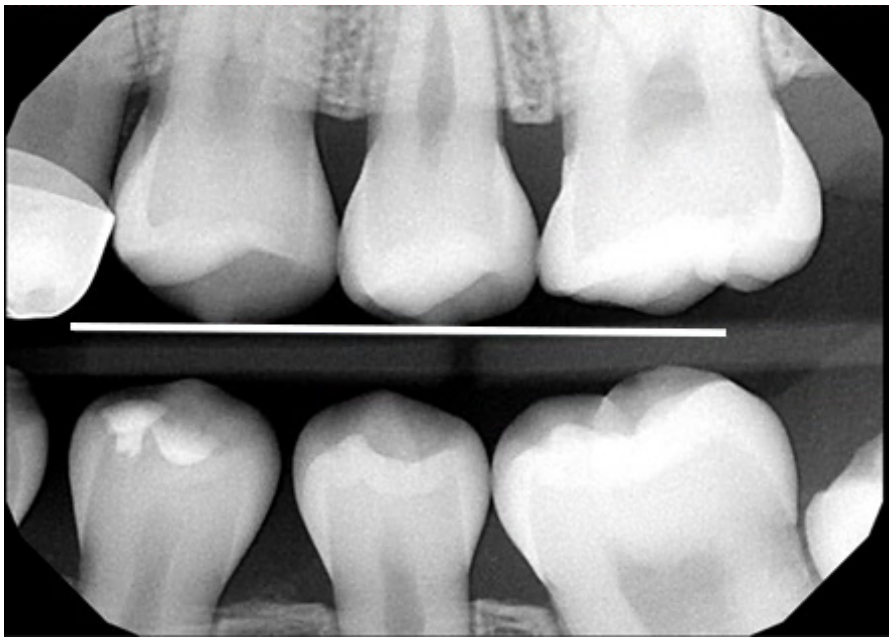

Figure 9: Example of a patient with an uncompensated extraction at age nine, demonstrating no supereruption after eight years of follow-up.

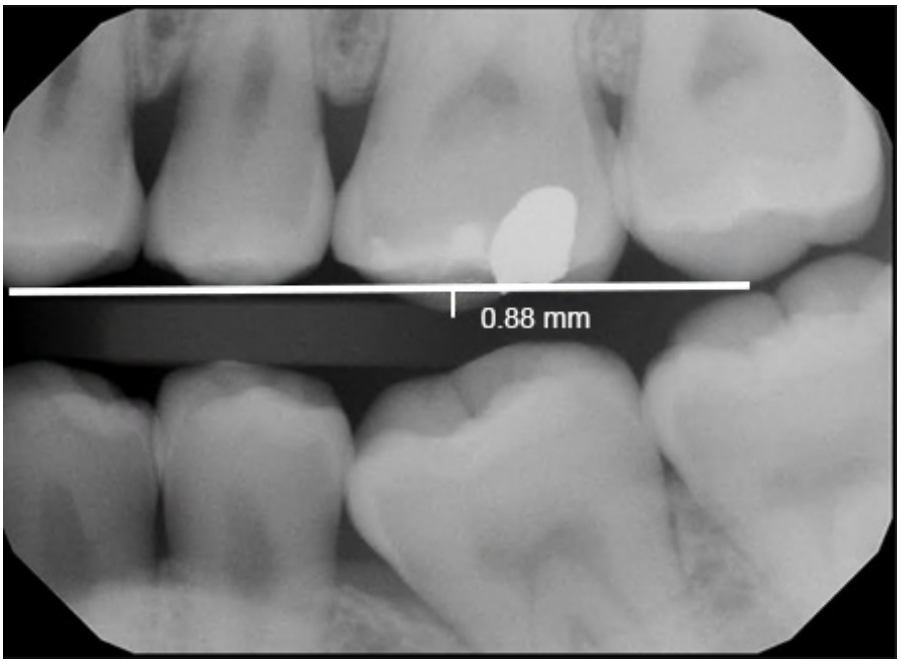

Figure 10: Example of a patient with an uncompensated mandibular first permanent molar extraction at age ten, demonstrating supereruption of the maxillary first permanent molar after twelve years of follow-up.

Statistical Analysis

Categorical measures were summarized using counts and rates, and continuous measures were summarized using means, standard deviations, and ranges. Intra-rater reliability was measured using the unweighted kappa statistic for categorical measures and the intraclass correlation coefficient for continuous measures.

The relationship between SPM Demirjian stage and complete space closure was examined using Fisher's exact test and logistic regression. The effects of compensation type, bitewing sensor type, age group, gender, and follow-up time on supererruption were examined using logistic regression models. The effects of SPM angulation, TPM presence, age group, gender, follow-up time, and compensation type on complete space closure were examined using logistic regression models. All statistical analyses were conducted using R version 4.1.1 (R Foundation for Statistical Computing, Vienna, Austria).

Results

Patient Demographics

There were a total of 190 patients with FPM extractions. Of these 126 patients were female, while 64 patients were male. All the patients had documented their ethnicity as Alaska Native. Data collected from the electronic dental record showed that most patients were 100% Alaska Native by blood quantum (Table 1). The patients represented the diverse geography throughout Southwestern Alaska, hailing from both the Bethel and Kusilvak census areas, and lived in 34 of the communities serviced by YKHC.

Table 1: Patient demographics. Patients evaluated for supereruption and space closure were included in both categories.

	Total Unique Patients		**Evaluated for Supereruption**		**Evaluated for Space Closure**	
	n	%	n	%	n	%
Gender						
Female	126	66%	111	71%	83	62%
Male	64	34%	45	29%	51	38%
Ethnicity						
Alaska Native	190	100%	156	100%	134	100%
Blood Quantum						
100%	148	78%	124	79%	106	79%
>=50% to <100%	23	12%	16	10%	15	11%
>= 25% to <50%	2	1%	1	1%	2	1%
>0% to <25%	1	1%	1	1%	1	1%
Unspecified	16	8%	14	9%	10	7%

Repeatability

Results of repeatability testing are shown in Table 2. Reliability testing for the categoric variables showed substantial agreement to perfect agreement.[89] Reliability testing for the numeric data showed near-perfect agreement.[90]

Table 2: Reliability testing for categorical and continuous measurements.

Cohen's Kappa for Categorical Measurements			
Category	**Kappa**	**p**	**Interpretation**
Second permanent molar angulation	0.69	0.002	Substantial Agreement
Third molar presence	1	<0.0001	Perfect Agreement
Second permanent molar stage	0.85	<0.0001	Almost Perfect Agreement
Space closure	0.70	0.002	Substantial Agreement

Intraclass Correlation Coefficients for Continuous Measurements			
Continuous Measure	**ICC**	**p**	**Interpretation**
Supereruption	0.97	<0.0001	Near Perfect Agreement

ICC: intercorrelation coefficient

Mandibular First Permanent Molar Replacement Predictors

There were 134 unique patients representing 182 samples of mandibular FPM extractions. The number of FPMs extracted per patient ranged from one to four, and the mean age at extraction was 9.1 years. Extractions that occurred before age eight were considered "early," while extractions after age ten were considered "late." A total of 128 (70.33%) of the mandibular FPM extractions occurred within the "ideal" age range of 8 to 10 years, while 37 (20.33%) were early, and 17 (9.34%) were late (Table 3).

Table 3: Age and presence of third permanent molars at mandibular first permanent molar extraction in individuals evaluated for space closure.

Age Category	n	%
6 to 7	37	20.33%
8 to 10	128	70.33%
11 to 12	17	9.34%

A total of 133 (65%) of the panoramic films were taken within a month of extraction. The average time between the panoramic radiograph and extraction was minimal, at 1.28 months. The average time between extraction and re-evaluation was 4.6 years (SD 2.3; range 0.6 –14.8).

Table 4: Timepoint data for first permanent molar replacements.

Description	Mean (SD)	Range
Chronological age at initial radiograph (y)	8.9 (1.4)	5.7 – 12.4
Chronological age at extraction (y)	9.1 (1.4)	6.0 – 12.4
Interval between panoramic image and extraction (y)	0.1 (0.2)	0.0 – 1.0
Interval between extraction and final radiograph (y)	4.6 (2.3)	0.6 – 14.8

SD: standard deviation

The greatest number of extractions occurred at SPM Demirjian stage E. Stages E and F had the highest rates of spontaneous space closure, at 74% and 86%, respectively (Table 5). A study by Teo et al. suggested that stage F might yield the best odds of replacement.[78] As a result, this study compared the odds of space closure at stage F compared to other stages. A logarithmic regression demonstrated that stage F was a better predictor of space closure than stages C, D, and G (p=0.05). There was no statistical significance between the predictiveness of stages E and F.

Table 5: Complete space closure rate for second permanent molars extracted at Demirjian stage F compared to all other stages.

SPM Demirjian Stage	n	%	Complete Space Closure	Complete Space Closure %	p
B	3	2%	2	67%	0.42
C	14	8%	7	50%	0.03*
D	59	32%	32	54%	0.02*
E	65	36%	48	74%	0.27
F	21	12%	18	86%	–
G	17	9%	6	35%	0.003*
H	3	2%	0	0%	0.98

*: statistically significant

Mandibular FPM extractions between ages 8 to 10 years were more likely to attain space closure than extraction at ages 11 to 12 years (p=0.04). However, there was no statistically significant difference in space closure outcome between ages 6 to 7 years and 8 to 10 years (Table 7).

A total of 103 panoramic radiographs demonstrated visible TPM development, while 79 did not (Table 6). There is evidence that TPM presence increases the odds of complete space closure (p=0.02).

Table 6: Third permanent molars identified at the time of first permanent molar extraction.

Age Category	Third Molars Present	Third Molars Present %	Third Molars Absent	% Third Molars Absent %	Total
6 to 7	9	24.32%	28	75.68%	37
8 to 10	80	62.50%	48	37.50%	128
11 to 12	14	82.35%	3	17.65%	17

Each additional year of follow-up demonstrated an increased likelihood of space closure (p=0.0007). Finally, mesial SPM angulation appears to be a positive predictor of space closure, but it was not found to be a statistically significant predictor (p=0.05). Regardless of predictors, complete space closure occurred in 114 (62.30%) of the replacements.

Table 7: Multivariate logistic regression for complete space closure, third molar presence, age cohort, and follow-up time.

Category	OR	95% CI		p
Second permanent molar angulation: upright vs. mesial	0.46	0.21	0.99	0.05
Second permanent molar angulation: distal vs. mesial	0.4	0.05	3.87	0.39
Third molar presence: yes vs. no	2.35	1.16	4.9	0.02*
Age: 6 to 7 vs. 8 to 10	0.78	0.33	1.85	0.57
Age: 11 to 12 vs. 8 to 10	0.28	0.08	0.91	0.04*
Gender: male vs. female	0.78	0.39	1.58	0.50
Per additional 12 months of follow-up	1.38	1.16	1.69	0.0007*

OR: odds ratio
CI: confidence interval
*: statistically significant

Supererruption and Compensating Extractions

There were 83 maxillary SPMs that were compensated replacements for previously extracted maxillary FPMs and 123 uncompensated FPMs whose mandibular antagonist was extracted or absent. A total of 61 (73.49%) of the compensated extractions and 46 (37.40%) uncompensated showed 0 mm of supererruption. The median supererruption in the compensated group was 0.0 mm (IQR 0.00 – 0.35), while in the uncompensated group, it was 0.29 mm (IQR 0.00 – 0.76). Compensated supererruption ranged from 0 to 2.19 mm, while uncompensated ranged from 0 to 2.62 mm. Most of the compensated or uncompensated extractions occurred between ages 8 to 10 (Table 8).

Table 8: Age at mandibular first permanent molar extraction in individuals evaluated for supereruption.

Age Category	n	%
6 to 7	42	20
8 to 10	147	71
11 to 13	17	8

A multivariate logarithmic analysis compared a dichotomous presence of supereruption, compensation type, sensor type, age cohort, and follow-up time (Table 9). The analysis showed that uncompensated extractions are significantly associated with supereruption (p=0.0001). Additionally, antagonist molar extraction between ages 11 to 13 may increase the odds of supereruption but the results were not significant (p=0.06). Finally, each additional year of follow-up demonstrated an increase in the likelihood of supereruption (p=0.0005).

Table 9: Multivariate logarithmic analysis used to compare the presence of supereruption, compensation type, sensor type, age category, and follow-up time.

	OR	95% CI		p
Uncompensated vs. compensated	3.56	1.87	6.95	0.0002*
Sensor: Kodak vs. Gendex	0.91	0.39	2.11	0.83
Sensor: Sorodex vs Gendex	2.02	0.70	3.22	0.20
Age: 6 to 7 vs. 8 to 10	1.03	0.45	2.23	0.94
Age: 11 to 13 vs. 8 to 10	3.23	1.02	12.83	0.06
Gender: male vs. female	0.89	0.44	1.77	0.73
Per additional 12 months of follow-up	1.18	1.08	1.30	0.0005*

OR: odds ratio
CI: confidence interval
*: statistically significant

Space Closure and Uncompensated Extractions

Between the mandibular FPM replacement group and the supereruption group, there were 131 samples that could be evaluated for both space closure and supereruption. An additional model was created using multivariate logistic

regression to assess the impact of compensated extractions on space closure. The model compared SPM angulation, TPM presence, age cohort, follow-up time, and whether the maxillary FPM was uncompensated or extracted and compensated by the SPM. The results showed no statistically significant difference in the odds of space closure (Table 10).

Table 10: Multivariate logarithmic analysis used to compare space closure, the presence of supereruption, compensation type, sensor type, age cohort, uncompensated vs. compensated extractions, and follow-up time.

Category	**OR**	**95% CI**		**p**
SPM Angulation: Upright vs. Mesial	0.40	0.16	0.98	0.05
SPM Angulation: Distal vs. Mesial	0.18	0.01	2.63	0.22
Third Molar Presence: Yes vs. No	0.45	0.18	1.07	0.07
Age: 6 to 7 vs. 8 to 10	1.67	0.58	4.82	0.34
Age: 11 to 12 vs. 8 to 10	0.51	0.08	2.97	0.47
Uncompensated vs. Compensated	1.30	0.56	3.008	0.54
Per Additional 12 Months of Follow-up	1.38	1.16	1.68	0.0007*

OR: odds ratio
CI: confidence interval
*: statistically significant

Discussion

Limitations

Record limitations prevented equal distributions of ages, gender, SPM Demirjian stage, SPM angulation, and TPM presence. In this study's sample population, 66% of the patients were female. Development of both the SPM and the second bicuspid is approximately 0.3 to 0.4 years more advanced in females than in males.[91] However, gender was an insignificant predictor for space closure and supereruption, making it unlikely to have significantly affected the results. There is no apparent explanation for more females receiving FPM extractions than males.

All the patients within this study were Yup'ik. The Yup'ik people have characteristically powerful masticatory muscles, with the average Yup'ik bite force two times greater than the average European.[92] While diets have changed over time, many Yup'ik people continue to consume a traditional diet of hard, dry meat, which may increase the rate of chipping and abrasions.[39,92] It is possible that these characteristics reduce the measured supereruption compared to other populations. However, these potential dietary impacts should have an equivalent impact on compensated and uncompensated extractions and not affect the difference of eruption between the two groups.

As with any retrospective cohort study, there is risk of bias. This was mitigated by separating the initial conditions of the FPM and the subsequent follow-up

evaluation of space closure with the investigator blinded to the status of compensated vs. uncompensated at review. However, the total number of teeth present in the bitewing made complete blinding impossible.

Additionally, many of the DICOM data associated with the panoramic images lacked a description of the original capture source. As a result, any variance that may have occurred from panoramic images captured from the various machine types could not be accounted for. While some variation in angulation may be present, one study demonstrated that panoramic machines only vary by three or fewer degrees from machine to machine at molar sites.[75] It is unlikely that this level of variation would alter SPM angulation classification.

Linear measurements of supereruption were made exclusively on bitewing radiographs. Although bitewings spanned three different manufacturers, there was no statistical difference in the linear measurements of the compensated and uncompensated supereruption across sensor types.

Determining the position of the occlusal plane is more difficult when fewer teeth are visible within the bitewing. Some radiographs had as few as two reference teeth relative to the subject FPM. Therefore, these teeth were assumed to reflect the patients' true occlusal plane.

Like supereruption, space closure assessment was made exclusively on bitewing radiographs. This decision was made to standardize the outcome measure and

decrease the risk of false-positive space closure from panoramic radiographs. Previous studies have assessed space closure radiographically, clinically, with models, and with a combination of each. Clinical or model assessment allows visualization of the entire contact area in 3D space, providing the most precise assessment of space closure. However, an adequately made bitewing allows for an optimal view of the contact area.

This study did not record spontaneous space closure as a continuous measure. Previous studies by Teo et al. [9,78] attempted to quantify space closure through a tiered scoring system during a clinical exam. However, the authors explained that a successful replacement was only classified as complete space closure. For this reason, the present study evaluated space closure as a dichotomous "complete" or "incomplete." The consequence of treating space closure as dichotomous means that minor spacing (i.e., 0.25 mm) is considered a failure, though it may be an acceptable result to the patient.

The presence of space closure does not explain how the closure occurred. It is possible that closure occurred through mesial drift of the SPM, distal drift of the second premolar, or a combination of the two. Additionally, the angulation of the replacement SPM or its vertical height in the arch were not measured, which may be a component of spontaneous space closure. As a result, complete space closure may not directly correlate to a patient's need for future orthodontic treatment.

Second Permanent Molar Demirjian Staging

Previous studies have proposed that SPM Demirjian stage E is the ideal replacement time to attain spontaneous SPM space closure.[10,13] In this study, overall stage F was the most likely to attain space closure, which suggests that stage F might be an equivalent predictor of space closure compared to stage E. Stage F appears to be a statistically significant predictor compared to stages C, D, and G but not E. This finding is similar to the findings of Teo et al. and suggests that there may be a range of favorable stages for FPM extraction leading to predictable replacement.[78] The development of a radicular bifurcation appears to signal the beginning of optimal FPM extraction timing. Timing remains favorable through stage F, as the molar roots develop to a length equal to or greater than the crown height. Upon further development into stage G, root development continues towards partial apical root closure, and the odds of complete space closure diminishes. Future studies should consider evaluation of spontaneous space closure when FPMs are extracted at stages E and F.

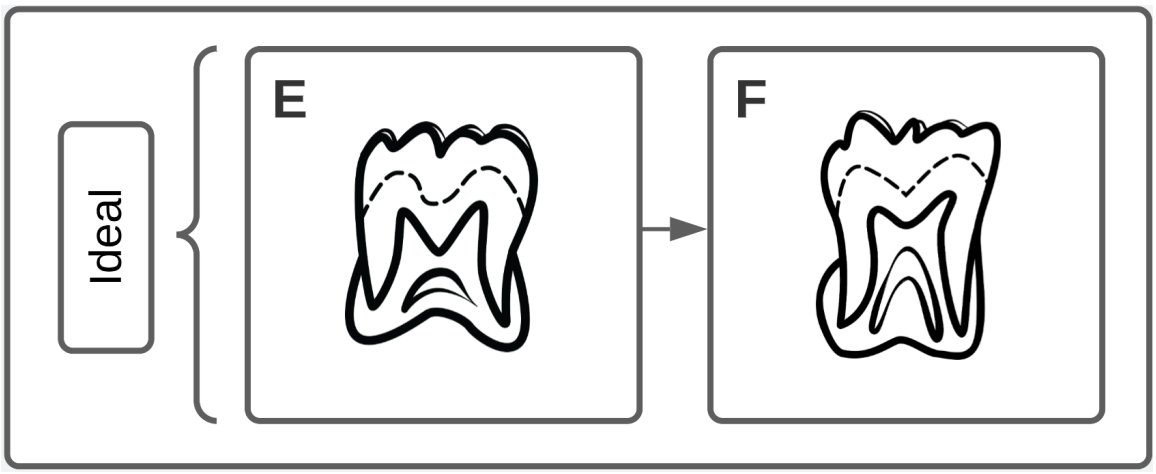

Figure 11: Representation of stages E and F, the most favorable stages for second permanent molar tooth replacement, adapted from Demirjian et al.[77]

Third Permanent Molar Considerations

When assessing a quadrant for possible FPM extraction, the presence of a TPM is considered favorable for spontaneous space closure. Under ideal conditions, the FPM will be replaced by the SPM, and the SPM by the TPM. In concordance with both Patel et al.[12] and Çiftçi et al.,[79] this study found that presence of a TPM increase the odds of complete space closure by the SPM.

However, using the TPM as a predictor has limitations. There is significant variation in TPM crypt formation across populations, averaging as early as 7.16 to as late as 10.59 years of age.[93] In some patients, crypt formation is detected as early as age 6.[80] The average timing for TPM crypt formation is unknown in Yup'ik patients.

In addition, only one-fifth of the patients younger than 8 years had visual evidence of a TPM. Using the TPM as a predictor is a potential weakness of the

tool kit, primarily when predicting space closure in young patients who may develop a TPM later in life. The tool kit may underestimate the odds of replacement in these patients.

Chronologic Age

Mandibular FPM eruption typically occurs between the ages of six and seven,[4] which coincides with the “early” extraction age range. At this age, clinicians only consider FPM extractions after significant loss of tooth structure and guidelines have recommended against this early extraction timing. Therefore, it is reasonable to expect that there would be fewer extractions in this early timeframe. This is consistent with previous studies as well as this study’s sample distribution.

Jälevik and Möller evaluated a small number of FPM replacements among patients under eight years of age.[21] From their data, 75% of the mandibular FPM replacements had favorable outcomes. While this is greater than the early FPM replacement rates found in this study (57%), the comparison has several limitations. First, Jälevik and Möller’s assessments were at the patient level instead of the quadrant level. Second, they categorized a favorable outcome as “spontaneous space reduction” and not necessarily complete closure, making a direct comparison difficult.

Çiftçi et al. described space closure outcomes of early FPM extraction on a quadrant basis, concluding that chronologic age was not a significant predictor of

space closure. This conclusion is meaningful for two reasons. First, their study sample size only included patients between 6 and 10 years of age, meaning that their chronologic age comparisons indirectly evaluated both “early” and “ideal” extractions. Second, their conclusion that chronologic age has no clinical significance suggests that early extraction is no different than ideal extraction, which is in direct contrast to existing treatment guidelines on mandibular FPM extraction timing.[20,86]

In this study, approximately one-fifth of the extractions occurred before the age of eight. The finding that there was no statistically significant difference in space closure between the 6 to 7 and the 8 to 10 age groups suggests that there is no need to delay FPM extractions until age eight or later.

While early and ideal FPM extraction was found to be comparable predictors of space closure, this was not the case with late extraction. FPM extraction past the age of 10 years was found to have a decreased odds of space closure. As a result, clinicians should carefully balance restorability and long-term prognosis of FPMs as patients approach age 11 years.

Clinical Implications of Supereruption

British National Guidelines have loosely recommended compensating extraction “of an upper first permanent molar […] when extraction of the lower first permanent molar is required.”[13] They also note that there should be a

consideration for extraction should the FPM be expected to be without an antagonist for a “significant length of time.”[13]

This study provides additional evidence relevant to the British National Guidelines. There was no evidence that supereruption was more likely to occur in the early extraction groups, but instead more likely in late extractions. While late extractions were not a statistically significant predictor of supereruption, it appears likely that this later age may increase the odds of supereruption. It is possible that the decreased odds of space closure after late-stage mandibular extractions may increase the odds of supereruption of the remaining maxillary antagonists.

In this study, the median supereruption observed in compensated and uncompensated FPM replacements were very small. It is unlikely that dentists would make a clinical note of 0.29 mm or less supereruption, nor would they likely refer for orthodontic treatment to correct this finding. If necessary, this amount of eruptive change is well within the ability of enameloplasty or occlusal equilibration to correct.

However, supereruption of more than 2–3 mm is clinically relevant and was observed towards the far end of the sample distribution in both compensated and uncompensated extractions. Once a tooth has erupted beyond 2 mm, orthodontic treatment may be required to return the tooth to an optimal position. If access to

orthodontic services is unavailable, significant occlusal equilibration, and potentially endodontic therapy and final restoration, may be the only non-orthodontic means for correction.

Finally, this study has demonstrated that compensated and uncompensated extractions have similar rates of spontaneous space closure. As a result, healthy maxillary FPMs do not need to be extracted to increase the chance of mandibular FPM replacement.

Follow-up Time for Space Closure

The average difference in time between the initial radiograph and extraction was 1.28 months. It is unlikely that there would be a clinically significant change in SPM angulation or the occlusal plane during this timeframe. Additionally, molar development stages span from 0.6 to 3.4 years, and thus it is improbable that SPM Demirjian stage would change during this timeframe.[91]

For mandibular FPM extraction, the time to spontaneous space closure varied through the sample. The median follow-up duration to spontaneous space closure was 4.77 years. While some replacements occurred more readily, the frequency of such was lower. This is expected, as the SPM typically erupts 1.3 years after the attainment of stage F, and many teeth were extracted at earlier stages.[91] In this study, only two replacements had complete space closure in less than two years. Considering this study has provided evidence that the length of

follow-up time is a significant predictor for space closure, it is conceivable that if additional records had been available to follow these patients longer, additional space closure may have been recorded.

Follow-up Time for Supereruption

The median follow-up for compensated extractions was 5.17 years. The earliest observed supereruption occurred in an uncompensated extraction at 13 months, while the earliest instance of compensated supereruption occurred at 21 months. This finding reaffirms that supereruption may occur as early as one year without an antagonist.[61] Additionally, there is a statistically significant correlation between follow-up time and the presence of any supereruption: the longer a tooth was followed, the more likely it was found to be supererupted. However, absolute supereruption did not always increase with follow-up time as one might anticipate. It is likely that at some point during the supereruption process, an antagonist replaces the missing tooth and either significantly slows or completely stops eruption, consistent with Weinstein's theory.[54] It is also possible that supereruption in growing individuals may be masked by maxillary and mandibular growth and differential eruption that is known to occur at this time.[94]

Use of the Tool Kit To Predict Space Closure in the Yup'ik Population

In the present study, complete mandibular space closure occurred in 62.30% of the replacements. This is similar to the findings of Teo (66%),[78] Patel et al. (49%),[12] and Çiftçi et al. (52.5%).[79] TPM presence along with mesial SPM

angulation yielded the best likelihood of space closure, while the absence of TPM and distal SPM angulation yielded the worst.

Observed space closure predictions fell within the confidence intervals in five of six categories within the tool kit (Table 11). The only category that did not fall within the confidence interval was upright SPMs without the presence of a TPM, which showed a 47% likelihood of space closure, compared to that of Patel's 21.3%.[12] Additionally, it is impossible to make predictive conclusions about distally angulated SPMs due to the small number of samples in this caetgory.[79] Other studies have also shown a low prevalence of distally angulated SPMs.[79]

While the predictiveness by category does not perfectly match the previous Patel model,[12] there were striking similarities in the trends amongst the mesial and upright groups. Spontaneous space closure is more likely to occur in the presence of a TPM and a mesially angulated SPM. The effects appear to be additive as mesially angulated cases with TPMs have the highest odds of space closure, while upright SPMs without TPMs have the lowest odds of space closure. While this study did not validate the Patel et al. tool kit[12] for the distally angulated SPMs, the tool may have predictive value for mesial and upright SPMs.

Table 11: Prediction of spontaneous space closure after first permanent molar extraction, presented in a format similar to Patel et al.[12]

Probability of Space Closure % (CI)				
		Second Molar Angulation		
		Mesial	Upright	Distal
Third Molar	Present	77 (56 – 91)	64 (52 – 75)	75 (19 – 99)
	Absent	68 (49 – 83)	47 (32 – 62)	0 (0–98)

CI: Confidence interval

General Recommendations for First Permanent Molar Extractions

When considering FPM extraction in a child, clinicians should capture a pre-operative panoramic radiograph as part of the diagnostic data collection. Once the image is acquired, YKHC dentists and DHATs may use this study's modified version of the Patel tool kit[12] to identify the angulation category of the a developing SPM. Clinicians should evaluate the image for other positive predictors of space closure in the quadrant such as the presence of a TPMs and favorable SPM Demirjian stages E and F. FPMs with slowly progressing conditions such as hypoplastic enamel may be maintained conservatively with glass ionomer or silver diamine fluoride until optimal predictors are identified, while FPMs with urgent conditions like non-restorable caries or acute infection may require immediate removal. Ultimately, severely compromised mandibular FPMs may be extracted anytime between the ages of 6 and 10 as there is no difference in the odds of spontaneous space closure. There is no reason to delay

needed extractions until 8 years of age or beyond, but clinicians should aim to extract severely compromised teeth before there age of 11.

Healthy maxillary FPMs do not appear to require compensatory extraction, nor will they impede space closure of lower SPMs. One should strongly consider alternative treatment, especially if a TPM is not identified in the quadrant, or if general anesthesia is required to accomplish this additional extraction. Patients and parents should be informed that their teeth will be more likely to supererupt over time without a retainer.[95] Additional future treatment, such as occlusal equilibration or orthodontic treatment may be necessary to idealize these molars.

Conclusions

1. Chronologic age, particularly between the ages of 8 to 10 years, appears to be a positive predictor for spontaneous space closure in the mandible after FPM extraction. Conversely, FPM extraction before the age of 8 years is not associated with a lack of space closure.

2. The Patel et al.[12] tool kit's categorical predictiveness appears to be partially valid for FPM replacements in the Yup'ik population. Mesial angulation may be a positive predictor of space closure when compared to upright angulation.

3. Uncompensated extractions are more likely to supererupt than compensated extractions over time, but the amount is frequently clinically insignificant. Additional prospective studies are needed to assess the impact of supereruption of compensated and uncompensated extractions.

4. Failure to compensate a mandibular molar extraction with a maxillary molar extraction does not appear to inhibit mandibular SPM space closure.

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Appendix

Table 12: Calibration data for bitewing sensors.

Manufacturer	Sensor Type	Size	Dimension (mm)	Image Size (px)
Gendex	GX PS-500	2	27 x 57	886 x 1171
Carestream	RVG 6100	2	27 x 36	1440 x 1920
Sorodex	GSX-500 Phosphor Plates	2	31 x 41	886 x 1171

Table 13: Demographic data captured from the "Dental" database from Clinical Product Suite.

Table Name	Field Name	Description
Patient	Patient_Id	Used to link data prior to de-identifying study data.
Patient	City	Patient City
Patient	Zip	Patient Zipcode
Patient	Sex	Gender
Patient	Birth_date	To calculate the timing for extraction, re-evaluation, and follow up and age at respective time points. Secondary radiograph ID
Patient	Other_id	ID used to link radiographic record location. XRayVision DCV stores records by this ID number
Transactions	Tran_date	Date of transaction
Transactions	Service_code	Validate the type of service provided
Transactions	Tooth	Tooth letter or number
Transactions	Description	To ensure service code and service rendered match
Transactions	Deleted_id	To ensure service or charting was not deleted
Transactions	Data_entered	Entry date of service
Transactions	Date_n_a	To ensure charting was not marked as "not applicable"
Location_Desc_ykhc	Dental_locn_	Unique Location ID – links to other tables
DFM_Data	All Fields	To validate missing and extracted tooth status and establish charting at various examination time points for missing teeth

Table 14: Demographic data captured from the "DataMiner" database from Clinical Product Suite.

Table Name	**Field Name**	**Description**
Pf_addl_patient_info	Unique_id	Demographics: unique id
Pf_addl_patient_info	Most_recent_yn	Demographics: recent
Pf_addl_patient_info	Pf_beneficiary_class	Demographics: ben status
Pf_addl_patient_info	Pf_tribe_code	Demographics: tribal affiliation
Pf_addl_patient_info	Pf_blood_quantum	Demographics: blood quantum