Cone Beam Computed Tomographic Analysis Demonstrates a 94% Radiographic Success Rate in 783 Alveolar Bone Grafts

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Purpose: Success of alveolar bone grafting has been estimated using 2-dimensional periapical radiographs that are associated with image distortion. Cone beam computed tomography (CBCT) accurately displays 3-dimensional anatomy. This study sought to develop and apply a radiographic measure of alveolar bone grafting success using CBCT.

Methods: This was a retrospective case series composed of patients with cleft lip/palate who had iliac crest bone grafting by 1 surgeon from 2005 to 2020. CBCT scans were obtained ≥4 months after graft. The outcome variables included vertical bone height on cleft adjacent teeth, labiopalatal thickness, and nasal floor symmetry and were scored using a 1 to 4 ordinal scale. Vertical height was determined by the distance from the cementoenamel junction to the marginal bone level of cleft adjacent teeth (1: ≥75% root length, 2: ≥50 to <75%, 3: ≥25 to <50%, 4: <25%), labiopalatal thickness was scored by comparing graft thickness with root width of cleft adjacent teeth (1: <50%, 2: ≥50, 3: ≥75%, 4: ≥100%), and piriform symmetry was established by comparing the nasal floor height between sides (1: ≥6 mm, 2: ≥3 and < 6 mm, 3: ≥1 and < 3 mm, 4: a score of ≥3 < 1 mm). To be considered a successful graft, each dimension scored ≥3. Grafts were also successful if piriform symmetry scored 2, when all other measures indicated success.

Results: The sample was composed of 618 patients with 783 alveolar cleft sites. Subjects' median age was 10.0 (interquartile range 1.6 years), and 59% were male. CBCT scans were obtained a median of 9.7 months (interquartile range 68.8 months) after grafting. There was good-to-excellent intrarater and inter-rater agreement for measurements. Alveolar bone grafting was radiographically successful in 94% of patients.

Conclusions: This is a valid and reliable assessment tool, and when applied to a large cohort, it demonstrated a 94% graft success rate. Future studies will identify predictor variables associated with bone graft outcomes.

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The success rate for alveolar bone grafting in patients with cleft lip and palate ranges from 32% to 95%. This wide variability is in part due to different definitions of success which include restoration of the alveolar bone height and width, eruption and periodontal health of the permanent incisor and canine teeth, adequate attached gingiva adjacent to the cleft, and successful placement of implant-supported restorations.[1,2] Most studies, however, determine success based on bony volume measured on periapical radiographs taken >6 months after the graft.[3,4] Unfortunately, periapical radiographs have been shown to overestimate bone volume, and it is not possible to obtain adequate information about the amount of bone in the horizontal dimension.[5] Two-dimensional (2D) analyses overvalue the osseous bridge as these images include superimposition effects and distortions that prevent bone volume measurement.[6,7] Cone beam computed tomography (CBCT) scans provide 3-dimensional (3D) imaging and accurately display the bony anatomy that can be used to determine success. The study purpose was to develop and apply a radiographic measure of alveolar bone grafting success using CBCT in a large cohort of patients treated by 1 surgeon.

Materials and Methods

STUDY DESIGN

This is a retrospective case series of patients with cleft lip and alveolus with or without cleft of the secondary palate who had a cancellous iliac crest bone graft to the alveolar cleft(s) by 1 surgeon at Boston Children's Hospital from 2005 to 2020. This study was approved by the Institutional Review Board of the Center for Applied Investigation at Boston Children's Hospital (protocol #P00033122) with a waiver of informed consent, and all research activities were conducted as per the Declaration of Helsinki.

SAMPLE

The study population included patients with cleft lip and alveolus with or without cleft of the secondary palate. All study patients underwent an alveolar bone graft with cancellous marrow from the iliac crest performed by 1 surgeon (BLP) and had a CBCT scan obtained at least 4 months after alveolar bone grafting. Patients were excluded if they had a missing or inadequate CBCT scan or had a corticocancellous block graft.

DATA COLLECTION METHODS

Patients had CBCT images acquired with a standard protocol on either an i-CAT 3D (Imaging Sciences International Inc, Hatfield, PA) or a Planmeca ProMax 3D Max (Planmeca Oy, Helsinki, Finland) imaging system. Images with 1-mm cuts were assessed in the axial and coronal planes using Medview PACS Viewer software (Chicago, IL, 2001) by 2 independent observers. Images were analyzed, and the vertical bone level, labiopalatal (horizontal) thickness, and nasal piriform symmetry were measured.

ORDINAL SCORING/OUTCOME VARIABLES

The vertical bone level of the erupted cleft-adjacent mesial and distal teeth was scored by determining the distance from the cemento-enamel junction (CEJ) to the marginal bone level (Fig 1).[8] Images were oriented along the long axis of the tooth, and the measurement was made in the midpoint of the labiopalatal dimension. If the canine was not erupted, then the vertical bone level of this tooth could not be scored.

1 = CEJ to marginal bone is ≥75% of root length (least successful)
2 = CEJ to marginal bone is ≥50 to <75% of root length
3 = CEJ to marginal bone is ≥25 to <50% of root length
4 = CEJ to marginal bone is <25% of root length (most successful)

The labiopalatal (horizontal) bone thickness in the axial plane was scored by comparing bone thickness

FIGURE 1. Vertical bone level of erupted cleft-adjacent mesial and distal teeth scored by determining distance from the cemento-enamel junction (CEJ) to the marginal bone level. 1 = CEJ to marginal bone is ≥ 75% of root length, 2 = CEJ to marginal bone is ≥ 50 to <75% of root length, 3 = CEJ to marginal bone is ≥ 25 to <50% of root length, and 4 = CEJ to marginal bone is <25% of root length (most successful).

Padwa et al. CBCT Shows 94% Success in Alveolar Bone Grafts. J Oral Maxillofac Surg 2022.

with the root width of the cleft-adjacent teeth. Scoring was performed at the cervical, middle, and apical thirds of the cleft-adjacent roots. The cervical third could only be scored when the distal tooth (canine) adjacent to the graft had erupted (Figs 2-5).[9]

1 = Labiopalatal thickness was <50% of the root width of the cleft-adjacent teeth (least successful).
2 = Labiopalatal thickness was ≥50 of the root width of the cleft-adjacent teeth.
3 = Labiopalatal thickness was ≥75% of the root width of the cleft-adjacent teeth.
4 = Labiopalatal thickness was ≥100% of the root width of the cleft-adjacent teeth (most successful).

Piriform symmetry was scored by comparing the height of the nasal floor on both sides in the coronal plane. For unilateral clefts, the grafted and unaffected sides were compared, and for bilateral clefts, the 2 grafted sides were compared for symmetry (Figs 6-9).[10]

1 = ≥6 mm difference (least successful).
2 = ≥3 and < 6 mm difference.
3 = ≥1 and < 3 mm difference.
4 = <1 mm difference (most successful).

To be considered a successful alveolar cleft graft, each dimension (vertical bone level, labiopalatal [horizontal] thickness at the cervical, middle, and apical thirds, and nasal piriform symmetry) had to have a score of 3 or 4. There were, however, circumstances where a graft was considered successful even though some measurement(s) could not be scored, including: grafts where the canine had not erupted at the time of the CBCT scan precluding the ability to score the vertical bone height of the distal tooth (canine) and the horizontal thickness at the cervical level (Figs 2 and 10-14), and where the central incisor (mesial tooth) had a pre-graft periodontal defect (score 1 or 2). In addition, if the alveolar cleft bone had good-to-excellent vertical dimension and labiopalatal thickness (score 3 or 4), but the piriform symmetry was fair (score of 2), these grafts were still considered successful.

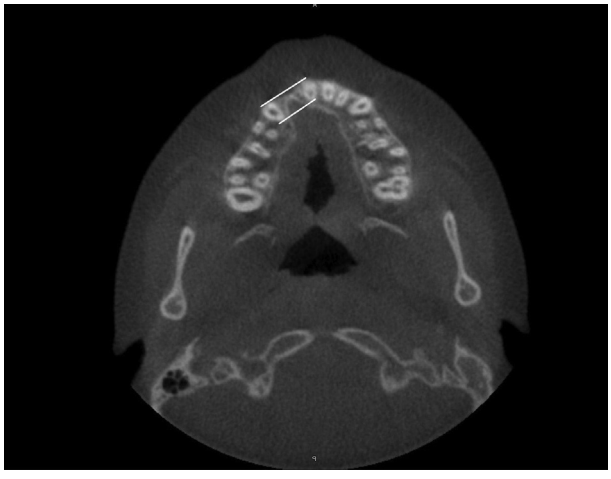

FIGURE 2. Labiopalatal bone thickness in the axial plane scored by comparing bone thickness with root width of cleft-adjacent teeth. Labiopalatal thickness was <50% of root width of cleft-adjacent teeth (score 1).

Padwa et al. CBCT Shows 94% Success in Alveolar Bone Grafts. J Oral Maxillofac Surg 2022.

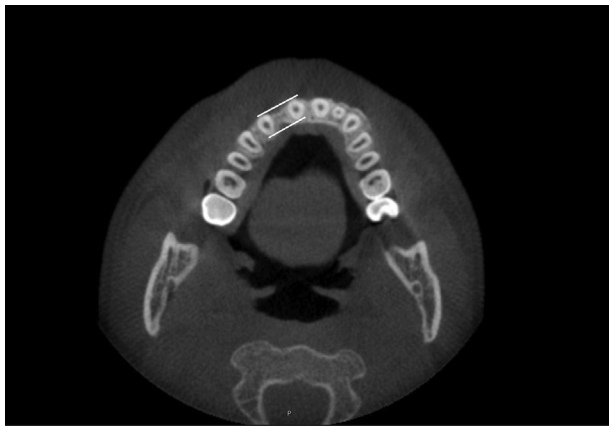

FIGURE 3. Labiopalatal thickness was ≥50% of root width of cleft-adjacent teeth (score 2).

Padwa et al. CBCT Shows 94% Success in Alveolar Bone Grafts. J Oral Maxillofac Surg 2022.

DATA ANALYSIS

Descriptive statistics were tabulated for demographic information, including sex, cleft type, age at bone graft, and time from bone graft to CBCT.

Inter-rater and intrarater reliability was assessed to confirm the accuracy of measurements. A subset of measurements was selected for intrarater reliability assessment using a random number generator

FIGURE 4. Labiopalatal thickness was ≥75% of root width of cleft-adjacent teeth (score 3).

Padwa et al. CBCT Shows 94% Success in Alveolar Bone Grafts. J Oral Maxillofac Surg 2022.

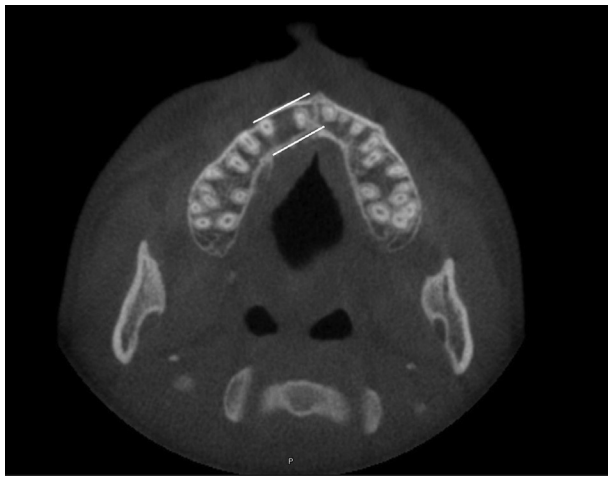

FIGURE 5. Labiopalatal thickness was ≥100% of root width of cleft-adjacent teeth (score 4).

Padwa et al. CBCT Shows 94% Success in Alveolar Bone Grafts. J Oral Maxillofac Surg 2022.

(https://www.random.org/integers/). Inter-rater and intrarater reliability was assessed for ordinal outcome variables using the linear weighted-kappa statistic. These statistics were interpreted following the guidelines of Landis and Koch. All reliability statistics were greater than 0.85, indicating good-to-excellent intrarater and inter-rater agreement (Table 1).

Results

STUDY SAMPLE

A total of 817 patients had alveolar bone grafting by 1 surgeon from 2005 to 2020. There were 199 patients (unilateral cleft lip with [n = 140] and without [n = 12] cleft of the secondary palate and bilateral cleft lip with [n = 44] and without [n = 3] cleft of the secondary palate) who did not meet inclusion (131 patients had 2D imaging, and 68 patients were lost to follow-up) criteria. This left 618 patients with 783 alveolar cleft sites (59% male) for analysis. There were 453 patients with unilateral cleft lip and alveolus with (n = 387) or without (n = 66) cleft of the secondary palate and 165 patients with bilateral cleft lip and alveolus with (n = 157) or without cleft of the secondary palate (n = 8) who had adequate CBCT scans taken a median of 9.7 months (interquartile range: 68.8 months, minimum: 4.9 months, maximum: 193.8 months) after

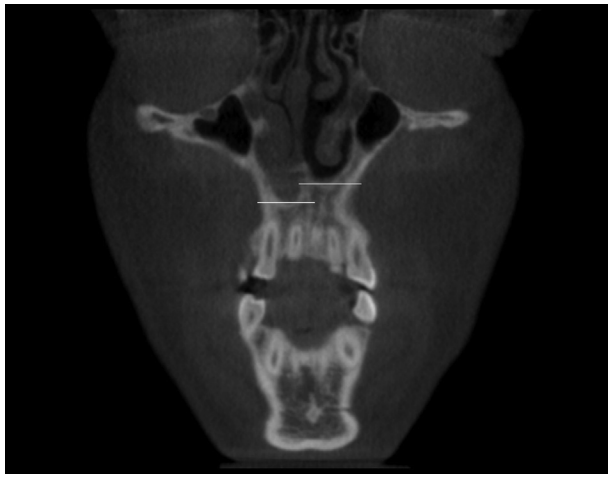

FIGURE 6. Piriform symmetry scored by comparing height of the nasal floor on both sides in the coronal plane. = ≥6 mm difference (score 1).

Padwa et al. CBCT Shows 94% Success in Alveolar Bone Grafts. J Oral Maxillofac Surg 2022.

FIGURE 7. ≥3 and < 6 mm difference (score 2).

Padwa et al. CBCT Shows 94% Success in Alveolar Bone Grafts. J Oral Maxillofac Surg 2022.

FIGURE 8. ≥1 and < 3 mm difference (score 3).

Padwa et al. CBCT Shows 94% Success in Alveolar Bone Grafts. J Oral Maxillofac Surg 2022.

FIGURE 9. <1 mm difference (score 4).

Padwa et al. CBCT Shows 94% Success in Alveolar Bone Grafts. J Oral Maxillofac Surg 2022.

grafting. The median age at alveolar bone graft was 10.0 years (interquartile range: 1.6 years, minimum: 5.6 years, maximum: 31.1 years).

GRAFT SUCCESS

A graft was considered successful if the vertical bone height of cleft adjacent teeth, labiopalatal thickness at the cervical, middle, and apical root levels of adjacent teeth, and symmetry of nasal floor heights each had a score of 3 or 4. Using this radiographic analysis in 3 dimensions, alveolar bone grafting was successful in 94% of this cohort. There were 44 of 783 cleft sites that had a fair-to-poor result. In 62% of the cohort, the canine was erupted at the time of the postoperative CBCT, and 94% had good-to-excellent periodontal bone levels, supporting the validity of this radiographic analysis.

There was a subset of 45 patients (5%) who had good-to-excellent results (score 3 or 4) for vertical height and labiopalatal thickness at all levels but who had a fair result (score of 2) for piriform symmetry. These patients

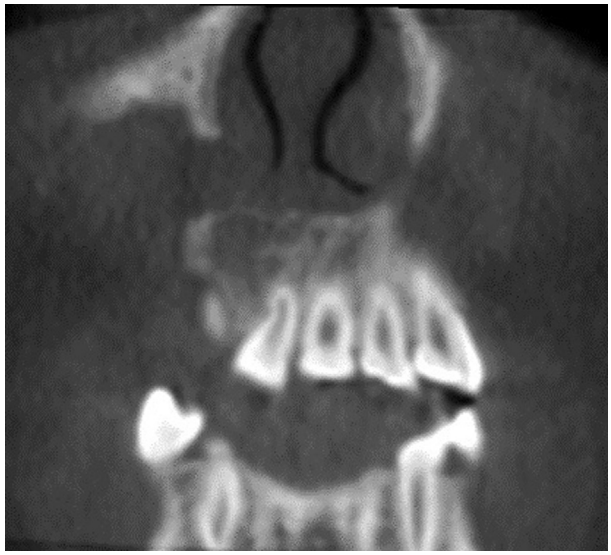

FIGURE 10. Canine not erupted at the time of CBCT scan but able to score vertical bone height of the mesial tooth (central incisor). CBCT, cone beam computed tomography.

Padwa et al. CBCT Shows 94% Success in Alveolar Bone Grafts. J Oral Maxillofac Surg 2022.

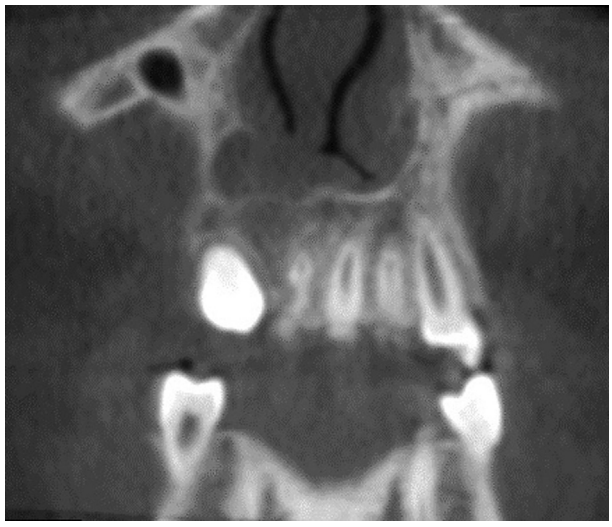

FIGURE 11. Canine not erupted at the time of the CBCT scan precluding ability to score vertical bone height of the distal tooth (canine). CBCT, cone beam computed tomography.

Padwa et al. CBCT Shows 94% Success in Alveolar Bone Grafts. J Oral Maxillofac Surg 2022.

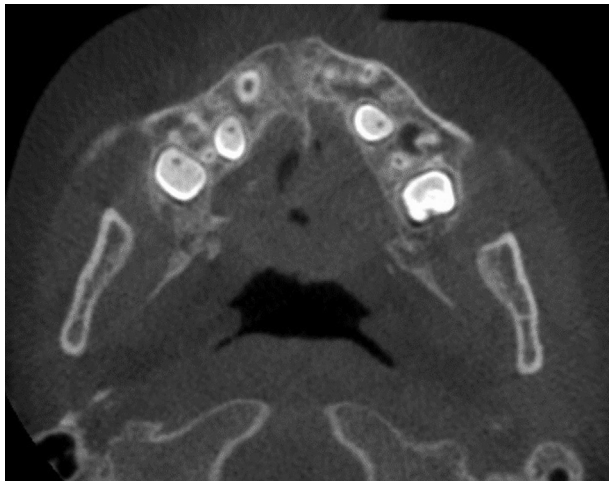

FIGURE 12. Canine not erupted at the time of CBCT scan but able to score horizontal thickness at apical third. CBCT, cone beam computed tomography.

Padwa et al. CBCT Shows 94% Success in Alveolar Bone Grafts. J Oral Maxillofac Surg 2022.

FIGURE 13. Canine not erupted at the time of the CBCT scan but able to score horizontal thickness at middle third. CBCT, cone beam computed tomography.

Padwa et al. CBCT Shows 94% Success in Alveolar Bone Grafts. J Oral Maxillofac Surg 2022.

had a significantly deviated septum and nasal crest of the maxilla, making it difficult to lift the nasal floor high enough to obtain symmetry with the noncleft side at the time of alveolar bone grafting (Fig 15). These grafts were considered successful despite asymmetry of >3 mm at the piriform rims because clinically these grafts provided adequate bone for tooth support and orthodontic movement.

Discussion

The purpose of this study was to establish a radiographic outcome assessment tool using CBCT and use it to evaluate the radiographic success of alveolar bone grafting in the largest cohort of patients treated by 1 surgeon. The success rate of 94% in 783 alveolar clefts using radiographic scoring criteria in 3 dimensions is comparable to those obtained in other smaller cohort studies using 2D and 3D imaging. The literature has demonstrated success rates up to 95% for secondary alveolar bone grafts using the 2D radiographic Bergland and Kindeland grading systems which have been standardly used to assess cleft outcomes.[3,4] Dental radiographs and 2D analyses are known, with the help of computed tomographic scans, to overestimate bone formation.[5] They do not show the amount of bone in the horizontal dimension and, therefore, considerably overvalue the osseous bridge.[6,7] Overestimation occurs because these images have superimposition of adjacent structures, image enlargement and distortion, positioning problems, and insufficient anatomical landmarks that prevent measurement of bone volume.[11]

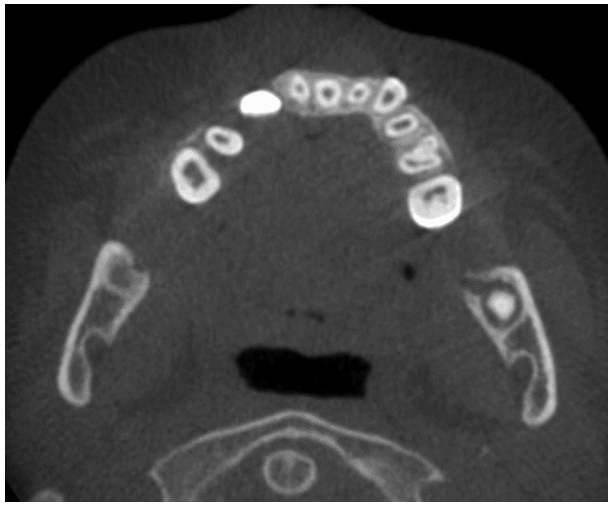

FIGURE 14. Canine not erupted at the time of CBCT scan precluding ability to score horizontal thickness at the cervical level. CBCT, cone beam computed tomography.

Padwa et al. CBCT Shows 94% Success in Alveolar Bone Grafts. J Oral Maxillofac Surg 2022.

CBCT scans provide 3D imaging with low radiation exposure. Hamada et al compared CBCT with dental occlusal and panoramic radiographs in evaluating alveolar cleft bone grafts.[7] They found that CBCT images provided more precise information about the 3D morphology of the bone bridge at the cleft site and the relationship between the bone bridge and the roots of the teeth adjacent to the cleft. Iino et al compared intraoral radiographs to CT images and reported that in 40% of cases where, based on intraoral radiographs, the interdental bone height was regarded as a successful surgical outcome, the labiolingual thickness was actually shown to be less than the root width of the cleft-adjacent teeth on CT images.[5]

Anver et al developed a modified assessment tool using CBCT scans based on the Wangsrimongkol et al, Liu et al, and Suomalainen et al scoring systems used in our study.[8,9,10,12] These 3 assessment tools measured 1 or 2 radiographic dimensions on the postgraft CBCT scan. In Anver's study, each cleft site was given a vertical score for the mesial tooth, 1 horizontal score at the mid-root of the mesial tooth, and a nasal support (piriform symmetry) score.[12] Our radiographic analysis included all these measures in addition to the vertical score on the distal tooth and the horizontal score at the apical and cervical thirds. Anver et al defined a successful graft as having a score indicating at least acceptable results in the vertical and horizontal dimensions and nasal support (piriform symmetry). Using their modified assessment tool with fewer parameters, they reported a success rate of 94% in 79 patients with 105 clefts, mirroring the results of the present study, which used a more rigorous analysis in a considerably larger cohort.

In addition to these studies that assessed bone graft success using CBCT scans and a radiographic analysis in 3 dimensions, there are several reports using CBCT

Table 1. INTRARATER AND INTER-RATER ANALYSIS

Measurement	Intrarater Agreement*	Inter-Rater Agreement*
Postoperative vertical bone height of cleft-adjacent teeth		
Tooth distal to cleft	.999	.897
Tooth mesial to cleft	.997	.894
Postoperative labiopalatal bone thickness		
Cervical third of the cleft-adjacent root	.975	.852
Middle third of the cleft-adjacent root	.982	.861
Apical third of the cleft-adjacent root	.978	.873
Postoperative nasal piriform symmetry	.972	.879

* Weighted kappa statistic.

Padwa et al. CBCT Shows 94% Success in Alveolar Bone Grafts. J Oral Maxillofac Surg 2022.

scans for volumetric assessment of the alveolar cleft to calculate the bone volume necessary for grafting the defect.[13-15] There are relatively few published studies with a small number of patients where volumetric analysis was used to determine alveolar bone graft success. This is because this technique requires comparing preoperative and postoperative CBCT scans and most cleft programs continue to use dental radiographs. In addition, volumetric assessment requires selecting anatomic landmarks, tracing the boundaries of the bone defect, and setting the reconstruction parameters which are criteria that have not been standardized.[16] The data obtained with a volumetric analysis are given in percent of bone fill or bone volume in cm^3, which do not provide information as to whether there is bone in places that are clinically relevant.[17,18] From a research standpoint, volumetric analysis of the grafted alveolus is an interesting technique. However, clinicians do not judge bone graft success by bone volume but by assessing whether there is adequate bone in the vertical, sagittal, and coronal dimensions to provide periodontal support to adjacent teeth, canine eruption, orthodontic tooth movement, implant placement, and piriform symmetry. For these reasons, the authors chose to use a radiographic outcome assessment in 3 dimensions rather than a volumetric analysis to determine radiographic success of alveolar grafting.

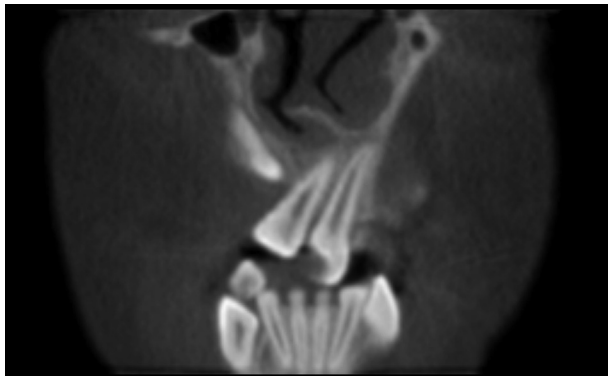

FIGURE 15. Deviated septum and nasal crest of the maxilla interfering with ability to obtain piriform symmetry.

Padwa et al. CBCT Shows 94% Success in Alveolar Bone Grafts. J Oral Maxillofac Surg 2022.

This study has several limitations. Our standard clinical protocol is to perform alveolar bone grafting well before canine eruption and obtain CBCT imaging 6 months later. In many patients, the canine had not erupted at the time of the postgraft CBCT scan which precluded our ability to score the vertical bone height of the distal tooth (canine) and the horizontal thickness at the cervical level. However, in the 62% of the cohort, the canine was erupted at the time of the postoperative CBCT, and 94% had good-to-excellent periodontal bone levels, supporting the validity of this radiographic analysis. Given the retrospective study design, there were many patients who did not have CBCT imaging 6 months but rather years after the graft which resulted in a broad range for timing of postgraft CBCT scans. In addition, many patients did not meet inclusion criteria as they were not routinely followed in our cleft program (only came for the operation) and had 2D imaging (panorex, periapical radiographs) for evaluation of graft success or were lost to clinical follow-up.

In conclusion, this radiographic analysis of 783 alveolar bone grafts performed by 1 surgeon demonstrates good-to-excellent outcomes in 94% of alveolar cleft sites. Inter-rater and intrarater analyses showed that this is a reliable and valid assessment tool. Accurate evaluation of the grafted site, particularly the buccolingual dimension, is important to treating providers as insufficient thickness of grafted bone is likely to result in failure of orthodontic and prosthetic treatment. Future studies will assess predictor variables associated with bone graft outcomes.

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