# Alveolar Bone Height Preservation in Growing Patients After Decoronation, Extraction, or Retention of Ankylosed Primary Teeth: A Retrospective Cohort Study

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## ABSTRACT

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**Introduction:** Mandibular second premolars are frequently congenitally missing. Preservation of the alveolar ridge to facilitate future implant placement is critically important for favorable outcomes. Maintaining the retained primary tooth is desired unless the primary tooth becomes ankylosed during the growth period. This study examined three approaches to preserving alveolar bone height in growing patients when the retained primary tooth becomes ankylosed: decoronation, extraction, or retention of the tooth. We hypothesized that decoronation would show the greatest preservation of bone height, while retention would show the least. **Methods:** This retrospective cohort study used de-identified serial radiographs collected from practitioners in the greater Seattle-Tacoma area. Ankylosed primary mandibular second molars with congenitally missing mandibular second premolars were separated into three groups based on management method: decoronation, extraction, or retention. Alveolar bone height was measured at two time points and the change over time was calculated. **Results:** The mean age of each sample in years at T0 was 13.1, 13.6, and 12.6 for decoronation, extraction, and retention, respectively. The mean follow-up time in months for each sample was 22.9, 29.1, and 23.9 for decoronation, extraction, and retention, respectively. Decoronation of ankylosed mandibular primary second molars showed the most favorable change in alveolar bone height over time, with the bone height in the region either increasing or remaining stable. Retention showed the least favorable effect, with alveolar bone height decreasing as the patient matured. Extraction displayed an intermediate response. **Conclusions:** The alveolar ridge responds more positively during growth after decoronation in patients with ankylosed primary second molars. Growth may influence the extent of change observed in each group.

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# INTRODUCTION

**Background:**

Mandibular second premolars are the second most commonly congenitally missing teeth[1,2]. Agenesis of the mandibular second premolars presents in approximately 2.4-4.3% of the population [3]. When this occurs, mandibular primary second molars may be retained well into adulthood if not lost to caries or dental infection[4]. Retained primary teeth may require eventual permanent prosthetic restoration[4]. Ideal replacement for a congenitally missing mandibular premolar is often a single-tooth implant[5].

Successful implant placement and long-term survival hinges upon a robust alveolar ridge. Retained primary teeth have an ankylosis risk – the cementum fusing to the surrounding alveolar bone. The bone adjacent to the ankylosed tooth does not grow in height or width along with the surrounding alveolar bone, creating a bony defect. This leads to infraocclusion or “submergence” of the ankylosed tooth[6]. Hvaring *et al*. found that clinically significant infraocclusion could be observed in 43.6% of patients with retained primary molars[1].

In mild cases, infraocclusion may not significantly impact the mandibular alveolar ridge or implant placement, particularly if ankylosis occurs after growth is complete. However, if ankylosis happens during growth, significant infraocclusion is likely to develop as eruption of the dentition cannot compensate for patient growth[7]. In these cases, ridge augmentation may be necessary prior to implant placement to build the alveolar ridge up to the height and width of the adjacent dental alveolus.

Vertical ridge augmentation has poor predictability[8]. Thus, if bone height is lost, it cannot be predictably regained later. Accordingly, when a retained primary second molar begins to ankylose and infraocclude, it is important to choose the method of management that will best preserve the alveolar bone height for a possible future implant.

According to Kokich and Kokich, there are two commonly used methods of management of a retained mandibular primary second molar[5]. The first is to retain the primary tooth until the time of implant placement. If the primary tooth does not undergo ankylosis, this is the best method to maintain the alveolar ridge height in a growing patient. However, if the primary tooth begins to ankylose and develops infraocclusion, decisions must be made to prevent a severe vertical bone defect from developing. The recommendation in this case is extraction of the submerged primary tooth[5]. While this does eliminate the issue of ankylosis, the patient may be left with a vertical bone defect. It is reported 22% of the alveolar height and up to 63% of the alveolar width will be lost in the first six months after extraction[9]. Therefore, neither fully preserves the alveolar bone height.

A third approach is decoronation, which is advocated to offer the greatest potential for preserving alveolar bone height[10]. Decoronation is a procedure in which the primary tooth crown is removed, leaving the ankylosed root within the alveolar ridge to be resorbed[11]. When ankylosis occurs in growing individuals, the ankylosed root may begin to gradually become resorbed and replaced by bone. This technique is intended to preserve normal alveolar bone growth. Malmgren et al. concludes that this procedure is best done at the first sign of infraocclusion, prior to or during the growth spurt[6]. Since submergence tends to be progressive during growth, the earlier decoronation is performed, the better the result will be[7].

Cohenca *et al*. states that decoronation can help maintain existing bone volume and enable vertical bone growth coronally to the decoronated root[7]. The pooling of blood and growth of bone is theorized to promote additional replacement resorption from the internal aspect while external replacement resorption continues with no interruption. Decoronation allows periosteum to grow over the resorbing root[10]. As the adjacent teeth erupt, there is normal tension on the dent-alveolar fibers attached to the crestal periosteum which, in turn, facilitates vertical bone growth[10]. Thus, maintaining the resorbing root as a matrix for new bone development can lead to increased alveolar bone height[12].

Decoronation is routinely employed to prevent ankylosis and ridge resorption after trauma to permanent incisors [6,7,10,12]. While there is substantial research on anterior ridge preservation following decoronation of traumatized incisors, there are no studies investigating its effects on posterior mandibular alveolar ridge height preservation in submerged primary teeth when a permanent successor is absent.

**Specific objectives and hypothesis:**

This study aimed to determine the most effective management strategies for preserving posterior alveolar bone height in growing patients with an ankylosed mandibular primary second molar and missing mandibular second premolar. The three strategies compared were decoronation, extraction, and retention. We anticipated that decoronation will show the greatest preservation of alveolar bone height at follow-up, and retention will show the least.

# METHODS

**Study Design:**

This was a retrospective cohort study evaluating management methods of ankylosed and submerged mandibular primary second molars in adolescent patients. Subjects were split into three treatment groups based on management strategy: decoronation, extraction, or retention. Changes in alveolar bone height over time was the outcome of interest. The study was reviewed and approved by the University of Washington Institutional Review Board on August 4, 2023.

**Setting, Participants, and Eligibility Criteria:**

Practitioners were approached and asked for de-identified records of all patients with retained ankylosed mandibular primary second molars.

Inclusion and exclusion criteria for subjects were as follows:

*Inclusion Criteria:*

- Under 18 years old at initial records
- Congenitally missing at least one mandibular second premolar (#20 and/or #29)
- Possessing at least one retained and ankylosed mandibular primary second molar (#K and/or #T)
- Primary second molar managed with decoronation, extraction, or retention
- Serial radiographs (panoramic images, periapical images, or CBCTs) of the site must be available

*Exclusion Criteria:*

- Conditions or syndromes that may impact dental development
- Conditions or syndromes that may impact quality of the bone
- Periodontal disease diagnosis
- Primary mandibular second molars extracted due to caries or disease

Patients were divided into three groups based on management strategy: decoronation, extraction, or retention. Each tooth was counted as a separate “subject” or unit of analysis. If a patient had two teeth that met the criteria, each was considered individually with the rationale that environmental factors in the mouth have a greater influence than genetic factors[13].

**Research Procedures:**

Radiographs (panoramic images, periapical images, orthodontic CBCTs, and lateral cephalometric images) were de-identified and collected from participating practitioners. Radiographs were required to include the distal aspect of the first mandibular premolar (#21 or #28) and the mesial aspect of the first mandibular molar (#19 or #30) to ensure accurate measurement of alveolar bone at each time point. Radiographs were grouped into two distinct timepoints:

- T0 = Initial
  - *Decoronation or extraction*
    - Radiographs must be taken within one year of the procedure date
  - *Retention*
    - Radiographs must confirm submergence of the ankylosed mandibular primary second molar (defined as infraocclusion ≥1 mm)
- T1 = Follow-Up
  - *All groups*
    - Radiographs must be taken at least 12 months from initial timepoint and no more than 60 months from initial timepoint

Demographics (gender and age) and applicable procedure dates were recorded as well.

**Measurement Technique:**

Changes in the alveolar ridge at the location of the ankylosed primary molar were evaluated at the above timepoints. The primary outcome assessed was change in alveolar bone height (demonstrated Figure 1). The secondary outcome assessed was change in vertical bone defect (demonstrated in Figure 2).

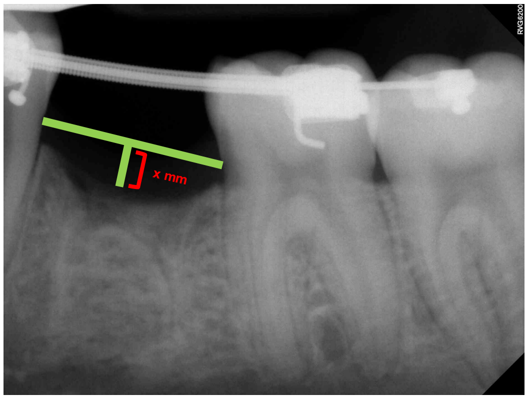


*Figure 1: Evaluation of change in alveolar bone height over time*

To evaluate the change in alveolar bone height over time, a horizontal line was drawn from CEJ of the adjacent tooth to CEJ of the adjacent tooth. A vertical line was drawn from the center of the first line straight down to the crestal bone and measured in millimeters. The difference between the two vertical measurements was calculated. A decrease in this vertical measurement would indicate bone deposition or preserved alveolar bone height, while an increase in this vertical measurement would indicate vertical bone loss.

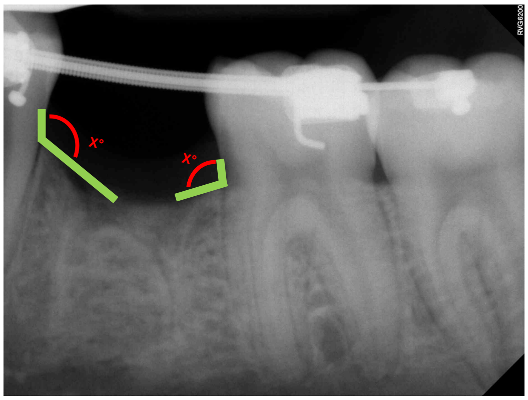


*Figure 2: Measurement to evaluate vertical bone defect*

The vertical bone defect was measured by assessing the angle formed at the intersection of two reference lines: one drawn vertically along the crown of the tooth, representing its long axis, and the other following the contour of the crestal bone. Measurements were taken on both the mesial and distal aspects of the tooth at both time points. The difference between the two time points was calculated to assess whether the vertical bone defect was worsening or improving. A decrease in the size of the angle over time would indicate an improvement of the vertical bone defect, while an increase in the size of the angle would indicate a worsening of the vertical bone defect.

**Calibration Technique:**

The majority of the images used for analysis were panoramic images. Panoramic images may show some degree of distortion[14]. To account for this, images at each timepoint were calibrated. This was achieved by measuring a landmark on the first image and using that measurement to set the scale for the second image. Since there is less variation found in vertical magnification values than horizontal, a vertical measurement was taken[14]. If a patient had two teeth included in the study, each side was calibrated separately, with independent measurements for each tooth. This was done to ensure accuracy in measurements and in changes measured over time.

**Evaluation of Growth:**

To assess the correlation between growth and the findings, the cervical vertebral maturation (CVM) method was used as a surrogate indicator of growth[15]. De-identified lateral cephalometric images were collected for available cases. Lateral cephalometric images were required to be taken within one year of the initial timepoint. CVM stages (1-6) were assessed and recorded for each patient when a lateral cephalometric image was available.

**Reliability:**

To assess the intra-examiner reliability of the measurement of bone height and distal and mesial angles, measurements were repeated for 10 teeth from 9 patients and the reliability and measurement error at T0, T1 and changed from T0 to T1 were summarized by the intraclass correlation coefficient (ICC) and the Dahlberg error, respectively[16,17].

**Sample Size Calculation:**

The study was designed with a sample size of 25 subjects, providing 80% power to detect moderate or larger changes (effect size of 0.5 or greater) in the quantitative outcome of alveolar ridge height. This was based on two-sided paired t-tests at a 0.05 significance level, comparing measurements between the time of the procedure and follow-up within each study group. Each tooth was counted as a “subject” or separate unit of analysis.

When comparing differences between the three study groups using a one-way ANOVA or two-sample t-test, the study had 80% power to detect only relatively large differences (effect size of 0.75 or greater) at a 0.05 significance level.

Power estimates were based on findings from Lin (2013)[18]. In that study, an effect size of 0.5 corresponded to an approximate change of 0.6 mm, while an effect size of 0.75 corresponded to an approximate difference of 1 mm between groups.

**Statistical Analysis:**

The change in bone height and the change in the vertical bony defect from T0 to T1 were compared between the three study groups (decoronation, extraction and retention) using the tooth as the unit of analysis. Linear regression was used to test for differences between the study groups using generalized estimating equations (GEE) to account for the possibility of multiple teeth per patient. If there were statistically significant group differences, pairwise testing was performed between groups (decoronation vs extraction, decoronation vs retention, and extraction vs retention) using GEE linear regression and Holm’s method to adjust for the multiple testing. GEE logistic regression was used to test for group differences by gender and GEE linear regression was used to test for group differences by age and time from T0 to T1.  All analysis were performed using R statistical software (Version 4.4.1) and a significance level of 0.05 used to determine statistical significance.

# RESULTS

**Sample**

Subject demographics and follow-up time are outlined in Table 1, with individual teeth used as the unit of analysis. The decoronation group had adequate sample size for 80% power (30 teeth). The extraction and retention groups were underpowered at 19 and 23 teeth, respectively. No significant differences were found between groups for gender or mean age at time of procedure (or at T0 for retention). No significant differences were detected between groups for follow-up time. Figure 3 displays a boxplot of values for the age at time of procedure or T0 for retention.

*Table 1: Subject Characteristics and Follow-up time*

| Characteristic | Decoronation N = 30 | Extraction N = 19 | Retention N = 23 | p-value[1] |
|---|---|---|---|---|
| **Gender, n (%)** | | | | 0.145 |
| Female | 18 (60.0%) | 12 (63.2%) | 7 (30.4%) | |
| Male | 12 (40.0%) | 7 (36.8%) | 16 (69.6%) | |
| **Age at time of procedure (y)** | | | | |
| Mean (SD) | 13.1 (1.3) | 13.6 (2.3) | Not applicable | |
| Median (IQR) | 12.9 (12.7, 13.9) | 13.4 (12.1, 16.0) | | |
| Min to Max | 9.3, 15.5 | 6.9, 16.2 | | |
| Skewness | -0.5 | -1.1 | | |
| Missing | 0 | 0 | | |
| **Age at T0 (y)** | | | | 0.435 |
| Mean (SD) | 12.9 (1.4) | 13.5 (1.6) | 12.6 (1.9) | |
| Median (IQR) | 12.7 (12.3, 14.0) | 13.8 (12.4, 14.8) | 13.4 (11.2, 14.1) | |
| Min to Max | 9.0, 15.6 | 10.8, 15.7 | 9.0, 14.7 | |
| Skewness | -0.4 | -0.3 | -0.6 | |
| **Age at procedure or T0 (y)** | | | | 0.422 |
| Mean (SD) | 13.1 (1.3) | 13.6 (2.3) | 12.6 (1.9) | |
| Median (IQR) | 12.9 (12.7, 13.9) | 13.4 (12.1, 16.0) | 13.4 (11.2, 14.1) | |
| Min to Max | 9.3, 15.5 | 6.9, 16.2 | 9.0, 14.7 | |
| Skewness | -0.5 | -1.1 | -0.6 | |
| **Time from T0-T1 (mo)** | | | | 0.508 |
| Mean (SD) | 22.9 (7.9) | 29.1 (16.9) | 23.9 (12.5) | |
| Median (IQR) | 20.1 (18.6, 27.1) | 29.0 (11.6, 47.7) | 19.4 (15.1, 25.5) | |
| Min to Max | 12.9, 50.5 | 6.2, 58.5 | 12.6, 58.8 | |
| Skewness | 1.5 | 0.3 | 1.4 | |

[1]P-value, GEE logistic regression test for any group difference in gender and GEE linear regression test for any group difference in age or in time from T0 to T1. The null hypothesis is group percentages or means are all equal.

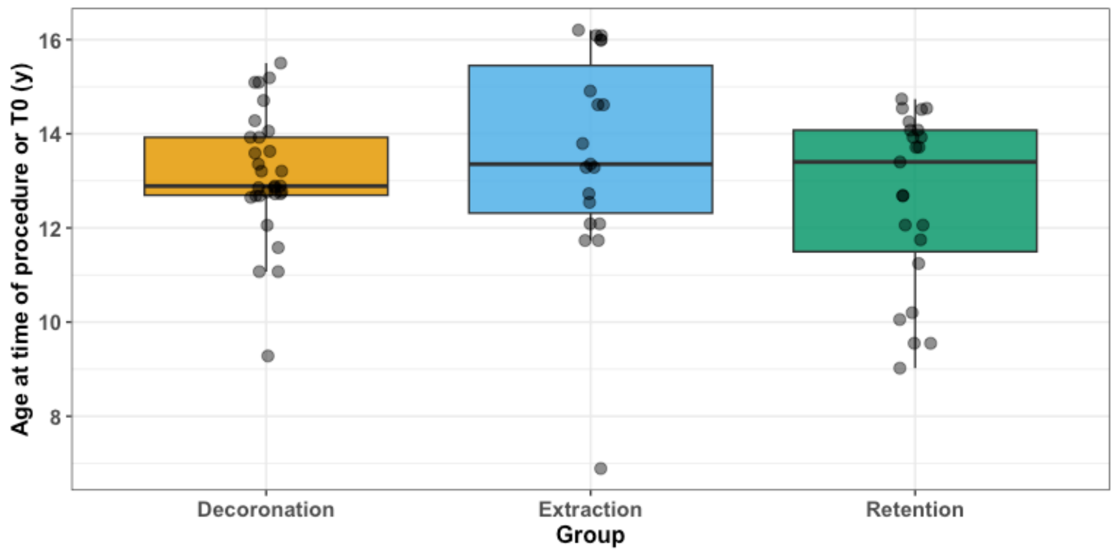


*Figure 3: Age at time of procedure for decoronation and extraction and age at T0 for retention*

**Reliability**

Reliability data is listed in the appendix in Tables 1A, 2A, and 3A. Intra-examiner reliability results were high for bone height measurements and mesial and distal angle measurements. The reliability of the bone height measurements was excellent (ICC $\geq$ 0.99) and Dahlberg's error was 0.1 mm for T0, T1 and the change from T0 to T1. The reliability of the distal and mesial angles was also very good (ICC $\geq$ 0.86) and Dahlberg's error ranged from 1.8 to 4.7 degrees.

**Alveolar Bone Height**

Change in alveolar bone height was calculated by subtracting T0 from T1. A negative value would imply that from T0 to T1, the distance from the determined horizontal line to the crestal bone had decreased. This would indicate bone deposition rather than resorption or no progress in infraocclusion. Thus, a negative value for bone height change would be a favorable result. A positive value for bone height change would imply that the distance to the crestal bone had increased and would be an unfavorable result. The full summary of bone height data is outlined in Table 2.

Figure 4 displays a boxplot of values for the bone height change over time in each group. Boxplots displaying bone height data in all three groups at T0 and T1 are listed in the appendix (Figures 1A and 2A).

Decoronation showed the most favorable result for change in bone height change over time between the three groups, with bone height either improving or staying the same over time. The mean bone height change (T1-T0) for decoronation in mm was -1.2. The extraction group showed minimal change but did not significantly worsen, and had a reported mean change of 0.2 mm. Retention displayed the least favorable change in bone height and either worsened or stayed the same over time, with a mean change of 0.7 mm.

The difference between all three groups for change in bone height was significant (p-value <0.001). The value for bone height at T0 does appear to be a little larger for the decoronation group than the extraction and retention group. This would suggest that the degree of submergence was slightly increased in the decoronation group compared with the other two. There were no significant differences between the groups at T1.

*Table 2: Bone height*

| **Characteristic** | **Decoronation** N = 30 | **Extraction** N = 19 | **Retention** N = 23 | **p-value**[1] |
|---|---|---|---|---|
| **Bone height (mm), T0** | | | | 0.034 |
| Mean (SD) | 3.6 (1.3) | 2.6 (1.1) | 2.6 (1.6) | |
| Min to Max | 1.5, 6.9 | 0.8, 4.9 | 0.6, 6.1 | |
| **Bone height (mm), T1** | | | | 0.121 |
| Mean (SD) | 2.4 (0.7) | 2.7 (1.3) | 3.3 (1.6) | |
| Min to Max | 1.2, 3.7 | 0.8, 5.7 | 1.1, 7.1 | |
| **Bone height change (mm), T1 - T0** | | | | <0.001 |
| Mean (SD) | -1.2 (1.1)[A] | 0.2 (0.9)[B] | 0.7 (0.6)[C] | |
| Min to Max | -3.2, 0.9 | -1.0, 2.8 | -0.1, 2.8 | |

[1]P-value, GEE linear regression test for any group difference. The null hypothesis is group means are all equal. Mean (SD) with difference superscript capital letters are significantly different at a 0.05 significance level after adjusting for multiple testing (Holm's adjusted p-value < 0.05).

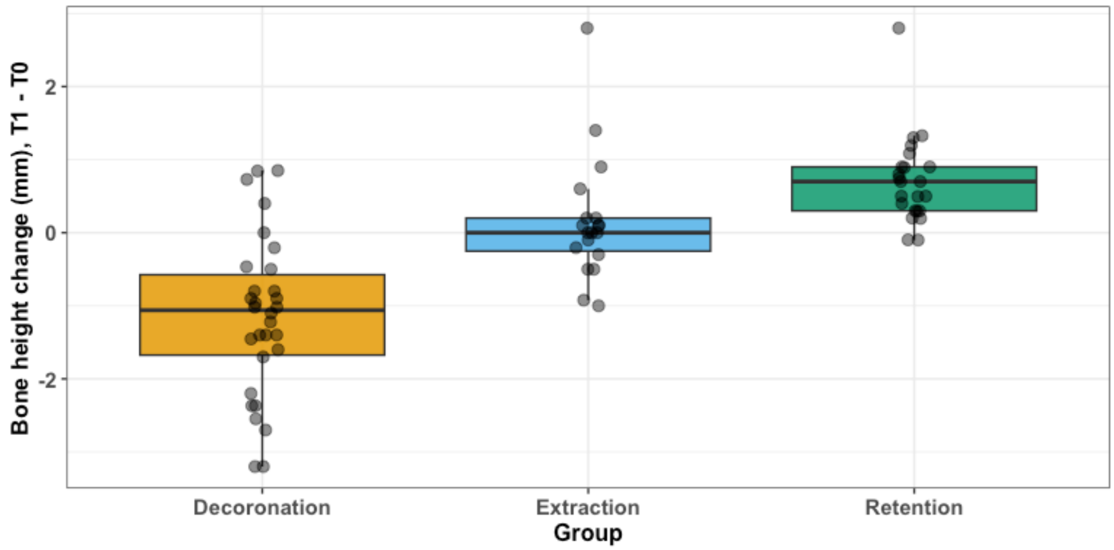


*Figure 4: Bone height change, T1-T0*

**Vertical Bone Defect**

Mesial and distal angles were measured to evaluate the vertical bone defect. A larger or more obtuse angle would suggest a greater vertical bone defect. Change in mesial and distal angles were calculated by subtracting T0 from T1. A negative value would mean that from T0 to T1, the angle had reduced which would indicate improvement of the vertical bone defect. Conversely, a positive value would indicate a worsening of the vertical bone defect. A summary of the data for mesial and distal angle measurements is outlined in Table 3.

Box plots displaying change in mesial and distal angles are shown in Figure 5 and Figure 6. Figures 3A, 4A, 5A, and 6A are listed in the appendix and display box plots of mesial and distal angles at T0 and T1. Several mesial angle values were not reported due to an unerupted or missing first premolar.

For both mesial and distal angle measurements, decoronation showed the greatest improvement of the vertical bone defect. Decoronation showed the most favorable change in mesial and distal angles in degrees (-9.3, -11.4). Extraction showed a slight improvement on average, but was less favorable than decoronation (-1.1, -4.7). Retention showed the least favorable result for change in both angles (10.5, 8.4), indicating that the vertical bone defect had worsened over time.

For the change in mesial angles from T0 to T1, there was a significant difference between decoronation and retention (p-value <0.05). For the change in distal angles from T0 to T1, there was a significant difference between decoronation and retention and retention and extraction (p-value <0.05).

For mesial angle values at T0, there was a significant difference between decoronation and retention (p-value<0.05). This would suggest that the vertical bone defect may have been slightly worse in the decoronation group at the initial timepoint than in the retention. There were no significant differences between the three groups at T1. For distal angle values, there were no significant differences between the three groups at T0 or T1.

*Table 3: Mesial and distal angles*

| **Characteristic** | **Decoronation** N = 30 | **Extraction** N = 19 | **Retention** N = 23 | **p-value**[1] |
|---|---|---|---|---|
| **Mesial angle (deg), T0** | | | | 0.011 |
| Mean (SD) | 109.4 (17.5)[A] | 103.8 (14.3)[A,B] | 95.0 (10.5)[B] | |
| Min to Max | 70.6, 140.9 | 83.1, 127.9 | 70.4, 111.0 | |
| Missing | 10 | 6 | 5 | |
| **Mesial angle (deg), T1** | | | | 0.361 |
| Mean (SD) | 100.1 (14.5) | 102.7 (15.9) | 105.5 (10.0) | |
| Min to Max | 70.0, 124.4 | 82.2, 134.7 | 90.3, 121.0 | |
| Missing | 10 | 6 | 5 | |
| **Mesial angle change (deg), T1 - T0** | | | | <0.001 |
| Mean (SD) | -9.3 (15.6)[A] | -1.1 (17.1)[A,B] | 10.5 (10.7)[B] | |
| Min to Max | -49.4, 16.8 | -28.2, 41.8 | -5.0, 33.6 | |
| Missing | 10 | 6 | 5 | |
| **Distal angle (deg), T0** | | | | 0.189 |
| Mean (SD) | 99.3 (14.9) | 93.3 (20.9) | 87.9 (21.6) | |
| Min to Max | 69.8, 129.8 | 57.8, 129.8 | 58.0, 152.5 | |
| Missing | 0 | 0 | 1 | |
| **Distal angle (deg), T1** | | | | 0.156 |
| Mean (SD) | 87.8 (15.8) | 88.6 (18.0) | 98.1 (19.5) | |
| Min to Max | 53.0, 121.8 | 48.4, 116.0 | 63.4, 137.8 | |
| Missing | 0 | 0 | 1 | |
| **Distal angle change (deg), T1-T0** | | | | <0.001 |
| Mean (SD) | -11.4 (18.9)[A] | -4.7 (18.8)[A] | 8.4 (12.7)[B] | |
| Min to Max | -46.1, 31.0 | -59.2, 27.8 | -14.7, 29.2 | |
| Missing | 0 | 0 | 1 | |

[1]P-value, GEE linear regression test for any group difference. The null hypothesis is group means are all equal. Mean (SD) with difference superscript capital letters are significantly different at a 0.05 significance level after adjusting for multiple testing (Holm's adjusted p-value < 0.05).

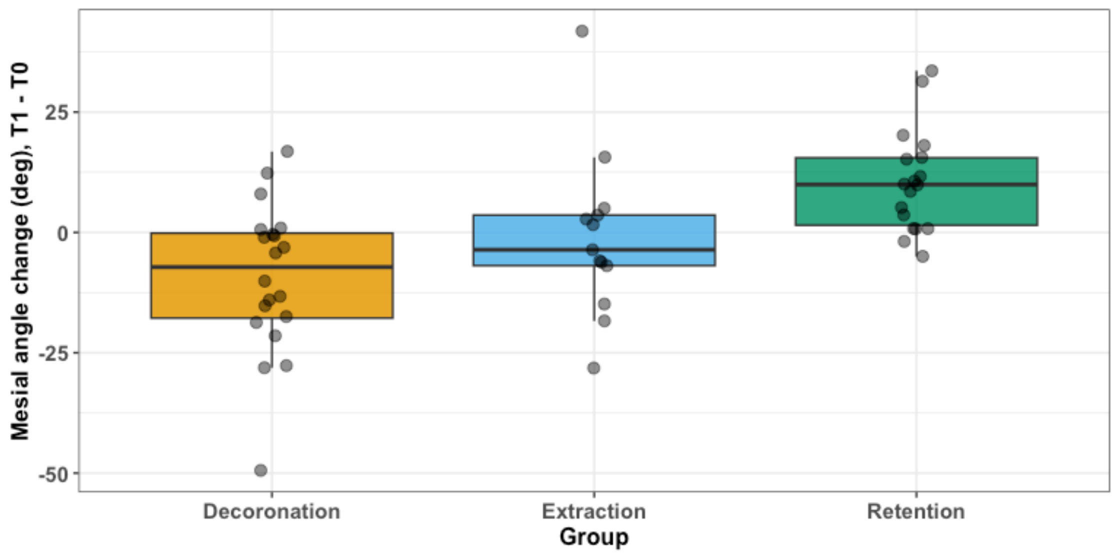


*Figure 5: Mesial angle change, T1-T0*

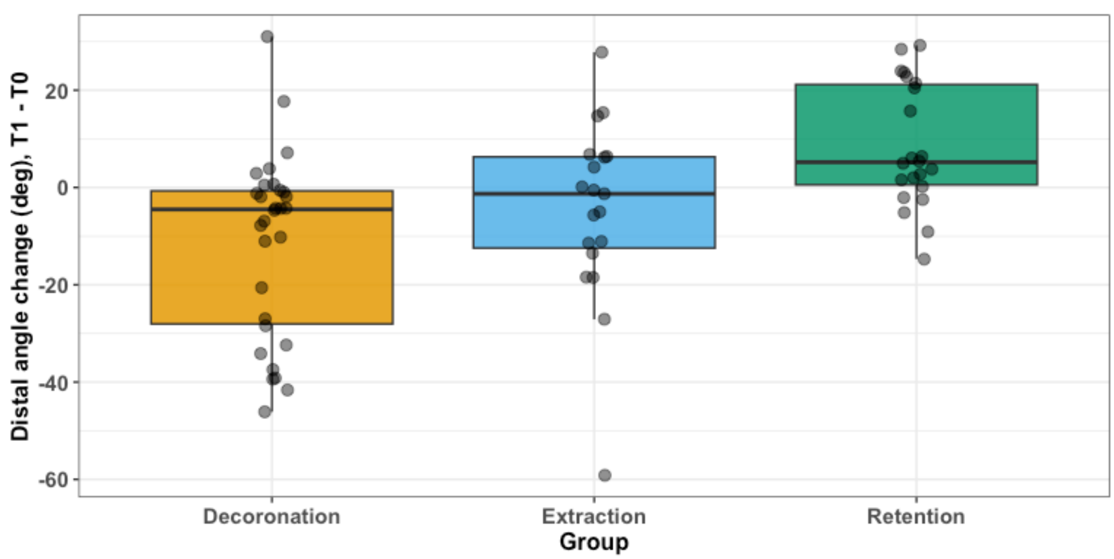


*Figure 6: Distal angle change, T1-T0*

**Analysis by CVM**

The cervical vertebral maturation index was used a surrogate growth measure or indicator. CVM stage by group is outlined in Table 4A (listed in the appendix). Figure 7A, also listed in the appendix, displays bone height change by CVM stage. No significant differences were found for CVM stages between groups. CVM data was taken from lateral cephalometric images available within one year of the initial timepoint. These records were unavailable for many patients.

A notable confounder in this study was the higher proportion of growing patients in the decoronation group, likely reflecting the existing preference for performing decoronation in younger patients. To account for this, a subgroup analysis was conducted, restricting skeletal age to cervical vertebral maturation (CVM) stage 4. This analysis is summarized in Table 5A (listed in the appendix). After controlling for growth, differences between management strategies were no longer significant. However, trends remained the same, with decoronation being the most favorable and retention remaining the least.

**Analysis by Age, Gender, and Time**

Bone height change versus age is displayed for all three groups in the appendix in Figure 8A. For the retention group the increase in bone height from T0 to T1 decreased with age. For the decoronation group, the decrease (in general) in bone height from T0 to T1 increases with age. There is no association between the change in bone height and age.

Bone height versus age by gender is displayed in the appendix in Figure 9A. Table 6A (appendix) reports correlations between change in bone height and age separated by gender. In general, there is a negative correlation between bone height change and age. This indicates that as age increases, less change is seen. This correlation was fairly weak in general, but stronger for the extraction and retention groups, and for females.

Figure 10A is listed in the appendix and displays bone height change versus follow-up time in all three groups. No association was found between follow-up time and bone height change.

A sensitivity analysis adjusting for gender, age, and time is summarized in Table 4. Adjusted and unadjusted results were similar. Only age was significantly related to bone height. Bone height was positively associated with age at T0. A 1-year increase in age was associated with a 0.2 mm greater bone height. Additionally, age was related to the change in bone height. A 1-year increase in age was associated with a 0.1 mm smaller change in bone height.

*Table 4: Sensitivity analysis adjusting for gender, age, and time*

| | | Unadjusted | Adjusted |
|---|---|---|---|
| Bone height at T0 | | | |
| | Extraction vs decoronation | -1.0 | -1.0* |
| | Retention vs decoronation | -1.0 | -0.8 |
| | | | |
| | Test for group differences | 0.034 | 0.038 |
| | | | |
| Bone height at T0 | | | |
| | Extraction vs decoronation | 0.3 | 0.3 |
| | Retention vs decoronation | 0.9 | 1.0 |
| | | | |
| | Test for group differences | 0.121 | 0.096 |
| | | | |
| Bone height change, T1-T0 | | | |
| | Extraction vs decoronation | 1.3* | 1.4* |
| | Retention vs decoronation | 1.9* | 1.8* |
| | | | |
| | Test for group differences | <.001 | <.001 |

## DISCUSSION

This study evaluated the effects of three management strategies for ankylosed primary molars on bone height and vertical bone defect improvement. Among the three approaches, decoronation demonstrated the most favorable outcomes for both bone height and vertical bone defect. Bone height increased on average and vertical bone defect improved on average. Bone height for extraction remained largely unchanged, and vertical bone defect improved only marginally. Retention demonstrated a worsening of both outcomes on average. This would suggest that decoronation may offer the most improvement in bone height and vertical bone defect of the three strategies. Regardless, retention of the ankylosed primary will offer the worst outcome in growing patients: a worsening of both the infraocclusion and the vertical bone defect. These findings align with the proposed benefits of decoronation in maintaining alveolar bone volume.

From a clinical perspective, the key consideration is the long-term outcome—specifically, which site provides the most robust alveolar ridge for implant placement. According to this study, in a growing patient, decoronation results in a few millimeters of additional bone height and an approximately 20-degree improvement in vertical bone defect compared to retention. Extraction does offer some correction of the vertical bone defect, but extraction cases do not show an increase in the bone height. From these findings, decoronation seems to be the best strategy to manage an ankylosed mandibular primary second molar with a missing permanent successor. However, this study was limited to evaluating only the vertical dimension.

A crucial factor in determining the optimal management strategy is how each treatment affects buccal-lingual width, since this is also affected by ankylosis. While extraction does offer some correction of the vertical bone defect, other have described a 63% loss of the buccal-lingual width in the first six months following extraction[9]. Buccal-lingual width is best assessed with 3-dimensional imaging such as CBCT. Unfortunately, repeat CBCTs are rarely indicated on growing patients. The lack of available records meant we were unable to assess buccal-lingual dimensions for this study. Further studies evaluating both the horizontal and vertical dimensions are needed to better determine the ideal management strategy.

Growth may be an important consideration for the outcome of each management strategy. Chonological age it is not a reliable indicator of when the pubertal growth spurt will occur. The CVM Index was used in this study as a surrogate measure for skeletal age to predict growth from available cephalograms. The CVM Index has been well-described to predict the timing of peak pubertal growth in orthodontic treatment, although the accuracy of this method is limited [15, 19]. Additionally, vertebral assessment does not allow differentiation between patient's growth increment or direction the way a superimposition of two lateral cephalometric images would – it simply indicates whether or not growth is occurring. Superimposition of serial lateral cephalometric images taken during the observation period would better evaluate the amount and direction of growth, but these were not available for most subjects evaluated.

The diminished difference in results between the three groups when restricted to a CVM stage of 4 (later in the growth stage) suggest that growth does play a role in the observed outcomes. If minimal growth remains, the differences between the three management methods are minimized. However, if an ankylosed primary second molar is retained through a significant portion of growth, the infraocclusion and vertical bone defect will likely worsen considerably. Conversely, a patient who undergoes decoronation before the growth spurt will experience the greatest benefits in terms of increased bone height and improvement in vertical bone defect. Extraction subjects with more growth left demonstrated less adverse changes to the remaining alveolar height, though not as favorable as those having decoronation. Timing is an important consideration in management of mandibular primary second molar infraocclusion. According to our findings, the best strategy to achieve a robust ridge for future implant placement from a vertical standpoint is to perform decoronation prior to the pubertal growth spurt. The second best option would be extraction. The optimal time to decoronate or extract the ankylosed primary tooth to obtain the most ideal outcome for future implant placement is at the first sign of infraocclusion, before the beginning of the growth spurt. Timing is likely to be a crucial factor in treating these patients effectively, and referrals to the appropriate provider should be sent accordingly.

The treating clinician faces a difficult decision: decoronate or extract the ankylosed primary tooth as early on as possible to potentially develop the best implant site, or retain the ankylosed primary tooth and hope that the patient does not have a significant amount of vertical facial growth in their future. Taking the amount of growth remaining into account may be helpful in making this decision. A more significant amount of growth (particularly vertical), would likely mean more submergence a worsening of the vertical bone defect if the primary tooth is retained. By this logic, taking action and decoronating or extracting would likely be the best option to develop the best implant site if the patient is showing infraocclusion prior to the pubertal growth spurt.

This study has several limitations. The small sample size reduces the statistical power of the findings. Additionally, the retrospective design introduces potential biases, including inconsistent record calibration, lack of group standardization, and selection bias. There is a need for future prospective, standardized studies with larger sample sizes to further validate these findings. Future studies should assess both the vertical and the horizontal (buccal-lingual) dimension. Additionally, lateral cephalometric images before and after with superimpositions would be best to evaluate the extent and direction of growth in these studies.

# CONCLUSIONS

Decoronation is a promising approach for the management of ankylosed primary mandibular molars, particularly in growing patients. The following conclusions can be drawn from this study:

1. Decoronation may offer the most favorable outcome in bone height increase or preservation in growing patients.
2. Decoronation may also offer the most favorable outcome for vertical bone defects associated with ankylosis. Extraction may not be as effective at preserving bone height but may offer minor correction of vertical bone defects by arresting further loss.
3. An ankylosed primary second molar retained during growth will likely show a worsening of the alveolar bone height and the progression of the vertical bone defect. Providers must keep careful watch on the growth status of patients with ankylosed primary teeth.
4. If no additional growth is anticipated, and submergence is minimal, no action is needed and the tooth may be maintained until adulthood.
5. The decision of decoronation or extraction of the ankylosed primary tooth should be made at the first sign of infraocclusion, before the beginning of the pubertal growth spurt.

# APPENDIX

*Table 1A: Intra-examiner reliability for bone height*

| Measure | 1st Mean (SD) | 2nd Mean (SD) | Diff. (SD) [95% CI)] | ICC | D. Error (Min, Max) |
|---|---|---|---|---|---|
| T0 | 3.4 (1.5) | 3.5 (1.4) | -0.1 (0.1) [-0.2, 0.0] | 0.99 | 0.1 (0.0, 0.2) |
| T1 | 2.8 (0.8) | 2.8 (0.8) | 0.0 (0.2) [-0.1, 0.1] | 0.98 | 0.1 (0.1, 0.2) |
| T1-T0 | -0.5 (1.2) | -0.6 (1.1) | 0.1 (0.2) [-0.1, 0.2] | 0.98 | 0.1 (0.0, 0.4) |

*Table 2A: Intra-examiner reliability for distal angle*

| Measure | 1st Mean (SD) | 2nd Mean (SD) | Diff. (SD) [95% CI)] | ICC | D. Error (Min, Max) |
|---|---|---|---|---|---|
| T0 | 93.7 (15.2) | 90.4 (13.0) | 3.3 (6.1) [-1.0, 7.7] | 0.89 | 4.7 (0.0, 12.5) |
| T1 | 89.1 (14.0) | 88.3 (15.3) | 0.8 (5.4) [-3.1, 4.7] | 0.94 | 3.7 (0.2, 13.1) |
| T1-T0 | -4.6 (12.8) | -2.0 (15.1) | -2.6 (6.1) [-6.9, 1.8] | 0.90 | 4.5 (0.8, 10.9) |

*Table 3A: Intra-examiner reliability for bone mesial angle*

| Measure | 1st Mean (SD) | 2nd Mean (SD) | Diff. (SD) [95% CI)] | ICC | D. Error (Min, Max) |
|---|---|---|---|---|---|
| T0 | 95.4 (6.2) | 94.9 (5.5) | 0.5 (3.4) [-3.1, 4.1] | 0.86 | 2.2 (0.2, 5.0) |
| T1 | 103.8 (16.8) | 101.7 (15.9) | 2.1 (2.6) [-0.7, 4.8] | 0.98 | 2.2 (0.7, 4.8) |
| T1-T0 | 8.4 (17.3) | 6.9 (18.0) | 1.6 (2.2) [-0.7, 3.9] | 0.99 | 1.8 (0.2, 4.6) |

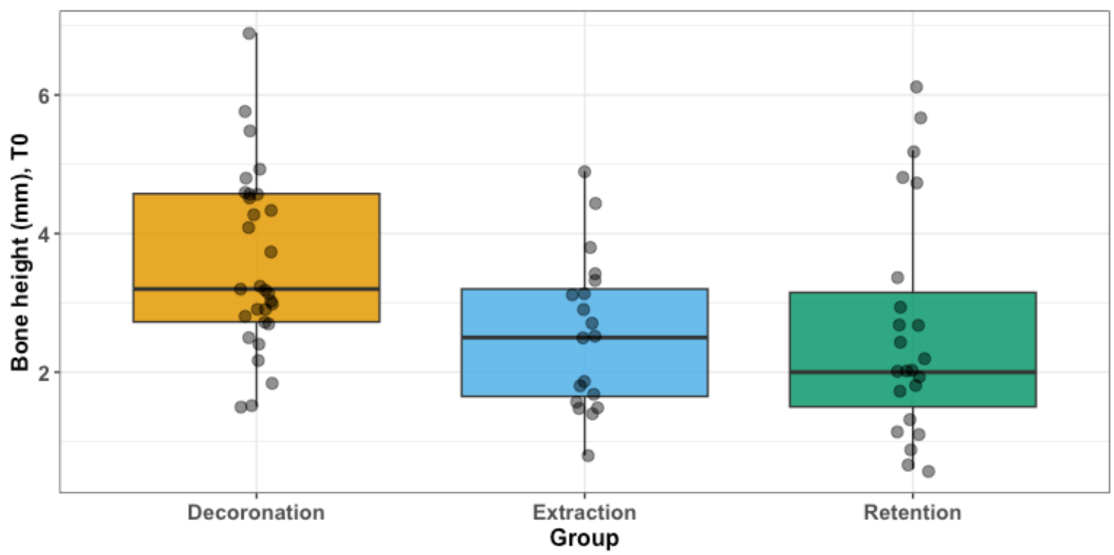


*Figure 1A: Bone height at T0*

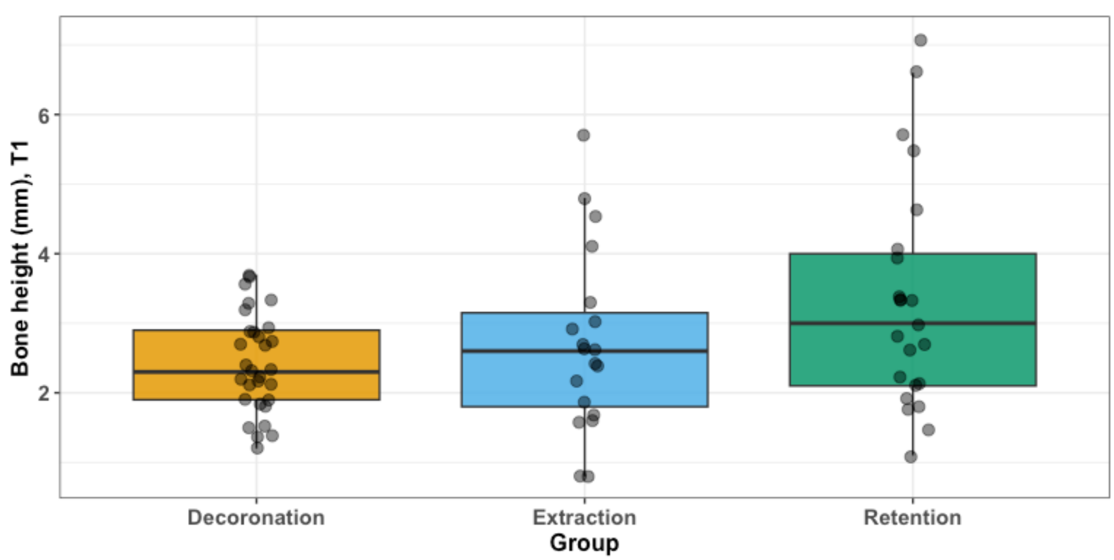


*Figure 2A: Bone height at T1*

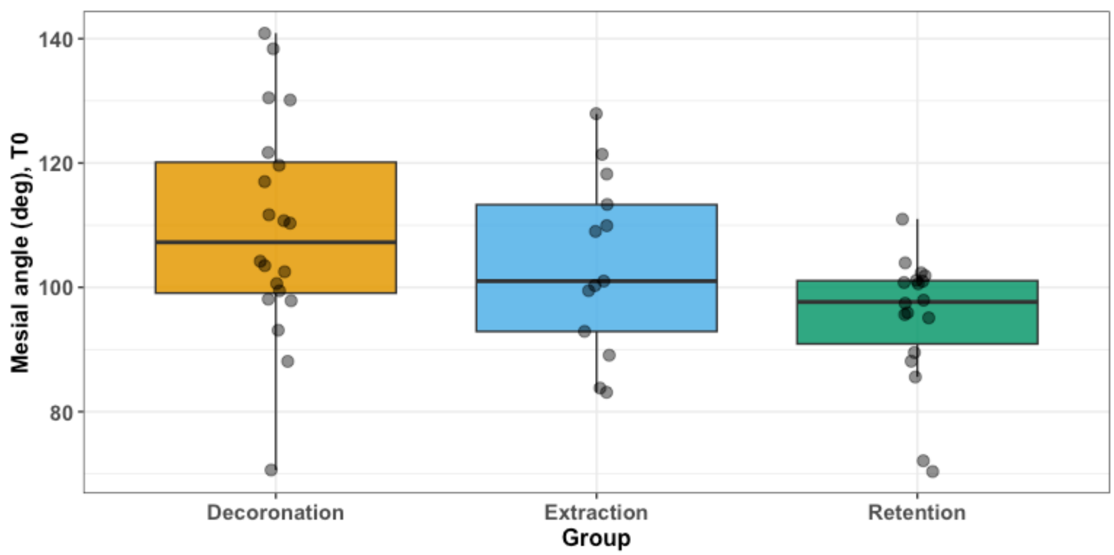


*Figure 3A: Mesial angle at T0*

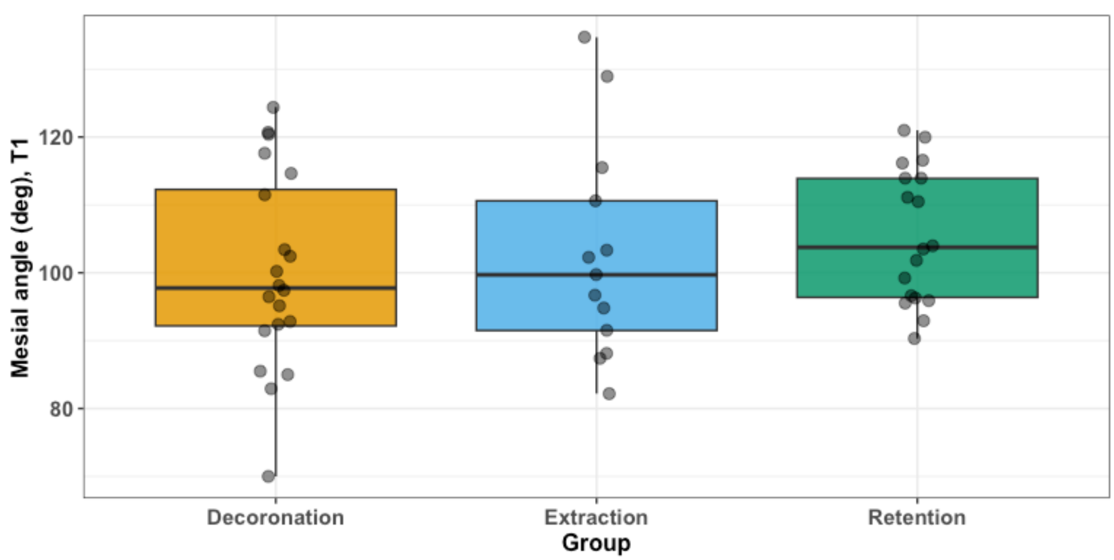


*Figure 4A: Mesial angle at T1*

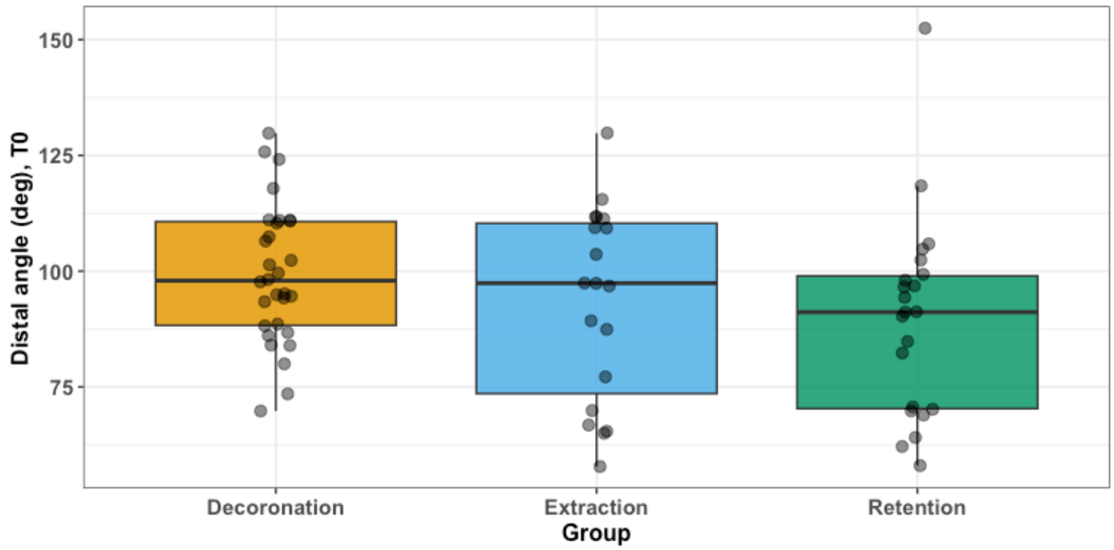


*Figure 5A: Distal angle at T0*

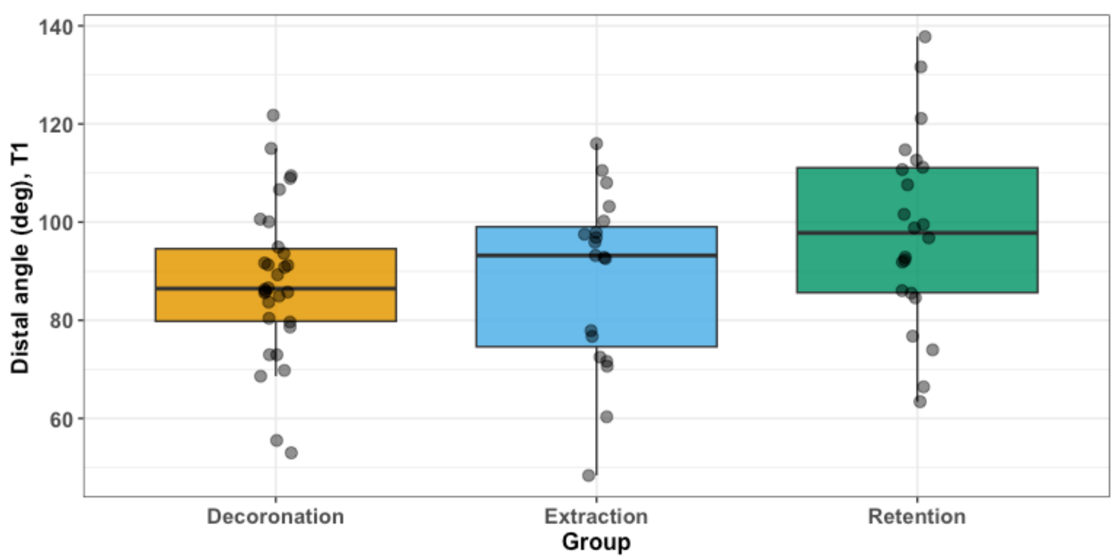


*Figure 6A: Distal angle at T1*

*Table 4A: CVM by group*

| Characteristic | Decoronation<br>N = 30[1] | Extraction<br>N = 19[1] | Retention<br>N = 23[1] |
|---|---|---|---|
| **CVM** | | | |
| 2 | 1 (6.7%) | 0 (0.0%) | 1 (10.0%) |
| 3 | 5 (33.3%) | 0 (0.0%) | 2 (20.0%) |
| 4 | 7 (46.7%) | 6 (66.7%) | 7 (70.0%) |
| 5 | 2 (13.3%) | 3 (33.3%) | 0 (0.0%) |
| Missing | 15 | 10 | 13 |

[1]n (%)

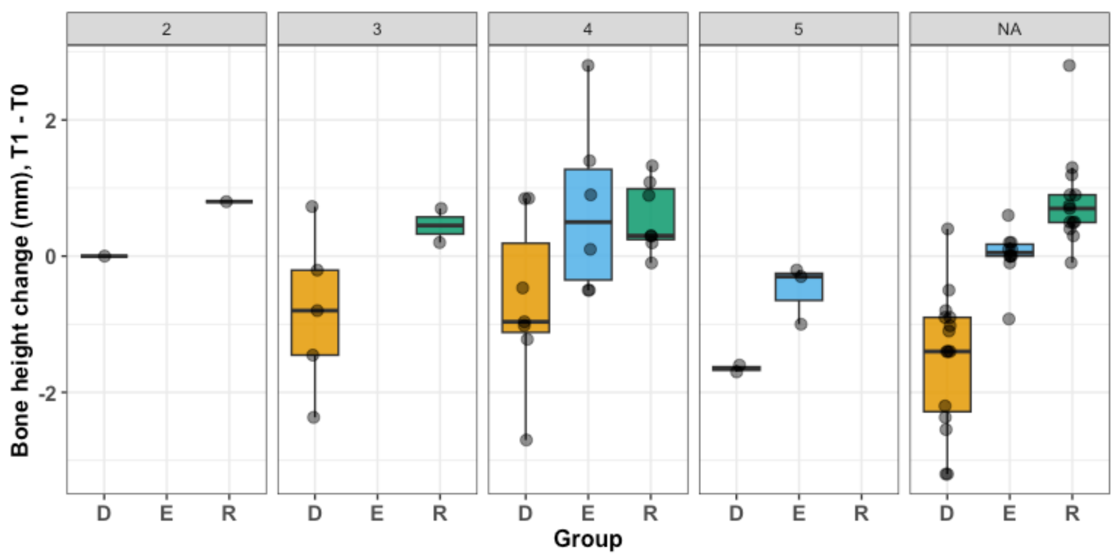


*Figure 7A: Bone height change, T1-T0, by CVM*

*Table 5A: Full summary, restricted to teeth with CVM of 4*

| Characteristic | Decoronation<br>N = 7 | Extraction<br>N = 6 | Retention<br>N = 7 | p-value[1] |
|---|---|---|---|---|
| **Bone height (mm), T0** | | | | 0.886 |
| Mean (SD) | 3.0 (1.3) | 3.1 (1.0) | 3.5 (2.0) | |
| Min to Max | 1.5, 4.9 | 1.5, 4.4 | 0.7, 5.7 | |
| **Bone height (mm), T1** | | | | 0.018 |
| Mean (SD) | 2.4 (0.8)[A] | 3.8 (1.3)[A,B] | 4.1 (2.1)[A] | |
| Min to Max | 1.5, 3.7 | 2.4, 5.7 | 1.8, 7.1 | |
| **Bone height change (mm), T1 - T0** | | | | 0.087 |
| Mean (SD) | -0.7 (1.2) | 0.7 (1.3) | 0.6 (0.5) | |
| Min to Max | -2.7, 0.9 | -0.5, 2.8 | -0.1, 1.4 | |
| **Adjusted bone height change (mm), T1 - T0** | | | | 0.088 |
| Mean (SD) | -0.7 (1.2) | 0.7 (1.3) | 0.6 (0.5) | |
| Min to Max | -2.7, 0.9 | -0.5, 2.8 | -0.1, 1.3 | |

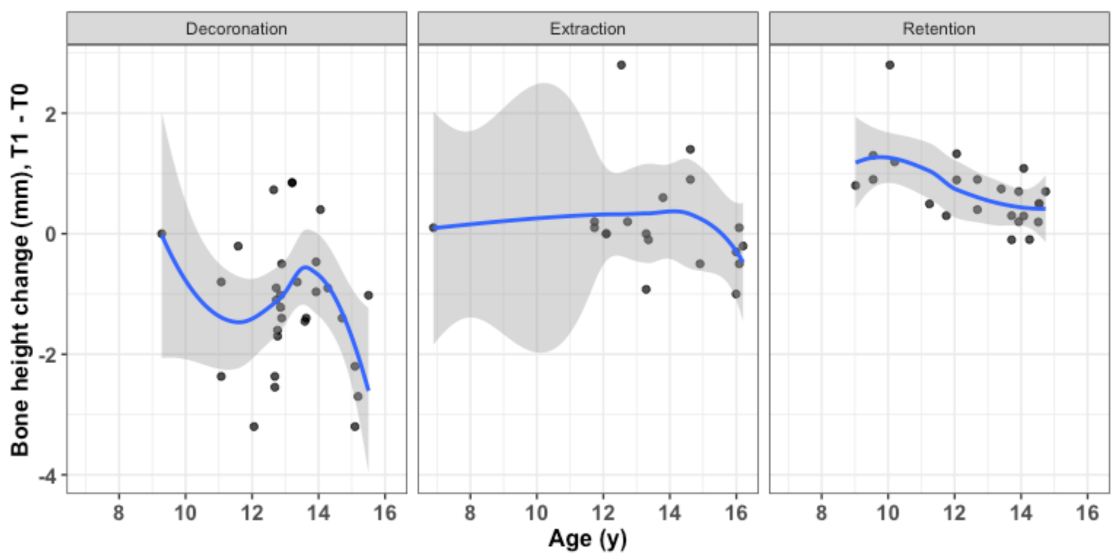


*Figure 8A: Bone height change (T1-T0) versus Age (age at time of procedure for decoronation and extraction, age at T0 for retention). Blue curve is the average bone height change by age. Ignore blue curve ignored or oldest and youngest patients. The gray shading is a 95% confidence band for the blue curve.*

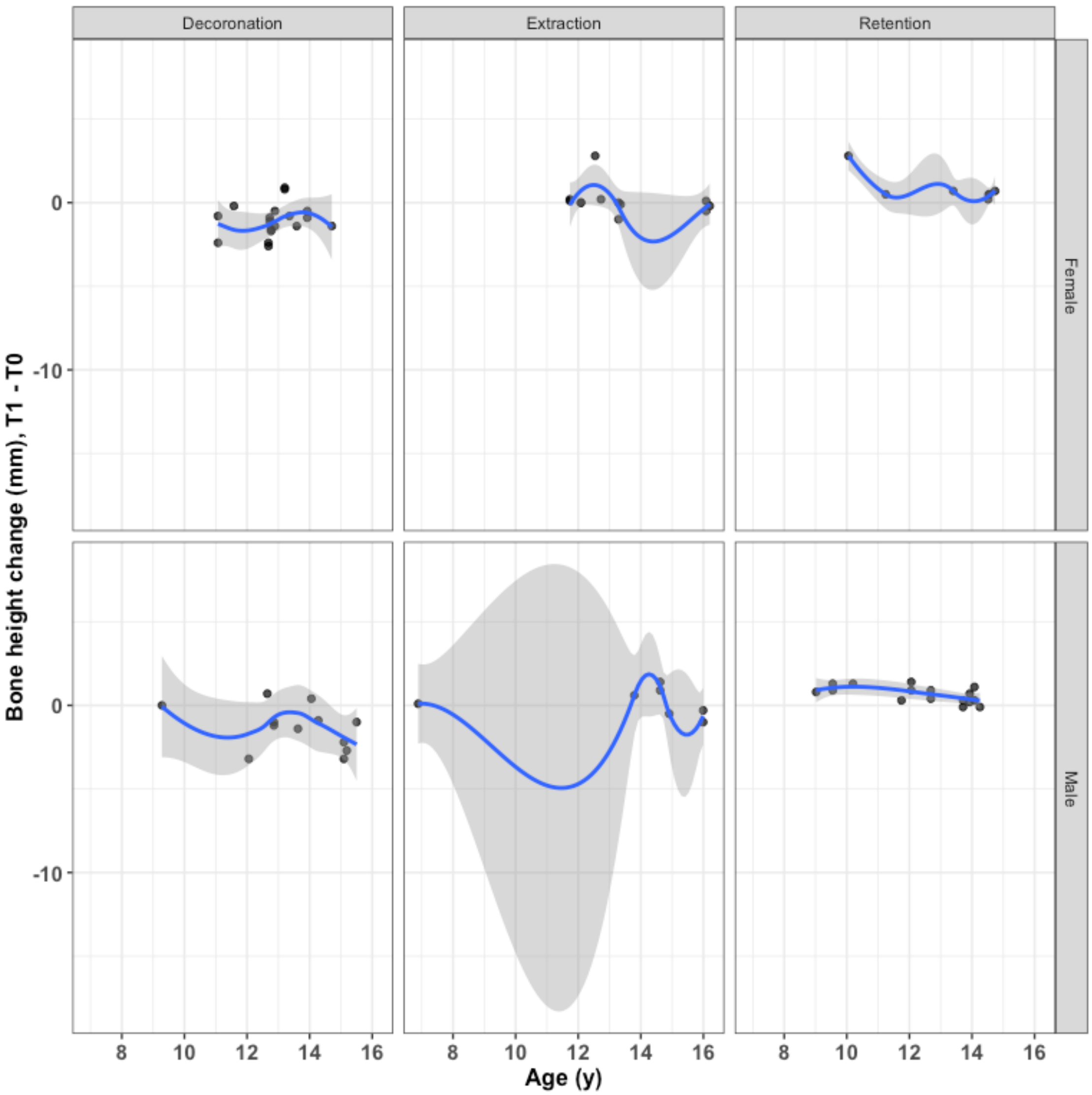


*Figure 9A: Bone height change (T1-T0) versus Age by Gender*

*Table 6A: Correlation between change in bone height and age*

| Group | All subjects | Males | Females |
|---|---|---|---|
| All | -0.22 | -0.41 | 0.05 |
| Decoronation | -0.08 | -0.35 | 0.32 |
| Extraction | -0.42 | -0.60 | -0.61 |
| Retention | -0.54 | -0.55 | -0.20 |

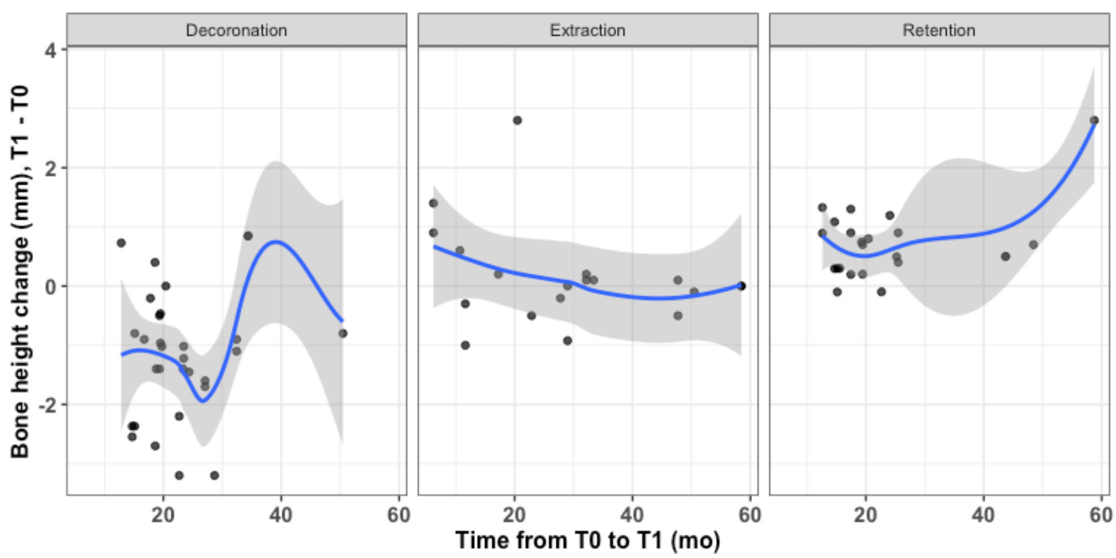


*Figure 10A: Bone height change (T1-T0) versus Time from T0-T1*

*Table 2: Association between bone height change and time from T0 to T1*

| Group | All subjects |
|---|---|
| All | -0.07 |
| Decoronation | 0.07 |
| Extraction | -0.29 |
| Retention | 0.06 |

# REFERENCES


1. Hvaring CL, Øgaard B, Stenvik A, Birkeland K. The prognosis of retained primary molars without successors: Infraocclusion, root resorption and restorations in 111 patients. *Eur J Orthod*. 2014;36(1):26-30. doi:10.1093/ejo/cjs105

2. Nunn JH, Carter NE, Gillgrass TJ, et al. *The Interdisciplinary Management of Hypodontia: Background and Role of Paediatric Dentistry*. Vol 194.; 2003.

3. Bjerklin K, Al-Najjar M, Kårestedt H, Andrén A. Agenesis of mandibular second premolars with retained primary molars. A longitudinal radiographic study of 99 subjects from 12 years of age to adulthood. *Eur J Orthod*. 2008;30(3):254-261. doi:10.1093/ejo/cjn027

4. Bjerklin K, Bennett J. The long-term survival of lower second primary molars in subjects with agenesis of the premolars. *Eur J Orthod*. 2000;22(3):245-255. doi:10.1093/ejo/22.3.245

5. Kokich VG, Kokich VO. Congenitally missing mandibular second premolars: Clinical options. *American Journal of Orthodontics and Dentofacial Orthopedics*. 2006;130(4):437-444. doi:10.1016/j.ajodo.2006.05.025

6. Malmgren B. Ridge preservation/decoronation. In: *Journal of Endodontics*. Vol 39. ; 2013. doi:10.1016/j.joen.2012.11.056

7. Cohenca N, Stabholz A. Decoronation - A conservative method to treat ankylosed teeth for preservation of alveolar ridge prior to permanent prosthetic reconstruction: Literature review and case presentation. *Dental Traumatology*. 2007;23(2):87-94. doi:10.1111/j.1600-9657.2006.00454.x

8. Rocchietta I, Fontana F, Simion M. Clinical outcomes of vertical bone augmentation to enable dental implant placement: A systematic review. In: *Journal of Clinical Periodontology*. Vol 35. ; 2008:203-215. doi:10.1111/j.1600-051X.2008.01271.x

9. Schneider D, Schmidlin PR, Philipp A, et al. Labial soft tissue volume evaluation of different techniques for ridge preservation after tooth extraction: A randomized controlled clinical trial. *J Clin Periodontol*. 2014;41(6):612-617. doi:10.1111/jcpe.12246

10. Janakievski J. The Value of a Tooth for Alveolar Ridge Management; Strategies to Manage Ankylosed Maxillary Anterior Teeth in Young Patients. *Journal of Esthetic and Restorative Dentistry*. Published online 2024. doi:10.1111/jerd.13379

11. Zhang L, Wang M, Xue L, et al. A retrospective analysis of the optimal time and psychological impact of decoronation in children and adolescents. *Dental Traumatology*. 2021;37(3):440-446. doi:10.1111/edt.12651

12. Malmgren B, Tsilingaridis G, Malmgren O. Long-term follow up of 103 ankylosed permanent incisors surgically treated with decoronation - a retrospective cohort study. *Dental Traumatology*. 2015;31(3):184-189. doi:10.1111/edt.12166

13. Caminiti MF, El-Rabbany M, Lou T, Reinish EI. Surgical uprighting of mandibular second molars: A single-group retrospective cohort study. *American Journal of Orthodontics and Dentofacial Orthopedics*. 2020;158(6):849-855. doi:10.1016/j.ajodo.2019.11.016

14. Devlin H, Yuan J. Object position and image magnification in dental panoramic radiography: A theoretical analysis. *Dentomaxillofacial Radiology*. 2013;42(1). doi:10.1259/dmfr/29951683

15. McNamara JA, Franchi L. The cervical vertebral maturation method: A user's guide. *Angle Orthodontist*. 2018;88(2):133-143. doi:10.2319/111517-787.1

16. Cicchetti D V. *Guidelines, Criteria, and Rules of Thumb for Evaluating Normed and Standardized Assessment Instruments in Psychology*.; 1994.

17. Kim HY. Statistical notes for clinical researchers: Evaluation of measurement error 2: Dahlberg's error, Bland-Altman method, and Kappa coefficient. *Restor Dent Endod*. 2013;38(3):182. doi:10.5395/rde.2013.38.3.182

18. Lin S, Schwarz-Arad D, Ashkenazi M. Alveolar bone width preservation after decoronation of ankylosed anterior incisors. *J Endod*. 2013;39(12):1542-1544. doi:10.1016/j.joen.2013.08.003

19. Santiago RC, De Miranda Costa LF, Vitral RWF, Fraga MR, Bolognese AM, Maia LC. Cervical vertebral maturation as a biologic indicator of skeletal maturity: A systematic review. *Angle Orthodontist*. 2012;82(6):1123-1131. doi:10.2319/103111-673.1